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Concrete deicing salts amelioration.

Sean Patrick. McCann
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CONCRETE DEICING SALTS AMELIORATION

by
Sean P. McCann

A Thesis
Submitted to the Faculty of Graduate Studies and Research
Through the Department of Civil and Environmental Engineering
in Partial Fulfillment
of the Requirements of the Degree of
Master of Applied Science
at the University of Windsor

Windsor, Ontario, Canada
1993

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ABSTRACT

Sodium chloride is the main deicing chemical used in winter on highways and sidewalks to melt unwanted ice accumulations. In this study, various salts and salt combinations were studied as alternatives to sodium chloride. Included were:

1) Sodium chloride
2) Calcium chloride
3) Potassium acetate (and chloride mixtures)
4) Calcium magnesium acetate (and chloride mixtures)
5) Monosodium phosphate plus chlorides
6) Monopotassium phosphate plus chlorides
7) Monocalcium phosphate plus chlorides

Several solution concentrations were used but the base concentration for comparison of the salts and mixtures was 0.5 molality. The salt solutions were used in tests to measure the following properties:

1) Ice melting
2) Mortar scaling
3) Metal corrosion

These properties, as well as estimates of cost and possible environmental damage were considered in a criterion function analysis. It was found that monosodium and monopotassium phosphates, in combination with sodium chloride, were the best choice for use as a deicer. A phosphate and sodium chloride mixture in the ratio of 1 : 9 was found to be the best combination. This phosphate/chloride mixture should be investigated further as a possible alternative to the present day use of sodium chloride.

Dedicated to My Beloved Wife, Maria,
and to Our Future Family,
Whenever They May Be

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INTRODUCTION

Calcium and sodium chloride salts are the most common deicers in use today. For ice and snow control of roads and bridges, sodium chloride is used. Because of the higher cost of calcium chloride, it is used in more localized ice control around buildings and more cold temperature deicer applications. Extensive use of chloride deicers has resulted in an increased surface scaling of concrete and increased corrosion of reinforcing steel.

Because of the negative effects from using sodium chloride as a highway deicer, a number of alternatives have been investigated in the past. Each alternative has been judged on the basis of its performance in comparison to sodium chloride. Thus far, no other deicing salt has proven itself superior to sodium chloride in cost and effectiveness.

The objective of this study, therefore, was to investigate alternative deicers to determine if one can be found which meets the following requirements of a good deicer:

1) Adequate ice melting
2) Minimal mortar scaling
3) Minimal metal corrosion
4) Minimal environmental damage
5) Inexpensive

The information discussed in the section to follow was used to select which deicing chemicals were to be investigated. The deicing chemicals selected were:

1) Sodium chloride (NaCl)

2) Calcium chloride ($CaCl_2$)
3) Potassium acetate ($KC_2H_3O_2$)
4) Calcium magnesium acetate (CMA)
5) Monosodium phosphate (NaH_2PO_4)
6) Monopotassium phosphate (KH_2PO_4)
7) Monocalcium phosphate ($Ca(H_2PO_4)_2*H_2O$)

These salts were used at various concentrations and mixtures to cover a range that included a pessimum concentration for maximum damage (if one existed) along with lower and higher (near saturated solution) concentrations. The concentrations of deicing salt solutions were based on molality for a more representable comparison of deicer effectiveness. The deicing chemical that produced the best result in the five main requirements of a good deicer was considered the best.

A more detailed investigation was performed with monocalcium phosphate. An estimate for the monocalcium phosphate in superphosphate was determined as well as an estimate for the minimum time required for monocalcium phosphate to effectively precipitate in the pores of mortar.

PROPERTIES OF A DEICER IN FREEZING CONCRETE

Negative physical manifestations, such as concrete scaling, corrosion of metal (reinforcing steel and automobile bodies) and environmental damage, brought about by the use of sodium and calcium chloride ice melting salts, have influenced deicer usage as well as helped to promote further research into deicer technology. Both laboratory and field experiences of deicer use have helped researchers ascertain which deicers have the least number of undesirable side effects. These undesirable characteristics of alternative deicers will be briefly outlined in the following sections.

A Current Alternative Deicers

A variety of salts and salt mixtures have been used for deicing purposes. Some of the more common ones used in the field and laboratory will be described in the following paragraphs.

(i) Widely Used Highway Deicers

Sodium chloride has been the most widely used deicing salt on highways in the snow belt. It is notorious for causing reinforcing steel (and automobile body) corrosion, concrete surface scaling and environmental damage. Since it is abundant, the cost of sodium chloride is low. Along with this, its ice melting ability is good; therefore, it is a highly desirable deicer and all other deicers tend to be compared to sodium chloride for their effectiveness. However, when the final costs of deicer use are considered (decaying infrastructure and environment), the higher application cost of alternative deicers can be justified. Estimates for the damage caused by using sodium chloride as a deicer range from six to twenty times the original application cost of sodium chloride (McCrum, 1988).

With increasing awareness of its deicing ability, sodium chloride usage grew in the 1950's and 60's when many new highways came into being. The usage growth leveled off in the 1970's when the public became aware of the damage to the surface and subsurface environment created by sodium chloride (Dickinson, 1983; Kostick, 1983). The leveling off of usage continued through the 1980's (**Table 1** after Kostick, 1983) and will most likely continue through the 1990's.

According to the Northern Miner (Morel-A-L' Huissier, 1992), the present average Canadian consumption of salt is 11.5 Mt/year (approximately 400kg per capita). Deicing and chemical uses account for 90 to 95 percent of the Canadian consumption.

Calcium chloride is the next most commonly used highway deicer. Its ice melting ability is superior to sodium chloride but it is equally damaging to concrete, metals and the environment. The initial cost of calcium chloride exceeds that of sodium chloride and this has had a major influence on its limited use (Borgmann, 1937; Locke et al., 1987; McElroy et al., 1988;

Anonymous, 1989b; Wyatt and Fritzsche, 1989; Anonymous, 1991b).

TABLE 1: Historical U.S. Per Capita Consumption of Salt

Year	Population (Millions)	Consumption (Millions Short Tons)	Per Capita Consumption (lbs.)	Per Capita Consumption (kg)
1880	50.2	1.3	52	24
1890	62.9	1.2	39	18
1900	76.1	3.1	82	37
1910	92.4	4.3	94	43
1920	106.5	6.9	128	58
1930	123.1	8.0	131	59
1940	132.6	10.2	155	70
1950	152.3	16.4	216	98
1960	180.7	26.1	289	131
1970	204.9	49.0	478	216
1980	223.0	44.8	402	182

One method of reducing the cost of calcium chloride application is by spraying liquid calcium chloride on to sodium chloride piles. This causes sodium chloride to bounce off the roads less often, to start ice melting sooner and to last longer (Rude, 1983; Anonymous, 1988; Anonymous, 1989b).

Browne and Cady (1975) compared the surface scaling ability of sodium and calcium chlorides on mortar and concrete cubes (5cm). Sodium chloride had significantly more scaling in both mortar and concrete during freeze-thaw cycling. Both salts produced maximum scaling at an intermediate concentration of 3 percent (pessimum concentration). During thermal cycling (above freezing temperatures), calcium chloride had significantly more scaling and maximum scaling occurred with saturated salt solutions for both chlorides. The results of Boies and Bortz (1965) using mortar bars support the results mentioned above from Browne and Cady (1975).

Other deicers, such as calcium magnesium acetate (CMA) and urea, have been used in the field but not on as regular a basis as chlorides have. Trial field deicers will be discussed in the next few paragraphs.

(ii) Limited Use Highway Deicers

The innovative research of Dunn and Schenk (1979) initiated a multitude of research papers based on the use of CMA as a deicer. It was found that CMA was significantly less corrosive than chlorides (sodium and calcium) on concrete and metals, while its ice melting ability was supposed to be comparable to sodium chloride. CMA is biodegradable and environmentally friendly at low concentrations but eutrophication may develop at higher concentrations. This would increase the oxygen demand in surface waters. Some controversy exists over its melting ability at low temperatures but it is known that its greater cost over sodium chloride is the main hinderance to its widespread use. Considering the decreased corrosion and environmental damage, greater initial cost would be justified because of the decreased future damage (Rabideau et al., 1987; Chollar, 1988; Horner, 1988; McCrum, 1988; Slick, 1988; Anonymous, 1989b; Wyatt and Fritzsche, 1989;

Anonymous, 1991c; Anonymous, 1991b).

The main reason why CMA is so expensive is that acetic acid is used in its production. Less expensive methods for producing acetic acid are being developed, such as incorporating agricultural supplies, municipal wastes or natural gas into its fabrication. The most common reaction for manufacturing CMA is by reacting dolomitic lime with acetic acid. Other processes are in the development stage, such as the bacterial production of acetate from sugars in the presence of calcium and magnesium ions (Sheridan Technical Associates Inc., 1990).

During the winter of 1986/87, four areas in the North American snow belt (Wisconsin, Massachusetts, Ontario and California) compared CMA with sodium chloride in actual field conditions. The general consensus was that CMA had more appealing qualities since it lasted longer, less was required (when the total seasonal use was considered), snow did not bulk up (slush) but remained loose, and black ice was prevented (Chollar, 1988).

Urea is another material with limited field service. It is a fertilizer that is produced from organic wastes. It produces less scaling in concrete and less corrosion in metal. Urea can disintegrate, producing ammonia that is toxic to aquatic life (Wyatt and Fritzsche, 1989). The major setbacks, besides being toxic, are that it has a high freezing point and it is expensive to use (Verbeck and Klieger, 1956; Boies and Bortz, 1965; Dunn and Schenk, 1979, 1980; McElroy et al., 1988; Trust et al., 1988; Wyatt and Fritzsche, 1989; Anonymous, 1991b).

The city of Ottawa, Ontario tried testing some of alternative deicers on their city streets in the mid 1980's. On their list was sodium chloride, CMA and sodium formate. They found that sodium formate was more effective than CMA but less effective than sodium chloride. Sodium formate was less corrosive and more expensive than sodium chloride while being less expensive than CMA (Palmer, 1987; Anonymous, 1989a). The major environmental concern about using sodium formate was that it contained sodium ions, which are known to cause hypertension. Also, sodium formate can form deadly formic acid when it reacts with automobile exhaust (Anonymous, 1989b).

The final deicer to be mentioned with regard to field experiences is magnesium chloride. Magnesium chloride and its mixtures with sodium and calcium chlorides have excellent ice melting abilities and produce less corrosion. The greater expense of magnesium chloride hinders it use (Anonymous, 1989b).

To summarize the field experiences of deicer use, **Table 2** has been developed. The listings in the table are by no means complete but can be used as an indicator of the research activity in this area.

(iii) Laboratory Studies of Deicers

Natural brine or oil and gas field brine should be effective deicers since they are mainly sodium chloride solutions with impurities. Also, they would be inexpensive deicers since natural brine is a product of salt mining and oil and gas field

TABLE 2: Deicing Compounds Used in the Field

Salt	Advantages	Disadvantages	References
Calcium chloride	Good ice penetration and undercutting, less frost damage, reduced corrosion, rapid melting, no surface residue, exothermic, hydrophilic, longer lasting, lower effective temperature, less required per application	Toxic to plant life, expensive, handling difficulties, black ice formation, corrosion	6, 8, 24, 68, 77, 115
Liquid calcium chloride + sodium chloride	Reduced corrosion, less required per application, rapid melting, low bounce off, less black ice, long lasting		4, 6, 93
Calcium magnesium acetate	Less required per year, improves soil, environmentally safe, noncorrosive, comparable deicing, prevents black ice, long lasting, loosens snow, lower effective temperature, exothermic, biodegradable, nonscaling, low bounce off	High freezing point, odour, eutrophication, expensive, slow acting, wind loss, requires high vehicle flow, low solubility, deposits build up on equipment, water hardness, reduced melting	6, 8, 9, 30, 51, 75, 89, 98, 115
Calcium magnesium acetate + sodium chloride	Low corrosion		75, 115
Magnesium chloride	Reduced corrosion, faster melting		6
Urea	Fertilizer (safe in low concentrations), less scaling, noncorrosive	High freezing point, toxic to plant and aquatic life, surface residue, expensive, poor ice penetration, endothermic	8, 23, 36, 37, 77, 102, 105, 115
Sodium chloride	Inexpensive, low melting temperature	Destroys soil permeability, hypertension, concrete damage, corrosion, surface residue, refreezing, heavy metal release, environmental damage, endothermic	
Sodium formate	Noncorrosive, similar effectiveness as NaCl, same application rate as NaCl	Hypertension	5, 6

brine is a by-product of the hydrocarbon exploration industry. Natural brine was compared with sodium chloride and with calcium chloride in the ASTM C672 mortar scaling test after 100 freeze-thaw cycles and had less scaling than either of the two chlorides (Eck and Sack, 1986). In steel corrosion weight loss tests, natural brine performed similar to sodium and calcium chlorides (Eck and Sack, 1986). One of the main problems of brine use would be the deleterious effects caused by the impurities. For example, oil and gas field brines are contaminated with sulphates that can attack concrete. Monitoring and regulating the impurities in the brines would be required and this will increase the cost for its use (Eck and Sack, 1986; Eck et al., 1987).

Dunn and Schenk (1979, 1980) had suggested the utilization of methanol as a deicer. It was noncorrosive, nonscaling and melted ice at temperatures far below the normal freezing temperatures in the snow belt. Since it was volatile, it did not leave deposits on concrete but it also did not last long for continuous ice melting over time. Reapplications were required. Besides this, methanol was expensive.

Phosphates have long been known for their corrosion inhibiting ability. Boies and Bortz (1965) and Dunn and Schenk (1979) suggested the use of phosphates but only when it was used as a mixture with chlorides. Phosphate alone was ineffective as a deicer. When used as a mixture (low ratio of phosphate to chloride), the expense may be reduced along with corrosion. Hudec et al. (1992) showed how phosphates could be used as a mixture with sodium chloride or as a pretreatment of aggregates to reduce freeze-thaw damage. Eutrophication of water bodies is a problem that can be caused by phosphates which therefore must be considered before widespread use could be contemplated.

Besides phosphates, Hudec et al. (1992) also suggested the use of potassium acetate. Potassium acetate had rapid ice melting ability (greater than sodium chloride and similar to calcium chloride) and did not produce scaling of mortar. Since acetates are noncorrosive and environmentally safe, potassium acetate appears to be a likely candidate as an alternative although it is more expensive than sodium chloride.

Table 3 is a summary of the properties outlined above on various deicers tested in laboratories. The information in **Tables 2** and **3** was used to formulate a list of deicers and tests for use in this research project to determine the best deicer. This list was discussed earlier.

B Theoretical Considerations

Research to explain the behaviour of deicing salts has been increasing with time, with the aim to find an alternative salt having fewer negative aspects. Some of the main developments concerned with a deicer's behaviour will be discussed in the following sections.

TABLE 3: Deicing Compounds Tested in the Laboratory

Salt	Advantages	Disadvantages	References
Calcium magnesium acetate	Less required per year, improves soil, environmentally safe, noncorrosive, comparable deicing, prevents black ice, long lasting, loosens snow, lower effective temperature, exothermic, biodegradable, nonscaling, low bounce off	High freezing point, eutrophication, expensive, dusting, more required per application, water hardness, reduced melting	36, 37, 40, 49, 51, 53, 68, 76, 78, 82, 96, 102, 115
Ethyl alcohol	Less scaling		105
Methanol	Difficult to ignite when wet, environmentally safe, very low eutectic temperature, rapid melting, noncorrosive, exothermic, nonscaling, volatile, miscible with water	Not long lasting, expensive	36, 37
Natural brine	Inexpensive, good ice penetration, low bounce off, similar performance to NaCl		39
Oil and gasfield brine	Inexpensive, less scaling, good ice melting	Possible sulphate attack, corrosive	38
Phosphate	Reduced scaling (mixed with chlorides), inhibits corrosion, use as a mixture, environmentally safe, low freezing point	Acidic solutions, eutrophication, expensive	7, 23, 36, 53
Potassium chloride		High freezing point, poor ice penetration, surface residue, endothermic, toxic to plants	8, 77
Potassium acetate	Noncorrosive, environmentally safe, nonscaling, rapid melting		53
Sodium formate	Noncorrosive, similar effectiveness and freezing point as NaCl, same application rate as NaCl, nonscaling, highly soluble, low toxicity	Hypertension, reacts with auto exhaust (deadly formic acid)	5, 6, 82
Urea + calcium formate + formamide	Noncorrosive, low freezing temperature		23

(i) Desired Chemical Characteristics of a Deicer

The ideal deicer would be cost effective, environmentally safe, noncorrosive to metal or concrete (Anonymous, 1989b), nonflammable, nonvolatile, nonacidic and nonpoisonous (Boies and Bortz, 1965). While being all of the aforementioned, it is most important that it also have an excellent ice melting ability. Understanding how the chemical characteristics, such as molecular weight and solubility, play a part in determining the potential of a material to act as a deicer is the key for explaining its behaviour.

A deicer can be almost anything soluble in water (Anonymous, 1989b) since the degree of freezing point lowering of water is increased with the solubility of the solute in solution and chemical deicing depends on the freezing point of the solution. Good deicers will produce the greatest depression of the freezing point. Molecules having a lower molecular weight will have a greater number of ions per unit weight compared to a higher molecular weight molecule with the same number of ions per given weight of deicer. Therefore, a substance with a low molecular weight and high solubility is preferred since it will have the maximum effect on the freezing point per unit weight applied to a surface (Boies and Bortz, 1965; Dunn and Schenk, 1979,1980; Palmer, 1987; Horner, 1988). Solubility of a salt at lower temperatures is also important (Boies and Bortz, 1965).

Figure 1 (after Browne and Cady, 1975) is a phase diagram for calcium chloride solutions. As the concentration of the brine is

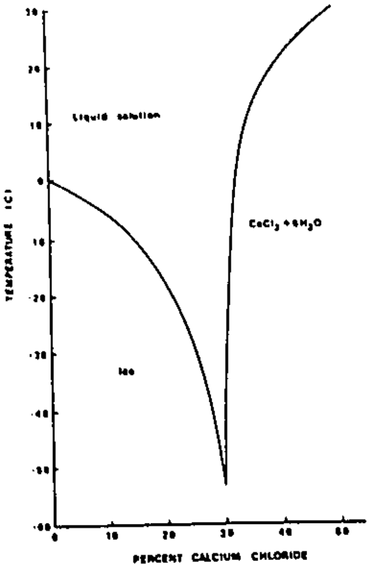

FIGURE 1: Phase Diagram for Calcium Chloride Solutions

increased, the freezing point of the solution is decreased. A dissolved substance decreases the freezing point of a solution by decreasing the vapour pressure over both the solute and solvent in the solution (Boies and Bortz, 1965; Litvan, 1976; Hutcheon and Handegord, 1989). The freezing point of an aqueous solution is the temperature at which the vapour pressures over the solvent in the solution and over ice are equal (Boies and Bortz, 1965). When pure water is cooled below 0°C, the super cooled water has a higher vapour pressure than ice and both of their vapour pressures decrease with decreased temperature. Because of the vapour pressure difference, super cooled water will have a tendency to transfer to the ice, allowing the ice to grow by sublimation of the water vapour to ice (ice accretion) (Hutcheon and Handegord, 1989).

When a substance is added to water and it decreases the vapour pressure of water over the solution to a level below that over ice, the lower vapour pressure solution will cause the ice to melt and dilute the solution (Boies and Bortz, 1965).

(ii) Mechanisms of Frost Action

Most processes in concrete, whether they be good or bad, chemical or physical, require water as either the direct or indirect source of the action. The main mechanisms of deterioration through frost action will be described on the basis that water is the agent of the action.

a) Hydraulic Pressure

The theory of hydraulic pressure as a destructive force in concrete was first developed by Powers (1955) and was based on the principle that water undergoes a 9 percent volume increase during freezing. Aggregate and/or paste that is saturated to 91.7 percent for volume (critical degree of saturation) or more will develop hydraulic pressures during freezing if the excess water volume cannot be accommodated by expulsion. Hydraulic pressures exceeding the tensile strength can cause local cracking and failure (Detwiler et al., 1989). Powers' original theory assumed that all water movement was away from the freezing front. According to ACI Committee 201 on the Durability of Concrete (1991), this theory only applies to aggregates (since pore size in aggregates is greater than in the paste) as water is pushed by the progressing ice front into the cement paste. Unfrozen water has an affinity for ice due to the lower vapour pressure of ice. The potential difference between the two phases causes water movement towards ice and leads to ice growth (ice accretion). If fluid movement is restricted, hydraulic pressures are generated. Continued dilation can occur at constant or decreasing freezing temperatures due to sustained ice growth. Experiments using benzene, which contracts on freezing, still produced dilations (Beaudoin and MacInnis, 1974). Unfrozen benzene flows towards the frozen benzene because of the vapour pressure difference. Once the unfrozen benzene reaches the site of the frozen benzene, it also freezes so that the total volume of frozen benzene is greater. Continued freezing of the unfrozen benzene fills the available volume around the frozen benzene. The frozen benzene applies a pressure on the pore walls once there is no more room for the increasing volume of frozen benzene. The pressure applied to the pore walls increases the volume of the cement paste and is expressed as a dilation. If cooling rate is increased, dilation is decreased (ACI Committee 201, 1991).

The facts above disprove the original hydraulic pressure theory. Hydraulic pressure is more of a force than a mechanism. Its development depends on the freezing rate, saturation degree, permeability and flow path length (Powers, 1955; Verbeck and Landgren, 1960; ACI Committee 201, 1991). Hydraulic pressures can be created by fluid movement either towards ice, away from ice or by the main freeze-thaw deterioration mechanisms of osmotic pressures, adsorption and ice accretion. Hydraulic pressures can develop by moisture movement either through the paste, aggregate or from the aggregate into the paste (Powers, 1955; Verbeck and Landgren, 1960). The stress produced by freezing appears at the same instant that freezing begins (Powers, 1955).

b) Osmotic Pressure

The theory behind osmotic pressure as a destructive mechanism in concrete was developed by Powers and Helmuth (1953). According to ACI Committee 201 (1991), it is the main cause of frost damage.

Osmotic pressure is a physical mechanism generated by the difference in osmotic potentials in either the paste (Banthia et al., 1989) or aggregate (Gillott, 1978). When a substance (such as salt) is dissolved in water, the solution has a higher osmotic potential and lower vapour pressure than pure water as the concentration is increased (Williams and Robinson, 1981). The pure water in small pores has an affinity for the dissolved ions surrounding ice in the larger pores. The affinity is caused by the vapour pressure difference between the pure water and the solution surrounding the ice. The increase in volume due to the fluid migration towards the dissolved ions results in hydraulic pressure if the excess solution is hindered from exiting. Both deicer salts and concrete alkalies can create osmotic potentials. Concentrations of these solutes will increase in unfrozen pores or around ice as water is removed from smaller pores and frozen

(Rusin, 1991). In either case, water is attracted by osmosis to the sites of high concentration causing expansion and cracking if the pressure is not relieved (Hudec, 1987). Hudec and Rigbey (1976) showed that salt can increase the osmotic potential during freezing. Salt significantly increases the water sorption in rock pores so that more water is available for freezing (Goudie, 1985). Gel pore water can be drawn to the alkalies and salts in order to dilute the concentrations in capillaries due to freezing. Because of the use of salts for deicing, osmotic pressure is a major factor in salt scaling (Powers, 1955; Gillott, 1978).

High active surface pores in aggregates have a strong attraction for cations and water. In small pores, water becomes an osmotic solution with a decreased vapour pressure due to the dissolved cations and an increased osmotic potential (Powers, 1975; Hudec, 1987). This potential increases with temperature decrease (Hudec, 1987). Water at a higher vapour pressure is attracted to the lower vapour pressure osmotic solution. Therefore, an increased osmotic potential leads to a higher degree of saturation at a given relative humidity (Litvan, 1976; Hutcheon and Handegord, 1989). A high degree of saturation allows for little to no drying between wetting and drying cycles (ACI Committee 201, 1991).

c) Adsorption

The water retained by the gel particle surface forces is termed adsorbed water. Adsorbed water can also collect in pores of both the paste and aggregate during the thawing of concrete (Powers, 1955; Helmuth, 1961; Larson and Cady, 1969; Litvan, 1972; Rusin, 1991). It forms a layered structure (one to multiple orderly layers depending on the magnitude of the surface force) on the negatively charged surfaces and is held by hydrogen bonding. Cations and anions have a greater charge and are attracted to the surface more than water (Hudec, 1987). They may cause water dipoles to collect around them. Deicing salts may supply the cations and anions for increased adsorption and decreased durability (Rogers 1977).

Adsorbed water is tightly held by the pore surface. This reduces the vapour pressure over adsorbed water (Hudec, 1987) below that of normal water so that adsorbed water does not freeze (ACI Committee 201, 1991) (even at temperatures of -78°C (Bouyoucos, 1923)) without redistribution into larger pores where freezing can occur. Litvan (1976) explained that in saturated samples, the vapour pressure over adsorbed water is greater than over ice when the two phases are separated by a distance and the difference in vapour pressure between them increases with temperature decrease. When their vapour pressures are equal, freezing can occur (Boies and Bortz, 1965). Desorption is the removal of adsorbed water from small pores to larger pores. This results in a subsequent lowering of the adsorbed water vapour pressure in the fine pores. Desorption is caused by the difference in vapour pressure between the small pores (high) and ice (low). The redistribution of the adsorbed water to locations of ice causes the freezing of the adsorbed water (Litvan, 1976). "Mechanical failure occurs when desiccation cannot proceed in an orderly fashion; the rate of water transport out of the pores is significantly less than is required by the conditions. Such a situation usually arises if permeability is low and porosity, the degree of saturation, and the cooling rate are high," (Litvan, 1976).

Researchers, such as Litvan (1976) and Hutcheon and Handegord (1989), discuss the formation of a glassy, noncrystalline state of water from a highly concentrated salt solution in fine pores during freezing temperatures. This highly concentrated adsorbate can render the pore system, which it has filled, rigid while preventing fluid movement (Litvan, 1976).

d) Accretion of Ice

Due to the difference in vapour pressure between ice and unfrozen adsorbed water, moisture migrates towards the ice. If the permeability of concrete is low, there can be a pressure build up as water is hindered from migrating to ice (Gillott, 1978). A pressure build up and subsequent dilation can also occur by forces other than hydraulic pressure related to fluid migration. During capillary ice growth, especially in hydrated cement paste with few capillaries, ice forms and draws water from the unfrozen paste capillaries causing shrinkage (Powers, 1955; Gillott, 1978; ACI Committee 201, 1991). This continues as long as the outer layers of adsorbed water in the pores has a higher vapour pressure than ice (Hudec, 1987). Dilation begins once capillaries are filled with ice and solution and continues long after the initial freezing occurs and the temperature is constant (Powers, 1955; Hudec, 1987; ACI Committee 201, 1991) but it is not noticeable immediately after freezing. Dilation due to ice growth more than overcomes the paste shrinkage (Powers, 1955) since the specific volume of ice is greater than water. The ice growth action is similar to frost heave and ice lensing in soils (Hudec, 1987; Detwiler et al., 1989).

e) Thermal Shock

When deicing salts are applied to an ice covered concrete surface, ice melts. As ice melts, it requires a large quantity of heat, part of which is extracted from the concrete. This extraction of heat reduces the temperature of the concrete. The rapid temperature drop that occurs in concrete due to the application of deicing salts is termed thermal shock. A thermal gradient is produced between the interior (warmer) and exterior (cooler) surfaces of concrete. This can initiate stresses and may result in damaging crack formations (Harnik et al., 1980; Rosli and Harnik, 1980).

f) Salt Weathering

The term salt weathering refers to the deterioration of concrete without the aid of excessive hydraulic pressures. Most of the mechanisms described earlier are based on the passage of water being hindered and creating pressure. In salt weathering, water may or may not be involved and it is normally a less common problem.

The three main types of salt weathering are: crystallization, hydration and differential thermal expansion. Each of these will be described briefly.

Crystallization consists of salt crystal growth by either evaporation, temperature change or a chemical reaction (Goudie, 1985). As crystals grow, they exert a crystallization pressure on pore walls (Chandra and Xu, 1992). This reaction can only take place when a supersaturated solution exists (Winkler and Singer, 1972; Winkler, 1975) and the ambient relative humidity is lower than the equilibrium relative humidity of a saturated solution (Goudie, 1985). If freezing temperatures are present, the salt decreases in solubility as the temperature decreases and the salt crystallizes (Winkler and Singer, 1972; Goudie, 1985). The solubility of sodium chloride in solution is affected less than other salts by temperature drops (Goudie, 1985) but its crystallization pressures are normally higher (Winkler, 1975). This pressure is dependent on the degree of supersaturation (Correns, 1949).

A salt crystal's volume can change by hydration depending on the temperature and/or humidity changes. As water is absorbed by the salt, a hydrate is formed and there is a subsequent volume increase resulting in an applied pressure on pore walls (Winkler, 1975; Goudie, 1985). Greater pressures are attained at low temperatures and higher relative humidities (Winkler, 1975). Though sodium chloride is an uncommon hydrate, it can be found at lower temperatures (Goudie, 1985). The order of cations for increasing ability to hydrate is:

$K^+ < Na^+ < Li^+ < Mg^{2+} < Ca^{2+}$ (Rogers 1977)

The differential thermal expansion of salt is higher than rock (Winkler, 1975; Goudie, 1985). Salt thermal expansion increases with increasing temperature (Winkler, 1975). If salt crystals are present in concrete aggregate at elevated temperatures, the salt will expand at a greater rate than the aggregate and may exceed the tensile strength of the aggregate. Cracking and deterioration may develop.

(iii) Physical Manifestations of a Deicer

The physical characteristics of ice melting, corrosion resistance, scaling resistance and D-cracking will be described in this section. The actual mechanisms involved with deicer use may be either physical or chemical in nature, but the damage created (melted ice, corroded metal, scaled or cracked concrete) will be physical in character.

a) Ice Melting

The process of a deicer melting ice can be broken down into the following stages:

1) Brine formation
2) Penetration through ice to pavement
3) Debonding of ice from pavement

Sodium chloride, in the solid form, reacts endothermically with ice. This reaction is slow in the absence of water and the salt requires moisture to form a brine for more rapid ice melting. The brine melts ice by lowering the freezing point of water (Anonymous, 1991b). The process of ice melting is diffusion controlled (Trust et al, 1988) as the brine penetrates into the ice and becomes more diluted. The greatest melting occurs at the bottom of the brine solution since this is where it is more dense and higher concentrations melt ice faster (Anonymous, 1991b). The rapid melting of ice in the first 15 minutes determines its usefulness (McElroy et al., 1988).

Once the brine reaches the pavement (or any other ice covered surface), it undercuts the ice by generating a thin pancake of concentrated solution (Trust et al., 1987; Anonymous, 1991b). Initially, undercutting is fast but it decreases with time and the area debonded is directly proportional to the concentration of solution (Trust et al., 1987). Lab experiments and equations have been used to estimate ice melting ability and compare various deicers (Trust et al., 1987, 1988). The results may or may not be entirely realistic when compared to actual field observations.

Deicing performance depends on temperature, traffic, time required to make a brine, shape of the particles and duration of the melting action (Anonymous, 1991b). Of these, the shape is the most controllable factor. Crystals or irregular shape particles tend to form a nonuniform melting front with tendrils spreading out in several directions (McElroy et al., 1988; Anonymous, 1991b). Crystals in the form of flakes are the worst performers since they have a tendency to melt ice both in a horizontal and vertical direction. Once the brine reaches the pavement, it is too diluted to effectively deice (Anonymous, 1991b). Spherical deicers, on the other hand, produce a uniform penetration front (McElroy et al., 1988) in a vertical direction. Particles with diameters of 1.6 to 4.8mm (1/16 to 3/16 inches) penetrate ice faster while dissolving ice evenly and vertically (Anonymous, 1991b).

b) Corrosion Resistance

Corrosion in metals is an electrochemical reaction having two locations with electrical charge concentrations: anode (location of a negative charge and oxidation reactions) and cathode (location of a positive charge and reduction reactions) (ACI Committee 222, 1989; ACI Committee 201, 1991). Between these points, an electrical conductor (usually the metal undergoing corrosion) is needed along with a medium (usually aqueous but may sometimes be combined with dirt) to pass charges in the opposite direction (ACI Committee 222, 1989). The two main chemical reactions of metal corrosion are (Boies and Bortz, 1965; ACI Committee 222, 1989; ACI Committee 201, 1991; Kruger, 1991):

$$Fe = Fe^{2+} + 2e^- \quad \text{(anode)}$$

$$2H_2O + O_2 + 4e^- = 4(OH)^- \quad \text{(cathode)}$$

Many known types of metal corrosion exist that use these basic reactions. They are too numerous to be discussed.

For corrosion to occur, moisture, oxygen and water soluble chloride ions must be present. If a variation in concentration of these elements occurs along the metal, accelerated corrosion may result at specific sites of variation (ACI Committee 201, 1991). The physical manifestation of corrosion is a volume increase of the metal due to rust formation (ACI Committee 222, 1989).

The passivity (inertness) of metal is maintained by a thin and tightly adhering oxide film around the metal that protects it from corrosion (ACI Committee 222, 1989). Passivity can be disrupted by pH variations outside of an acceptable range or by chloride ions breaking down the oxide film (Locke, 1986). The normal pH range of concrete (approximately 12.5) allows a lime rich layer to form and protect the metal when the pH is above 10. If it is decreased below 10, corrosion will result (Locke, 1986; ACI Committee 201, 1991; Berke, 1991). If pH is increased above 13, passivity can still be disrupted and cause corrosion (Locke, 1986; ACI Committee 222, 1989; ACI Committee 201, 1991) (**Figure 2** after Pourbaix, 1974).

Chloride concentration gradients can be formed especially in parking garages since salt deposits are not as readily washed away as on the exposed surfaces of highways. Many parking garages are decaying because of localized chloride contamination of the reinforced concrete along the driving lanes. This results in macrocell corrosion of the reinforcing bars. Highway bridge surfaces and seawater structures are two other structures related to corrosion problems. When parts of these structures are located in a splash zone, there is a significant oxygen and chloride availability (when deicers or sea water are present) and can result in more severe deterioration in the splash zone than the rest of

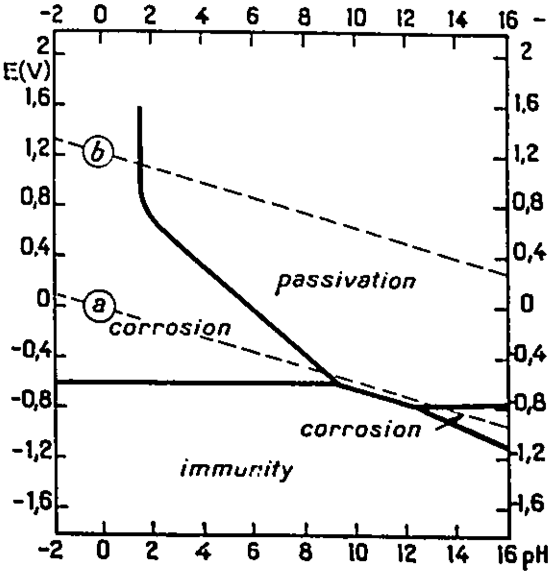

FIGURE 2: **Theoretical Conditions of Corrosion, Immunity and Passivation of Iron (Pourbaix Diagram)**

the structure (Locke, 1986). In submerged structures, diffusion of oxygen is decreased so that less corrosion results (Locke et al., 1987; ACI Committee 222, 1989). A similar effect occurs in salt solutions, such as sodium chloride, that reduce the solubility of oxygen at higher salt concentrations and produce minimal, if any, corrosion (Locke et al., 1987; ACI Committee 222).

The rate of corrosion in neutral solutions depends on which cation is present with the chloride. The rate is proportional to the cation size and the sequence of cations and corrosion rates are of the following order:

$$Mg<Cd<Mn<Ca<Sr<Ba<Li<Na<K<Al<NH_4<Cr<Fe$$

The alkali cations tend to have a greater corrosion rate than the alkaline earth. This is true for chlorides in neutral solutions

(Borgmann, 1937) but may not be true in the higher pH environment of concrete.

Salts tend to have a pessimum concentration, below saturation, that produces the greatest amount of corrosion. For sodium and calcium chloride, their pessimums are approximately 3 and 2 percent, respectively (Borgmann, 1937) while CMA has a pessimum of 1 percent. In comparing these three deicers, CMA produces the least corrosion by a significant factor (Locke et al., 1987). But, CMA cannot compete with the melting abilities of chlorides. To maintain ice melting, yet hinder corrosion, phosphate materials have been proven as an alternative when added to sodium chloride. Phosphates are known for their ability to inhibit corrosion (Boies and Bortz, 1965; Hudec et al., 1992).

The following are some of the more effective methods for producing corrosion resistance in concrete structures: low permeability concrete by using superplasticizers, microsilica in concrete, epoxy coating of steel reinforcement bars, cathodic protection of reinforcing bars, latex modified concrete, sealers, calcium nitrite inhibitor (Berke, 1991), phosphate materials (Boies and Bortz, 1965; Hudec et al., 1992) and the use of no deicer salts at all (Rendahl and Hedlund, 1991). If some of these methods were combined, corrosion could become a nonproblem in concrete structures.

c) Scaling Resistance

Concrete scaling is a physical mechanism that occurs when the near surface capillary voids are saturated during freezing. Salt may or may not be present. Scaling resistance is not dependent on the spacing factor of air voids as much as on the permeability since the permeability limits the distance over which solutions may flow to the available air voids (Foy et al., 1988). The quantity of frost susceptible aggregate and variations in the entrained air at the surface of the concrete (the surface has a lower air content than the bulk mortar due to finishing) are also important factors affecting scaling (Boies and Bortz, 1965; Rabideau et al., 1987). Scaling is most dependent on the degree of saturation and can even occur in the highest quality concrete when saturated (Cordon, 1966). Drying will reduce the water content below critical saturation and minimize scaling in both high and low quality concrete (Verbeck and Klieger 1956; Cordon, 1966).

Scaled material is in the form of small, flat flakes. Both the concrete mass and flakes are sound materials and it is the failure plane between them that is unsound (Browne and Cady, 1975). Most scaling occurs when salt is present. The presence of a deicer gradient (higher concentration on the exterior of concrete and lower in the interior) and a sufficient amount of solution for a critical degree of saturation may cause scaling through hydraulic pressure development (Cordon, 1966; Browne and Cady, 1975; Powers, 1975) at the zone of unsoundness. Above the scale (exterior of concrete), salt is too concentrated to produce sufficient freezing and failure. The surface saturation is dependent on the solution's vapour pressure. Dissolved salt ions decrease the solution's vapour pressure below that of water and cause moisture to be drawn to the site of ion concentrations so that the surface saturation is decreased. The background (interior of concrete) saturation is determined by the original mix proportions, curing conditions and the environment (water supply on the exterior of the concrete). Scaling may result when a sufficient quantity of moisture is drawn from the interior of the concrete by the dissolved ions near the surface so that critical saturation is attained at a specific level below the concrete surface. A higher background saturation results in a concrete more vulnerable to deicer scaling (Brown and Cady, 1975).

As in metal corrosion, deicers have a pessimum concentration for maximum scaling. Though variations occur, the pessimum percentage is generally between 2 and 5 percent for sodium chloride, calcium chloride, urea and ethyl alcohol (Verbeck and Klieger, 1956; Boies and Bortz, 1965; Browne and Cady, 1975). Concrete with a high concentration of salts were found to have a reduced fluid absorption. The flow rate through the fine capillaries is inversely proportional to viscosity, and therefore absorption is reduced at high concentrations when osmotic potential and viscosity are higher (MacInnis and Nathawad, 1980). Low concentrations are similar to water in that they do not have a sufficient quantity of dissolved ions to fill pores and increase the rigidity of the pores. Pessimum concentrations may have an adequate supply of dissolved ions to collect in and narrow pore openings so that permeability is reduced. The quantity of dissolved ions in the pessimum concentration may not be abundant enough to increase the pore rigidity. The effect described above increases at lower temperatures when salt solution viscosity is increased and permeability is decreased. Liquid flow through the pores is retarded or inhibited on freezing resulting in hydraulic pressures and damage (Litvan, 1973; Williams and Robinson, 1981).

Some salts, like calcium chloride, will cause more scaling in a wet-dry thermal cycling environment above the freezing level. Sodium chloride does not produce scaling in wet-dry cycling above freezing. In the presence of deicers, freezing and thawing is the most severe environment affecting concrete durability (Verbeck and Klieger, 1956; Boies and Bortz, 1965).

The best methods for reducing scaling include having adequate amounts of entrained air, at least a minimum curing period for hydration and sufficient time for the concrete to dry before deicer exposure (Klieger, 1956). To measure the effectiveness of these methods, as well as to compare various deicers, ASTM C672 concrete block scaling test can be used.

The mechanisms behind scaling are not very well understood. The mechanisms causing microcracking are better known (Pigeon, 1989) and will be described next.

d) D-Cracking

D-cracking is caused by water freezing in the paste and aggregate. Freeze-thaw cycling will cause parallel cracks to form along joints or edges in concrete called deterioration lines

(Cordon, 1966). The first sign of D-cracking is the discolouration or staining at joints and then cracking (Stark and Klieger, 1973).

During freezing, cracking failure is a result of the excess water in the saturated aggregate being expelled into the paste causing expansion (Marks and Dubberke, 1982; Dubberke and Marks, 1985). The Portland Cement Association has performed research on the mechanism of D-cracking and found that damage is more common in concrete containing sedimentary rocks. Sedimentary rocks vary significantly in composition and structure but they found aggregate with a carbonate and silicate composition (limestone to dolomite) to cause the most deterioration (Stark, 1976). Limestone and dolomite rocks are more common than other rock types in construction. This may be the reason for a greater number of D-cracking occurrences discovered by the Portland Cement Association when sedimentary rocks were used. If 15 percent or more of nondurable rock is included in concrete, there will be detrimental effects. Nondurable rocks (including limestone and dolomite) have a dominant pore size in the range from 0.04 to 0.2 microns and can be classified as fine pored. Aggregates having either coarse or extremely fine pores have a durable service record as far as D-cracking is concerned (Marks and Dubberke, 1982).

Cordon (1966) suggests the most probable theories on D-cracking. Since cracks and joints are exposed to more water, their degree of saturation is greater during freezing. When the forces on freezing exceed the tensile strength, cracking may form parallel to joints at lines of equal saturation. In corners and edges during temperature changes, there are stress concentrations built up which produce vertical and horizontal cracks. Parallel cracks form along the corners and edges when more water is available on continued freezing and thawing (Cordon, 1966).

Deicing salts can contribute to D-cracking failure. Some primary and secondary roads were compared in Iowa. Only two variables existed: cement and deicer content. The secondary roads were produced with a lower cement content and had a lower sodium chloride dosage during winter time deicing. Primary highways with their higher cement content, which should produce a more durable structure, deteriorated by D-cracking (Dubberke and Marks, 1985). Thus, D-cracking can be accelerated by a higher concentration of salt, probably because of the increased saturation of the salt susceptible aggregates. Boies and Bortz (1965) also showed that higher concentrations tend to produce deep cracks in mortar rather than surface scaling. Their testing was performed with various sodium and calcium chloride concentrations.

ASTM C666 (test for the resistance of concrete to rapid freezing and thawing) can be used as a potential measure of D-cracking. It was not specifically designed for D-cracking but can be used as a measure of freeze-thaw deterioration due to microcracking.

C Deicers in the Environment

Many environmental concerns are raised over the use of deicers. A deicer should have a minimal effect on the ecosystem in order to be considered. Some of the main deicers (mentioned in **Tables 2** and 3) will be compared in terms of the behaviour of their cations and anions.

The chloride ion can play a major role in the corrosion of metal, as described earlier. It can also contaminate our water supply. If continued excessive use of chloride deicers is maintained, the recommended drinking water limit of 250 mg/L for chloride may be exceeded by the year 2075 (Rabideau et al., 1987). Chloride anions are also highly mobile in organic soil systems in contrast to cations that are generally absorbed (Brady, 1974; Wilcox, 1986).

Excessive use of acetate deicers could be a problem. Acetates are routinely used for metal removal from the soil and sustained use will elevate the soil pH (Elliott and Linn, 1987). Acetates are also a food substance for lower life forms. In the presence of acetate, the lower life forms flourish, thus increasing the oxygen demand (Horner, 1988). If acetate is produced from agricultural waste containing phosphorous, algal blooms will blossom, the oxygen supply will be depleted and eutrophication of small ponds and lakes will be the end product over time (Encyclopedia of Chemical Technology, 1978; Horner, 1988).

Phosphates are used as builders (an abrasive or filler added to cleaning agents to increase their effectiveness) (Webster, 1989) in detergents and function as a water softener. Before phosphate enters the treatment plant, it is necessary to reduce the phosphate content since it can pass unchanged. Excess amounts in the water supply can be traced back to fertilizers, human excrement and detergents (trisodium polyphosphate) (Encyclopedia of Chemical Technology, 1978).

Sodium is known for its ability to increase hypertension in humans (Jones and Hutchon, 1983; Horner, 1988) and can be a veritable health hazard to bottle fed infants (Jones and Hutchon, 1983). Sodium is often used to reduce water hardness and a limit of 20 mg/L has been set for potable water.

Soils have a proclivity for cations, especially peat soils with a high binding capacity. Sodium is weakly retained compared to other cations, such as calcium, which is the least mobile (Brady, 1974; Wilcox, 1986). The increasing tendency for cations to exchange with and mobilize bound metals is proportional to decreasing ionic strength in the following ionic strength order:

$Li^+ > Na^+ > K^+ > H^+ = Mg^{2+} > Zn^{2+} > Ba^{2+} > Ca^{2+} > Cu^{2+}$ (Horner, 1988)

Lower ionic strength divalent cations such as calcium and magnesium increase water hardness and often precipitate as carbonates so that there is less effect on water density stratification (varying levels of water density due to the difference in water hardness caused by dissolved ions) (Dunn and Schenk, 1979, 1980; Horner, 1988). Calcium and magnesium divalent cations improve the soil structure (Baver, 1948; Lyon and Buckman, 1948; Russel, 1950; Dunn and Schenk, 1980; Horner, 1988) while monovalent cations (sodium) can cause structural breakdown (Baver, 1948; Lyon and Buckman, 1948; Russel, 1950; Dunn and Schenk, 1979, 1980; Jones and Hutchon, 1983; Horner, 1988) by reducing air and water permeability in the soil and creating serious agricultural problems (Joffee, 1949; Dunn and Schenk, 1980; Horner, 1988). Monovalent cations will more easily be displaced into solution (removal of nutrients out of the roots) (Jones and Hutchon, 1983; Horner, 1988) whereas divalent metals are more strongly held by exchangers in the soil (Horner, 1988). The monovalent cation of potassium is an exceptionally important cation since it is a requirement for plant metabolism (Encyclopedia of Industrial Chemical Analysis, 1966). It has been shown that an adequate amount of monopotassium phosphate helps to produce the best results in plant growth (Barrett et al., 1986).

Sodium chloride can seriously affect roadside vegetation by reversing the osmosis gradients necessary for water uptake in plants. The result is dehydration (Wyatt and Fritzsche, 1989). Rock salt can stimulate the release of toxic heavy metals such as mercury (Jones and Hutchon, 1983; Elliott and Linn, 1987; Horner, 1988) and lead (Oberts, 1986) from the sediments. Moose are even affected by rock salt since they are attracted to roadside brine pools as a seasonal dietary demand. Occasionally, they become a road-kill statistic (Jones and Hutchon, 1983).

There are various pathways by which sodium chloride, or any other deicer, can contaminate the ecosystem. As an airborne pollutant (powder or spray), between 1 and 10 percent of the total deicer applied has the potential to cover plants, such as conifer trees that are vulnerable to salt spray since they photosynthesize in the winter. Water borne deicer can take over a year to be removed so that there is an accumulation from year to year. The water borne deicer can infiltrate into the soil as sodium and chloride ions to affect deciduous trees and other plants through their root system. Surface waters are also seriously affected since the dissolved oxygen is reduced and fish mortality increases (Jones and Hutchon, 1983). Sodium and calcium chlorides can cause density stratification in natural waters and promote the growth of blue-green algal blooms that pose a nuisance to aquatic life (Horner, 1988).

CMA, which is biodegradable (Horner, 1988) and less toxic than sodium chloride (Elliott and Linn, 1987), is not without environmental problems. At high concentrations (0.5M concentration is the upper limit expected to be found in nature) (Winters et at.,1984; Elliott and Linn, 1987), CMA can remove significant amounts of metals from the soil, increase water hardness, increase osmotic stress, increase oxygen demand (Horner, 1988) and increase organic loadings at treatment plants (Rabideau et al., 1987). On the positive side, calcium and magnesium cations in CMA can increase the soil permeability up to twenty times without severely affecting hydraulic conductivity. Also, vegetation and fish are benign to CMA at low concentrations (Horner, 1988).

Each deicer alternative has positive and negative environmental side effects. They must be individually weighed and contrasted to determine the deicer with the greatest benefits.

D Measures for Improving the Durability of Concrete

Of all the methods for improving concrete durability, adequate air entrainment is the most effective method for preventing expansion and cracking of concrete by freezing because so much concrete is produced at water/cementaceous materials ratios greater than 0.40 (Whiteside and Sweet, 1950; Klieger, 1956; Cordon, 1966; MacInnis, 1968; Anonymous, 1935; Detwiler et al., 1989). Hardened paste has a higher porosity (higher capacity for freezable water at high water/cementaceous materials ratios) and lower permeability than most aggregates. Therefore, paste has a higher capacity to hold more unfrozen water below the normal freezing point (Powers, 1955). The use of air entrainment is not always required to produce freeze-thaw resistance. For example, high strength concretes do not require additional air (Gagne et al., 1991; Kukko and Matala, 1991) even at minimum curing period of 24 hours (Gagne et al., 1991).

Air entrainment is effective in concrete for a limited time (that depends on the rate of water absorption to a critical saturation degree) when concrete is continuously exposed to a source of water. In such a situation, it can only be used as a method of delaying deterioration. Freezing and thawing of concrete in the saturated state causes water to form larger passage ways as it moves towards the air bubbles so that permeability and saturation are increased.

Hooton (1993) suggested a 10 percent replacement of cement with silica fume to improve durability. Concrete samples with this silica fume content underwent 900 freeze-thaw cycles in the ASTM C666 test with minimal damage. This may have been caused by silica fume concrete becoming internally self-desiccated since unreacted silica fume would react with the available water. Permeability would be decreased on continued silica fume hydration (Hooton, 1993).

Water/cementaceous materials ratio is the next most important feature for durable concrete. A lower ratio is better especially if no air entrainment is used (MacInnis, 1968) but there is a minimum ratio required when air entrainment is used. Powers (1964) described the formation of air bubbles as only possible if there is a sufficient amount of water available. Water must form a film around each bubble but at low water contents, solid surfaces tend to be covered first so that the air bubbles and solids compete for the available water. Below a certain water/cementaceous materials ratio, the efficiency of air entrainment is reduced (Marchand et al., 1991). The advent of superplasticizers enables us to achieve very low water/cementaceous materials ratios without significant increases in the cement content.

Aggregate testing is very important for durability but it should be undertaken while in concrete instead of testing the aggregate alone (Whiteside and Sweet, 1950; Detwiler et al., 1989). Some testing procedures of concrete have extremely harsh environments and are not realistic when compared to field conditions. There are many instances of concrete failing lab testing, yet showing satisfactory field performance. When performing tests on concrete, it is important not to use accelerated curing methods. This often alters the pore structure so that it is less finely divided and more water can become freezable (Detwiler et al., 1989).

Many steps can be taken to effectively protect concrete from durability problems caused by freezing and thawing with deicing salts as summarized in **Table 4**. This list includes some of the more preferred methods of protection that will result in durable concrete.

TABLE 4: Measures for Improving the Durability of Concrete

Measure to be Taken	References
Adequate entrained air (>4%)	1, 3, 23, 31, 33, 58, 63, 70, 72, 86, 87, 104, 107, 109
Air bubble spacing factor of 0.2mm (0.008 inches)	1, 3, 31, 33
Low water/cementaceous materials ratio (<0.5)	1, 31, 33, 107
Sound aggregate and quality materials	1, 31, 107
Silica fume	50
Good construction practices	1, 31
Minimize vibration	107
Allow bleed water to disappear without rapid drying	31, 107
Minimize surface finishing	107
Proper curing (minimum time and proper procedures)	1, 31, 33, 58, 70, 107
Seal with linseed oil (allowing evaporation) after curing	31, 107
No freezing exposure until 3.4MPa (500psi) strength	1, 31, 58, 107
No deicer exposure until 3 months old	31, 107
No ammonium salts or sulphate exposure	107
Minimum 28 day strength of 24MPa (3500psi)	107
Proper drainage of hardened concrete	31, 107
Minimize moisture exposure	1, 31

EXPERIMENTAL PROCEDURES

The experimental program consisted of five parts: solution preparation, ice melting, mortar scaling, metal corrosion and superphosphate analysis. The three processes of ice melting, mortar scaling and metal corrosion are the most important for determining the best deicer. Because standard tests to measure these processes were either nonexistent or difficult to perform on a large number of samples, nonstandard tests were devised based on standard tests. Test conditions were such that increased ice melting, mortar scaling or metal corrosion were promoted. Parts of various standard ASTM tests were incorporated into simple test procedures. Though all tests were nonstandard, the results were directly comparable and can be used to rate the various combinations of deicing salts.

A Solution Preparation

The various deicers and deicer mixtures were prepared as solutions whose concentrations were expressed as a molality (M). The phosphate salts were selected because they were monovalent and it has been shown that monovalent deicers are superior to multivalent deicers (Hudec et al., 1992).

Solution preparation consisted of adding a specific number of moles of salt to a measured weight of solvent. Deionized-distilled water was used as the solvent in all cases. CMA and monocalcium phosphate had to be ground to powder form because of their low solubilities. CMA was ground to passing #50 sieve (300 microns) while monocalcium phosphate was ground to passing #100 sieve (150 microns). Monocalcium phosphate was ground finer than CMA because CMA was used as a deicer in the experiments without removing any of its impurities. Monocalcium phosphate, on the other hand, is the main component in superphosphate (commercially available agricultural phosphate). Finer grinding of superphosphate allowed the monocalcium phosphate to dissolve more readily. After 24 hours of dissolving, the superphosphate solution was filtered to remove the insolubles. The solvent passing the filter was used for all experimentation involving monocalcium phosphate.

The salt/chloride mixtures were prepared to a 0.5M total concentration. In each of the mixtures, a specified salt (phosphate, potassium acetate or CMA) molality was prepared and the chloride salts made up the difference to a 0.5M solution. For example, a mixture containing 0.005M NaH_2PO_4 and 0.495M NaCl has a sodium cation concentration of 0.5M (0.5 moles of sodium cation per 1L of solvent).

The prepared deicer solutions were stored and sealed in cleaned, single gallon (U.S.), plastic jugs. The freshly made solutions remained at room temperature (approximately 20°C) before use except when required to equilibrate in the freezer for ice melting experiments.

Tables 5a and **b** are summaries of the experiments performed

TABLE 5A: Experiments Performed with Various Concentrations of Salt Solutions

Salt	0.05M	0.1M	0.2M	0.5M	2.0M	3.5M
NaCl	--	--	s m c	s m c	s m c	s c
CaCl2	--	--	s m c	s m c	s m c	s c
KC2H3O2	--	--	s m c	s m c	s m c	s c
CMA	s c	s c	s c	s m c	--	--

TABLE 5B: Experiments Performed with Salt Solutions of Various Molality Ratios

Salt / Chloride Mixture	0.001/ 0.499	0.005/ 0.495	0.01/ 0.49	0.02/ 0.48	0.03/ 0.47	0.04/ 0.46	0.05/ 0.45	0.1/ 0.4	0.2/ 0.3	0.4/ 0.1
NaH2PO4 (+ NaCl)	s c	s c	s c	s m	s	s	s m c	--	--	--
NaH2PO4 (+ CaCl2)	--	--	s	s m	s	s	s m	--	--	--
KH2PO4 (+ NaCl)	s c	s c	s c	s m	s	s	s m c	--	--	--
KH2PO4 (+ CaCl2)	--	--	s	s m	s	s	s m	--	--	--
Ca(H2PO4)2*H2O (+ NaCl)	s c	s c	s c	m	--	--	s m c	--	--	--
Ca(H2PO4)2*H2O (+ CaCl2)	--	--	s	m	--	--	s m	s	s	s
KC2H3O2 (+ NaCl)	s c	s c	s c	--	--	--	s c	--	--	--
CMA (+ NaCl)	s	s	s	m	--	--	s m	--	--	--
CMA (+ CaCl2)	--	--	--	m	--	--	m	--	--	--
NaH2PO4 Pretreatment	--	--	--	--	--	--	s	--	--	--
KH2PO4 Pretreatment	--	--	--	--	--	--	s	--	--	--
Ca(H2PO4)2*H2O Pretreatment	--	--	--	--	--	--	s	--	--	--
Deion-Distill Water (Control)	s m c	--	--	--	--	--	--	--	--	--
Air (Control)	s c	--	--	--	--	--	--	--	--	--

Note: s = mortar surface scaling and compressive strength, m = ice melting, c = metal corrosion using the various salt solutions. It includes the salts and salt mixtures used in mortar scaling, ice melting and metal corrosion experiments. It should be noted that all mortar scaling cubes underwent compressive strength testing 3 weeks (drying) after the completion of freeze-thaw cycling.

B Ice Melting Tests

To test the ice melting effectiveness of the salts and salt mixtures, deionized-distilled water was frozen in the shape of 'popsicles' on plastic stir sticks. The popsicles were approximately 75mm (3 inches) long and 55mL (1.75fl.oz.) in volume. Three popsicles were submerged vertically in each 3L (96fl.oz.) ice melting solution for 4 hours. To ensure that solution temperatures were similar to the freezer temperature, solutions were stored in the freezer overnight before testing. Ice weight measurements and solution temperatures (approximately -1.0°C) were monitored once every half hour. Since some solutions had a tendency to 'slush up' and begin to freeze at the temperatures of testing, the solutions were continuously stirred using constant velocity magnetic stirrers. **Figures** 3 and **4** are photographs of the ice melting setup for stirring and for measuring, respectively.

In taking weight measurements, excess melt water was shaken off the popsicles. The popsicles were exposed to the freezer air for 2 minutes during weighing, then replaced into their solution. Up to five different salt solutions were tested in a 4 hour period.

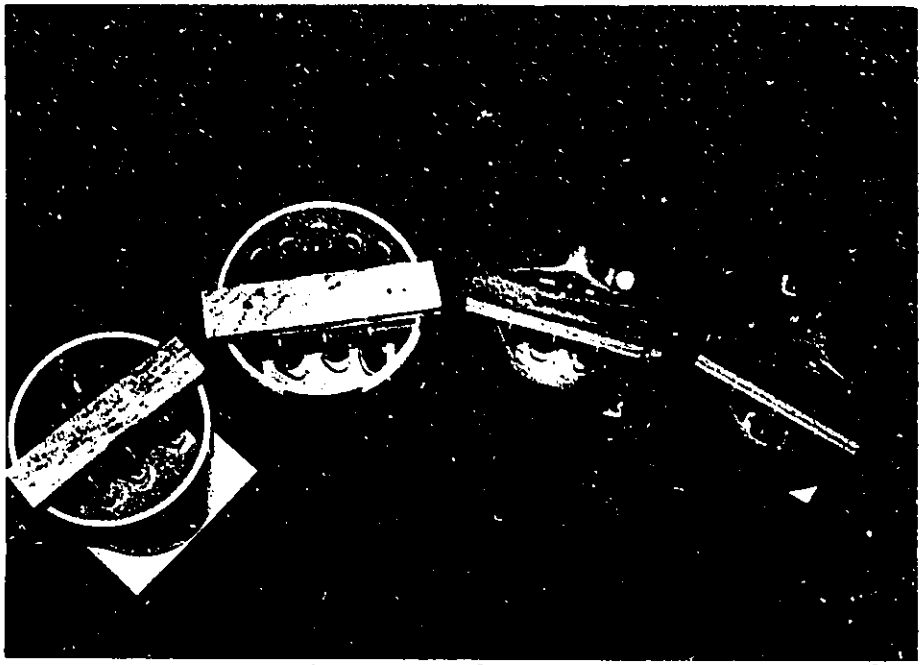
FIGURE 3: Ice Melting Experimental Set Up for Stirring

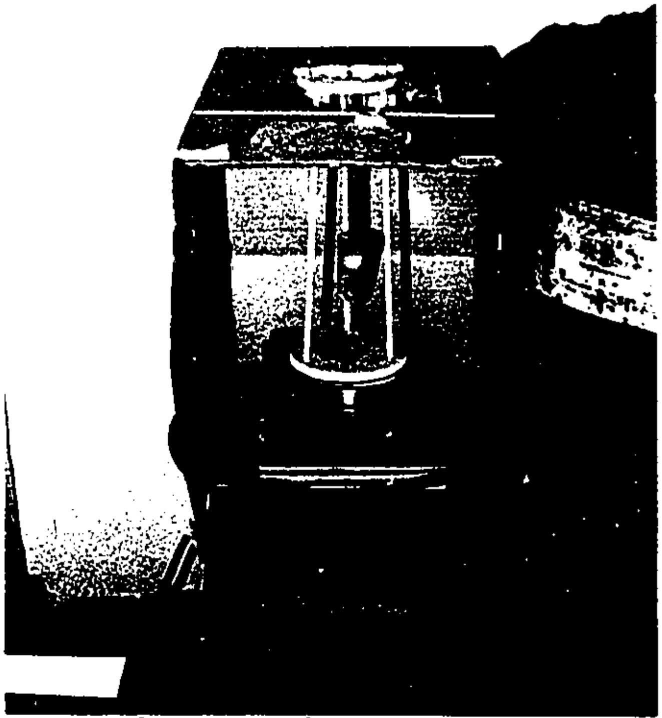
FIGURE 4: Ice Melting Experimental Set Up for Measurements

Although most solutions remained frost free in the freezer (0.5M sodium chloride will begin to freeze at approximately -1.7°C (Chemical Rubber Company, 1993)), some began to slush up and cause weight gain of the popsicles. The speed of the magnetic stirrer was increased and maintained overnight before testing to minimize the slushing of the solutions. The slushing solutions were: 0.02M KH_2PO_4 (monopotassium phosphate) + 0.48M NaCl, 0.2M $CaCl_2$, 0.2M $KC_2H_3O_2$ (potassium acetate), and deionized-distilled water. Solutions with 0.1M CMA and 0.2M CMA also slushed up and could not be melted. Thus, no results were obtained for these two CMA solutions.

C **Tests on Mortar Specimens**

The tests carried out on mortar specimens included scaling tests on mortar cubes and mortar blocks during freezing and thawing and compressive strength tests on the mortar cubes at the conclusion of the freeze-thaw cycling. Each of these will be described as follows.

(i) **Materials**

In order to accelerate the deterioration of mortar, a known frost susceptible, shaley sand aggregate (from Erie Sand and Gravel, Leamington, Ontario) was used. Two samples of the sand were procured (Lots #1 and Lot #2). The fineness modulus for Lots #1 and 2 were 3.48 and 3.20, respectively. The sieve analysis is shown in **Figure 5**. Bulk specific gravity (saturated surface dry) and absorption were measured according to ASTM C128-88. For unwashed and washed aggregates of Lot #1 and washed aggregate of Lot #2, the bulk specific gravity and absorption results are shown in **Table 6**. Absorption was noted as being very high.

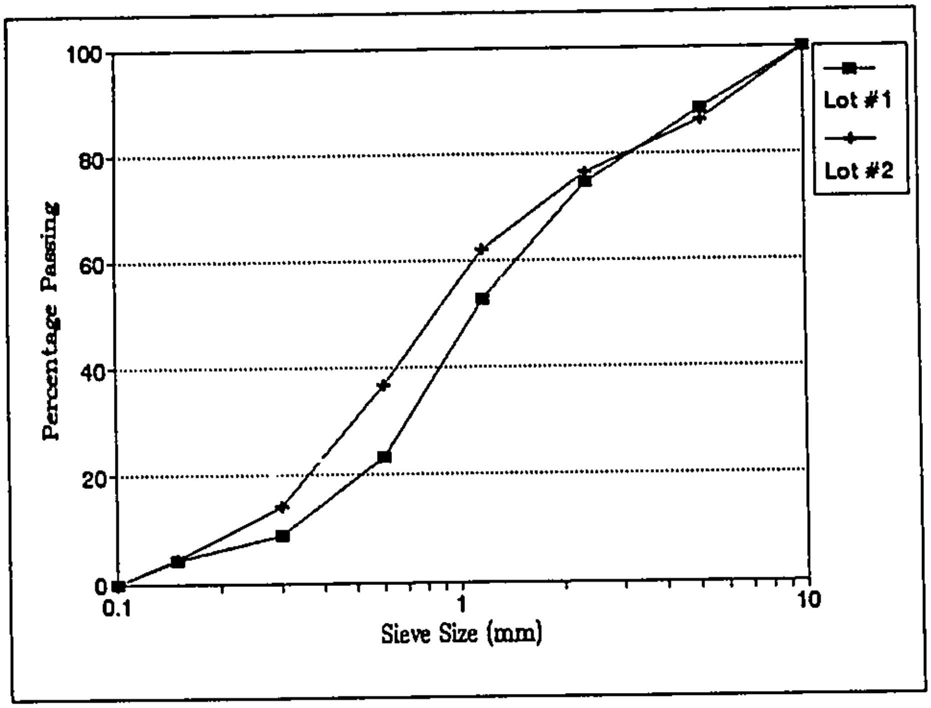

FIGURE 5: Sieve Analysis of Shaley Sand

TABLE 6: Bulk Specific Gravity and Absorption for Shaley Sand

Sand Lot No.	**Bulk Specific Gravity**	**Absorption (%)**
1 (unwashed)	2.56	3.67
1 (washed)	2.57	2.72
2 (washed)	2.57	2.95

The cement type used for mortar mixtures was Type 10. One bag was purchased from a local supplier.

(ii) Mortar Cube Scaling Tests

The only standard test for measuring scaling resistance of concrete is ASTM C672-91 and it requires large sample blocks for testing. For this series of tests, it was impractical to use such large quantities of materials so a new test was developed using smaller samples. More small samples could be tested under similar conditions simultaneously. The sample size used was 5cm (2 inch) mortar cubes.

Approximately one hundred cubes could be physically processed and cycled at one time. Two stages of mortar cube scaling tests were performed. Stage 1 used Lot #1 aggregate and Stage 2 used Lot #2 aggregate. This allowed for a wide variety of salt concentrations to be tested.

The mortar mixture design for Stages 1 and 2 was proportioned according to ASTM C109-90 and consisted of the following: a water/cementaceous materials ratio equal to 0.50 and a cement/aggregate ratio equal 1 : 2.75.

The fine aggregate was graded according to ASTM C227-88 using sieves #8, 16, 30, 50 and 100 (2.36, 1.18, 0.6, 0.3 and 0.15mm).

Stages 1 and 2 had slightly different mixing procedures since the mix sizes were different. In Stage 1, an 85L ($3ft^3$) barrel type mixer was used with the following mix procedure:

1) prewet mixer and equipment

2) add aggregate and half required water
3) start mixer and add cement and remaining water
4) mix for 3 minutes
5) stop mixer for 3 minutes and cover
6) mix for 2 minutes
7) stop mixer, measure flow and unit weight
8) remix for 30 seconds

It was found that this mixing procedure may be fine for concrete, but not for mortar. Cement balls were noted in the mortar. The mixture characteristics were as follows:

1) flow = 80 (according to ASTM C230-90)
2) unit weight = 2101 kg/m^3 (3553 lbs/yd^3)
3) air content = 6.3 percent (approximately)

The air content was estimated by comparing the measured and design unit weights and assuming deviations were caused by a variation in the air content.

To mix the mortar ingredients in Stage 2, an 11L (2.4 gallon) capacity, variable speed, mortar mixer was used for three consecutive batches, according to the steps outlined in ASTM C305. The mixture characteristics were as follows:

1) flow = 79
2) unit weight = 2167 kg/m^3 (3664 lbs/yd^3)
3) air content =3.4 percent (approximately)

For both Stages 1 and 2, three mortar slabs 36x36x5cm (14x14x2 inches) were cast, cured then sawn into thirty-six cubes each. After 24 hours curing at 100 percent humidity followed by 20 days immersion in a saturated lime water solution, sawing was performed. The sawing allowed for each cube to have four sawn surfaces, one moulded surface and one unfinished surface. After sawing, the cubes were labelled and allowed to air dry for 5 to 7 days.

Two types of control cubes were used for comparisons in the mortar scaling tests. One set of cubes was allowed to air dry outside of the freezer while freeze-thaw cycling was being performed. Another set of cubes was placed in deionized-distilled water and underwent freeze-thaw cycling with the cubes exposed to deicer solutions.

By comparing the mixture characteristics, it was forecast that Stage 2 samples would outperform Stage 1 samples. Scaling results from salt solutions used in both mixes were used for comparing the results in Stages 1 and 2 to determine if there was a significant difference in the two stages.

Since all cubes undergoing freeze-thaw cycling were initially dry before cycling, the water absorption due to cycling could not be determined. In plots of weight change versus freeze-thaw cycles, most solutions had an initial weight gain from water absorption due to freeze-thaw cycling. To estimate the water absorption in Stage 1 cube data, the water absorption data from the control cubes was used. The control cubes were not exposed to deicers, therefore water absorption was due to cycling alone. This value of water absorption was used as an estimate in the data for cubes in salt solutions (Stage 1). To minimize the effect of weight gain due to water absorption in Stage 2 cube data, the cubes were soaked for an additional 7 days after drying, weighed then dried again for 7 days. This wet weight was used as the initial weight in calculating weight change for Stage 2 cubes.

In preparation for freezing, sets of three cubes were placed, unfinished surface down, in 1.2L (9.6fl.oz.) containers with plastic mesh at the bottom. The plastic mesh was used to allow the flow of solution to the mortar surface undergoing scaling. Approximately 6mm (0.25 inches) depth salt solution was placed in the containers. The containers remained uncovered throughout the experiment.

The cubes in their containers were placed in the walk-in freezer and freeze-thaw cycling was carried out according to ASTM C672-91. The specimens remained in the walk-in freezer at approximately -17.7°C for 16 to 18 hours and were then removed to room temperature (approximately 20°C) for 6 to 8 hours of thawing. During periods of noncycling, such as weekends, the cubes remained in the freezer. If the solution level in the containers was below 6mm (0.25 inches), it was topped up with deionized-distilled water during the thawing cycle. It was assumed that volume loss would be due to water evaporation only.

The freezer temperature was monitored twice daily during cycling (when samples were removed from the freezer and when they were replaced). The normal average freezer temperature was -17.7°C. Extremes of -20.5 and -12.0°C were noted and ascribed to the 30 minute automatic freezer defrost period.

The thawing room temperature and relative humidity were also monitored twice a day. These values were different for Stages 1 and 2 since freeze-thaw testing occurred during different seasons of the year. The variations and averages for relative humidity and room temperature for Stages 1 and 2 are summarized in **Table 7.**

TABLE 7: Room Relative Humidity and Temperature Variations

Stage	Relative Humidity (%)			Temperature (°C)		
	Low	High	Average	Low	High	Average
1	16	46	27	16.7	24.5	22.3
2	40	75	54	17.5	23.0	19.9

After every five cycles, the scaled material was lightly rinsed off of the cubes. The cubes were towel dried, weighed, visually observed and photographed. Visual observations were made on the unfinished surface of each cube and rated on a zero to five scale. Zero represents no scaling and five represents scaling of the entire surface. Before replacing the cubes in the freezer, the solution in the containers was replaced with fresh salt solution.

ASTM C672-91 calls for at least fifty cycles of freezing and thawing. Since cube weight change versus time plots were linear, cubes were removed from cycling after forty cycles in Stage 1. Cubes in Stage 2 were removed after twenty five cycles since their plots were also linear.

(iii) Mortar Cube Scaling Tests After Phosphate Pretreatments

Four sets of cubes were used to investigate the possibility of pretreating mortar with a phosphate solution prior to the exposure of mortar to a 0.5M sodium chloride freeze-thaw solution. Testing was performed with Stage 2 scaling cubes using a 0.05M phosphate solution. The phosphate solutions were used to soak the cubes for 7 days and they were: NaH_2PO_4, KH_2PO_4,

$Ca(H_2PO_4)_2*H_2O$ (monosodium phosphate, monopotassium phosphate and monocalcium phosphate, respectively). Deionized-distilled water soaking was used as a control. After soaking and 7 days drying, the cubes were placed in 0.5M sodium chloride solutions for cycling with the other cubes in Stage 2.

(iv) Mortar Block Scaling Tests

To compare the ASTM C672-91 test to the nonstandard scaling test used in this study, two blocks, 23x23x8cm (9x9x3 inches), were cast and tested in Stage 1 with 0.36M calcium chloride (4g in 100mL water) as the deicing salt, according to the specifications. The same mortar mixed for the cube slabs of Stage 1 was also used for the blocks.

(v) Cube Compressive Strength Tests

ASTM C109-88 is the standard test for measuring the unconfined compressive strength of 5cm (2 inch) cubes. To determine the effect of different freeze-thaw salt exposures on cube strength, the mortar scaling cubes (Stages 1 and 2) were tested for their compressive strength. Three cubes were tested before freeze-thaw exposure as a control. The remaining cubes were tested after cycling and approximately 3 weeks drying. Scaling had severely damaged the unfinished, as well as the cut surfaces of the cubes. This made the measurement of surface areas difficult. The surface area was estimated from the ink imprints of the mortar cube sides to be tested. The outline of the imprints were used to determine the surface area using a planimeter and this area was used in calculating the strength per unit cross-sectional area of the specimens.

D Metal Bar Corrosion Tests

A simple test was devised to illustrate the various deicers' potential for metal corrosion. Metal bars 7.5cm (3 inches) long were cut from 3/16 inch steel dowels. Each piece was washed with laundry detergent (no bleach), rinsed with tap water then rinsed with acetone as suggested in ASTM G31-72. The bars were labelled and weighed, then a set of three was placed 'tepee style' in each 250mL (8fl.oz.) container. Each container was filled with a salt solution used in Stage 1 mortar cube scaling to the midpoint of the bar lengths. Evaporation losses were replaced with deionized-distilled water.

Once every 7 days, the solutions were observed and photographed. Bars were rinsed with tap water and lightly brushed to remove salt deposits and corrosion. After towel drying, the bars were weighed (during certain weeks), placed in fresh solution and allowed to corrode for 7 days more. At no time during the experiment were the bars handled without gloves to preclude the possibility of human oils contaminating the bars. Since the bars were approximately 12g (0.4oz.) each and weekly weight loss was small, weight measurements were only taken at 1, 3, 6 and 9 weeks.

E Superphosphate Analysis

The superphosphate analysis consisted of determining the proportions and approximate solubilities of the components making up superphosphate, as well as determining the rate of monocalcium phosphate absorption in mortar. These experiments will be described as follows.

(i) Chemical Composition

The exact chemical composition of superphosphate is not known since it is an industrial or farm grade fertilizer. The literature cites the following composition (United States Department of Agriculture, 1964):

1) $Ca(H_2PO_4)_2*H_2O$	63-73%
2) $CaSO_4$	3-6%
3) $CaHPO_4$, Fe and Al phosphates	13-18%
4) Silica, fluosilicates, unreacted rock, organic matter	5-10%
5) Free moisture	3-6%

With this information, along with assumed solubilities of the above constituents, a simple chemical analysis was performed.

Various concentrations of superphosphate were prepared as described previously. The filtrate that remained was weighed after drying at 105°C to a constant weight. Dry weights were compared to the original superphosphate weight and expressed as an insolubles content (percentage). The measured insolubles content was compared to the calculated insolubles content in a spreadsheet by varying the solubilities and quantities of its chemical components.

(ii) Phosphate Absorption Rate

The pretreatment of mortar with phosphate was investigated as a method to protect concrete from scaling due to deicing salts during freezing. Monocalcium phosphate will precipitate in the pores of concrete and this precipitation helps to minimize the scaling of concrete and the corrosion of metal. The time required for sufficient precipitation of the phosphate pretreatment in mortar was unknown, therefore an experiment was devised to estimate the minimum time required. Monocalcium phosphate was used for investigating the precipitation of phosphate by observing the absorption of phosphate.

Mortar cubes for phosphate absorption were prepared with the same sand, mixer, mixture design and curing procedures as in the Stage 2 cubes. Mixture characteristics were as follows:

1) flow = 81
2) unit weight = 2152 kg/m^3 (3639 lbs/yd^3)
3) air content = 4 percent (approximately)

The rate of drying of mortar cubes was determined as follows. After the cubes were cured and sawn (as in Stage 2 mortar cubes), they were soaked in water for one more day. After removal from water, they were surface dried and weighed. The cubes were allowed to bench dry and were weighed periodically. The amount of drying with time was plotted in **Figure 6**. This graph was used to determine if the cubes that were to be used for the phosphate absorption analysis were sufficiently dry.

After 36 days of drying, the cubes were judged to be adequately dry for the phosphate absorption solution test. The

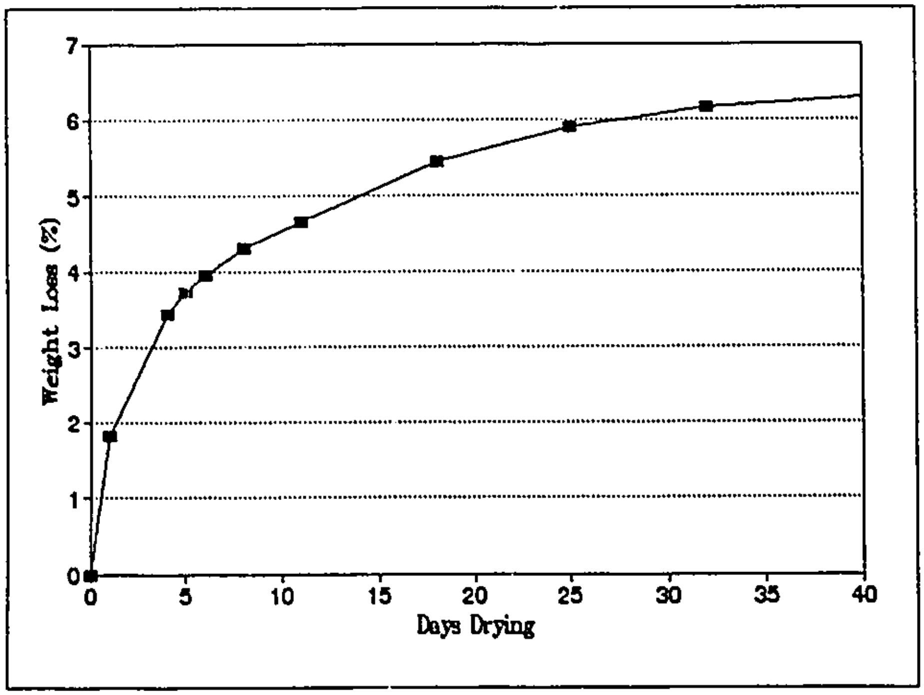

FIGURE 6: Mortar Cube Drying Rate

tests were done in replicates of three for each of the four monocalcium phosphate concentrations. Twelve containers with a volume of 250mL (8fl. oz.) were filled with 140mL (4.5fl. oz.) of solution (each set of three containers had the same phosphate concentration). Twelve 130mL (4.2fl. oz.) mortar cubes were placed in the containers with the solutions. The containers were tightly sealed except during readings. By using an amount of solution similar to the volume of the cube, small changes in the concentration of the solution due to phosphate absorption and precipitation was easier to detect.

The measuring of a solution's weight is easier than measuring its volume. By measuring the weight of a known concentration of phosphate in a volumetric flask, the density was determined. A density calibration curve for monocalcium phosphate concentrations is shown in **Figure 7**. This was used for the monocalcium phosphate solution preparation.

The relative refractive index (RRI) was used as a means of measuring the monocalcium phosphate concentration. A change in RRI corresponded to a change in concentration. This was used to determine the absorption of phosphate from the solution. The RRI was measured with an Abbe refractometer for known concentrations of monocalcium phosphate so that a calibration curve could be plotted as illustrated in **Figure 8**.

The concentrations of the solutions were monitored by measuring the RRI at specific times between 0 and 5,000,000 seconds (57.87 days). A sample of each solution was removed with eye-droppers. Three drops of solution were placed on the refractometer and the RRI was measured. Excess solution in the eye-droppers was returned to its container. The RRI readings were corrected to the deionized-distilled water reading that was taken as zero. Deionized-distilled water was also used to correct for RRI drift due to temperature and other conditions in the lab.

After the final reading was taken, the cubes were removed from their solution, allowed to drip dry for 15 minutes then weighed. The cube solution remaining in the containers was also weighed as a check for the total solution absorbed. A correction for losses of solution due to measuring of the RRI was made by accounting for every drop used in measuring. By counting the number of drops in a known volume, the volume of a single drop (0.02418mL or 0.00077fl.oz.) was calculated. Losses, other than from measuring,

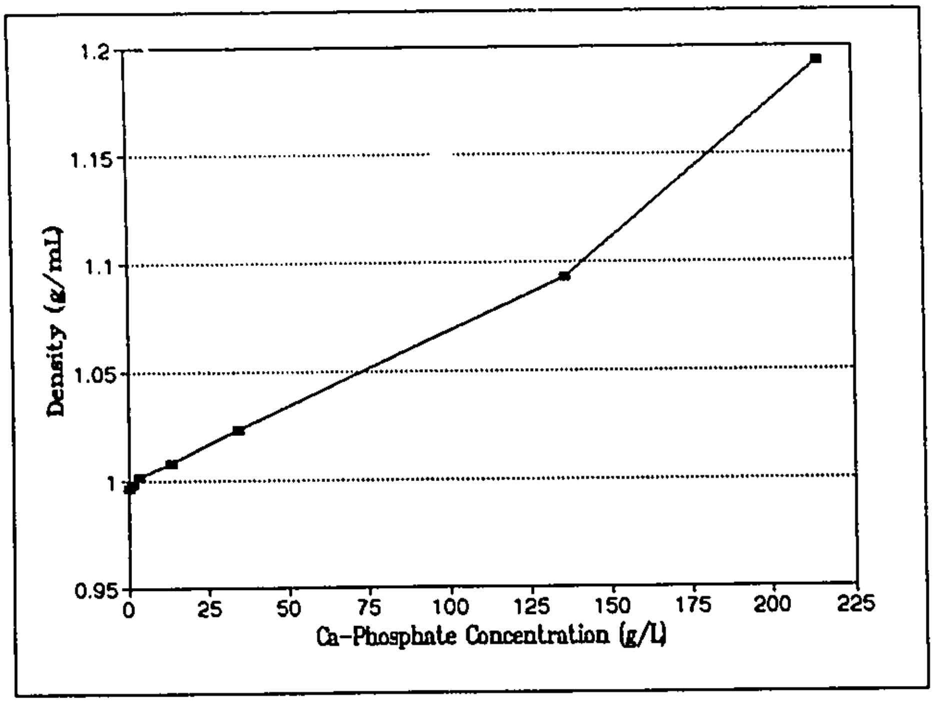

FIGURE 7: Monocalcium Phosphate Density Calibration Curve

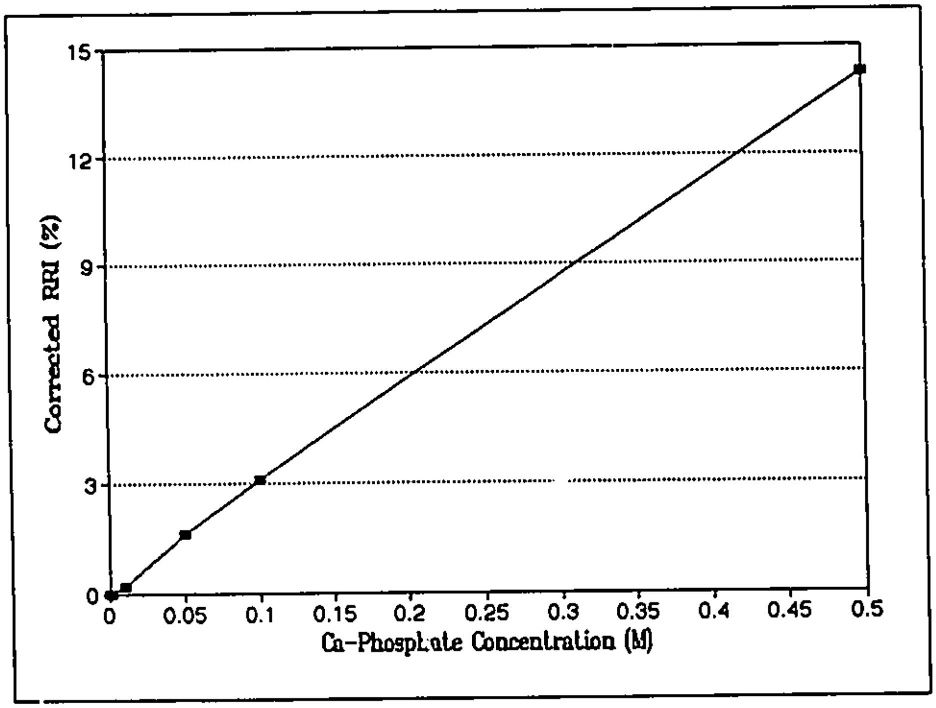

FIGURE 8: Monocalcium Phosphate Relative Refractive Index Calibration Curve

were assumed to be due to evaporation.

EXPERIMENTAL RESULTS

The detailed experimental results are presented in tabular and graphical form in the appendix. Selected figures and tables are presented in this section to highlight the major results of the research program.

A Mortar Testing

Mortar testing consisted of mortar cube scaling, mortar block scaling and mortar cube compressive strength testing. These results will be discussed in the following paragraphs.

(i) Mortar Surface Scale Rating System

According to ASTM C672-91, the values for visual surface rating are as follows:

1) No scaling (rating of zero)
2) Very slight scaling, no aggregate visible (rating of 1)
3) Slight to moderate scaling (rating of 2)
4) Moderate scaling, some aggregate visible (rating of 3)
5) Moderate to severe scaling (rating of 4)
6) Severe scaling, aggregate visible over entire surface (rating of 5)

Figures 9 to 13 are a series of photographs of the monosodium phosphate pretreatment cubes during 25 cycles of freezing and thawing. These photographs illustrate the visual surface scale rating system used in this study for estimating mortar scaling. The cube on the far left (Control 7) was a control cube with a

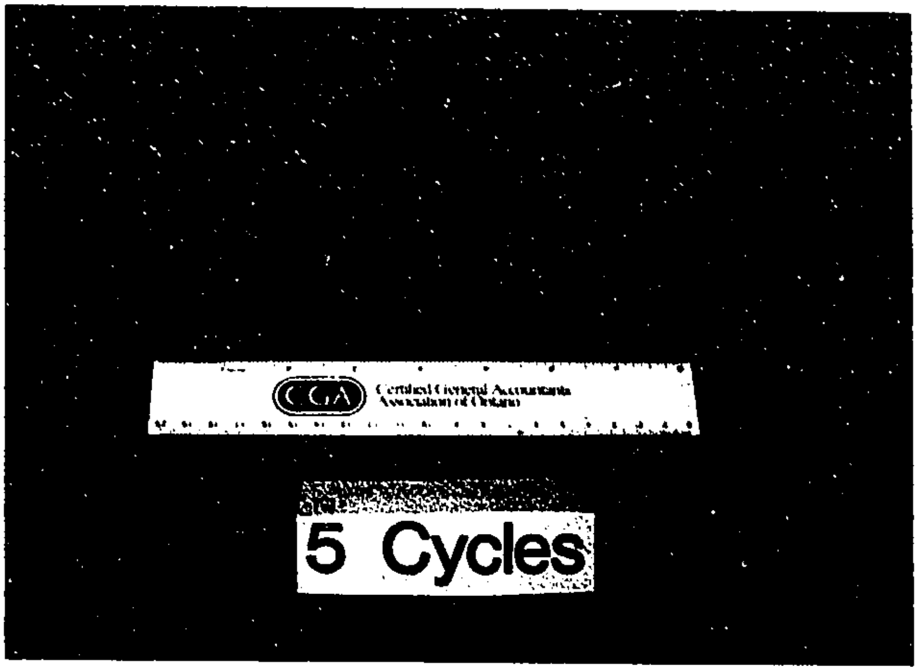

FIGURE 9: Photograph of Mortar Cubes Previously Exposed to a Monosodium Phosphate Pretreatment with a Surface Scale Rating of 1 (5 cycles)

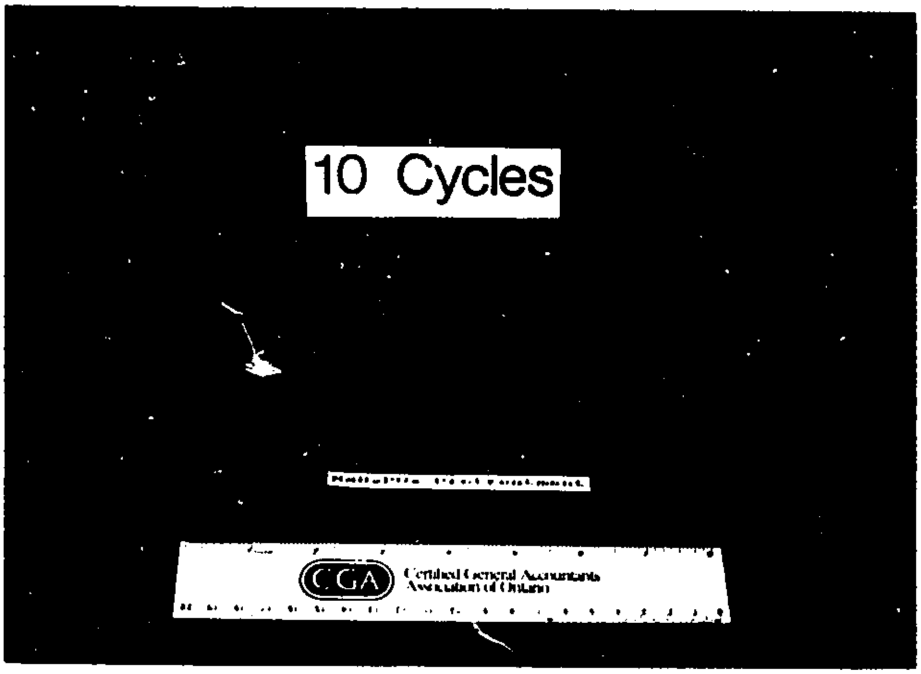

FIGURE 10: Photograph of Mortar Cubes Previously Exposed to a Monosodium Phosphate Pretreatment with a Surface Scale Rating of 2 (10 cycles)

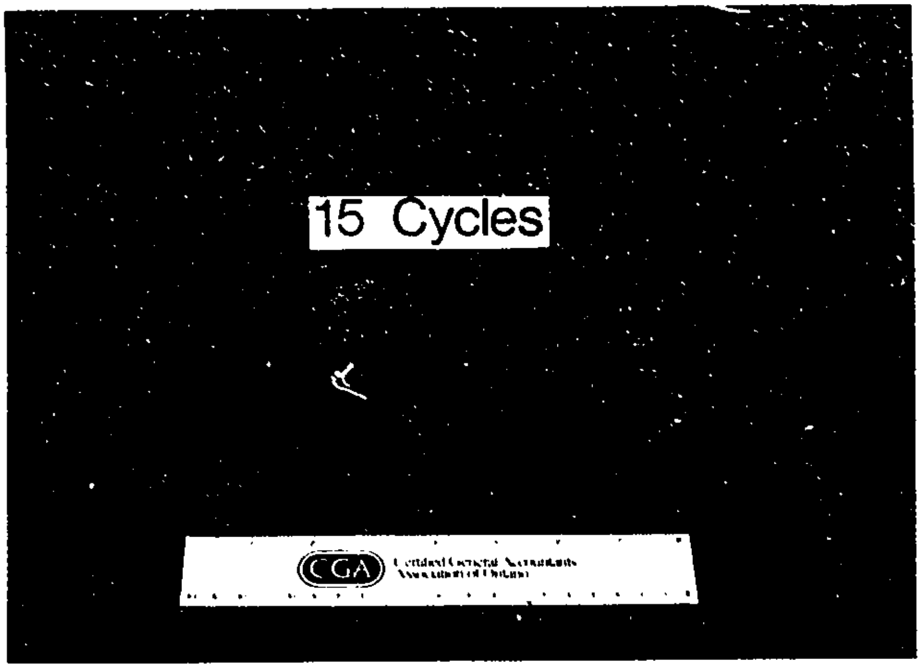

FIGURE 11: Photograph of Mortar Cubes Previously Exposed to a Monosodium Phosphate Pretreatment with a Surface Scale Rating of 3 (15 cycles)

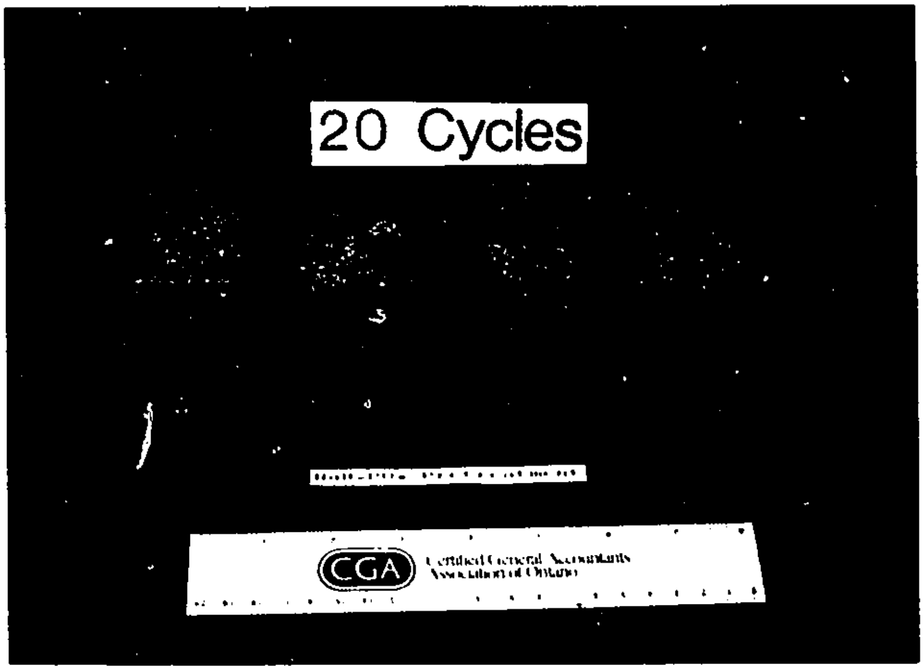

FIGURE 12: Photograph of Mortar Cubes Previously Exposed to a Monosodium Phosphate Pretreatment with a Surface Scale Rating of 4 (20 cycles)

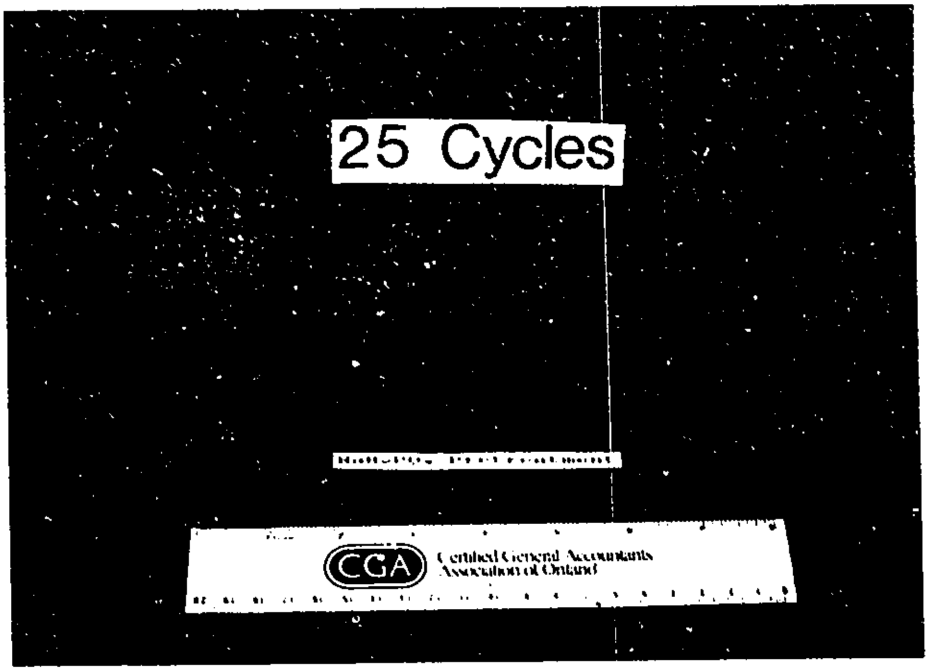

FIGURE 13: **Photograph of Mortar Cubes Previously Exposed to a Monosodium Phosphate Pretreatment with a Surface Scale Rating of 5 (25 cycles)**

surface scale rating of zero. It did not undergo freeze-thaw cycling but remained exposed to the lab air while drying. After 5 cycles, the scale rating was 1 for the pretreatment cubes. For every 5 cycles in this set of cubes, the rating increased by one until the rating was 5 at 25 cycles. The only exception to this trend was the cube on the far right (Na-Pre 3). After 15 cycles of freezing and thawing, this cube was rated as a 3 and remained so until completion of the cycling. The linear trend for surface scaling (scale rating increase of 1 for every 5 cycles) only occurred in the cubes exposed to the monosodium phosphate pretreatment (Figures 9 to 13). All of the other cubes exposed to different conditions had different surface scaling trends. The series of photographs (Figures 9 to 13) is to be used as a reference for the reader to identify the meaning of each scale rating. Note the dark aggregate (shale) exposed at the sites of scaling in **Figures 9** to **13**. **Figures 14** and **15** can be used to compare the weight change over time with the surface scale rating change over time for the monosodium phosphate pretreatment cubes.

(ii) Mortar Cube Scaling Tests

a) Cubes Exposed to NaCl, CaCl$_2$ and KC$_2$H$_3$O$_2$

Sodium chloride produced more scaling weight loss than all of the other salts, including calcium chloride, even when phosphate was used. A maximum scaling by weight loss of over 40 percent after 40 cycles was produced by a 0.5M (pessimum) concentration of sodium chloride (**Figures 16** and **17**). Potassium acetate also had a pessimum of 0.5M, while calcium chloride was between 0.2 and 0.5M. Scaling was less as the saturated solution concentration was approached when sodium chloride, calcium chloride or potassium acetate was used.

b) Cubes Exposed to CMA

When a significant amount of surface scaling was present, it was not always an indicator of significant weight loss since mortar scaling may have been near the surface only and had not penetrated deeply within the mortar. The performance of CMA is a good example of this. The samples treated with CMA (and no chloride) may have had an insignificant amount of weight loss due to scaling (**Figure 18**), but the mortar surface layer was severely

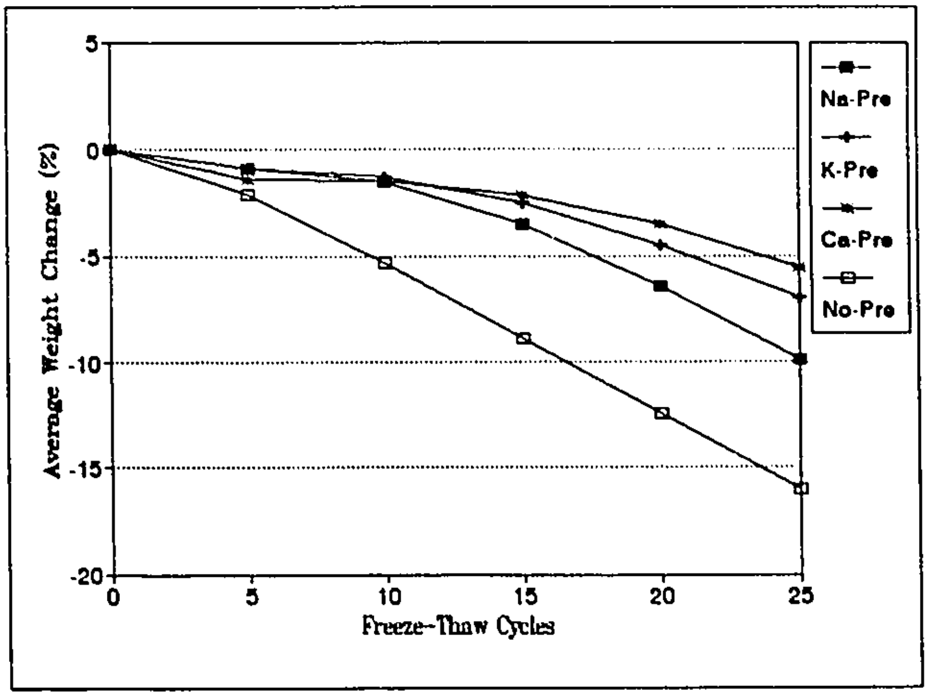

FIGURE 14: Mortar Scaling for Cubes Previously Exposed to Phosphate Pretreatments (Weight Loss Versus Cycles)

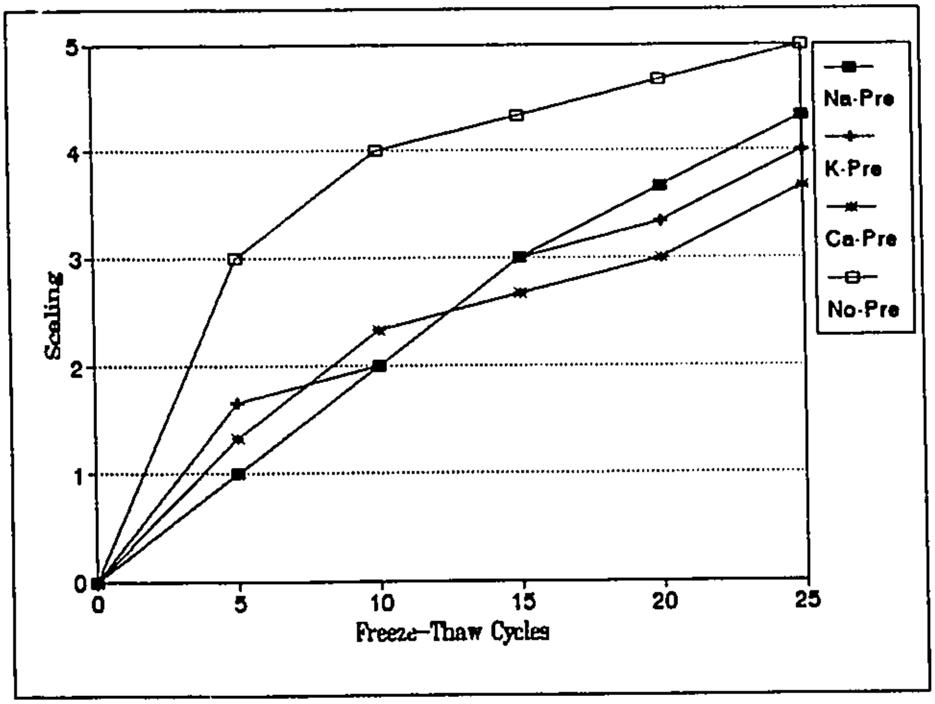

FIGURE _5: Mortar Scaling for Cubes Previously Exposed to Phosphate Pretreatments
(Surface Scaling Versus Cycles)

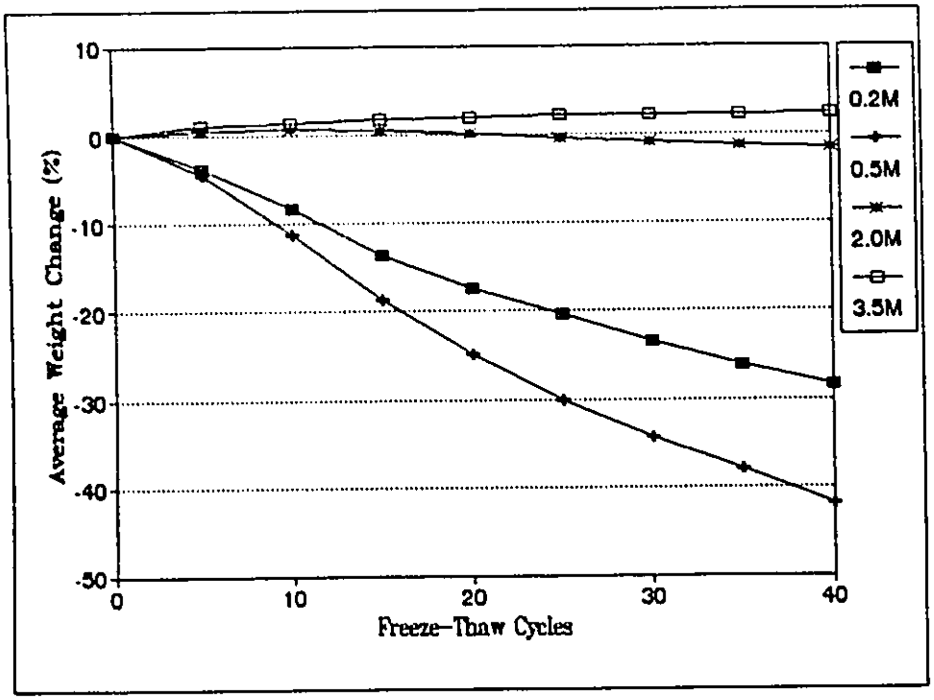

FIGURE 16: Mortar Scaling for Cubes Exposed to Sodium Chloride (Weight Loss Versus Cycles)

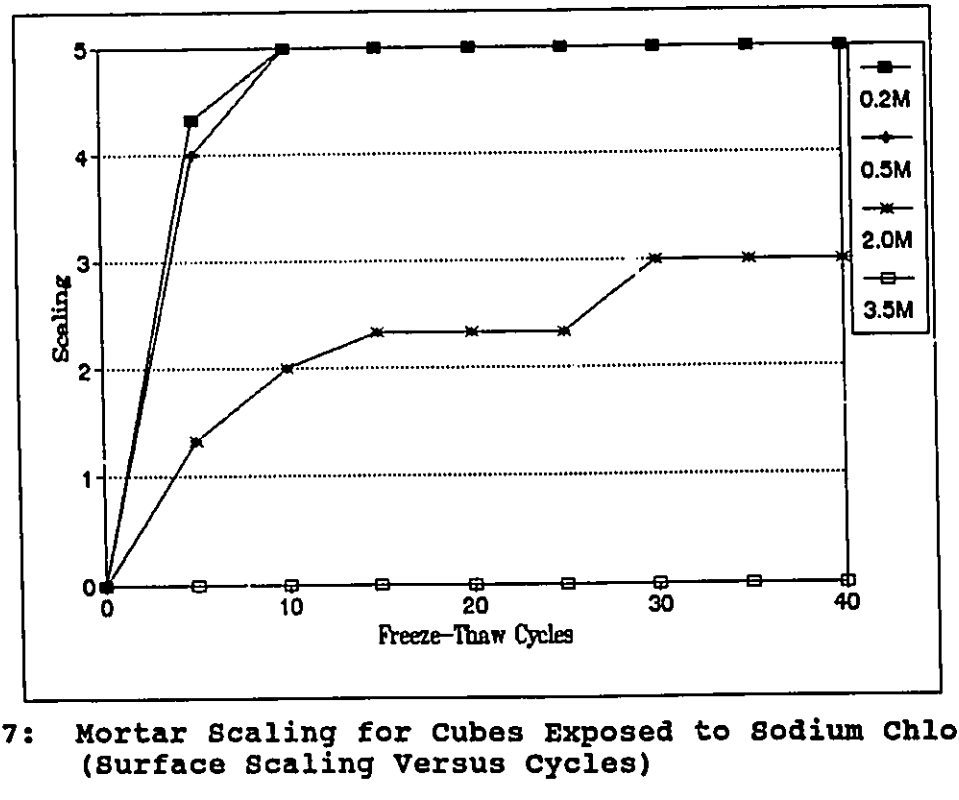

FIGURE 17: Mortar Scaling for Cubes Exposed to Sodium Chloride (Surface Scaling Versus Cycles)

scaled with time (Figure 19) especially at lower molality solutions (0.05M). A pessimum CMA concentration was not observed but may exist below a 0.05M concentration. When CMA was used as a mixture with sodium chloride, at least 0.05M CMA was required in a 0.5M mixture in order to significantly reduce surface scaling and weight loss (Figure 20).

c) Cubes Exposed to Phosphate/Chloride Mixtures

Reduced scaling occurred when phosphate was used in a mixture with chlorides (Figure 21). Monosodium and monopotassium phosphate were the most effective in mixtures with either sodium or calcium chloride, while monocalcium phosphate had the least effect. The minimum amount of phosphate required for minimal surface scaling and weight loss was 0.03, 0.03 and 0.05M for monosodium, monopotassium and monocalcium phosphates, respectively. The lowest concentration of phosphate additive (0.001M) produced greater scaling than the chloride solutions alone in some cases (monosodium and monocalcium phosphate). Figures 22 and 23 are photographs of cubes treated with a 0.5M sodium chloride and 0.05M monosodium phosphate (plus 0.45 sodium chloride) solutions, respectively. Both sets of cubes were from Stage 1 mortar scaling tests after 40 cycles. These figures clearly illustrate the effect of adding phosphate to sodium chloride. The large grey clumps (especially in the sodium chloride cubes) are balls of hydrated cement showing the poor mixing that occurred during Stage 1 mixing procedures. The addition of phosphate to a chloride solution was equally effective

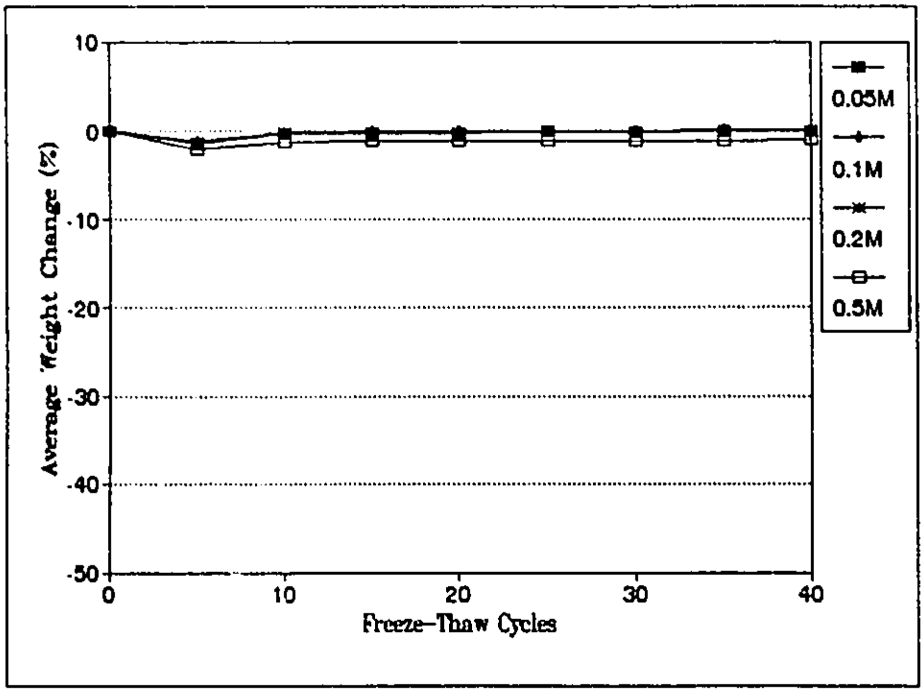

FIGURE 18: Mortar Scaling for Cubes Exposed to CMA (Weight Loss Versus Cycles)

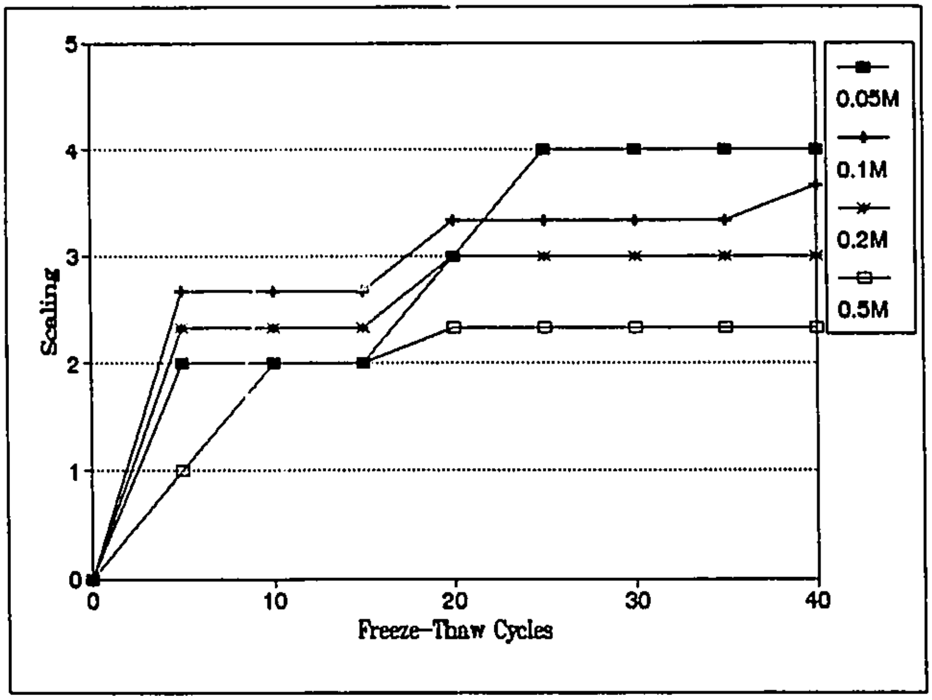

FIGURE 19: Mortar Scaling for Cubes Exposed to CMA (Surface Scaling Versus Cycles)

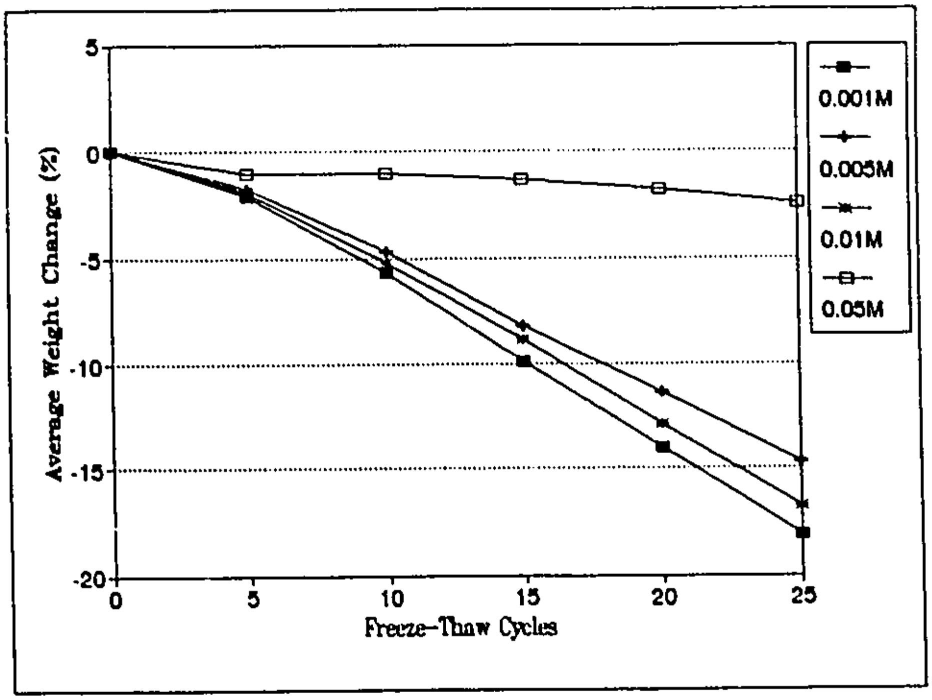

FIGURE 20: Mortar Scaling for Cubes Exposed to Various CMA Concentrations Mixed with NaCl (Weight Loss Versus Cycles)

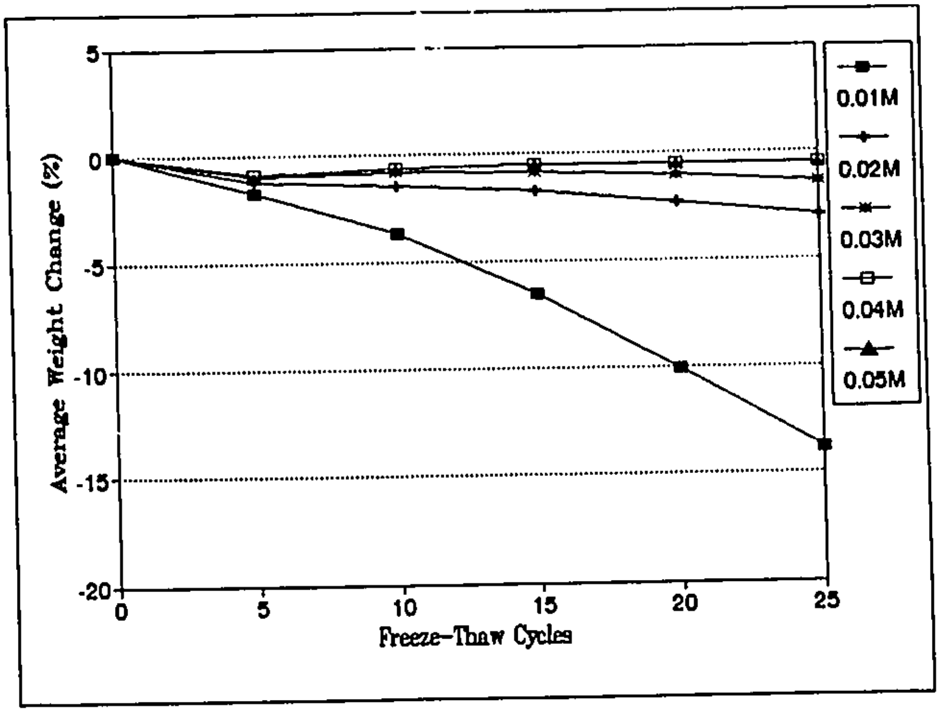

FIGURE 21: Mortar Scaling for Cubes Exposed to Various Monosodium Phosphate Concentrations Mixed with NaCl (Weight Loss Versus Cycles)

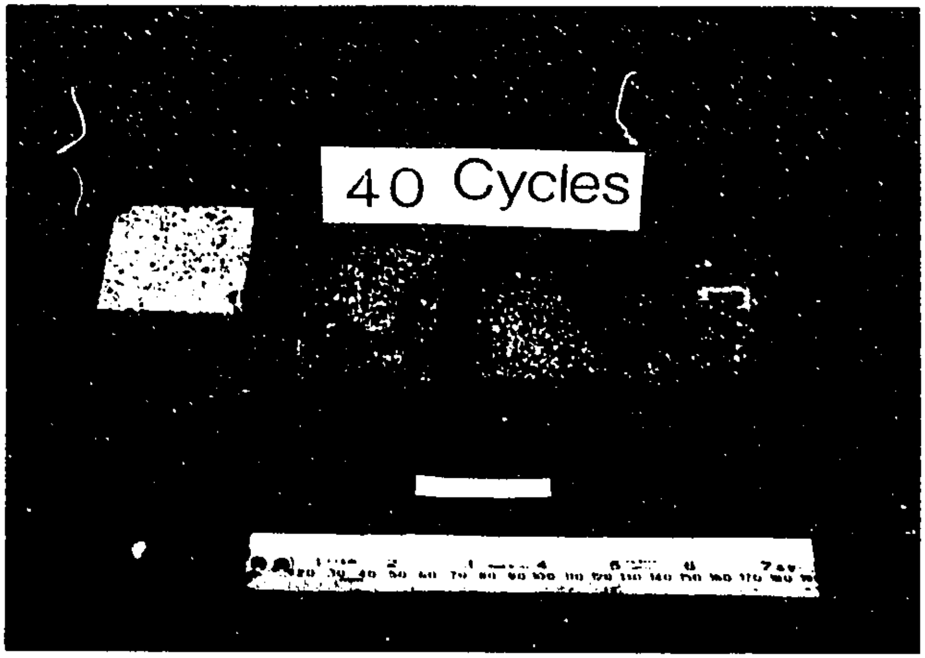

FIGURE 22: Photograph of Mortar Scaling Cubes Exposed to a 0.5M Sodium Chloride Solution (Stage 1)

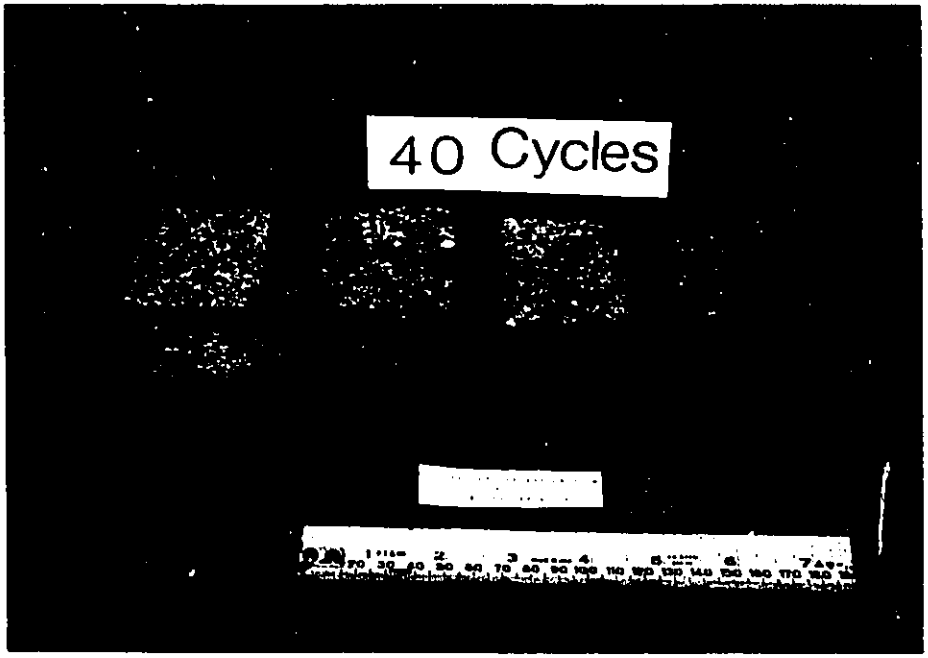

FIGURE 23: Photograph of Mortar Scaling Cubes Exposed to a 0.05M Monosodium Phosphate + 0.45M NaCl Solution (Stage 1)

in reducing scaling in both a sodium and calcium chloride solution. If the cations of the phosphate and chloride were the same, scaling was reduced even more.

d) Cubes Exposed to Phosphate Pretreatments

Phosphate pretreatment before freeze-thaw exposure was also effective in reducing scaling (**Figure 14**) but not as much as certain phosphate/chloride mixtures since there was a large amount of weight loss in the pretreated cubes. When potassium acetate was used in a mixture with sodium chloride, it was not effective at all in diminishing scaling.

e) Other Visual Observations

In addition to the surface scale rating, notes were also made on the following: approximate cube saturation, explosions (scaled material resting on the frozen solution surface 1cm or more from the cube edge), cracking of the cube (top or bottom), and the amount of unfrozen solution surrounding the mortar cubes. Cracking and cube saturation proved to be the most important of these observations, therefore they will be discussed further.

Salt present in the pores of mortar will attract water and increase the degree of saturation of the mortar. The degree of saturation is increased with increasing salt concentration. This was the case in the phosphate pretreatment cubes. The saturation line (horizontal moisture line along the side of a cube at the level of saturation) for these cubes was significantly higher than cubes with no pretreatment. On the other hand, the cubes exposed to CMA had a significantly lower level of saturation compared with the other cubes. A higher level of saturation is generally associated with greater deterioration. This was the case for mortar cubes with phosphate pretreatments and cubes exposed to CMA. As noted earlier, the pretreatment cubes had significant scaling and weight loss whereas cubes exposed to CMA had surface scaling and minor weight loss.

D-cracking was noted only in the cubes treated with the higher concentrations of calcium chloride. Cubes in 2.0M calcium chloride had cracks forming along the unfinished side surface edges between 20 and 25 freeze-thaw cycles while cubes in 3.5M calcium chloride solution developed cracks before 15 cycles. **Figure 24** is a photograph of the three cubes exposed to a 3.5M calcium chloride solution after 40 cycles. Note the D-cracking along the edges. High concentrations of calcium chloride produced D-cracking but minor scaling.

Figure 25 is a photograph of cubes in a 2.0M sodium chloride solution after 15 cycles. Note the cracking through the moulded surface (unfinished surface is facing down while the moulded surface is facing up) and the excessive salt deposits. After 15 cycles of freeze-thaw, this form of cracking developed in cubes treated with 2.0 and 3.5M sodium chloride and 2.0M potassium acetate solutions. After 19 cycles, 3.5M potassium acetate cubes formed this type of cracking. In most cases, these cracks were initiated at the moulded surface and progressed to the unfinished

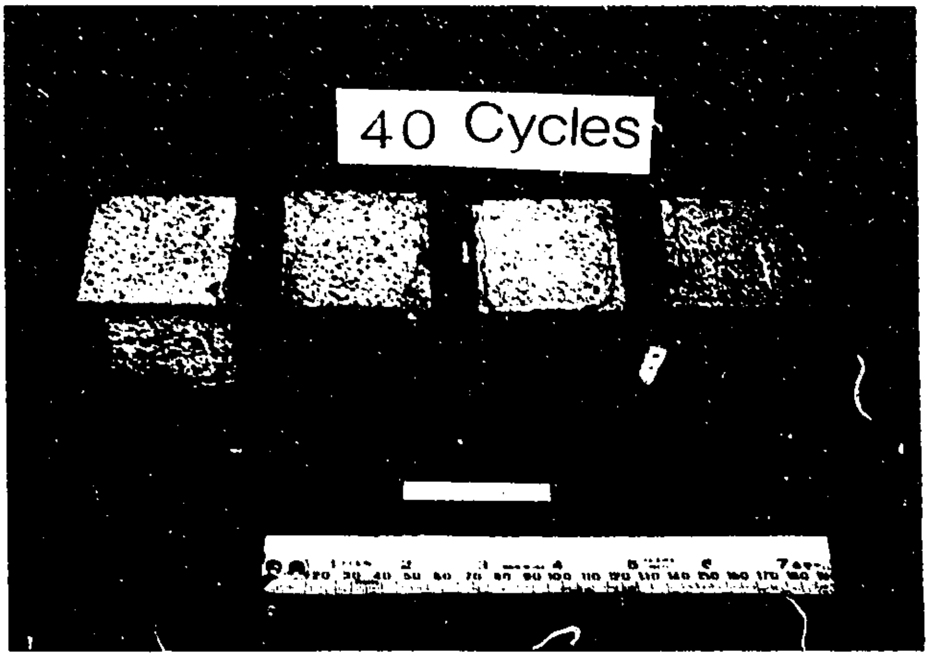

FIGURE 24: Photograph of Mortar Scaling Cubes Exposed to a 3.5M Calcium Chloride Solution (Stage 1)

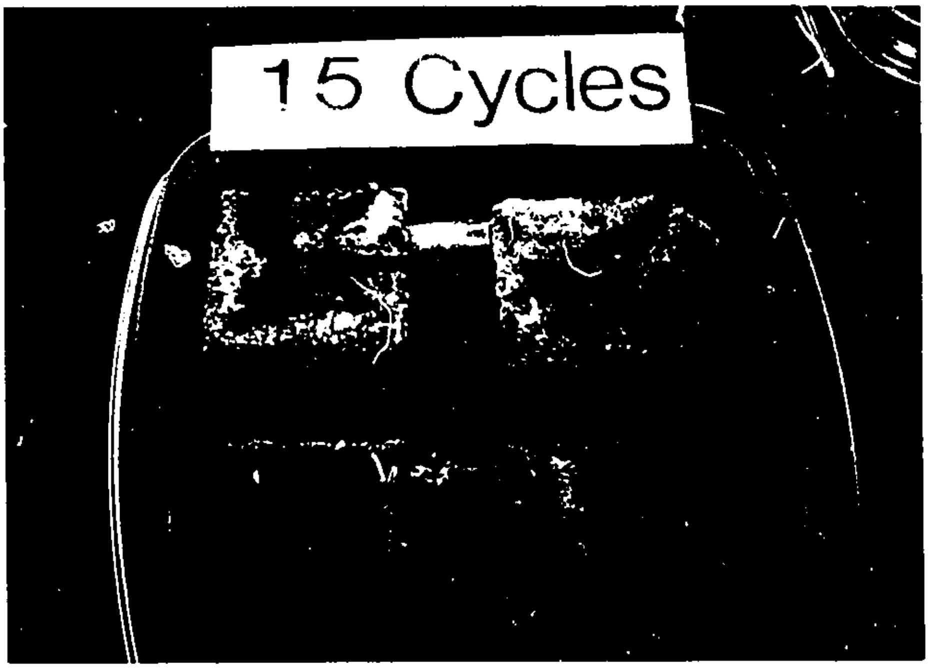

FIGURE 25: Photograph of Mortar Scaling Cubes Exposed to a 2.0M Sodium Chloride Solution (Stage 1)

surface (scaled surface). Figure 26 shows the extent of cracking in a 2.0M potassium acetate solution after 40 cycles. The cube on the far right (K-Ace 2.0-3) had a large crack progressing through its midsection. The four solutions described above produced cracking but minor scaling in the mortar cubes.

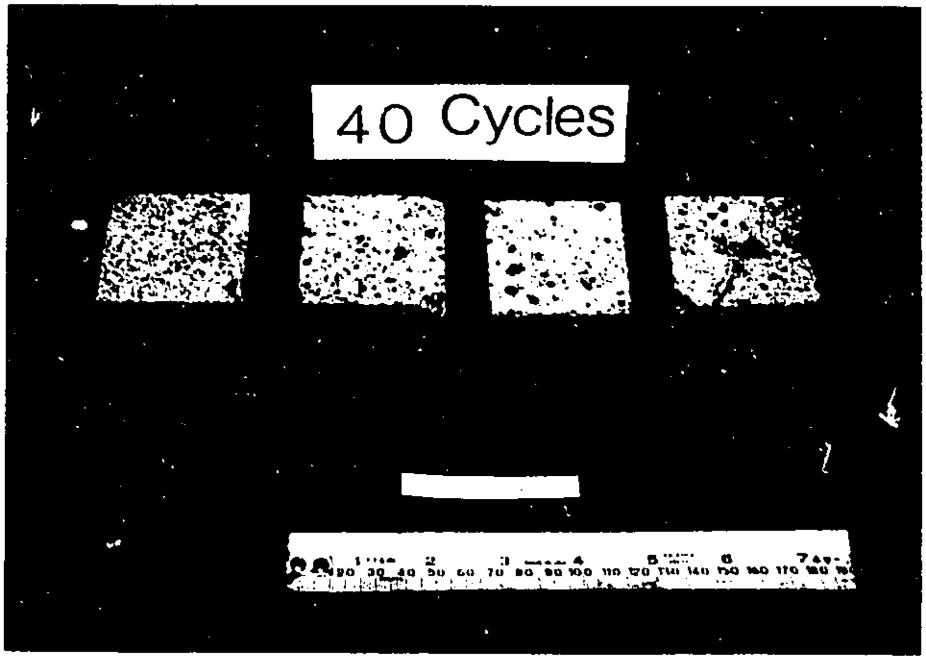

FIGURE 26: Photograph of Mortar Scaling Cubes Exposed to a 2.0M Potassium Acetate Solution (Stage 1)

f) Comparability of Mortar Cube Stages

The results of Stages 1 and 2 mortar cube scaling were not directly correlatable. The possible reasons have been explained earlier and will be dealt with more in the compressive strength testing section. The solutions that were used in both Stages 1 and 2 were:

1) 0.5M Sodium chloride
2) 0.01M Monosodium phosphate + 0.49M NaCl
3) 0.05M Monosodium phosphate + 0.45M NaCl
4) 0.01M Monopotassium phosphate + 0.49M NaCl
5) 0.05M monopotassium phosphate + 0.45M NaCl
6) Deionized-distilled water (control)
7) Air (control)

The mortar scaling caused by these solutions was not comparable between Stages 1 and 2 since the mortar scaling in cubes from Stage 1 was greater than cubes in Stage 2. Since the results were not comparable, analysis of the mortar scaling data was dealt with separately for each stage. Analysis within each stage was possible since conditions remained constant within each stage. The ranking of the slopes for the two stages of mortar cube scaling are summarized in **Tables 8** and **9**. Salts with the lower weight loss due to scaling are shown with a lower ranking number.

(iii) Mortar Block Scaling Tests

The two mortar blocks exposed to a 0.36M calcium chloride solution (4g of salt in 100mL of solution) had visual surface scaling similar to the cubes exposed to the 0.2 and 0.5M calcium chloride solutions. Therefore, using 5cm (2 inch) cubes with an unfinished surface will produce similar results to the larger samples required for the standard ASTM C672 test. The smaller size specimens allowed the weight loss measurements to be monitored more easily.

(iv) Compressive Strength Tests

The unconfined compressive strength testing showed no

TABLE 8: Cube Weight Loss Linear Regression Analysis - Stage 1
(Force lines through zero)

Salt / Chloride Mixture	R Square	# of Observ.	X Coef.	Rank
3.5M NaCl	0.5438	9	-0.0745	1
3.5M KC2H3O2	0.7888	9	-0.0675	2
2.0M KC2H3O2	0.8377	9	-0.0628	3
0.05M NaH2PO4 + 0.45M NaCl	0.0814	9	-0.0026	4
Deionized-Distilled Water (Control)	0.0717	9	-0.0021	5
0.1M CMA	-0.1436	9	0.0006	6
0.2M CMA	-0.2985	9	0.0045	7
0.05M CMA	-0.3544	9	0.0052	8
2.0M CaCl2	0.0281	9	0.0128	9
3.5M CaCl2	-0.6032	9	0.0144	10
2.0M NaCl	0.4669	9	0.0261	11
0.05M KH2PO4 + 0.45M NaCl	0.6039	9	0.0293	12
0.5M CMA	-1.3020	9	0.0389	13
Air (Control)	0.4625	9	0.0795	14
0.5M CaCl2	0.9837	9	0.4809	15
0.2M KC2H3O2	0.9943	9	0.4894	16
0.2M CaCl2	0.9952	9	0.5351	17
0.05M Ca(H2PO4)2*H2O + 0.45M NaCl	0.9181	9	0.6281	18
0.5M KC2H3O2	0.9777	9	0.7393	19
0.2M NaCl	0.9795	9	0.7675	20
0.01M KH2PO4 + 0.49M NaCl	0.9617	9	0.7721	21
0.01M NaH2PO4 + 0.49M NaCl	0.9734	9	0.9412	22
0.01M KC2H3O2 + 0.49M NaCl	0.9820	9	0.9725	23
0.005M KH2PO4 + 0.495M NaCl	0.9881	9	1.0045	24
0.05M KC2H3O2 + 0.45M NaCl	0.9905	9	1.0112	25
0.005M KC2H3O2 + 0.495M NaCl	0.9872	9	1.0394	26
0.001M KC2H3O2 + 0.499M NaCl	0.9719	9	1.0469	27
0.005M Ca(H2PO4)2*H2O + 0.495M NaCl	0.9807	9	1.0485	28
0.005M NaH2PO4 + 0.495M NaCl	0.9802	9	1.0967	29
0.001M KH2PO4 + 0.499M NaCl	0.9748	9	1.1068	30
0.5M NaCl	0.9861	9	1.1168	31
0.001M NaH2PO4 + 0.499M NaCl	0.9780	9	1.1231	32
0.001M Ca(H2PO4)2*H2O + 0.499M NaCl	0.9837	9	1.1434	33
0.01M Ca(H2PO4)2*H2O + 0.49M NaCl	0.9894	9	1.1579	34

Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Square = Correlation coefficient squared

TABLE 9: Cube Weight Loss Linear Regression Analysis - Stage 2
(Force lines through zero)

Salt / Chloride Mixture	R Square	# of Observ.	X Coef.	Rank
0.05M Ca(H2PO4)2*H2O + 0.45M CaCl2	-0.2045	6	0.0010	1
0.1M Ca(H2PO4)2*H2O + 0.4M CaCl2	-0.2270	6	0.0017	2
Deionized-Distilled Water (Control)	-0.3819	6	0.0052	3
0.05M NaH2PO4 + 0.45M CaCl2	-0.5931	6	0.0131	4
0.05M KH2PO4 + 0.45M CaCl2	-0.4991	6	0.0219	5
0.2M Ca(H2PO4)2*H2O + 0.3M CaCl2	-0.7287	6	0.0229	6
0.05M KH2PO4 + 0.45M NaCl	-0.6644	6	0.0258	7
0.04M NaH2PO4 + 0.46M NaCl	-0.7257	6	0.0294	8
0.05M NaH2PO4 + 0.45M NaCl	-0.7008	6	0.0309	9
0.4M Ca(H2PO4)2*H2O + 0.1M CaCl2	-0.8350	6	0.0315	10
0.04M NaH2PO4 + 0.46M CaCl2	-0.2254	6	0.0341	11
0.04M KH2PO4 + 0.46M CaCl2	0.3982	6	0.0590	12
0.03M NaH2PO4 + 0.47M NaCl	0.5270	6	0.0599	13
0.04M KH2PO4 + 0.46M NaCl	0.6868	6	0.0667	14
0.03M KH2PO4 + 0.47M NaCl	0.5522	6	0.0694	15
0.01M Ca(H2PO4)2*H2O + 0.49M CaCl2	0.8569	6	0.0763	16
0.05M CMA + 0.45M NaCl	0.8995	6	0.0967	17
Air (Control)	0.4162	6	0.1032	18
0.03M KH2PO4 + 0.47M CaCl2	0.9293	6	0.1057	19
0.03M NaH2PO4 + 0.47M CaCl2	0.9091	6	0.1093	20
0.02M KH2PO4 + 0.48M NaCl	0.7099	6	0.1106	21
0.02M NaH2PO4 + 0.48M NaCl	0.9171	6	0.1215	22
0.02M KH2PO4 + 0.48M CaCl2	0.9465	6	0.1514	23
0.02M NaH2PO4 + 0.48M CaCl2	0.9408	6	0.1514	24
0.01M NaH2PO4 + 0.49M CaCl2	0.9666	6	0.1762	25
0.01M KH2PO4 + 0.49M CaCl2	0.9692	6	0.1809	26
0.05M Ca(H2PO4)2*H2O Pretreatment	0.9207	6	0.1912	27
0.05M KH2PO4 Pretreatment	0.8981	6	0.2321	28
0.01M KH2PO4 + 0.49M NaCl	0.9523	6	0.2797	29
0.05M NaH2PO4 Pretreatment	0.8822	6	0.3251	30
0.01M NaH2PO4 + 0.49M NaCl	0.9645	6	0.5022	31
0.005M CMA + 0.495M NaCl	0.9845	6	0.5609	32
No Pretreatment	0.9877	6	0.6156	33
0.01M CMA + 0.49M NaCl	0.9789	6	0.6327	34
0.001M CMA + 0.499M NaCl	0.9829	6	0.6886	35

Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Square = Correlation coefficient squared

correlation with molality or salt and salt mixture type. It was initially anticipated that the higher salt concentrations causing microcracks (and D-cracks) would reduce the cube strength. This did not occur in calcium chloride solutions as illustrated in **Figures 27** and **28**. Also, there was no correlation between strength and weight loss due to scaling (**Figures 29** and **30**).

In most cases, when cubes were exposed to salt solutions and freeze-thaw cycling, their strengths were higher than the control cube strengths. This can be explained by salt accumulating and crystallizing within the pores and making the mortar more dense. Along with increasing density, these salt crystals can support an applied load. Higher salt concentrations can increase the density. Therefore, salt solution exposure can increase the compressive strength. The exceptions to this were cubes exposed to high concentrations of sodium chloride and potassium acetate solutions. These cubes had lower strengths. The reason for the lower strengths in cubes exposed to higher sodium chloride or potassium acetate concentrations can be explained by the microcracking. But cubes exposed to high concentrations of CMA or calcium chloride did not have reduced strengths and this cannot be explained at present.

Cubes made using the standard (ASTM C109-90) moulds (not sawn) were also tested. The moulded cubes had compressive strengths 25 percent greater than sawn cubes undergoing the similar curing procedures. The only difference in the curing procedures was that the sawn cubes remained as a mortar slab until 21 days after mixing. After the 21 days from mixing, the cubes were sawn from

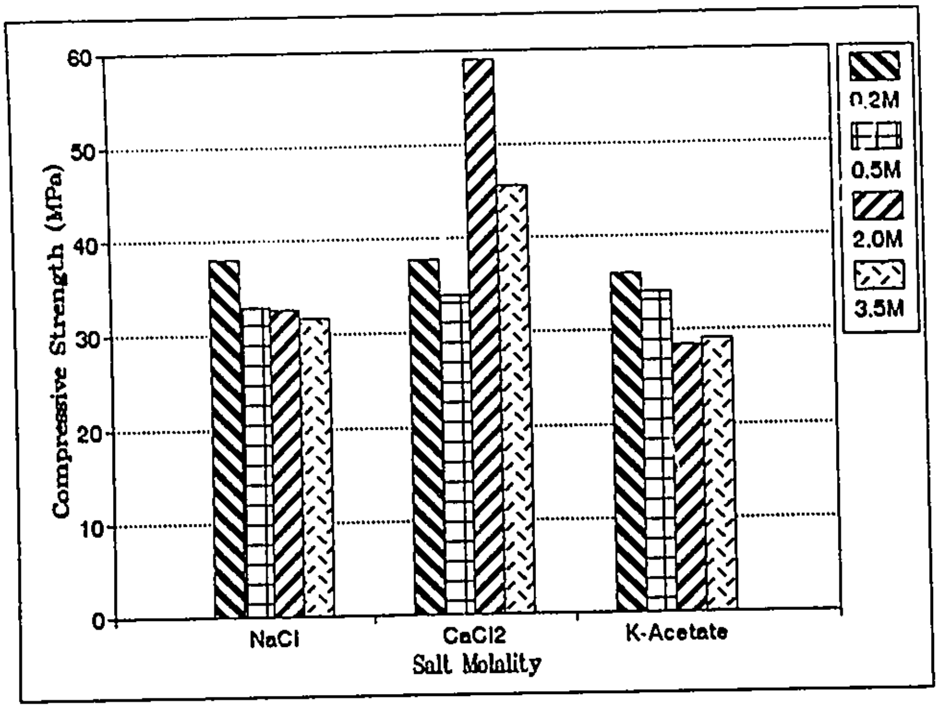

FIGURE 27: Mortar Cube Strengths for Cubes Exposed to Salts Alone in Solution (Stage 1)

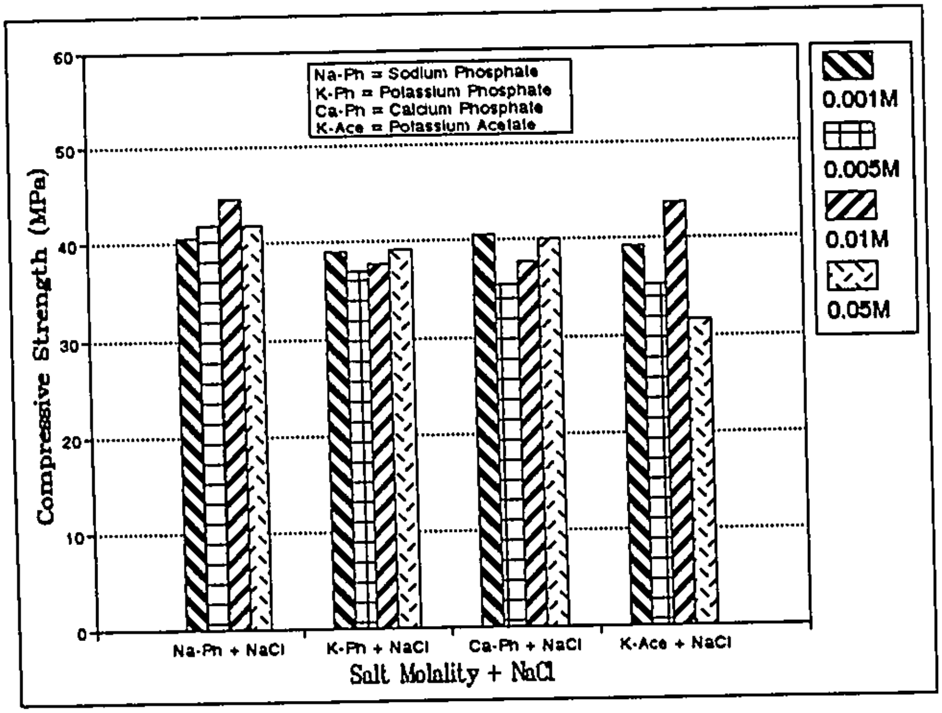

FIGURE 28: Mortar Cube Strengths for Cubes Exposed to Various Phosphate Concentrations Mixed with NaCl (Stage 1)

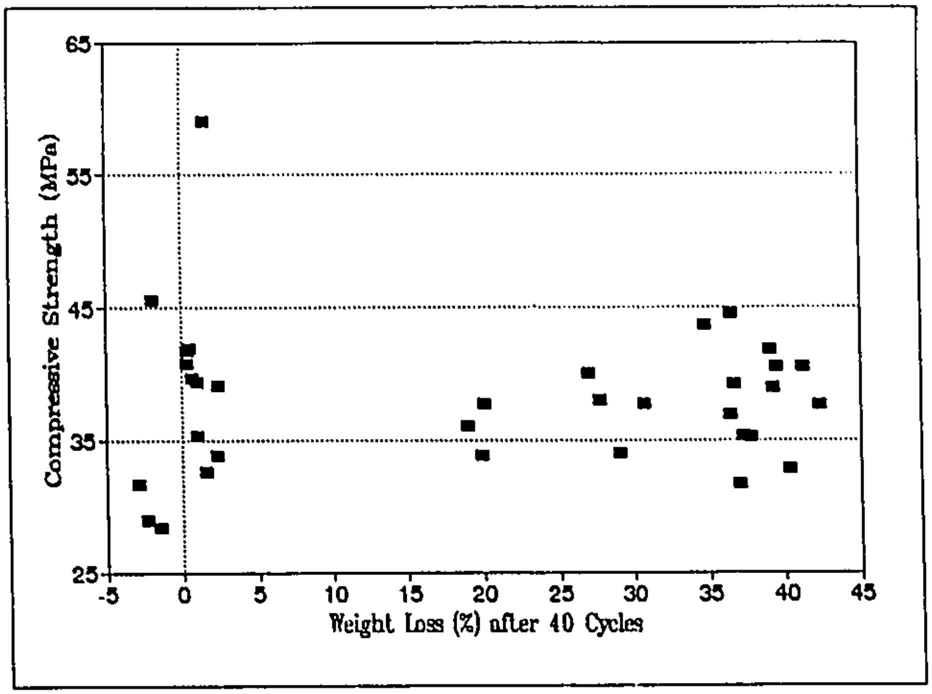

FIGURE 29: Cube Strength Versus Weight Loss (Stage 1)

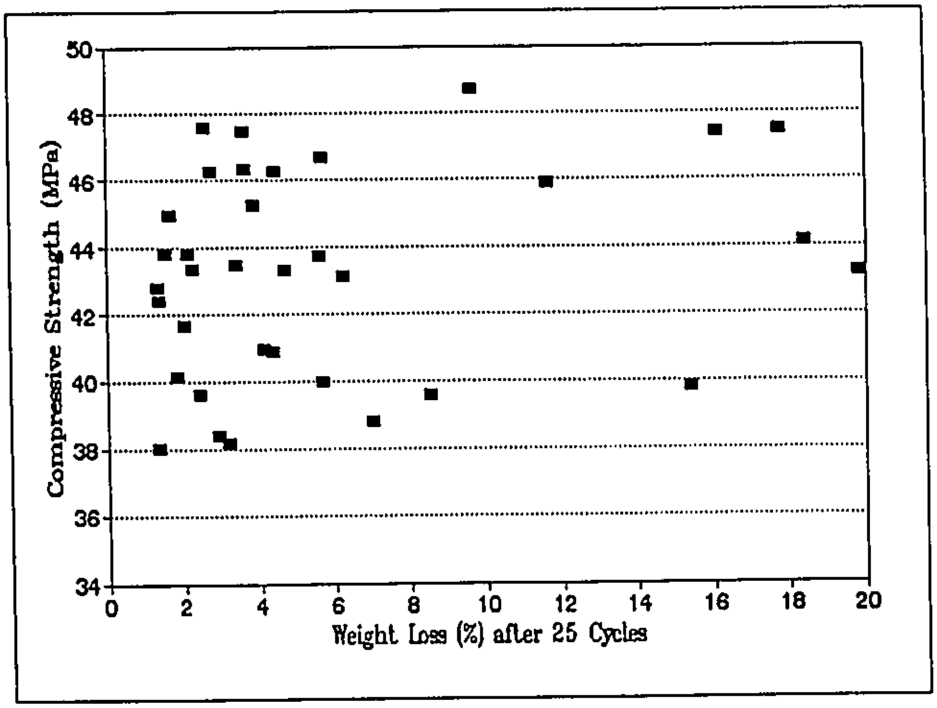

FIGURE 30: Cube Strength Versus Weight Loss (Stage 2)

the mortar slab. Thus, sawing of mortar slabs may have a significant effect on the compressive strength. Sawing of the mortar slabs may have initiated microcracking in the cubes.

The most obvious deviation from the average compressive strength occurred in cubes exposed to 2.0M calcium chloride. The strength was significantly greater (over 30 percent) than cubes in the other solutions. The reason for the higher strength of the cubes in this solution is unknown but may be due to calcium chloride filling some of the pores in the mortar. This would allow for an increased load to be supported by the mortar before failure.

In order to prove statistically that a difference existed in the strength values for Stages 1 and 2 mortar cubes, a 'student t' test was performed on the group means of these two stages. It was found that there was a difference in the group means at a significance level of 0.1 percent. This means that there was a 0.1 percent chance that Stages 1 and 2 results were from the same population. Therefore, the strength results of Stages 1 and 2 were not comparable because of the significant difference between them.

A 't' test on the paired means for cubes with the same conditioning (same salt mixture, same environmental conditions) was also performed and the difference was significant at 5 percent. This supports the conclusion of the group mean test that the two stages were significantly different.

Another paired means 't' test was performed on the data to find if a difference existed between cubes undergoing freeze-thaw cycling with a sodium chloride mixture and a calcium chloride mixture. The difference was not significant at a 10 percent level, therefore the two different chlorides had the same effect on strength when used as mixtures with phosphate.

B Metal Bar Corrosion

The maximum weight loss due to metal corrosion was approximately 2 percent and occurred in a 0.05M potassium acetate plus 0.45 sodium chloride solution. **Figure 31** is a photograph showing the solution colours after 9 weeks (63 days) of corrosion. Solutions having a darker orange colour indicate greater corrosion. The sample solutions in the photograph are ordered as follows in **Table 10**.

A pessimum concentration was not observed for any of the deicing salts and salt mixtures used in the corrosion experiments. The results may not be conclusive as far as a pessimum is concerned since all salt solutions (sodium chloride, calcium chloride and CMA, alone as salts) caused increased weight loss with decreased concentrations. **Figure 32** shows that a lower concentration of salt (sodium chloride) can cause the most corrosion. Therefore, a pessimum concentration may exist below the lowest concentrations used for each of the deicers.

Figure 33 illustrates the effect of a monosodium phosphate and sodium chloride solution on corrosion. It can be seen that as little as 0.005M monosodium phosphate in solution is sufficient to reduce corrosion significantly. Greater phosphate contents

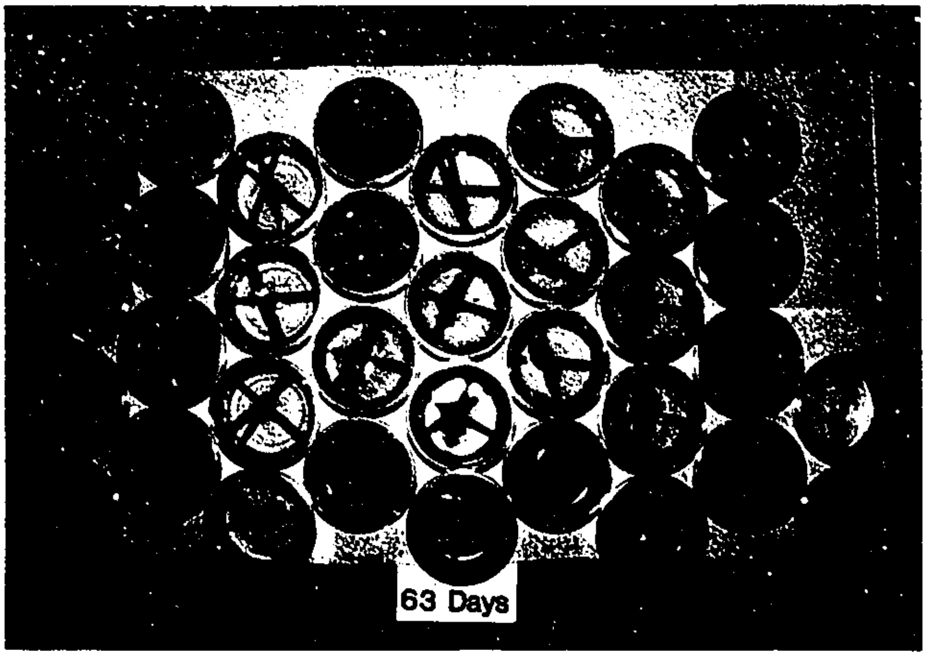

FIGURE 31: Photograph of Metal Corrosion Solutions (63 Days)

TABLE 10: Salt Solution Concentrations (M) in Figure 31

	Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9
	NaCl	$CoCl_2$	$KC_2H_3O_2$	CMA	Mono sodium phosphate + NaCl	Mono potassium phosphate + NaCl	Mono calcium phosphate + NaCl	$KC_2H_3O_2$ + NaCl	Control
Row 1	3.5	3.5	3.5	0.5	0.05	0.05	0.05	0.05	
Row 2	2.0	2.0	2.0	0.2	0.01	0.01	0.01	0.01	
Row 3	0.5	0.5	0.5	0.1	0.005	0.005	0.005	0.005	air
Row 4	0.2	0.2	0.2	0.05	0.001	0.001	0.001	0.001	water

produced less corrosion. Similar corrosion reduction was observed for monopotassium and monocalcium phosphates when they were combined with sodium chloride in a solution. The monopotassium

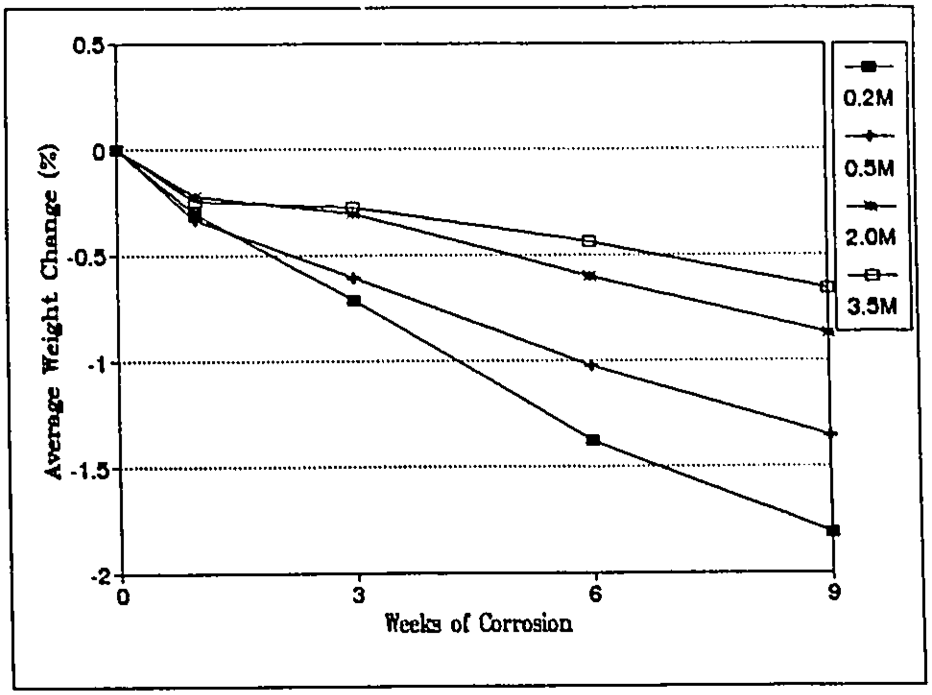

FIGURE 32: Metal Bar Corrosion in Sodium Chloride Solutions

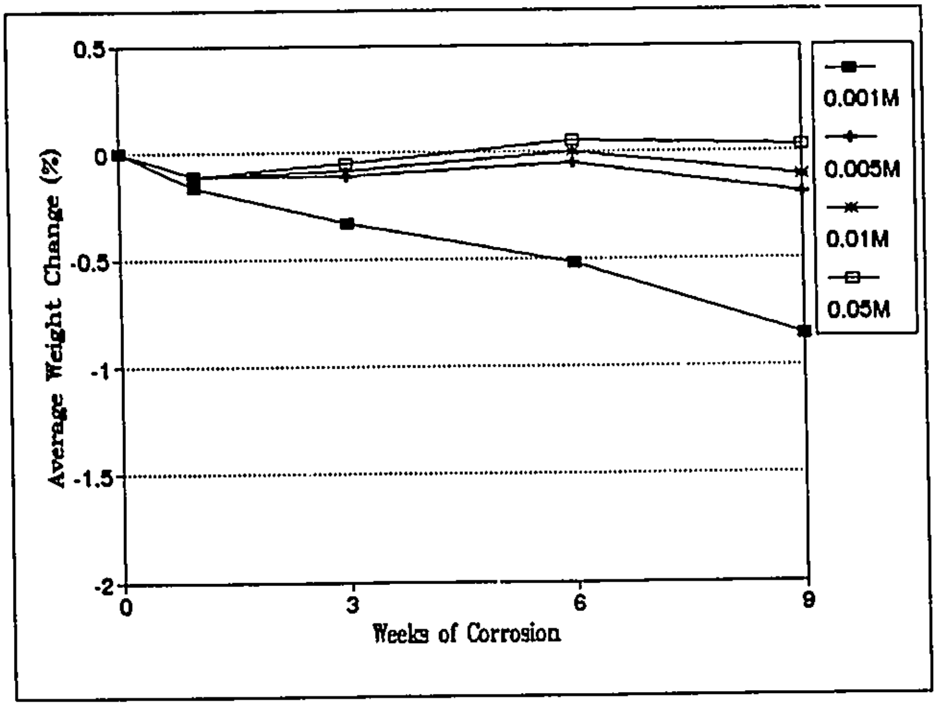

FIGURE 33: Metal Bar Corrosion in Various Monosodium Phosphate Concentrations Mixed with NaCl

phosphate solutions produced less corrosion than either monosodium or monocalcium phosphates while monosodium and monocalcium phosphates had similar amounts of corrosion. Careful observation of **Figure 33** reveals that a minor weight gain occurred on bars in 0.005, 0.01 and 0.05M monosodium phosphate solutions. This was due to salt accumulations on the bars. The accumulations formed were most likely phosphate since phosphate can precipitate from solution and once precipitated, is insoluble. Phosphate accumulations occurred on most bars and were difficult to remove during the bar rinsing procedure.

Sodium chloride was found to be the most corrosive salt - even more than calcium chloride. Potassium acetate and CMA, on the other hand, were relatively benign, although the lowest concentration for both of these salts caused some weight loss. When potassium acetate was added to sodium chloride, the weight loss due to corrosion was greater for the 0.05M potassium acetate (plus 0.45M sodium chloride) concentration than for the 0.5M sodium chloride solution by itself. As the potassium acetate content of the solution was decreased, corrosion also decreased. Potassium acetate has been considered a corrosion inhibitor; thus the explanation for the behaviour of potassium acetate in a sodium chloride solution is not readily forthcoming.

The results of metal corrosion may or may not be representative of actual field occurrences. A more representative experiment would have been to use reinforcing steel bars in concrete for the metal corrosion experiment.

Table 11 summarizes the ranked slopes from the weight loss (due to corrosion) versus time data generated after 9 weeks of corrosion. Solutions producing the least corrosion were ranked with the lowest number.

C Ice Melting

Figure 34 is a graph of the ice weight loss in various sodium chloride solutions. The rate of melting by 2.0M calcium chloride, potassium acetate and sodium chloride was more than three times greater than the next lower concentration (0.5M). In general, higher salt concentrations produced faster melting but there were some exceptions. One exception was potassium acetate: a 0.2M potassium acetate solution produced faster ice melting than a 0.5M solution (**Figure 35**). Also, it was expected that a 0.5M calcium chloride solution would melt ice faster than a 0.5M sodium chloride solution since a 2.0M calcium chloride solution melted ice faster than a 2.0M sodium chloride solution (**Figure 36**). But a 0.5M sodium chloride solution melted ice faster than a 0.5M calcium chloride solution.

When a phosphate or CMA was added to a chloride, there were some unexpected results in the ice melting experiment. Ice melting behaviour for these mixtures was variable. Depending on the conditions, ice melting was similar, faster or slower than chlorides by themselves. Some mixtures performed better than a 0.5M sodium chloride solution while others performed less

TABLE 11: Metal Bar Corrosion Weight Loss Linear Regression Analysis

Salt / Chloride Mixture	R Square	# of Observ.	X Coef.	Rank
0.05M NaH2PO4 + 0.45M NaCl	0.3944	5	-0.0113	1
3.5M CaCl2	0.2324	5	-0.0099	2
0.01M KH2PO4 + 0.49M NaCl	0.1243	5	-0.0068	3
0.05M Ca(H2PO4)2*H2O + 0.45M NaCl	0.1366	5	-0.0056	4
0.2M CMA	0.0619	5	-0.0028	5
Air (Control)	1.0000	5	0.0000	6
0.5M CMA	0.0007	5	0.0002	7
0.1M CMA	0.0479	5	0.0021	8
3.5M KC2H3O2	0.0476	5	0.0021	9
0.01M NaH2PO4 + 0.49M NaCl	0.0563	5	0.0036	10
0.01M Ca(H2PO4)2*H2O + 0.49M NaCl	0.1578	5	0.0055	11
0.05M KH2PO4 + 0.45M NaCl	0.3670	5	0.0068	12
0.005M KH2PO4 + 0.495M NaCl	0.4096	5	0.0072	13
0.5M KC2H3O2	0.4778	5	0.0076	14
2.0M KC2H3O2	0.4790	5	0.0076	15
0.005M Ca(H2PO4)2*H2O + 0.495M NaCl	0.4891	5	0.0110	16
0.005M NaH2PO4 + 0.495M NaCl	0.4656	5	0.0132	17
2.0M CaCl2	0.8472	5	0.0308	18
0.2M KC2H3O2	0.8054	5	0.0454	19
0.001M KH2PO4 + 0.499M NaCl	0.8945	5	0.0565	20
3.5M NaCl	0.9261	5	0.0636	21
0.05M CMA	0.9968	5	0.0749	22
0.5M CaCl2	0.9673	5	0.0867	23
0.001M NaH2PO4 + 0.499M NaCl	0.9860	5	0.0887	24
2.0M NaCl	0.9806	5	0.0915	25
0.2M CaCl2	0.9836	5	0.1056	26
0.001M KC2H3O2 + 0.499M NaCl	0.9774	5	0.1115	27
0.005M KC2H3O2 + 0.495M NaCl	0.9889	5	0.1353	28
0.01M KC2H3O2 + 0.49M NaCl	0.9821	5	0.1365	29
0.001M Ca(H2PO4)2*H2O + 0.499M NaCl	0.9895	5	0.1383	30
0.5M NaCl	0.9764	5	0.1433	31
Deionized-Distilled Water (Control)	0.9996	5	0.1479	32
0.2M NaCl	0.9905	5	0.2009	33
0.05M KC2H3O2 + 0.45M NaCl	0.9950	5	0.2130	34

Note: 1) X Coef. = Slope of the weight loss versus time plots
2) R Square = Correlation coefficient squared

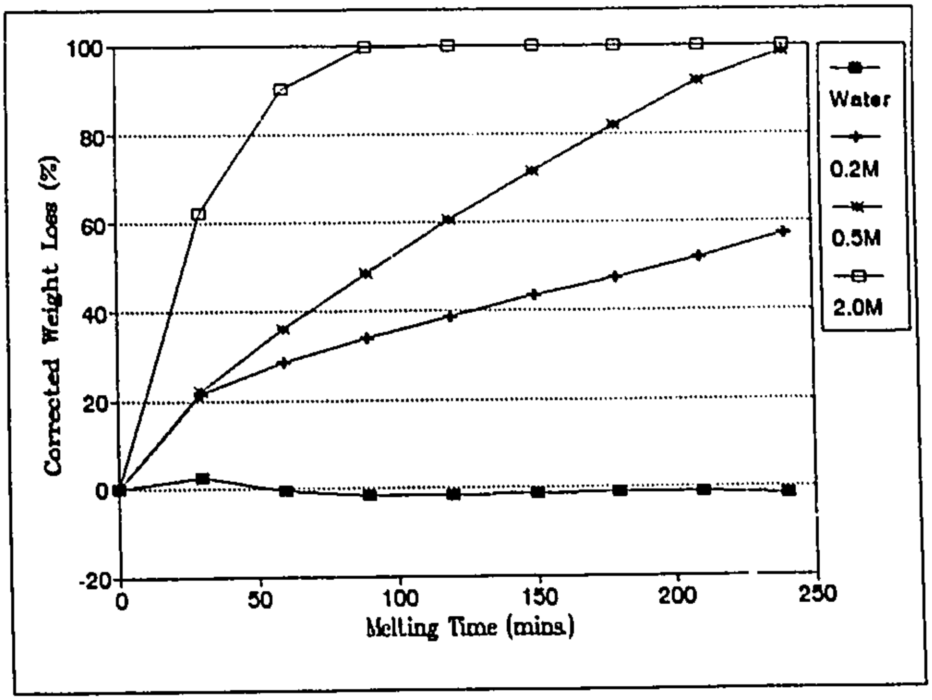

FIGURE 34: Ice Melting in Sodium Chloride Solutions

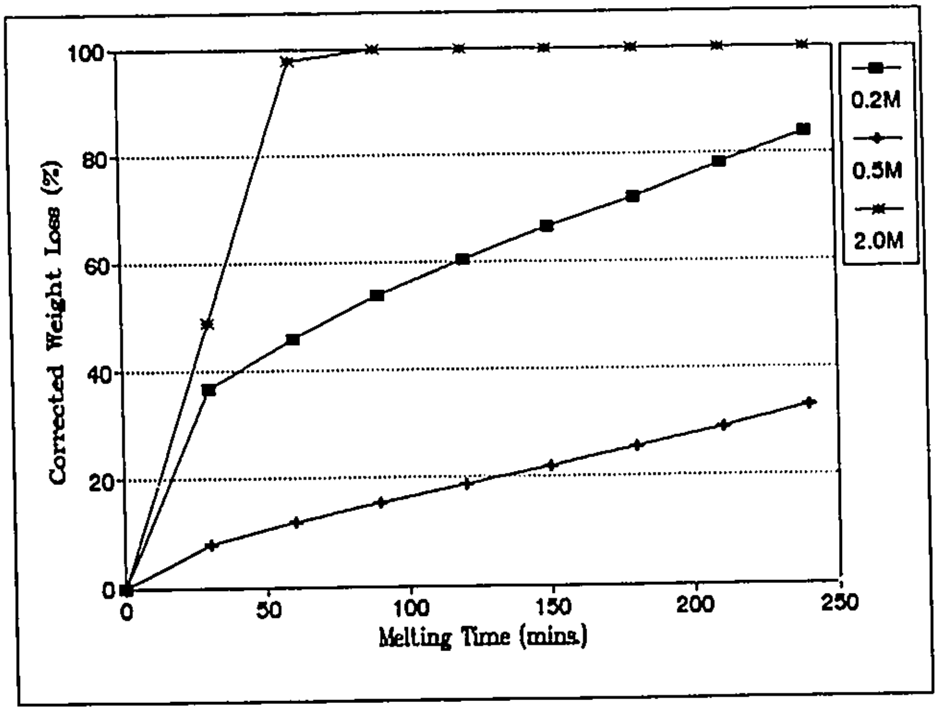

FIGURE 35: Ice Melting in Potassium Acetate Solutions

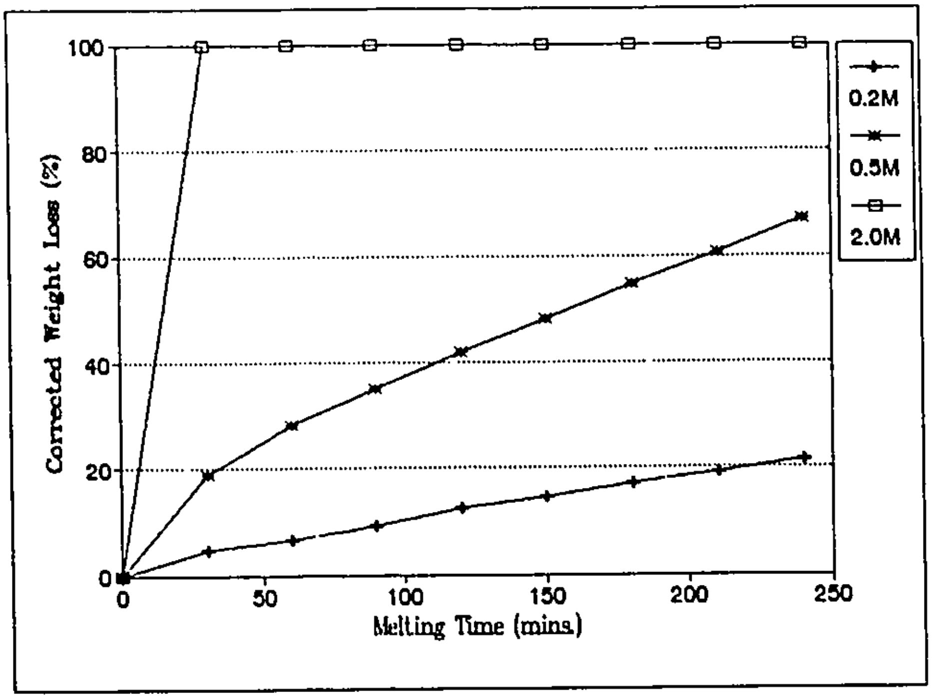

FIGURE 36: Ice Melting in Calcium Chloride Solutions

effectively (Figure 37). The results were inconsistent. It appears that the addition of phosphate or CMA to a chloride solution may decrease the melting rate of the pure chloride solution. This effect was less prominent in solutions containing calcium chloride. Monocalcium phosphate appears to have had the greatest effect on lowering the melting rate of the chloride solutions (Figure 38).

Problems in the ice melting experiments were discovered after the ice melting tests were performed. Certain deicers produced unexpected results, so a reproducibility experiment was performed using a 0.5M sodium chloride solution in four different ice melting containers (the same four containers used in earlier ice melting experiments). Two containers were cylindrical while the other two were more square in plan view. They were labelled Cylinder (1),

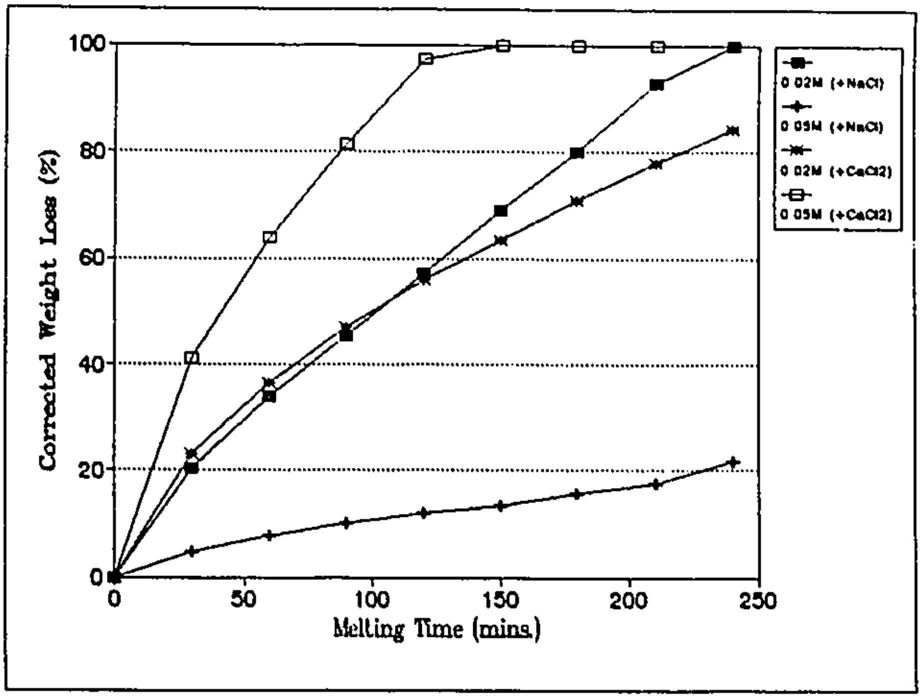

FIGURE 37: Ice Melting in Monosodium Phosphate (+ Chloride) Solutions

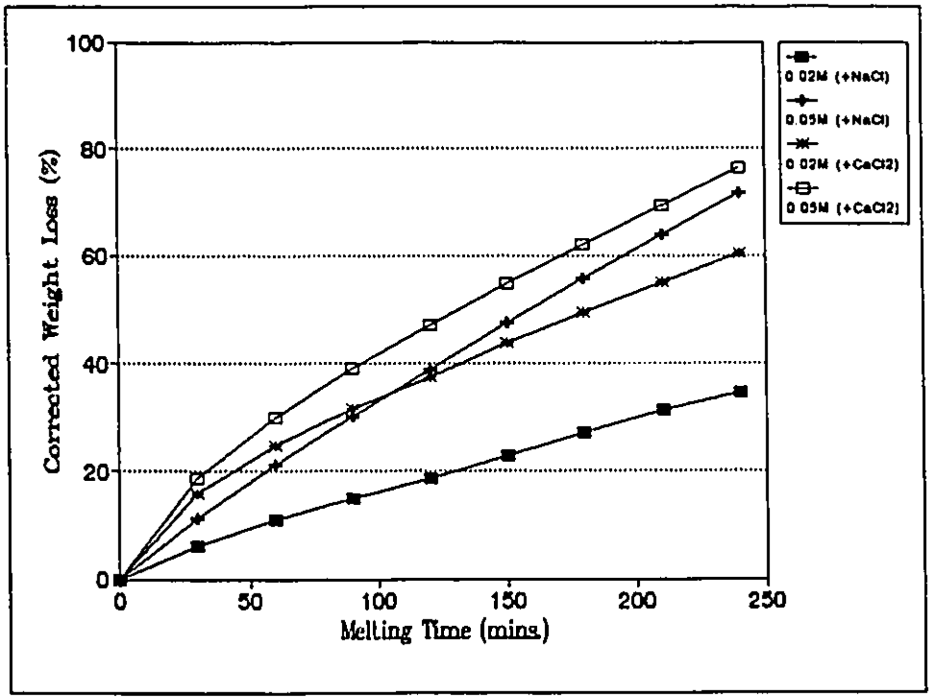

FIGURE 38: Ice Melting in Monocalcium Phosphate (+ Chloride) Solutions

Cylinder (2), Square (1) and Square (2), respectively. **Figure 39** shows the results of the repeatability test. This figure clearly shows the effect that container shape had on the melting of ice popsicles. The cylindrical containers had comparable results while the two square containers also had comparable results to each other but lower than the cylindrical containers. The difference was probably a function of the fluid flow while stirring. This leads to another contributing factor that may have caused the unexpected results. The stirring rate of the different magnetic stirrers could not be set at a specific rate. The rates were adjusted manually, and therefore were not the same each time. The unequal stirring rates may have caused unequal melting rates.

The results obtained and shown in **Figure 39** were used to correct the ice melting data as follows: the average slope of the line described by the two square containers was used to increase the results (correct the weight loss data) when square containers were used. **Figure 40** shows the corrected weight loss plot for the 0.5M sodium chloride retrial ice melting solutions of **Figure 39**. The corrected values of the square containers were almost identical to the cylindrical containers. When the corrected data was compared to the initial 0.5M sodium chloride solution (data collected before the reproducibility experiment and shown in **Figure 40**), it was noted that the retrial results did not compare to the initial 0.5M sodium chloride solution results. This deviation cannot be readily explained other than that the stirring rates may have been different.

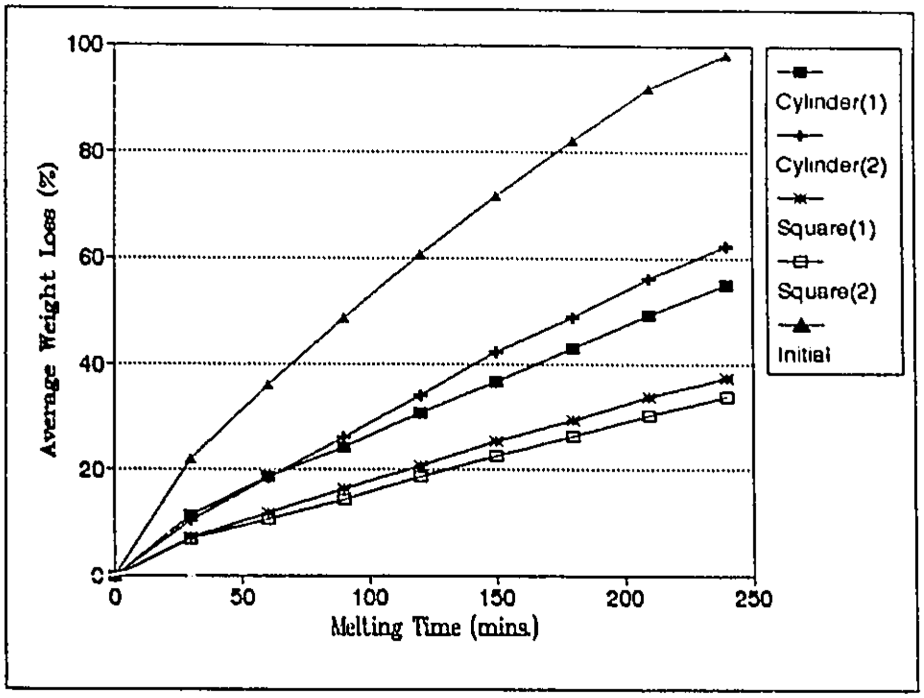

FIGURE 39: 0.5M Sodium Chloride Ice Melting Repeatability Experiment

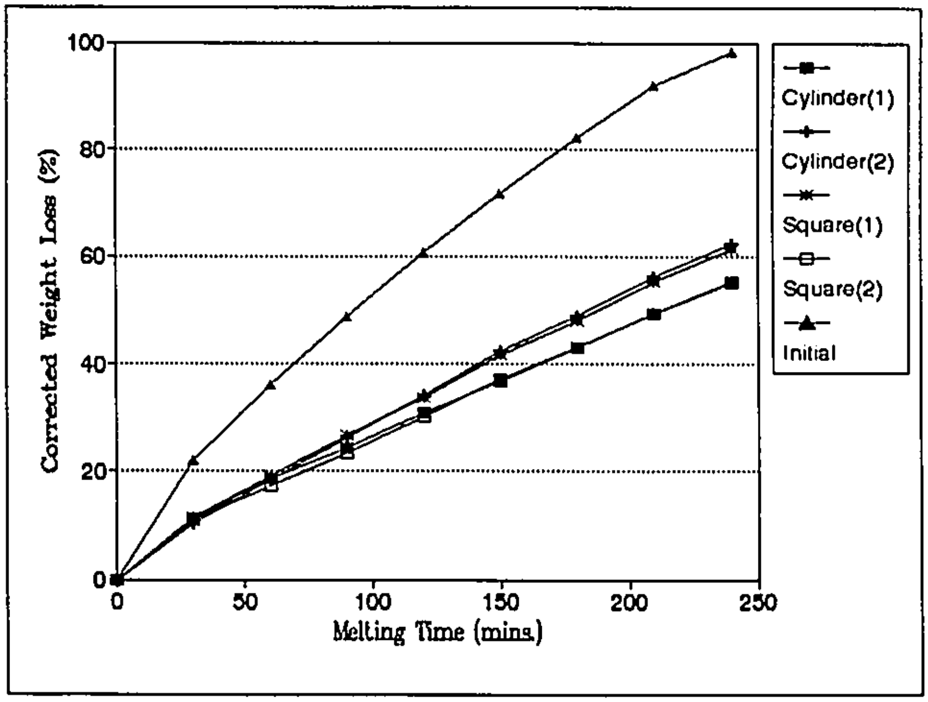

FIGURE 40: Corrected Ice Melting Repeatability Test

Table 12 contains the regression analysis and ranking for the salt and salt mixture solutions used. A lower ranking number represents a solution with a faster ice melting ability.

D Superphosphate Analysis

Initial experimentation (Hudec et al. 1992) had shown that monocalcium phosphate had some promise as an additive to a chloride deicer. A relatively inexpensive supply is readily available since superphosphate is a common agricultural fertilizer. This was the source used in this research. The exact composition of superphosphate is somewhat variable. The soluble portion of superphosphate used in these experiments was determined as shown below.

(i) Solubilities and Proportions of Superphosphate Components

A superphosphate concentration versus insolubles content plot is shown in **Figure 41**. Using assumed values for solubility and proportions of components in superphosphate, values of insolubles content were calculated for each of the constituents in superphosphate. The calculated insolubles values were totaled and compared with the measured insolubles content. Deviations between the measured and calculated insolubles content were minimized by adjusting the solubilities and constituent proportions. The final values of solubility and constituent proportions, which produced the calculated curve in **Figure 41**, are listed in **Table 13**. In both

TABLE 12: Ice Melting Linear Regression Analysis After Data Corrections

Salt / Chloride Mixture	R Square	# of Observ.	X Coef.	Container	Freeze Over	Rank
2.0M CaCl2	1.0000	2	3.3333	square	no	1
2.0M KC2H3O2	1.0000	3	1.6295	square	no	2
2.0M NaCl	0.9537	3	1.5039	cylinder3	no	3
0.02M CMA + 0.48M CaCl2	0.9939	4	0.6921	square	no	4
0.05M NaH2PO4 + 0.45M CaCl2	0.9930	4	0.6198	square	no	5
0.5M CMA	0.9977	7	0.4005	square	no	6
0.02M NaH2PO4 + 0.48M NaCl	0.9995	7	0.3973	square	no	7
0.05M KH2PO4 + 0.45M CaCl2	0.9979	6	0.3941	cylinder2	no	8
0.5M NaCl	0.9967	7	0.3865	cylinder2	no	9
0.05M CMA + 0.45M NaCl	0.9983	8	0.3456	square	no	10
0.05M CMA + 0.45M CaCl2	0.9904	8	0.3036	square	no	11
0.05M Ca(H2PO4)2*H2O + 0.45M	0.9987	8	0.2854	cylinder2	no	12
0.02M NaH2PO4 + 0.48M CaCl2	0.9850	8	0.2826	square	no	13
0.02M KH2PO4 + 0.48M CaCl2	0.9943	8	0.2794	cylinder1	no	14
0.05M Ca(H2PO4)2*H2O + 0.45M	0.9944	8	0.2673	cylinder2	no	15
0.02M KH2PO4 + 0.48M NaCl	0.9623	8	0.2316	cylinder2	yes	16
0.5M CaCl2	0.9964	8	0.2233	cylinder3	no	17
0.2M KC2H3O2	0.9931	8	0.2196	cylinder2	yes	18
0.02M Ca(H2PO4)2*H2O + 0.48M	0.9941	8	0.2068	cylinder3	no	19
0.2M NaCl	0.9950	8	0.1626	cylinder1	no	20
0.02M Ca(H2PO4)2*H2O + 0.48M	0.9992	8	0.1365	cylinder1	no	21
0.5M KC2H3O2	0.9995	8	0.1170	cylinder3	no	22
0.05M KH2PO4 + 0.45M NaCl	0.9938	8	0.1081	cylinder1	no	23
0.02M CMA + 0.48M NaCl	0.9497	8	0.1078	square	no	24
0.2M CaCl2	0.9977	8	0.0825	cylinder1	yes	25
0.05M NaH2PO4 + 0.45M NaCl	0.9838	8	0.0738	square	no	26
Deion-Distill Water (Control)	0.1101	7	-0.0020	cylinder3	yes	27

Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Square = Correlation coefficient squared

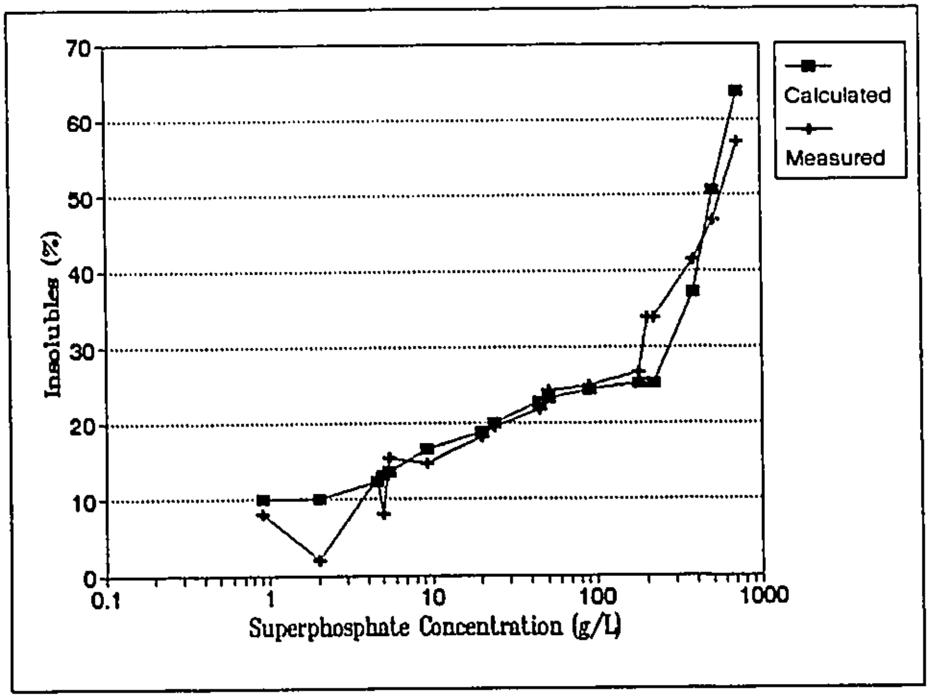

FIGURE 41: Superphosphate Analysis - Insolubles Content

TABLE 13: Superphosphate Analysis

Chemical	Solubility (g/L)	Proportion (%)
$Ca(H_2PO_4)_2*H_2O$	215	68
$CaSO_4$	1	5
$CaHPO_4$	0.4	11
SiO_2	0	10
H_2O	--	6
Total	--	100

the measured and calculated curves, the slopes increased significantly at a superphosphate content of approximately 200 g/L. This indicates that the solution was saturated. Therefore, the solute of a saturated superphosphate solution would contain 68 percent monocalcium phosphate at approximately 215 g/L. Since the phosphate was in an acidified form, the solubility was increased above its normal value (United States Department of Agriculture, 1964). When not acidified, monocalcium phosphate has a solubility of approximately 18 g/L (Chemical Rubber Company, 1993).

(ii) Phosphate Absorption

An estimate of monocalcium phosphate absorption rate was determined by monitoring phosphate concentration variations with time in mortar cubes. **Figure 42** is a semilog plot of monocalcium phosphate concentration variations with time in the phosphate solutions the cubes were immersed in. The concentrations of all four solutions (0.001, 0.01, 0.05 and 0.1M) remained constant for the first 1.5 hours (5000 seconds) as the solutions were absorbed by the cubes. This initially suggests that there was no precipitation of phosphate. However, after 1.5 hours the concentrations changed indicating that phosphate was beginning to precipitate on the mortar cubes. The higher the initial phosphate concentration, the longer it took for phosphate to precipitate out to minimal levels.

Visual observations of all cubes were made at the completion of the phosphate absorption testing. Monocalcium phosphate had a tendency to coat the surface of the mortar cubes. The unascetically pleasing residue was noted on all the cubes.

Along with the residue, a white crystalline substance had formed on the exterior of the cubes in the 0.05M solution. Surface

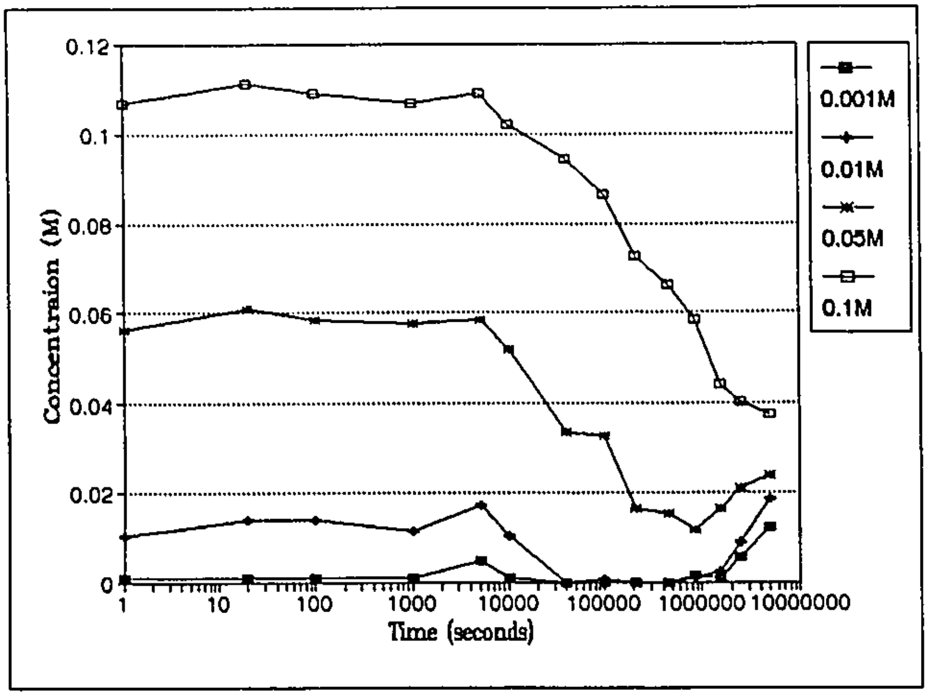

FIGURE 42: Monocalcium Phosphate Absorption - Concentration Variation

scaling of the exposed shale occurred when cubes were soaking in 0.1M monocalcium phosphate. These two conditions (white crystalline substance and scaling) of the cubes are not acceptable. Use of a 0.1M monocalcium phosphate solution is not recommended in concrete deicing because of the potential for scaling the shaley materials without freeze-thaw cycling. The use of a 0.05M monocalcium phosphate solution is not recommended because of the excess crystalline salt formations.

E Criterion Function Analysis

The criterion function is a means by which various products are compared using several properties that they have in common. A superior deicer was not prevalent in all five of the main requirements for a good deicer (ice melting, mortar scaling, metal corrosion, environmental damage and cost), therefore the criterion function was performed using the data in this study. It was decided that a 0.5M salt solution would be the basis for comparison since this was the most common solution used as well as being one of the most destructive. The basis for comparing the chloride mixtures was a 0.05M salt plus 0.45M sodium chloride solution. The following is a list of the salts and salt mixtures compared:

1) 0.5M Sodium chloride
2) 0.5M Calcium chloride
3) 0.5M Potassium acetate
4) 0.5M CMA
5) 0.05M Monosodium phosphate + 0.45M NaCl
6) 0.05M Monopotassium phosphate + 0.45M NaCl
7) 0.05M Monocalcium phosphate + 0.45M NaCl
8) 0.05M CMA + 0.45M NaCl

The slopes of weight loss versus time graphs for the salt solutions above in ice melting, mortar scaling and metal corrosion experiments were compared for the eight solutions above. A value of cost was generated by calculating the price of salt required to make 1L of the solutions. The prices were based on technical grade salts according to the Aldrich (1990) chemical catalogue. Environmental damage was estimated using a scale from 0.1 to 1.0 and basing the damage on the information contained in the section titled "Deicers in the Environment", explained earlier.

The five properties of a good deicer were given different weight values. These values were multiplied by the actual measurements for each of the deicers in each of the properties. The summation of the products for each of the properties was the criterion function value for that specific deicer and weighting conditions used. The weight values for the good deicer properties were varied in different trials to show the effect of greater weightings on the different properties. The equation for the criterion function value is:

$$CF = \text{Summation of } \left[\frac{W_i\ (c_i)}{(c_i)_{max}} \right]$$

where, CF = criterion function value
W_i = weighting for property
c_i = data of individual deicer property 'i'
$(c_i)_{max}$ = maximum data value in property 'i'

Table 14 is the criterion function analysis for the various deicing salts compared. The lowest value for each of the individual criterion function trials was the best deicer. **Table 15** is a summary of the criterion function analysis with the properties that were weighted more heavily (of more interest) in the different trials. The deicers that proved to be the best in each trial are also listed in the table.

As can be seen from **Table 15**, the deicer with the best result varies with the properties of most concern since these properties were given higher weightings. CMA was the best in four of the ten trials. If the trials having a higher weighting for the ice melting experiment are neglected (because of the poor results), monosodium and monopotassium phosphates as mixtures with sodium chloride are the best deicers. In most of the ten trials performed, both monosodium and monopotassium phosphates were near the top.

TABLE 14: Criterion Function Analysis of 0.5M Salt Solutions

Salt Type	Ice Melting	Mortar Scaling	Metal Corrosion	Cost	Environment Damage
Sodium chloride	0.3865	1.1168	0.1433	0.3179	1.0
Calcium chloride	0.2233	0.4809	0.0867	1.5341	0.9
Potassium acetate	0.1170	0.7393	0.0076	3.2777	0.2
CMA	0.4005	0.0389	0.0002	4.8020	0.3
0.05M Sodium phosphate + NaCl	0.0738	0.0000	0.0000	0.3630	1.0
0.05M Potassium phosphate + NaCl	0.1081	0.0293	0.0068	0.4236	0.8
0.05M Calcium phosphate + NaCl	0.2854	0.6281	0.0000	1.2301	0.8
0.05M CMA + NaCl	0.3456	0.0967	0.0749	0.7663	0.7
Maximum value	0.4005	1.1168	0.1433	4.802	1.0
Factor weighting (Trial 1)	-0.35	0.20	0.20	0.20	0.05
Factor weighting (Trial 2)	-0.15	0.40	0.20	0.20	0.05
Factor weighting (Trial 3)	-0.15	0.20	0.40	0.20	0.05
Factor weighting (Trial 4)	-0.15	0.20	0.20	0.40	0.05
Factor weighting (Trial 5)	-0.10	0.20	0.20	0.20	0.30
Factor weighting (Trial 6)	-0.20	0.30	0.30	0.15	0.05
Factor weighting (Trial 7)	-0.05	0.30	0.30	0.30	0.05
Factor weighting (Trial 8)	-0.20	0.15	0.15	0.30	0.20
Factor weighting (Trial 9)	-0.05	0.30	0.30	0.15	0.20
Factor weighting (Trial 10)	-0.15	0.25	0.25	0.25	0.10
Salt Type	CF Trial 1	CF Trial 2	CF Trial 3	CF Trial 4	CF Trial 5
Sodium chloride	0.125	0.518	0.518	0.332	0.617
Calcium chloride	0.121	0.319	0.353	0.296	0.485
Potassium acetate	0.187	0.378	0.256	0.382	0.310
CMA	-0.128	0.079	0.073	0.272	0.197
0.05M Sodium phosphate + NaCl	0.001	0.037	0.037	0.053	0.297
0.05M Potassium phosphate + NaCl	-0.022	0.037	0.041	0.050	0.245
0.05M Calcium phosphate + NaCl	-0.046	0.209	0.097	0.148	0.332
0.05M CMA + NaCl	-0.113	0.077	0.164	0.091	0.277
Salt Type	CF Trial 6	CF Trial 7	CF Trial 8	CF Trial 9	CF Trial 10
Sodium chloride	0.467	0.622	0.327	0.762	0.472
Calcium chloride	0.292	0.424	0.320	0.511	0.345
Potassium acetate	0.268	0.415	0.294	0.342	0.326
CMA	-0.024	0.276	0.165	0.171	0.139
0.05M Sodium phosphate + NaCl	0.024	0.063	0.186	0.202	0.091
0.05M Potassium phosphate + NaCl	0.021	0.075	0.144	0.182	0.080
0.05M Calcium phosphate + NaCl	0.105	0.250	0.179	0.332	0.178
0.05M CMA + NaCl	0.069	0.223	0.107	0.304	0.133

TABLE 15: Criterion Function Analysis Summary

Trial	Properties of Concern	Best Deicer
1	Ice melting	CMA
2	Mortar scaling	Monosodium and monopotassium phosphates + NaCl mixtures
3	Metal corrosion	Monosodium phosphate + NaCl mixture
4	Cost	Monopotassium phosphate + NaCl mixture
5	Environmental damage	CMA
6	Ice melting, mortar scaling, metal corrosion	CMA
7	Mortar scaling, metal corrosion, cost	Monosodium phosphate + NaCl mixture
8	Ice melting, cost, environmental damage	CMA + NaCl mixture
9	Mortar scaling, metal corrosion, environmental damage	CMA
10	All categories	Monopotassium phosphate + NaCl mixture

CONCLUSIONS AND RECOMMENDATIONS

The general conclusions of this study are be presented below. Following this, recommendations are suggested for improvements in experiments as well as possible areas of further research that were inspired by the results of this research program.

A Conclusions

The conclusion from the criterion function analysis was that monosodium and monopotassium phosphates (used in combination with sodium chloride) were the best alternative deicers. These mixtures had criterion function values similar to each other and better than the rest in most of the trials for the analysis.

Monosodium and monopotassium phosphates could most likely be used effectively as a mixture with either sodium or calcium chloride. The experimental results did not vary significantly when either of these chlorides was used with phosphate. The best combination of phosphate to chloride would be a molality ratio of 1:9 for phosphate:chloride. Ice melting ability may be slightly reduced relative to chloride alone while mortar scaling and metal corrosion would be significantly reduced. The initial cost of the monosodium or monopotassium phosphate/chloride deicer would be slightly more (approximately two to three times that of sodium chloride alone) because of the higher price of phosphate along with the actual processing of the mixture. Final costs would be significantly reduced because of less scaling and corrosion. Environmental damage may be similar to the present day situation, but controlled deicing and proper storage of the deicer should minimize this effect. All in all, the phosphate/chloride mixture would be an effective deicer.

The use of superphosphate or monocalcium phosphate in combination with chlorides is not highly recommended because of the residue it leaves on the surface of mortar. As a pretreatment, it should not be used at concentrations of greater than or equal to 0.05M because of surface scaling of shaley aggregate and excess crystalline formations on the surface of mortar when mortar remained at room temperature. Superphosphate may be an inexpensive source of phosphate but it has some detrimental side effects.

B Recommendations

The mortar cube experiment used in this report was effective in producing enough scaling for distinguishing between good and bad deicer solutions. The mortar cube results were similar to the standard size (ASTM C672) mortar blocks. The question remains concerning the difference in scaling for mortar and concrete. This is a possible area for further research. Brown and Cady (1975) had compared moulded mortar and concrete cubes. Both the mortar and concrete scaled in similar quantities. Therefore, it is recommended that mortar cubes replace concrete blocks in the ASTM

C672 test for mortar scaling. Periodic comparison of concrete blocks with mortar cubes may be required to ensure that the results from mortar cubes are representative of the results from concrete block testing.

There is a definite need for an experiment to test the rate of ice melting by a deicer. Results in this study were nonreproducible, therefore, more research is required in this area.

The simple metal corrosion experiment used was sufficient for this study, though very little corrosion of the bars actually occurred. It is recommended that future efforts try steel wool as a source of metal. Greater corrosion should occur because of the greater surface area of the steel wool.

If phosphate (monosodium or monopotassium) is going to be used in combination with sodium chloride, the main drawback will be the increased cost of processing. The best method to adequately combine these chemicals is not known and should be researched. One possible method of combining phosphate with chloride would be to spray phosphate onto a chloride pile. Liquid calcium chloride is applied to sodium chloride in this manner (Anonymous, 1989b). The method of spraying fluoride on table salt along a conveyor belt (Marthaler, 1980) could also be used for phosphate. There is a definite need for more research in this area.

The final area to be mentioned that requires further research is the mechanism behind mortar scaling. This mechanism is not fully understood. It is known that a pessimum concentration of salt will produce the greatest amount of surface scaling. It is also known that a deicer gradient exists between the interior and exterior of concrete. After deicer application, the exterior of concrete has a higher concentration of salt compared to the interior. Along this salt gradient, could there be a pessimum concentration at which scaling occurs? Concentrations above this pessimum concentration would occur near the exterior of concrete while concentrations below this pessimum concentration would occur away from the exterior of concrete. During freezing and thawing, a salt solution can penetrate deeper into a concrete so that there is an increased amount of salt present in the concrete pores. Could the depth at which a pessimum concentration of salt penetrates into concrete be the depth where scaling is initiated during freezing? Experiments of chloride penetration during freeze-thaw cycling may reveal the answer. Therefore, it is recommended that further research be initiated to find if the depth into concrete at which a certain deicer concentration penetrates is the location where scaling occurs.

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APPENDIX A

Shaley Sand Sieve Analysis

SHALEY SAND SIEVE ANALYSIS

Lot #1

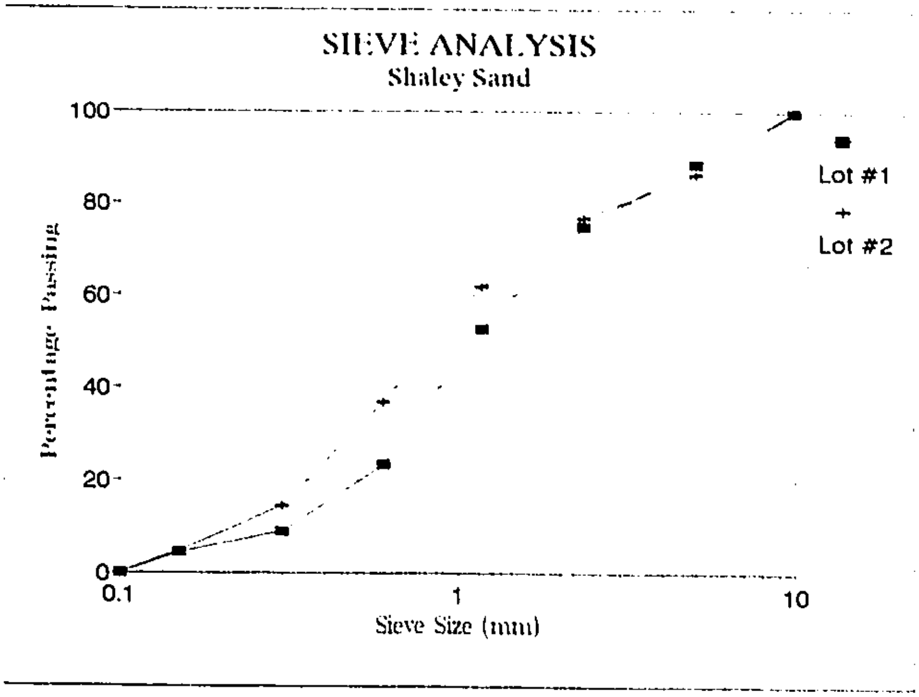
	Opening			%	%
Sieve#	(mm)	Wt.(kg)	Wt.(%)	Passing	Retained
+4	10.00			100.0	
4	5.08	21.7	11.6	88.4	11.6
8	2.36	25.4	13.6	74.8	25.2
16	1.18	41.2	22.1	52.7	47.3
30	0.60	54.7	29.3	23.4	76.6
50	0.30	27.0	14.5	8.9	91.1
100	0.15	8.6	4.6	4.3	95.7
pan	0.10	8.1	4.3	0.0	
Total		186.7	100		347.5

Fineness Modulus = 3.48

Lot #2

	Opening			%	%
Sieve#	(mm)	Wt.(kg)	Wt.(%)	Passing	Retained
+4	10.00			100.0	
4	5.08	33.1	13.8	86.2	13.8
8	2.36	23.1	9.6	76.6	23.4
16	1.18	35.3	14.7	61.9	38.1
30	0.60	60.0	25.0	36.9	63.1
50	0.30	54.2	22.6	14.3	85.7
100	0.15	23.8	9.9	4.4	95.6
pan	0.10	10.6	4.4	0.0	
Total		240.1	100		319.7

Fineness Modulus = 3.20


SIEVE ANALYSIS
Shaley Sand
Percentage Passing
100
80
60
40
20
0
0.1
1
10
Sieve Size (mm)
Lot #1
Lot #2

APPENDIX B

Mortar Cube Scaling Observations (Stage 1)

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

Note: Solution abbreviations

K-Ace = potassium acetate
CMA = calcium magnesium acetate
Na-Ph = sodium phosphate/NaCl mixture
K-Ph = potassium phosphate/NaCl mixture
Ca-Ph = calcium phosphate/NaCl mixture
K-Na = potassium acetate/NaCl mixture
Control (1to4) = control cubes in deionized-distilled water with freeze-thaw
Control (5to8) = control cubes drying in air with no freeze-thaw cycling
Control (9to12) = control cubes for initial compressive strength

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Feb. 23 (dry - 0 cycles)			Mar. 2 (5 cycles)					
	Weight (g)			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.2M NaCl	271.34	251.33	272.95	273.98	252.99	275.13	4	4	5
0.5M NaCl	278.51	237.17	273.18	278.63	237.00	274.22	4	4	4
2.0M NaCl	275.02	258.03	265.92	289.48	271.89	279.15	2	1	1
3.5M NaCl	276.55	254.80	263.67	291.75	269.66	278.90	0	0	0
0.2M CaCl2	282.22	260.45	271.05	286.39	265.52	277.22	3	3	3
0.5M CaCl2	272.78	255.84	256.66	279.85	264.15	264.12	3	3	3
2.0M CaCl2	285.87	246.12	266.93	296.10	255.43	275.14	0	0	0
3.5M CaCl2	278.23	257.80	270.78	284.42	264.01	276.19	0	0	0
0.2M K-Ace	273.44	260.32	258.60	280.56	268.29	264.37	3	3	3
0.5M K-Ace	280.72	257.92	271.86	288.60	266.66	281.47	3	3	3
2.0M K-Ace	267.94	251.12	273.52	279.39	262.78	286.45	1	0	0
3.5M K-Ace	279.60	255.68	263.28	291.47	267.04	275.89	0	0	0
0.05M CMA	286.02	246.08	275.05	295.19	254.48	283.26	2	2	2
0.1M CMA	282.82	253.29	274.71	292.42	262.34	283.34	3	2	3
0.2M CMA	275.40	255.52	263.72	284.99	264.34	272.33	2	3	2
0.5M CMA	281.90	259.24	272.65	288.15	265.75	279.80	1	1	1
0.001M Na-Ph	273.47	260.32	260.76	272.81	262.18	262.99	5	4	4
0.005M Na-Ph	279.13	241.10	268.94	281.93	242.02	273.83	4	4	3
0.01M Na-Ph	277.24	256.01	269.03	286.77	265.29	277.26	3	3	3
0.05M Na-Ph	280.31	250.22	268.53	291.81	261.62	279.01	2	1	2
0.001M K-Ph	278.18	253.58	265.87	280.77	253.62	267.61	4	5	4
0.005M K-Ph	278.22	259.87	273.77	280.00	263.72	278.06	4	3	3
0.01M K-Ph	286.49	255.65	268.12	295.05	264.76	278.26	2	3	2
0.05M K-Ph	278.01	255.42	258.93	289.15	267.97	270.63	1	1	2
0.001M Ca-Ph	268.98	249.00	269.62	269.91	250.83	270.83	4	4	5
0.005M Ca-Ph	280.53	250.35	270.11	282.61	251.78	272.02	4	4	4
0.01M Ca-Ph	269.55	255.89	263.11	274.85	258.84	265.62	3	3	4
0.05M Ca-Ph	281.31	257.86	266.53	292.47	267.54	276.48	2	2	2
0.001M K-Na	275.76	253.85	263.48	276.14	253.77	266.15	4	4	4
0.005M K-Na	280.33	258.59	275.01	283.88	260.83	276.75	4	4	4
0.01M K-Na	278.62	251.59	273.19	280.69	254.90	275.67	4	4	4
0.05M K-Na	275.81	251.91	273.87	280.05	254.52	276.87	4	4	4
Control 1	279.43			290.74			0		
Control 2	243.80			254.50			1		
Control 3	265.76			276.81			0		
Control 4	271.81			282.32			0		
Control 5	276.98			273.70					
Control 6	274.23			271.25					
Control 7	245.42			242.29					
Control 8	244.85			241.89					
Control 9	254.18			251.15					
Control 10	273.38			270.04					
Control 11	257.63			254.59					
Control 12	258.86			256.04					
Block D							3		
Block E							3		

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Mar. 7 (10 cycles)						Mar. 13 (15 cycles)					
	Weight (g)			Scaling			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.2M NaCl	260.85	240.84	264.16	5	5	5	246.32	227.44	250.59	5	5	5
0.5M NaCl	262.31	217.03	257.56	5	5	5	243.56	195.81	239.90	5	5	5
2.0M NaCl	290.27	271.98	278.80	2	2	2	290.38	271.19	278.24	2	2	3
3.5M NaCl	293.23	270.43	279.63	0	0	0	293.80	271.11	280.32	0	0	0
0.2M CaCl2	280.04	256.72	272.10	4	4	4	271.97	247.28	264.63	4	5	4
0.5M CaCl2	276.26	260.09	259.10	3	3	3	270.56	253.82	251.23	4	4	4
2.0M CaCl2	297.74	257.69	277.60	0	0	0	298.78	258.82	278.64	0	0	0
3.5M CaCl2	286.45	266.26	278.72	0	0	0	287.08	267.06	279.75	0	0	0
0.2M K-Ace	276.78	262.78	258.71	5	5	5	268.35	255.57	251.13	5	5	5
0.5M K-Ace	282.48	257.89	274.61	4	4	4	270.43	242.13	261.57	5	5	5
2.0M K-Ace	283.60	265.08	288.90	1	1	1	284.44	265.79	289.91	1	1	1
3.5M K-Ace	295.96	270.12	279.00	0	0	0	297.20	270.96	279.93	0	0	0
0.05M CMA	297.82	256.87	286.49	2	2	2	298.30	257.03	287.01	2	2	2
0.1M CMA	294.87	265.23	286.41	3	2	3	295.08	265.55	287.00	3	2	3
0.2M CMA	287.70	266.49	275.57	2	3	2	287.91	266.63	275.96	2	3	2
0.5M CMA	291.02	267.85	281.72	2	2	2	291.73	268.46	282.31	2	2	2
0.001M Na-Ph	249.53	241.72	245.10	5	5	5	229.37	222.04	228.81	5	5	5
0.005M Na-Ph	261.90	218.42	253.94	5	5	5	241.18	200.47	237.54	5	5	5
0.01M Na-Ph	275.08	254.63	269.76	4	4	4	257.42	238.31	252.85	5	5	5
0.05M Na-Ph	293.86	262.50	281.47	2	1	2	293.54	262.40	281.19	2	1	2
0.001M K-Ph	256.60	230.08	250.99	5	5	5	234.36	209.39	234.92	5	5	5
0.005M K-Ph	260.82	243.41	262.24	5	5	5	241.47	225.75	247.37	5	5	5
0.01M K-Ph	288.74	258.04	274.86	4	4	3	271.86	245.06	264.56	5	5	5
0.05M K-Ph	291.27	268.79	270.44	2	2	2	291.39	268.86	269.80	2	2	2
0.001M Ca-Ph	248.56	230.57	251.95	5	5	5	228.33	210.96	231.87	5	5	5
0.005M Ca-Ph	260.28	233.38	256.81	5	5	5	238.87	215.44	239.33	5	5	5
0.01M Ca-Ph	256.33	240.12	247.77	5	5	5	235.53	219.89	227.54	5	5	5
0.05M Ca-Ph	290.84	263.67	274.97	3	3	3	283.74	254.70	267.93	3	4	3
0.001M K-Na	254.45	236.19	248.62	5	5	5	234.66	216.96	231.64	5	5	5
0.005M K-Na	265.88	244.37	258.40	5	5	5	246.52	229.44	238.71	5	5	5
0.01M K-Na	262.49	239.51	262.24	5	5	5	242.35	222.97	245.64	5	5	5
0.05M K-Na	264.55	240.19	262.02	5	5	5	246.37	223.22	244.97	5	5	5
Control 1	292.61			1			292.27			1		
Control 2	255.53			2			255.02			2		
Control 3	279.15			1			278.80			1		
Control 4	284.07			1			283.76			1		
Control 5	273.26						272.68					
Control 6	270.08						269.09					
Control 7	241.25						240.23					
Control 8	240.79						239.80					
Control 9												
Control 10												
Control 11												
Control 12												
Block D				4						4		
Block E				4						4		

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Mar. 20 (20 cycles)						Mar. 27 (25 cycles)					
	Weight (g)			Scaling			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.2M NaCl	235.97	217.28	240.89	5	5	5	226.83	210.94	232.82	5	5	5
0.5M NaCl	227.99	179.55	223.75	5	5	5	215.08	164.26	211.28	5	5	5
2.0M NaCl	289.93	269.85	277.00	2	2	3	288.54	268.81	274.59	2	2	3
3.5M NaCl	294.41	271.68	280.94	0	0	0	295.02	272.16	281.54	0	0	0
0.2M CaCl2	263.22	236.98	258.62	4	5	4	256.14	228.05	253.29	5	5	4
0.5M CaCl2	263.48	245.45	242.53	4	4	4	257.45	238.63	235.41	4	4	4
2.0M CaCl2	299.29	258.90	279.01	0	1	0	300.10	259.76	278.28	0	1	1
3.5M CaCl2	287.67	267.50	280.15	0	0	0	288.59	268.60	281.19	0	0	0
0.2M K-Ace	256.86	249.11	244.03	5	5	5	246.73	241.49	238.13	5	5	5
0.5M K-Ace	256.24	227.83	248.54	5	5	5	241.33	214.81	237.14	5	5	5
2.0M K-Ace	285.02	266.24	290.38	1	1	1	285.59	266.82	291.08	1	1	1
3.5M K-Ace	297.67	271.38	280.42	0	0	0	298.21	271.86	280.81	0	0	0
0.05M CMA	298.30	257.07	287.27	3	3	3	298.90	257.37	287.53	4	4	4
0.1M CMA	295.27	265.65	286.99	4	3	3	295.29	265.72	287.14	4	3	3
0.2M CMA	287.90	266.73	275.45	3	3	3	288.10	266.91	275.45	3	3	3
0.5M CMA	291.72	268.41	281.97	2	2	3	291.99	268.60	282.14	2	2	3
0.001M Na-Ph	210.19	205.80	212.41	5	5	5	195.70	191.51	200.31	5	5	5
0.005M Na-Ph	223.04	183.57	224.30	5	5	5	207.79	170.28	214.43	5	5	5
0.01M Na-Ph	238.66	220.33	233.47	5	5	5	220.87	206.31	215.23	5	5	5
0.05M Na-Ph	293.42	261.91	280.81	2	2	2	293.62	262.21	281.02	3	2	2
0.001M K-Ph	218.41	194.02	221.21	5	5	5	205.38	180.26	208.55	5	5	5
0.005M K-Ph	225.58	211.67	234.36	5	5	5	212.09	198.43	221.63	5	5	5
0.01M K-Ph	255.79	227.02	248.11	5	5	5	240.68	210.80	234.89	5	5	5
0.05M K-Ph	290.67	268.69	268.65	3	2	3	289.59	268.68	267.48	4	3	4
0.001M Ca-Ph	212.29	195.58	215.96	5	5	5	197.32	181.09	201.36	5	5	5
0.005M Ca-Ph	221.56	200.27	227.49	5	5	5	207.77	187.83	215.85	5	5	5
0.01M Ca-Ph	219.26	201.14	209.20	5	5	5	202.38	186.12	192.40	5	5	5
0.05M Ca-Ph	271.16	242.44	253.50	4	5	4	256.46	229.19	237.29	5	5	5
0.001M K-Na	220.21	203.27	216.10	5	5	5	207.29	191.08	203.25	5	5	5
0.005M K-Na	227.08	213.62	223.78	5	5	5	210.80	200.52	211.08	5	5	5
0.01M K-Na	224.99	210.05	231.37	5	5	5	207.16	198.40	219.51	5	5	5
0.05M K-Na	227.29	207.12	230.39	5	5	5	211.76	191.88	218.47	5	5	5
Control 1	292.08			2			292.45			2		
Control 2	254.82			3			255.13			3		
Control 3	278.58			2			278.97			2		
Control 4	283.69			2			284.17			2		
Control 5	272.44						272.55					
Control 6	268.13						267.66					
Control 7	239.44						239.02					
Control 8	239.05						238.60					
Control 9												
Control 10												
Control 11												
Control 12												
Block D				4						4		
Block E				4						5		

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Apr. 3 (30 cycles)						Apr. 10 (35 cycles)					
	Weight (g)			Scaling			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.2M NaCl	218.56	202.13	225.44	5	5	5	211.40	194.69	218.58	5	5	5
0.5M NaCl	204.72	150.53	202.02	5	5	5	196.46	138.89	193.10	5	5	5
2.0M NaCl	287.86	267.55	273.43	3	3	3	287.07	265.92	272.16	3	3	3
3.5M NaCl	295.25	272.45	281.67	0	0	0	295.45	272.49	281.91	0	0	0
0.2M CaCl2	249.62	221.17	247.67	5	5	5	243.20	215.40	241.45	5	5	5
0.5M CaCl2	250.00	229.27	226.96	5	5	5	243.65	221.36	220.63	5	5	5
2.0M CaCl2	299.98	260.68	278.43	1	1	1	297.62	259.43	277.34	2	2	2
3.5M CaCl2	289.77	269.53	281.91	0	0	0	291.06	270.72	283.20	1	1	1
0.2M K-Ace	240.07	235.57	234.01	5	5	5	233.02	229.73	230.46	5	5	5
0.5M K-Ace	229.01	204.99	228.08	5	5	5	218.54	193.68	220.49	5	5	5
2.0M K-Ace	285.83	267.17	291.25	1	1	1	286.22	267.45	291.64	1	1	2
3.5M K-Ace	298.54	272.19	281.11	0	0	0	298.87	272.32	281.28	0	0	0
0.05M CMA	298.73	257.23	287.53	4	4	4	299.04	257.39	287.84	4	4	4
0.1M CMA	295.33	265.76	287.08	4	3	3	295.57	266.12	267.32	4	3	3
0.2M CMA	288.03	266.88	275.29	3	3	3	288.48	267.12	275.44	3	3	3
0.5M CMA	291.86	268.56	281.97	2	2	3	292.08	268.67	282.13	2	2	3
0.001M Na-Ph	184.07	180.18	190.34	5	5	5	174.84	169.96	182.22	5	5	5
0.005M Na-Ph	197.24	159.74	204.33	5	5	5	188.65	149.68	194.73	5	5	5
0.01M Na-Ph	206.13	194.09	201.47	5	5	5	193.34	183.14	190.44	5	5	5
0.05M Na-Ph	293.11	261.90	280.77	3	2	2	293.55	262.26	281.17	3	2	2
0.001M K-Ph	195.22	169.14	199.69	5	5	5	186.10	159.40	191.59	5	5	5
0.005M K-Ph	199.14	186.50	212.57	5	5	5	189.08	177.90	203.31	5	5	5
0.01M K-Ph	228.52	197.24	224.34	5	5	5	218.61	186.09	215.46	5	5	5
0.05M K-Ph	288.96	268.47	265.29	4	3	4	288.62	268.55	263.09	4	3	4
0.001M Ca-Ph	187.12	170.06	192.17	5	5	5	177.69	159.22	181.95	5	5	5
0.005M Ca-Ph	196.79	175.14	206.73	5	5	5	187.73	165.20	199.48	5	5	5
0.01M Ca-Ph	187.19	174.60	179.67	5	5	5	174.55	164.37	169.52	5	5	5
0.05M Ca-Ph	243.31	217.22	224.11	5	5	5	230.96	206.64	210.88	5	5	5
0.001M K-Na	196.68	182.46	193.14	5	5	5	188.66	174.97	186.58	5	5	5
0.005M K-Na	197.99	191.44	201.18	5	5	5	185.76	183.71	192.67	5	5	5
0.01M K-Na	195.88	190.24	211.56	5	5	5	186.72	183.11	204.52	5	5	5
0.05M K-Na	198.57	180.07	208.25	5	5	5	185.50	171.23	200.43	5	5	5
Control 1	292.25			2			292.72			3		
Control 2	254.79			3			255.08			3		
Control 3	278.65			2			278.99			3		
Control 4	283.86			2			284.24			2		
Control 5	272.48						273.06					
Control 6	267.21						267.08					
Control 7	238.54						238.40					
Control 8	238.15						238.06					
Control 9												
Control 10												
Control 11												
Control 12												
Block D				5						5		
Block E				5						5		

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Apr. 17 (40 cycles)					
	Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.2M NaCl	205.71	188.52	212.67	5	5	5
0.5M NaCl	188.78	126.97	182.74	5	5	5
2.0M NaCl	286.42	265.53	270.75	3	3	3
3.5M NaCl	295.68	272.75	282.13	0	0	0
0.2M CaCl2	238.48	210.27	236.47	5	5	5
0.5M CaCl2	236.31	213.30	213.36	5	5	5
2.0M CaCl2	294.21	255.08	270.78	2	2	2
3.5M CaCl2	290.98	271.85	284.60	1	1	1
0.2M K-Ace	225.12	223.38	226.44	5	5	5
0.5M K-Ace	208.73	183.40	212.45	5	5	5
2.0M K-Ace	286.44	267.71	291.58	1	1	2
3.5M K-Ace	299.04	272.57	281.48	0	0	0
0.05M CMA	298.95	257.28	287.63	4	4	4
0.1M CMA	295.07	266.04	287.42	4	3	4
0.2M CMA	288.34	267.16	275.32	3	3	3
0.5M CMA	292.19	268.75	282.20	2	2	3
0.001M Na-Ph	167.48	162.16	174.28	5	5	5
0.005M Na-Ph	180.63	140.94	184.40	5	5	5
0.01M Na-Ph	182.60	170.62	180.94	5	5	5
0.05M Na-Ph	293.36	262.02	281.03	3	2	2
0.001M K-Ph	178.20	150.18	182.26	5	5	5
0.005M K-Ph	177.64	170.85	193.14	5	5	5
0.01M K-Ph	207.95	175.27	206.59	5	5	5
0.05M K-Ph	287.18	267.71	258.28	4	3	4
0.001M Ca-Ph	167.55	148.75	170.63	5	5	5
0.005M Ca-Ph	179.42	155.74	193.02	5	5	5
0.01M Ca-Ph	162.96	154.50	159.86	5	5	5
0.05M Ca-Ph	220.09	198.56	199.43	5	5	5
0.001M K-Na	179.80	166.95	180.74	5	5	5
0.005M K-Na	173.02	175.13	184.28	5	5	5
0.01M K-Na	178.65	174.90	196.80	5	5	5
0.05M K-Na	176.52	161.97	192.72	5	5	5
Control 1	292.80			3		
Control 2	255.08			3		
Control 3	279.08			3		
Control 4	284.42			2		
Control 5	273.24					
Control 6	266.88					
Control 7	238.32					
Control 8	237.92					
Control 9						
Control 10						
Control 11						
Control 12						
Block D				5		
Block E				5		

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Mar. 2 (5 cycles)					Mar. 7 (10 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.2M NaCl	0.97	0.66	0.80	0.81	4.3	-3.87	-4.17	-3.22	-3.75	5.0
0.5M NaCl	0.04	-0.07	0.38	0.12	4.0	-5.82	-8.49	-5.72	-6.68	5.0
2.0M NaCl	5.26	5.37	4.98	5.20	1.3	5.55	5.41	4.84	5.26	2.0
3.5M NaCl	5.50	5.83	5.78	5.70	0.0	6.03	6.13	6.05	6.07	0.0
0.2M CaCl2	1.48	1.95	2.28	1.90	3.0	-0.77	-1.43	0.39	-0.61	4.0
0.5M CaCl2	2.59	3.25	2.91	2.92	3.0	1.28	1.66	0.95	1.30	3.0
2.0M CaCl2	3.58	3.78	3.08	3.48	0.0	4.15	4.70	4.00	4.28	0.0
3.5M CaCl2	2.22	2.41	2.00	2.21	0.0	2.95	3.28	2.93	3.06	0.0
0.2M K-Ace	2.60	3.06	2.23	2.63	3.0	1.22	0.94	0.04	0.74	5.0
0.5M K-Ace	2.81	3.39	3.53	3.24	3.0	0.63	-0.01	1.01	0.54	4.0
2.0M K-Ace	4.27	4.64	4.73	4.55	0.3	5.84	5.56	5.62	5.68	1.0
3.5M K-Ace	4.25	4.44	4.79	4.49	0.0	5.85	5.65	5.97	5.82	0.0
0.05M CMA	3.21	3.41	2.98	3.20	2.0	4.13	4.38	4.16	4.22	2.0
0.1M CMA	3.39	3.57	3.14	3.37	2.7	4.26	4.71	4.26	4.41	2.7
0.2M CMA	3.48	3.45	3.26	3.40	2.3	4.47	4.29	4.49	4.42	2.3
0.5M CMA	2.22	2.51	2.62	2.45	1.0	3.24	3.32	3.33	3.29	2.0
0.001M Na-Ph	-0.24	0.71	0.86	0.44	4.3	-8.75	-7.15	-6.01	-7.30	5.0
0.005M Na-Ph	1.00	0.38	1.82	1.07	3.7	-6.17	-9.41	-5.58	-7.05	5.0
0.01M Na-Ph	3.44	3.62	3.06	3.37	3.0	-0.78	-0.54	0.27	-0.35	4.0
0.05M Na-Ph	4.10	4.56	3.90	4.19	1.7	4.83	4.91	4.82	4.85	1.7
0.001M K-Ph	0.93	0.02	0.65	0.53	4.3	-7.76	-9.27	-5.60	-7.54	5.0
0.005M K-Ph	0.64	1.48	1.57	1.23	3.3	-6.25	-6.33	-4.21	-5.60	5.0
0.01M K-Ph	2.99	3.56	3.78	3.44	2.3	0.79	0.93	2.51	1.41	3.7
0.05M K-Ph	4.01	4.91	4.52	4.48	1.3	4.77	5.23	4.45	4.82	2.0
0.001M Ca-Ph	0.35	0.73	0.45	0.51	4.3	-7.59	-7.40	-6.55	-7.18	5.0
0.005M Ca-Ph	0.74	0.57	0.71	0.67	4.0	-7.22	-6.78	-4.92	-6.31	5.0
0.01M Ca-Ph	1.97	1.15	0.95	1.36	3.3	-4.90	-6.16	-5.83	-5.63	5.0
0.05M Ca-Ph	3.97	3.75	3.73	3.82	2.0	3.39	2.25	3.17	2.94	3.0
0.001M K-Na	0.14	-0.03	1.01	0.37	4.0	-7.73	-6.96	-5.64	-6.77	5.0
0.005M K-Na	1.27	0.87	0.63	0.92	4.0	-5.15	-5.50	-6.04	-5.56	5.0
0.01M K-Na	0.74	1.32	0.91	0.99	4.0	-5.79	-4.80	-4.01	-4.87	5.0
0.05M K-Na	1.54	1.04	1.10	1.22	4.0	-4.08	-4.65	-4.33	-4 35	5.0
Control 1	4.05					4.72				
Control 2	4.39					4.81				
Control 3	4.16					5.04				
Control 4	3.87			4.12	0.3	4.51			4.77	1.3
Control 5	-1.18					-1.34				
Control 6	-1.09					-1.51				
Control 7	-1.28					-1.70				
Control 8	-1.21			-1.19		-1.66			-1.55	
Control 9	-1.19									
Control 10	-1.22									
Control 11	-1.18									
Control 12	-1.09			-1.17						
Block D					3.0					4.0
Block E					3.0					4.0

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Mar. 13 (15 cycles)					Mar. 20 (20 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.2M NaCl	-9.22	-9.51	-8.19	-8.97	5.0	-13.04	-13.55	-11.75	-12.78	5.0
0.5M NaCl	-12.55	-17.44	-12.18	-14.06	5.0	-18.14	-24.29	-18.09	-20.18	5.0
2.0M NaCl	5.59	5.10	4.63	5.11	2.3	5.42	4.58	4.17	4.72	2.3
3.5M NaCl	6.24	6.40	6.31	6.32	0.0	6.46	6.62	6.55	6.54	0.0
0.2M CaCl2	-3.63	-5.06	-2.37	-3.69	4.3	-6.73	-9.01	-4.59	-6.78	4.3
0.5M CaCl2	-0.81	-0.79	-2.12	-1.24	4.0	-3.41	-4.06	-5.51	-4.33	4.0
2.0M CaCl2	4.52	5.16	4.39	4.69	0.0	4.69	5.19	4.53	4.80	0.3
3.5M CaCl2	3.18	3.59	3.31	3.36	0.0	3.39	3.76	3.46	3.54	0.0
0.2M K-Ace	-1.86	-1.82	-2.89	-2.19	5.0	-6.06	-4.31	-5.63	-5.33	5.0
0.5M K-Ace	-3.67	-6.12	-3.79	-4.52	5.0	-8.72	-11.67	-8.58	-9.65	5.0
2.0M K-Ace	6.16	5.84	5.99	6.00	1.0	6.37	6.02	6.16	6.19	1.0
3.5M K-Ace	6.29	5.98	6.32	6.20	0.0	6.46	6.14	6.51	6.37	0.0
0.05M CMA	4.29	4.45	4.35	4.36	2.0	4.29	4.47	4.44	4.40	3.0
0.1M CMA	4.33	4.84	4.47	4.55	2.7	4.40	4.88	4.47	4.58	3.3
0.2M CMA	4.54	4.35	4.64	4.51	2.3	4.54	4.39	4.45	4.46	3.0
0.5M CMA	3.49	3.56	3.54	3.53	2.0	3.48	3.54	3.42	3.48	2.3
0.001M Na-Ph	-16.13	-14.70	-12.25	-14.36	5.0	-23.14	-20.94	-18.54	-20.88	5.0
0.005M Na-Ph	-13.60	-16.85	-11.68	-14.04	5.0	-20.09	-23.86	-16.60	-20.18	5.0
0.01M Na-Ph	-7.15	-6.91	-6.01	-6.69	5.0	-13.92	-13.94	-13.22	-13.69	5.0
0.05M Na-Ph	4.72	4.87	4.71	4.77	1.7	4.68	4.67	4.57	4.64	2.0
0.001M K-Ph	-15.75	-17.43	-11.64	-14.94	5.0	-21.49	-23.49	-16.80	-20.59	5.0
0.005M K-Ph	-13.21	-13.13	-9.64	-11.99	5.0	-18.92	-18.55	-14.40	-17.29	5.0
0.01M K-Ph	-5.11	-4.14	-1.33	-3.53	5.0	-10.72	-11.20	-7.46	-9.79	5.0
0.05M K-Ph	4.81	5.26	4.20	4.76	2.0	4.55	5.20	3.75	4.50	2.7
0.001M Ca-Ph	-15.11	-15.28	-14.00	-14.80	5.0	-21.08	-21.45	-19.90	-20.81	5.0
0.005M Ca-Ph	-14.85	-13.94	-11.40	-13.40	5.0	-21.02	-20.00	-15.78	-18.93	5.0
0.01M Ca-Ph	-12.62	-14.07	-13.52	-13.40	5.0	-18.66	-21.40	-20.49	-20.18	5.0
0.05M Ca-Ph	0.86	-1.23	0.53	0.05	3.3	-3.61	-5.98	-4.89	-4.83	4.3
0.001M K-Na	-14.90	-14.53	-12.08	-13.84	5.0	-20.14	-19.93	-17.98	-19.35	5.0
0.005M K-Na	-12.06	-11.27	-13.20	-12.18	5.0	-19.00	-17.39	-18.63	-18.34	5.0
0.01M K-Na	-13.02	-11.38	-10.08	-11.49	5.0	-19.25	-16.51	-15.31	-17.02	5.0
0.05M K-Na	-10.67	-11.39	-10.55	-10.87	5.0	-17.59	-17.78	-15.88	-17.08	5.0
Control 1	4.60					4.53				
Control 2	4.60					4.52				
Control 3	4.91					4.82				
Control 4	4.40			4.63	1.3	4.37			4.56	2.3
Control 5	-1.55					-1.64				
Control 6	-1.87					-2.22				
Control 7	-2.11					-2.44				
Control 8	-2.06			-1.90		-2.37			-2.17	
Control 9										
Control 10										
Control 11										
Control 12										
Block D					4.0					4.0
Block E					4.0					4.0

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Mar. 27 (25 cycles)					Apr. 3 (30 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.2M NaCl	-16.40	-16.07	-14.70	-15.73	5.0	-19.45	-19.58	-17.41	-18.81	5.0
0.5M NaCl	-22.77	-30.74	-22.66	-25.39	5.0	-26.49	-36.53	-26.05	-29.69	5.0
2.0M NaCl	4.92	4.18	3.26	4.12	2.3	4.67	3.69	2.82	3.73	3.0
3.5M NaCl	6.68	6.81	6.78	6.76	0.0	6.76	6.93	6.83	6.84	0.0
0.2M CaCl2	-9.24	-12.44	-6.55	-9.41	4.7	-11.55	-15.08	-8.63	-11.75	5.0
0.5M CaCl2	-5.62	-6.73	-8.28	-6.88	4.0	-8.35	-10.39	-11.57	-10.10	5.0
2.0M CaCl2	4.98	5.54	4.25	4.92	0.7	4.94	5.92	4.31	5.05	1.0
3.5M CaCl2	3.72	4.19	3.84	3.92	0.0	4.15	4.55	4.11	4.27	0.0
0.2M K-Ace	-9.77	-7.23	-7.92	-8.31	5.0	-12.20	-9.51	-9.51	-10.41	5.0
0.5M K-Ace	-14.03	-16.71	-12.77	-14.51	5.0	-18.42	-20.52	-16.10	-18.35	5.0
2.0M K-Ace	6.59	6.25	6.42	6.42	1.0	6.68	6.39	6.48	6.52	1.0
3.5M K-Ace	6.66	6.33	6.66	6.55	0.0	6.77	6.46	6.77	6.67	0.0
0.05M CMA	4.50	4.59	4.54	4.54	4.0	4.44	4.53	4.54	4.50	4.0
0.1M CMA	4.41	4.91	4.52	4.61	3.3	4.42	4.92	4.50	4.62	3.3
0.2M CMA	4.61	4.46	4.45	4.51	3.0	4.59	4.45	4.39	4.47	3.0
0.5M CMA	3.58	3.61	3.48	3.56	2.3	3.53	3.60	3.42	3.52	2.3
0.001M Na-Ph	-28.44	-26.43	-23.18	-26.02	5.0	-32.69	-30.79	-27.01	-30.16	5.0
0.005M Na-Ph	-25.56	-29.37	-20.27	-25.07	5.0	-29.34	-33.75	-24.02	-29.04	5.0
0.01M Na-Ph	-20.33	-19.41	-20.00	-19.91	5.0	-25.65	-24.19	-25.11	-24.98	5.0
0.05M Na-Ph	4.75	4.79	4.65	4.73	2.3	4.57	4.67	4.56	4.60	2.3
0.001M K-Ph	-26.17	-28.91	-21.56	-25.55	5.0	-29.82	-33.30	-24.89	-29.34	5.0
0.005M K-Ph	-23.77	-23.64	-19.05	-22.15	5.0	-28.42	-28.23	-22.35	-26.34	5.0
0.01M K-Ph	-15.99	-17.54	-12.39	-15.31	5.0	-20.23	-22.85	-16.33	-19.80	5.0
0.05M K-Ph	4.17	5.19	3.30	4.22	3.7	3.94	5.11	2.46	3.83	3.7
0.001M Ca-Ph	-26.64	-27.27	-25.32	-26.41	5.0	-30.43	-31.70	-28.73	-30.29	5.0
0.005M Ca-Ph	-25.94	-24.97	-20.09	-23.67	5.0	-29.85	-30.04	-23.46	-27.79	5.0
0.01M Ca-Ph	-24.92	-27.27	-26.87	-26.35	5.0	-30.55	-31.77	-31.71	-31.35	5.0
0.05M Ca-Ph	-8.83	-11.12	-10.97	-10.31	5.0	-13.51	-15.76	-15.92	-15.06	5.0
0.001M K-Na	-24.83	-24.73	-22.86	-24.14	5.0	-28.68	-28.12	-26.70	-27.83	5.0
0.005M K-Na	-24.80	-22.46	-23.25	-23.50	5.0	-29.37	-25.97	-26.85	-27.40	5.0
0.01M K-Na	-25.65	-21.14	-19.65	-22.15	5.0	-29.70	-24.38	-22.56	-25.55	5.0
0.05M K-Na	-23.22	-23.83	-20.23	-22.43	5.0	-28.00	-28.52	-23.96	-26.83	5.0
Control 1	4.66					4.59				
Control 2	4.65					4.51				
Control 3	4.97					4.85				
Control 4	4.55			4.71	2.3	4.43			4.59	2.3
Control 5	-1.60					-1.62				
Control 6	-2.40					-2.56				
Control 7	-2.61					-2.80				
Control 8	-2.55			-2.29		-2.74			-2.43	
Control 9										
Control 10										
Control 11										
Control 12										
Block D					4.0					5.0
Block E					5.0					5.0

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

	Apr. 10 (35 cycles)					Apr. 17 (40 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.2M NaCl	-22.09	-22.54	-19.92	-21.52	5.0	-24.19	-24.99	-22.08	-23.75	5.0
0.5M NaCl	-29.46	-41.44	-29.31	-33.40	5.0	-32.22	-46.46	-33.11	-37.26	5.0
2.0M NaCl	4.38	3.06	2.35	3.26	3.0	4.15	2.91	1.82	2.96	3.0
3.5M NaCl	6.83	6.94	6.92	6.90	0.0	6.92	7.04	7.00	6.99	0.0
0.2M CaCl2	-13.83	-17.30	-10.92	-14.01	5.0	-15.50	-19.27	-12.76	-15.84	5.0
0.5M CaCl2	-10.68	-13.48	-14.04	-12.73	5.0	-13.37	-16.63	-16.87	-15.62	5.0
2.0M CaCl2	4.11	5.41	3.90	4.47	2.0	2.92	3.64	1.44	2.67	2.0
3.5M CaCl2	4.61	5.01	4.59	4.74	1.0	4.58	5.45	5.10	5.05	1.0
0.2M K-Ace	-14.78	-11.75	-10.88	-12.47	5.0	-17.67	-14.19	-12.44	-14.77	5.0
0.5M K-Ace	-22.15	-24.91	-18.90	-21.98	5.0	-25.64	-28.89	-21.85	-25.46	5.0
2.0M K-Ace	6.82	6.50	6.62	6.65	1.3	6.90	6.61	6.60	6.70	1.3
3.5M K-Ace	6.89	6.51	6.84	6.75	0.0	6.95	6.61	6.91	6.82	0.0
0.05M CMA	4.55	4.60	4.65	4.60	4.0	4.52	4.55	4.57	4.55	4.0
0.1M CMA	4.51	5.07	4.59	4.72	3.3	4.33	5.03	4.63	4.66	3.7
0.2M CMA	4.75	4.54	4.44	4.58	3.0	4.70	4.56	4.40	4.55	3.0
0.5M CMA	3.61	3.64	3.48	3.58	2.3	3.65	3.67	3.50	3.61	2.3
0.001M Na-Ph	-36.07	-34.71	-30.12	-33.63	5.0	-38.76	-37.71	-33.16	-36.54	5.0
0.005M Na-Ph	-32.42	-37.92	-27.59	-32.64	5.0	-35.29	-41.54	-31.43	-36.09	5.0
0.01M Na-Ph	-30.26	-28.46	-29.21	-29.31	5.0	-34.14	-33.35	-32.74	-33.41	5.0
0.05M Na-Ph	4.72	4.81	4.71	4.75	2.3	4.66	4.72	4.65	4.68	2.3
0.001M K-Ph	-33.10	-37.14	-27.94	-32.73	5.0	-35.94	-40.78	-31.45	-36.05	5.0
0.005M K-Ph	-32.04	-31.54	-25.74	-29.77	5.0	-36.15	-34.26	-29.45	-33.29	5.0
0.01M K-Ph	-23.69	-27.21	-19.64	-23.51	5.0	-27.41	-31.44	-22.95	-27.27	5.0
0.05M K-Ph	3.82	5.14	1.61	3.52	3.7	3.30	4.81	-0.25	2.62	3.7
0.001M Ca-Ph	-33.94	-36.06	-32.52	-34.17	5.0	-37.71	-40.26	-36.71	-38.23	5.0
0.005M Ca-Ph	-33.08	-34.01	-26.15	-31.08	5.0	-36.04	-37.79	-28.54	-34.12	5.0
0.01M Ca-Ph	-35.24	-35.77	-35.57	-35.53	5.0	-39.54	-39.62	-39.24	-39.47	5.0
0.05M Ca-Ph	-17.90	-19.86	-20.88	-19.55	5.0	-21.76	-23.00	-25.18	-23.31	5.0
0.001M K-Na	-31.59	-31.07	-29.19	-30.62	5.0	-34.80	-34.23	-31.40	-33.48	5.0
0.005M K-Na	-33.74	-28.96	-29.94	-30.88	5.0	-38.28	-32.28	-32.99	-34.52	5.0
0.01M K-Na	-32.98	-27.22	-25.14	-28.45	5.0	-35.88	-30.48	-27.96	-31.44	5.0
0.05M K-Na	-32.74	-32.03	-26.82	-30.53	5.0	-36.00	-35.70	-29.63	-33.78	5.0
Control 1	4.76					4.78				
Control 2	4.63					4.63				
Control 3	4.98					5.01				
Control 4	4.57			4.73	2.8	4.64			4.77	2.8
Control 5	-1.42					-1.35				
Control 6	-2.61					-2.68				
Control 7	-2.86					-2.89				
Control 8	-2.77			-2.41		-2.83			-2.44	
Control 9										
Control 10										
Control 11										
Control 12										
Block D					5.0					5.0
Block E					5.0					5.0

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

Salt Type	0 Cycle Wt Chg	5 Cycle Wt Chg	10 Cycle Wt Chg	15 Cycle Wt Chg	20 Cycle Wt Chg	25 Cycle Wt Chg	30 Cycle Wt Chg	35 Cycle Wt Chg	40 Cycle Wt Chg
0.2M NaCl	0.00	0.81	-3.75	-8.97	-12.78	-15.73	-18.81	-21.52	-23.75
0.5M NaCl	0.00	0.12	-6.68	-14.06	-20.18	-25.39	-29.69	-33.40	-37.26
2.0M NaCl	0.00	5.20	5.26	5.11	4.72	4.12	3.73	3.26	2.96
3.5M NaCl	0.00	5.70	6.07	6.32	6.54	6.76	6.84	6.90	6.99
0.2M CaCl2	0.00	1.90	-0.61	-3.69	-6.78	-9.41	-11.75	-14.01	-15.84
0.5M CaCl2	0.00	2.92	1.30	-1.24	-4.33	-6.88	-10.10	-12.73	-15.62
2.0M CaCl2	0.00	3.48	4.28	4.69	4.80	4.92	5.05	4.47	2.67
3.5M CaCl2	0.00	2.21	3.06	3.36	3.54	3.92	4.27	4.74	5.05
0.2M K-Ace	0.00	2.63	0.74	-2.19	-5.33	-8.31	-10.41	-12.47	-14.77
0.5M K-Ace	0.00	3.24	0.54	-4.52	-9.65	-14.51	-18.35	-21.98	-25.46
2.0M K-Ace	0.00	4.55	5.68	6.00	6.19	6.42	6.52	6.65	6.70
3.5M K-Ace	0.00	4.49	5.82	6.20	6.37	6.55	6.67	6.75	6.82
0.05M CMA	0.00	3.20	4.22	4.36	4.40	4.54	4.50	4.60	4.55
0.1M CMA	0.00	3.37	4.41	4.55	4.58	4.61	4.62	4.72	4.66
0.2M CMA	0.00	3.40	4.42	4.51	4.46	4.51	4.47	4.58	4.55
0.5M CMA	0.00	2.45	3.29	3.53	3.48	3.56	3.52	3.58	3.61
0.001M Na-Ph	0.00	0.44	-7.30	-14.36	-20.88	-26.02	-30.16	-33.63	-36.54
0.005M Na-Ph	0.00	1.07	-7.05	-14.04	-20.18	-25.07	-29.04	-32.64	-36.09
0.01M Na-Ph	0.00	3.37	-0.35	-6.69	-13.69	-19.91	-24.98	-29.31	-33.41
0.05M Na-Ph	0.00	4.19	4.85	4.77	4.64	4.73	4.60	4.75	4.68
0.001M K-Ph	0.00	0.53	-7.54	-14.94	-20.59	-25.55	-29.34	-32.73	-36.05
0.005M K-Ph	0.00	1.23	-5.60	-11.99	-17.29	-22.15	-26.34	-29.77	-33.29
0.01M K-Ph	0.00	3.44	1.41	-3.53	-9.79	-15.31	-19.80	-23.51	-27.27
0.05M K-Ph	0.00	4.48	4.82	4.76	4.50	4.22	3.83	3.52	2.62
0.001M Ca-Ph	0.00	0.51	-7.18	-14.80	-20.81	-26.41	-30.29	-34.17	-38.23
0.005M Ca-Ph	0.00	0.67	-6.31	-13.40	-18.93	-23.67	-27.79	-31.08	-34.12
0.01M Ca-Ph	0.00	1.36	-5.63	-13.40	-20.18	-26.35	-31.35	-35.53	-39.47
0.05M Ca-Ph	0.00	3.82	2.94	0.05	-4.83	-10.31	-15.06	-19.55	-23.31
0.001M K-Na	0.00	0.37	-6.77	-13.84	-19.35	-24.14	-27.83	-30.62	-33.48
0.005M K-Na	0.00	0.92	-5.56	-12.18	-18.34	-23.50	-27.40	-30.88	-34.52
0.01M K-Na	0.00	0.99	-4.87	-11.49	-17.02	-22.15	-25.55	-28.45	-31.44
0.05M K-Na	0.00	1.22	-4.35	-10.87	-17.08	-22.43	-26.83	-30.53	-33.78
Control 1									
Control 2									
Control 3									
Control 4	0.00	4.12	4.77	4.63	4.56	4.71	4.59	4.73	4.77
Control 5									
Control 6									
Control 7									
Control 8	0.00	-1.19	-1.55	-1.90	-2.17	-2.29	-2.43	-2.41	-2.44
Control 9									
Control 10									
Control 11									
Control 12	0.00	-1.17							
Block D									
Block E									

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

Salt Type	0 Cycle Scale	5 Cycle Scale	10 Cycle Scale	15 Cycle Scale	20 Cycle Scale	25 Cycle Scale	30 Cycle Scale	35 Cycle Scale	40 Cycle Scale
0.2M NaCl	0.0	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.5M NaCl	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
2.0M NaCl	0.0	1.3	2.0	2.3	2.3	2.3	3.0	3.0	3.0
3.5M NaCl	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2M CaCl2	0.0	3.0	4.0	4.3	4.3	4.7	5.0	5.0	5.0
0.5M CaCl2	0.0	3.0	3.0	4.0	4.0	4.0	5.0	5.0	5.0
2.0M CaCl2	0.0	0.0	0.0	0.0	0.3	0.7	1.0	2.0	2.0
3.5M CaCl2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0
0.2M K-Ace	0.0	3.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.5M K-Ace	0.0	3.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0
2.0M K-Ace	0.0	0.3	1.0	1.0	1.0	1.0	1.0	1.3	1.3
3.5M K-Ace	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.05M CMA	0.0	2.0	2.0	2.0	3.0	4.0	4.0	4.0	4.0
0.1M CMA	0.0	2.7	2.7	2.7	3.3	3.3	3.3	3.3	3.7
0.2M CMA	0.0	2.3	2.3	2.3	3.0	3.0	3.0	3.0	3.0
0.5M CMA	0.0	1.0	2.0	2.0	2.3	2.3	2.3	2.3	2.3
0.001M Na-Ph	0.0	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.005M Na-Ph	0.0	3.7	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.01M Na-Ph	0.0	3.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0
0.05M Na-Ph	0.0	1.7	1.7	1.7	2.0	2.3	2.3	2.3	2.3
0.001M K-Ph	0.0	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.005M K-Ph	0.0	3.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.01M K-Ph	0.0	2.3	3.7	5.0	5.0	5.0	5.0	5.0	5.0
0.05M K-Ph	0.0	1.3	2.0	2.0	2.7	3.7	3.7	3.7	3.7
0.001M Ca-Ph	0.0	4.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.005M Ca-Ph	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.01M Ca-Ph	0.0	3.3	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.05M Ca-Ph	0.0	2.0	3.0	3.3	4.3	5.0	5.0	5.0	5.0
0.001M K-Na	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.005M K-Na	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.01M K-Na	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
0.05M K-Na	0.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Control 1	0.0								
Control 2	0.0								
Control 3	0.0								
Control 4	0.0	0.3	1.3	1.3	2.3	2.3	2.3	2.8	2.8
Control 5	0.0								
Control 6	0.0								
Control 7	0.0								
Control 8	0.0								
Control 9	0.0								
Control 10	0.0								
Control 11	0.0								
Control 12	0.0								
Block D	0.0	3.0	4.0	4.0	4.0	4.0	5.0	5.0	5.0
Block E	0.0	3.0	4.0	4.0	4.0	5.0	5.0	5.0	5.0

MORTAR CUBE SCALING OBSERVATIONS - STAGE 1

WEIGHT CHANGE NEGLECTING WATER ABSORPTION (ie. 4.61%)

Salt Type	0 Cycle Wt Chg	5 Cycle Wt Chg	10 Cycle Wt Chg	15 Cycle Wt Chg	20 Cycle Wt Chg	25 Cycle Wt Chg	30 Cycle Wt Chg	35 Cycle Wt Chg	40 Cycle Wt Chg
0.2M NaCl	0.00	-3.80	-8.36	-13.58	-17.39	-20.34	-23.42	-26.13	-28.36
0.5M NaCl	0.00	-4.49	-11.29	-18.67	-24.79	-30.00	-34.30	-38.01	-41.87
2.0M NaCl	0.00	0.59	0.65	0.50	0.11	-0.49	-0.88	-1.35	-1.65
3.5M NaCl	0.00	1.09	1.46	1.71	1.93	2.15	2.23	2.29	2.38
0.2M CaCl2	0.00	-2.71	-5.22	-8.30	-11.39	-14.02	-16.36	-18.62	-20.45
0.5M CaCl2	0.00	-1.69	-3.31	-5.85	-8.94	-11.49	-14.71	-17.34	-20.23
2.0M CaCl2	0.00	-1.13	-0.33	0.08	0.19	0.31	0.44	-0.14	-1.94
3.5M CaCl2	0.00	-2.40	-1.55	-1.25	-1.07	-0.69	-0.34	0.13	0.44
0.2M K-Ace	0.00	-1.98	-3.87	-6.80	-9.94	-12.92	-15.02	-17.08	-19.38
0.5M K-Ace	0.00	-1.37	-4.07	-9.13	-14.26	-19.12	-22.96	-26.59	-30.07
2.0M K-Ace	0.00	-0.06	1.07	1.39	1.58	1.81	1.91	2.04	2.09
3.5M K-Ace	0.00	-0.12	1.21	1.59	1.76	1.94	2.06	2.14	2.21
0.05M CMA	0.00	-1.41	-0.39	-0.25	-0.21	-0.07	-0.11	-0.01	-0.06
0.1M CMA	0.00	-1.24	-0.20	-0.06	-0.03	0.00	0.01	0.11	0.05
0.2M CMA	0.00	-1.21	-0.19	-0.10	-0.15	-0.10	-0.14	-0.03	-0.06
0.5M CMA	0.00	-2.16	-1.32	-1.08	-1.13	-1.05	-1.09	-1.03	-1.00
0.001M Na-Ph	0.00	-4.17	-11.91	-18.97	-25.49	-30.63	-34.77	-38.24	-41.15
0.005M Na-Ph	0.00	-3.54	-11.66	-18.65	-24.79	-29.68	-33.65	-37.25	-40.70
0.01M Na-Ph	0.00	-1.24	-4.96	-11.30	-18.30	-24.52	-29.59	-33.92	-38.02
0.05M Na-Ph	0.00	-0.42	0.24	0.16	0.03	0.12	-0.01	0.14	0.07
0.001M K-Ph	0.00	-4.08	-12.15	-19.55	-25.20	-30.16	-33.95	-37.34	-40.66
0.005M K-Ph	0.00	-3.38	-10.21	-16.60	-21.90	-26.76	-30.95	-34.38	-37.90
0.01M K-Ph	0.00	-1.17	-3.20	-8.14	-14.40	-19.92	-24.41	-28.12	-31.88
0.05M K-Ph	0.00	-0.13	0.21	0.15	-0.11	-0.39	-0.78	-1.09	-1.99
0.001M Ca-Ph	0.00	-4.10	-11.79	-19.41	-25.42	-31.02	-34.90	-38.78	-42.84
0.005M Ca-Ph	0.00	-3.94	-10.92	-18.01	-23.54	-28.28	-32.40	-35.69	-38.73
0.01M Ca-Ph	0.00	-3.25	-10.24	-18.01	-24.79	-30.96	-35.96	-40.14	-44.08
0.05M Ca-Ph	0.00	-0.79	-1.67	-4.56	-9.44	-14.92	-19.67	-24.16	-27.92
0.001M K-Na	0.00	-4.24	-11.38	-18.45	-23.96	-28.75	-32.44	-35.23	-38.09
0.005M K-Na	0.00	-3.69	-10.17	-16.79	-22.95	-28.11	-32.01	-35.49	-39.13
0.01M K-Na	0.00	-3.62	-9.48	-16.10	-21.63	-26.76	-30.16	-33.06	-36.05
0.05M K-Na	0.00	-3.39	-8.96	-15.48	-21.69	-27.04	-31.44	-35.14	-38.39
Control 1									
Control 2									
Control 3									
Control 4	0.00	-0.49	0.16	0.02	-0.05	0.10	-0.02	0.12	0.16
Control 5									
Control 6									
Control 7									
Control 8	0.00	-1.19	-1.55	-1.90	-2.17	-2.29	-2.43	-2.41	-2.44
Control 9									
Control 10									
Control 11									
Control 12	0.00	-1.17							

CUBE WEIGHT LOSS LINEAR REGRESSION ANALYSIS - STAGE 1
(Force lines through zero)

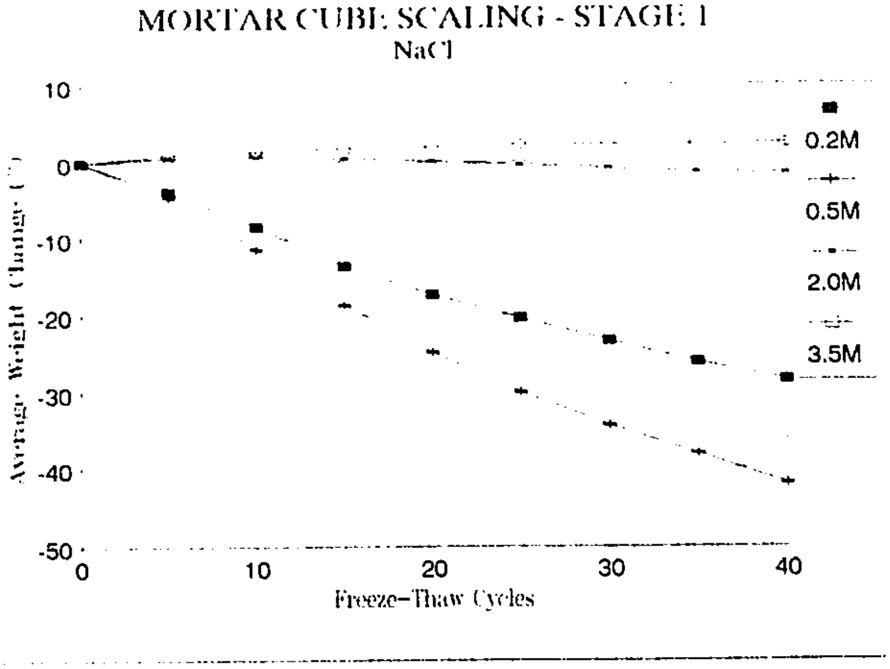
Salt / Chloride Mixture	Constant	Std Err of Y Est	R Squared	# of Observ.	Degrees of Freedom	X Coef.	Std Err of Coef.	Rank
3.5M NaCl	0	0.5152	0.5438	9	8	-0.0745	0.0072	1
3.5M KC2H3O2	0	0.4106	0.7888	9	8	-0.0675	0.0057	2
2.0M KC2H3O2	0	0.3338	0.8377	9	8	-0.0628	0.0047	3
0.05M NaH2PO4 + 0.45M NaCl	0	0.1826	0.0814	9	8	-0.0026	0.0026	4
Deionized-Distilled Water (Control)	0	0.1932	0.0717	9	8	-0.0021	0.0027	5
0.1M CMA	0	0.4466	-0.1436	9	8	0.0006	0.0063	6
0.2M CMA	0	0.4284	-0.2985	9	8	0.0045	0.0060	7
0.05M CMA	0	0.5148	-0.3544	9	8	0.0052	0.0072	8
2.0M CaCl2	0	0.7652	0.0281	9	8	0.0128	0.0107	9
3.5M CaCl2	0	1.1523	-0.6032	9	8	0.0144	0.0161	10
2.0M NaCl	0	0.6273	0.4669	9	8	0.0261	0.0088	11
0.05M KH2PO4 + 0.45M NaCl	0	0.4505	0.6039	9	8	0.0293	0.0063	12
0.5M CMA	0	0.8304	-1.3020	9	8	0.0389	0.0116	13
Air (Control)	0	0.5932	0.4625	9	8	0.0795	0.0083	14
0.5M CaCl2	0	0.9143	0.9837	9	8	0.4809	0.0128	15
0.2M KC2H3O2	0	0.5238	0.9943	9	8	0.4894	0.0073	16
0.2M CaCl2	0	0.4987	0.9952	9	8	0.5351	0.0070	17
0.05M Ca(H2PO4)2*H2O + 0.45M NaCl	0	3.0423	0.9181	9	8	0.6281	0.0426	18
0.5M KC2H3O2	0	1.6718	0.9777	9	8	0.7393	0.0234	19
0.2M NaCl	0	1.4310	0.9795	9	8	0.7675	0.0200	20
0.01M KH2PO4 + 0.49M NaCl	0	2.3668	0.9617	9	8	0.7721	0.0331	21
0.01M NaH2PO4 + 0.49M NaCl	0	2.3453	0.9734	9	8	0.9412	0.0328	22
0.01M KC2H3O2 + 0.49M NaCl	0	1.7562	0.9820	9	8	0.9725	0.0246	23
0.005M KH2PO4 + 0.495M NaCl	0	1.4811	0.9881	9	8	1.0045	0.0207	24
0.05M KC2H3O2 + 0.45M NaCl	0	1.3679	0.9905	9	8	1.0112	0.0192	25
0.005M KC2H3O2 + 0.495M NaCl	0	1.5978	0.9872	9	8	1.0394	0.0224	26
0.001M KC2H3O2 + 0.499M NaCl	0	2.3070	0.9719	9	8	1.0469	0.0323	27
0.005M Ca(H2PO4)2*H2O + 0.495M NaCl	0	1.9412	0.9807	9	8	1.0485	0.0272	28
0.005M NaH2PO4 + 0.495M NaCl	0	2.0696	0.9802	9	8	1.0967	0.0290	29
0.001M KH2PO4 + 0.499M NaCl	0	2.3210	0.9748	9	8	1.1068	0.0325	30
0.5M NaCl	0	1.7618	0.9861	9	8	1.1168	0.0247	31
0.001M NaH2PO4 + 0.499M NaCl	0	2.2146	0.9780	9	8	1.1231	0.0310	32
0.001M Ca(H2PO4)2*H2O + 0.499M NaCl	0	1.9546	0.9837	9	8	1.1434	0.0274	33
0.01M Ca(H2PO4)2*H2O + 0.49M NaCl	0	1.6585	0.9894	9	8	1.1579	0.0232	34

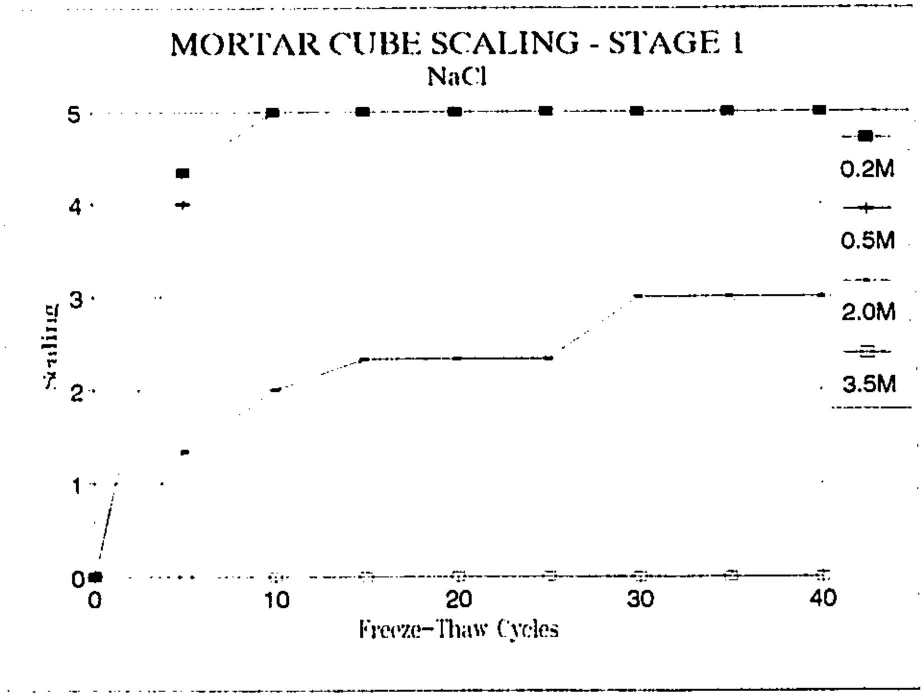
Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Squared = Correlation coefficient squared

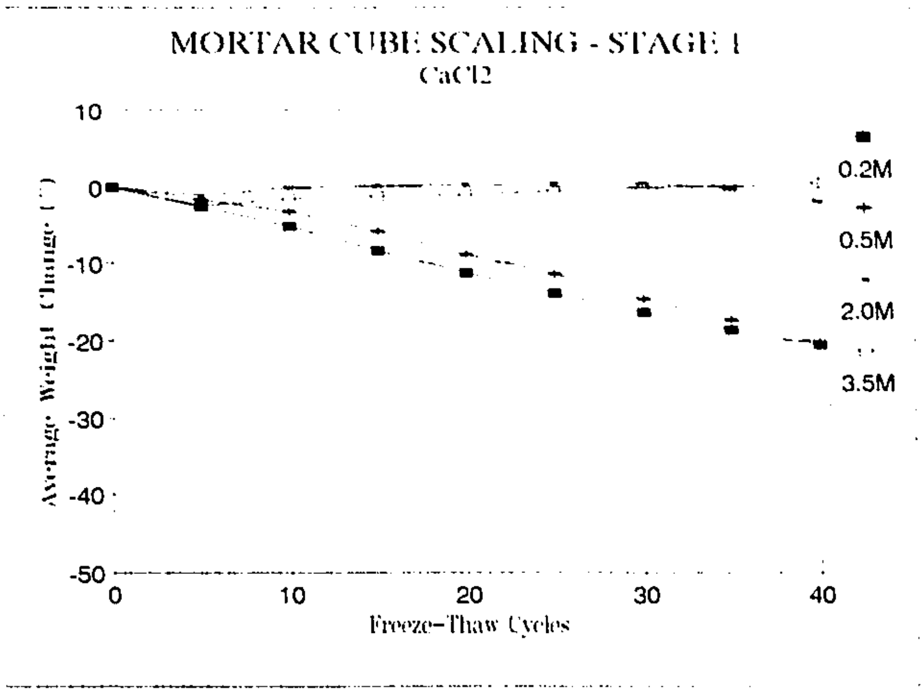
MORTAR CUBE VISUAL OBSERVATIONS - STAGE I

	After 4 Cycles		After 12 Cycles		After 15 Cycles		After 19 Cycles	
Solution	Unfrozen Solution	Explosions	Unfrozen Solution	Saturation of Cubes (%)	Cracking	Salt Accumulation	Explosions	Cracking
0.2M NaCl		Minor		30			Minor	
0.5M NaCl		Minor		90				
2.0M NaCl	Minor			100	On top, side	Significant on top		
3.5M NaCl	Little		Little	100	On top	Less on top, side		
0.2M CaCl2		Abundant		10			Significant	
0.5M CaCl2		Less abundant		50			Significant	
2.0M CaCl2	Abundant		Little	80				
3.5M CaCl2	All		All	85				
0.2M K-Ace		Minor		10			Little	
0.5M K-Ace		Trace		95			Minor	
2.0M K-Ace	Little		Little	95	On top, side			
3.5M K-Ace	All		Almost all	100				On top
0.05M CMA				0				
0.1M CMA				5				
0.2M CMA			Minor	10				
0.5M CMA	Minor		Minor	15				
0.001M Na-Ph		Minor		75			Little	
0.005M Na-Ph				65			Little	
0.01M Na-Ph				60			Little	
0.05M Na-Ph				50				
0.001M K-Ph		Minor		75			Minor	
0.005M K-Ph				50			Little	
0.01M K-Ph				50			Little	
0.05M K-Ph				50				
0.001M Ca-Ph		Trace		50			Little	
0.005M Ca-Ph		Trace		50			Little	
0.01M Ca-Ph				50			Minor	
0.05M Ca-Ph				50			Minor	
0.001M K-Na				50			Little	
0.005M K-Na		Trace		50			Little	
0.01M K-Na		Trace		50			Minor	
0.05M K-Na		Trace		50			Minor	
Control(1-4)				0				

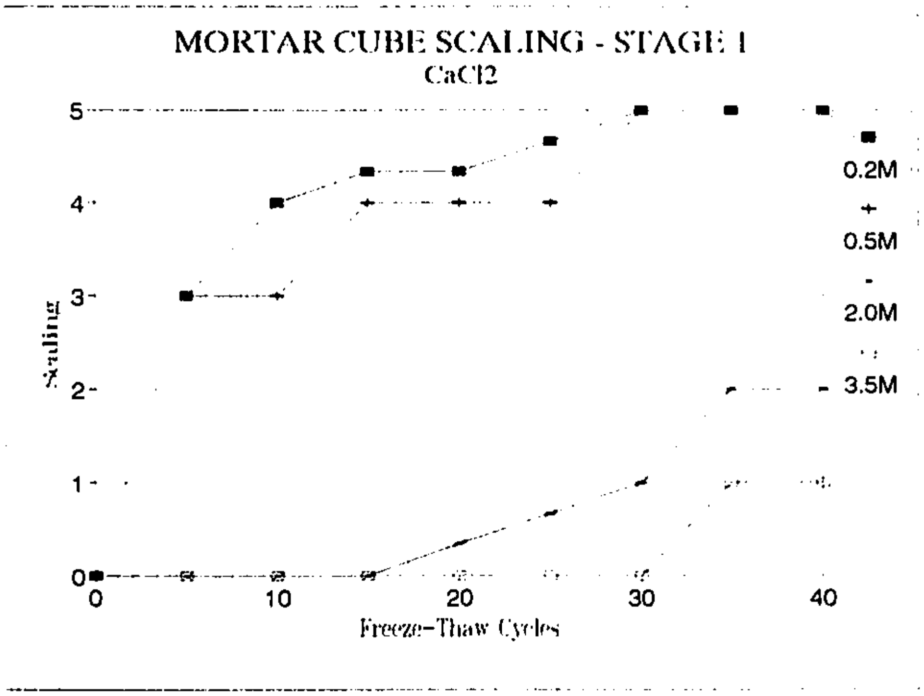
Note: 1) Mortar cube observations listed were taken immediately after removal from the freezer.
2) Unfrozen solution is melt water present in the container.
3) Explosions are scaled material which have been ejected from the cube surface over 1cm away.
4) Saturation of cube refers to the height at which the cube side appears damp.
5) Solution abbreviations used:
K-Ace = potassium acetate
CMA = calcium magnesium acetate
Na-Ph = sodium phosphate/NaCl mixture
K-Ph = potassium phosphate/NaCl mixture
Ca-Ph = calcium phosphate/NaCl mixture
K-Na = potassium acetate/NaCl mixture
Control(1-4) = deionized-distilled water freeze-thaw cycling


MORTAR CUBE SCALING - STAGE 1
NaCl
10
0
-10
-20
-30
-40
-50
Average Weight Change (%)
0
10
20
30
40
Freeze–Thaw Cycles
0.2M
0.5M
2.0M
3.5M

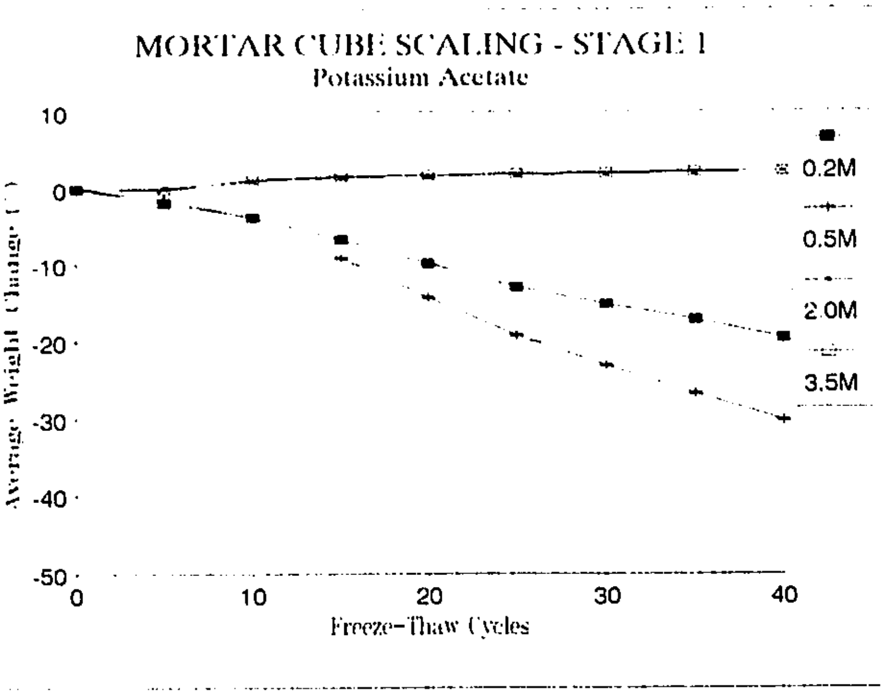

MORTAR CUBE SCALING - STAGE 1
NaCl
5
4
3
2
1
0
Scaling
0
10
20
30
40
Freeze–Thaw Cycles
0.2M
0.5M
2.0M
3.5M

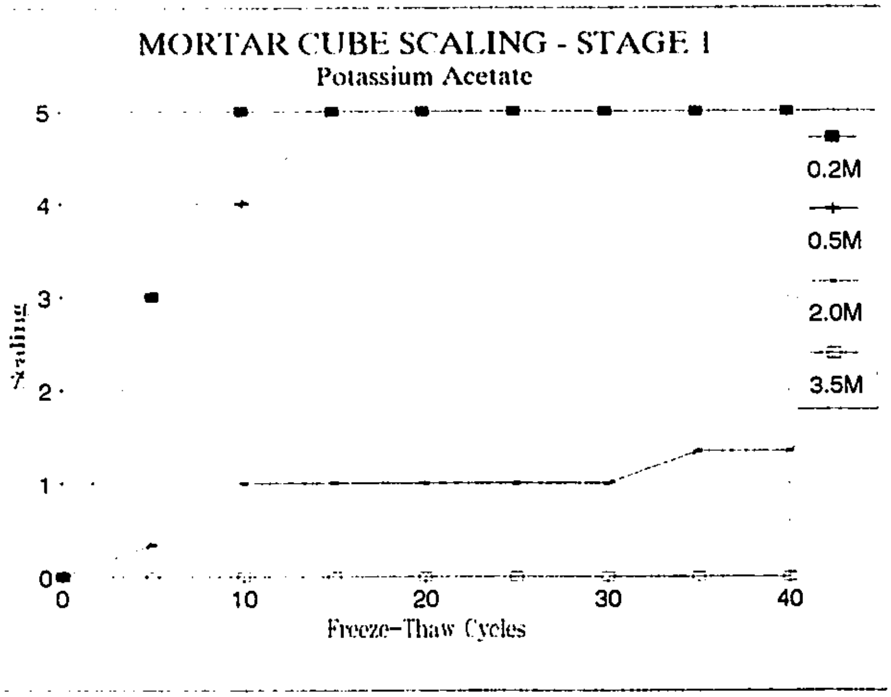


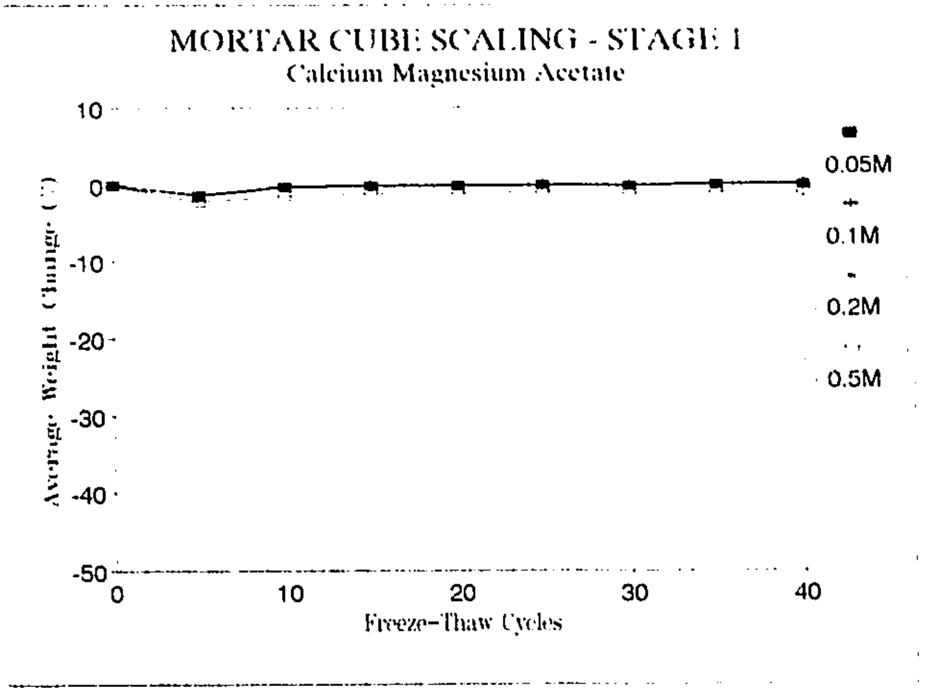
MORTAR CUBE SCALING - STAGE 1
CaCl2
Average Weight Change (%)
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
Freeze-Thaw Cycles
0.2M
0.5M
2.0M
3.5M

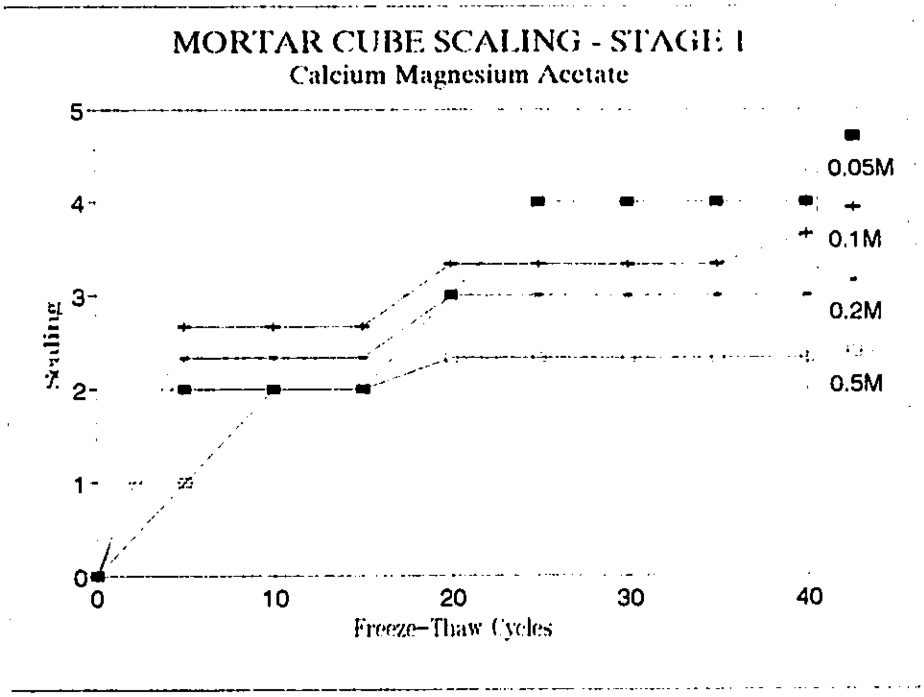


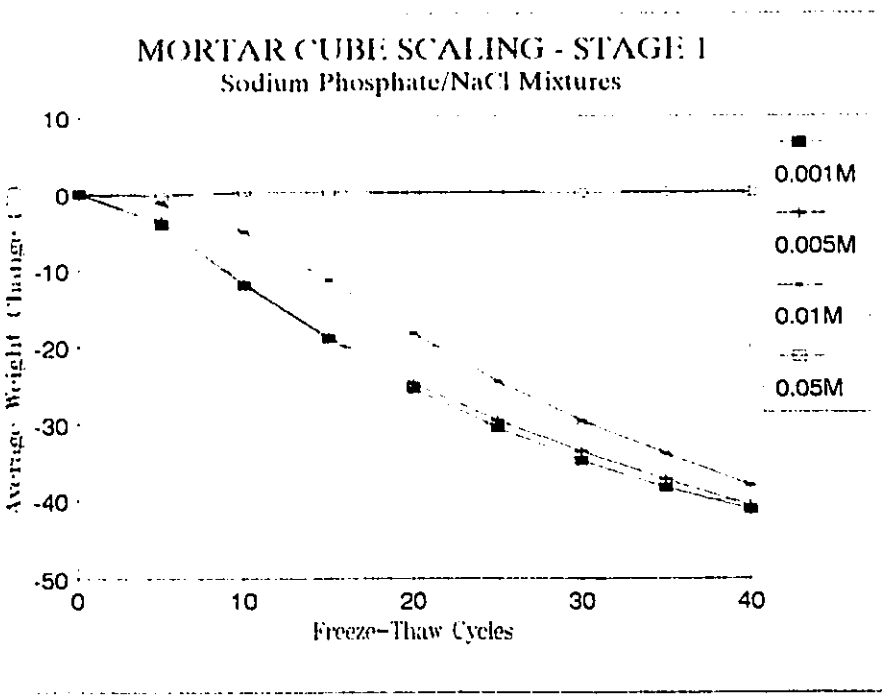
MORTAR CUBE SCALING - STAGE 1
CaCl2
Scaling
5
4
3
2
1
0
0
10
20
30
40
Freeze-Thaw Cycles
0.2M
0.5M
2.0M
3.5M

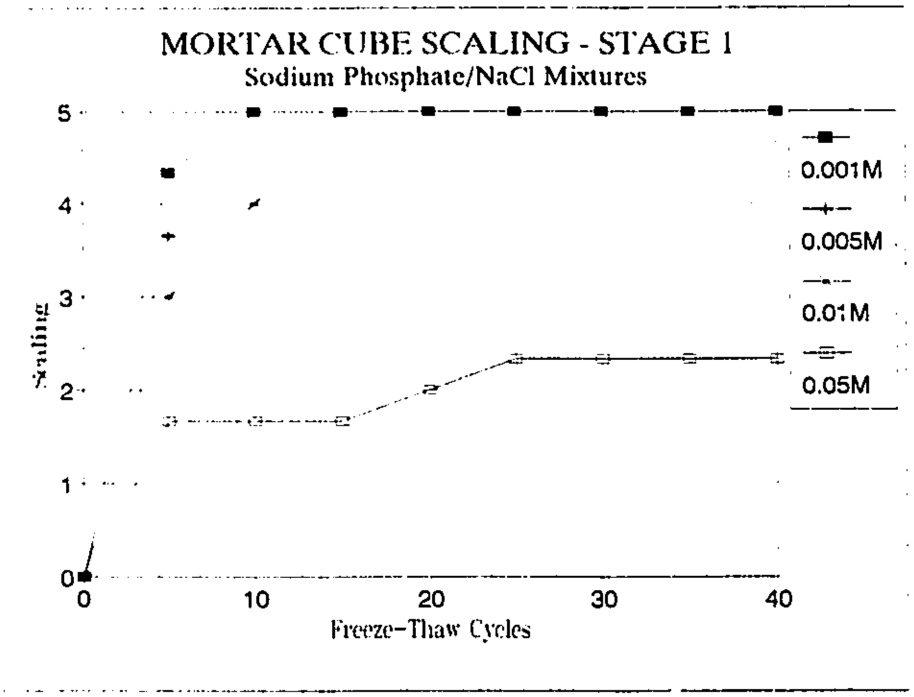

MORTAR CUBE SCALING - STAGE 1
Potassium Acetate
Average Weight Change (%)
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
Freeze-Thaw Cycles
0.2M
0.5M
2.0M
3.5M


MORTAR CUBE SCALING - STAGE 1
Potassium Acetate
Scaling
5
4
3
2
1
0
0
10
20
30
40
Freeze-Thaw Cycles
0.2M
0.5M
2.0M
3.5M


MORTAR CUBE SCALING - STAGE 1
Calcium Magnesium Acetate


MORTAR CUBE SCALING - STAGE 1
Calcium Magnesium Acetate


MORTAR CUBE SCALING - STAGE 1
Sodium Phosphate/NaCl Mixtures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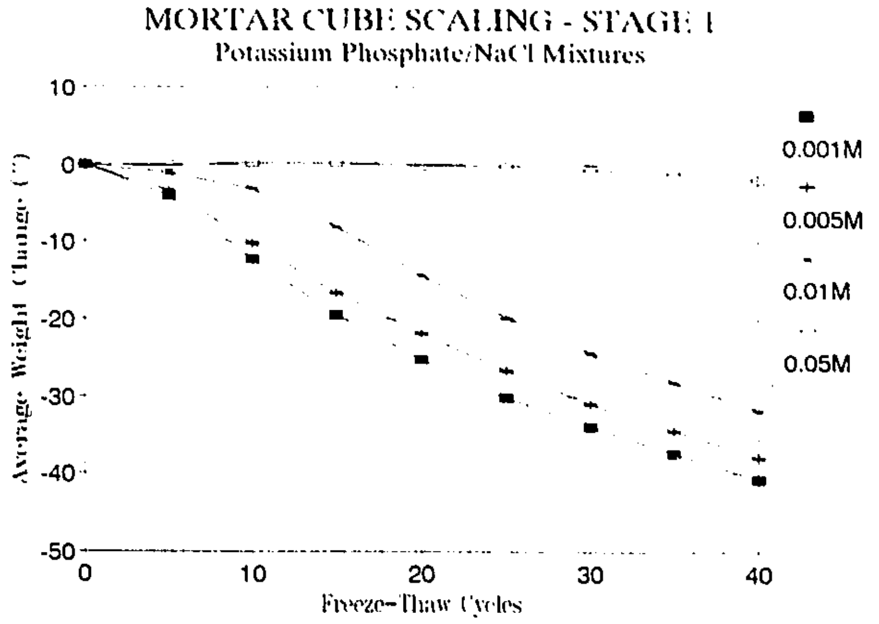
Sodium Phosphate/NaCl Mixtures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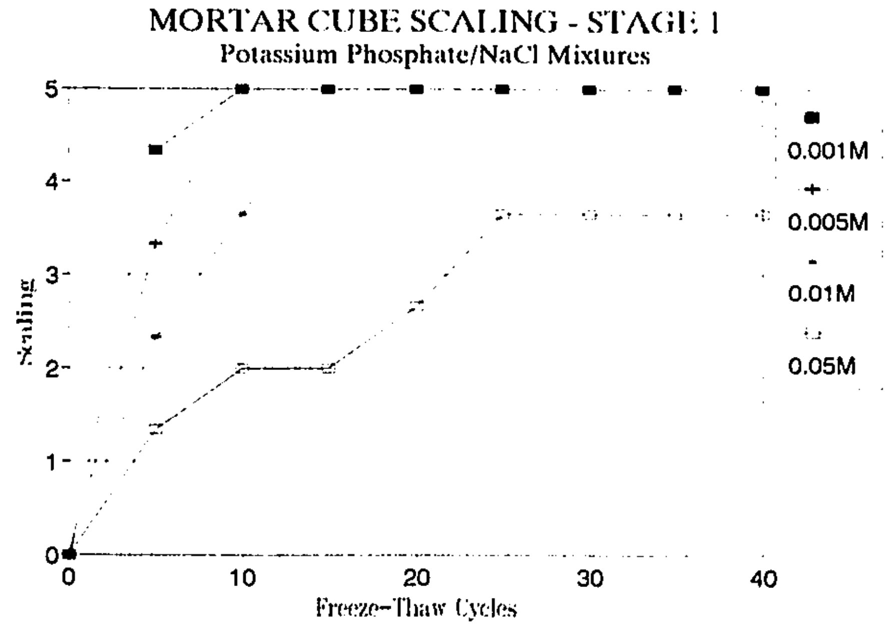
Potassium Phosphate/NaCl Mixtures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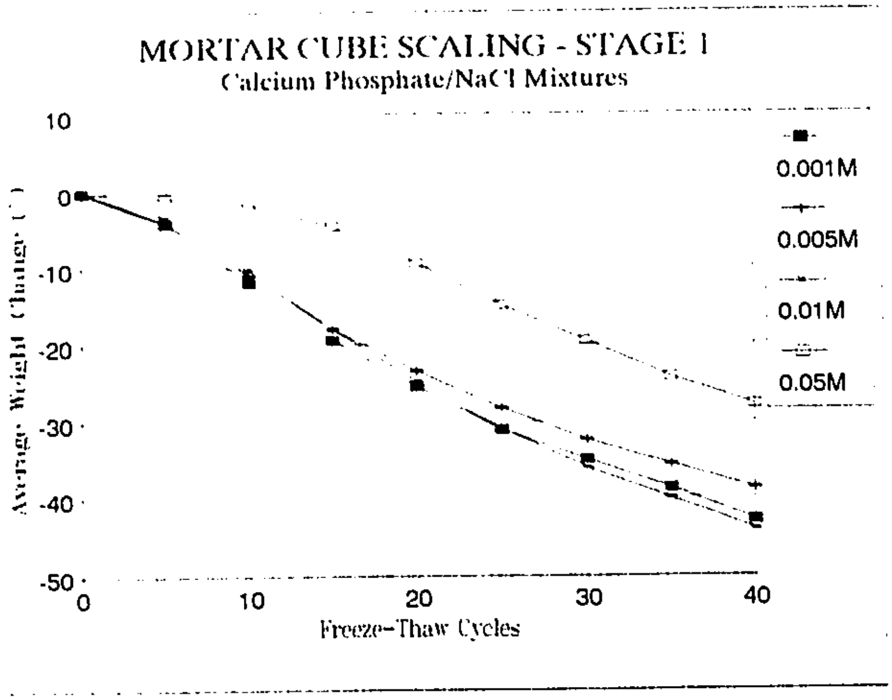
Potassium Phosphate/NaCl Mixtures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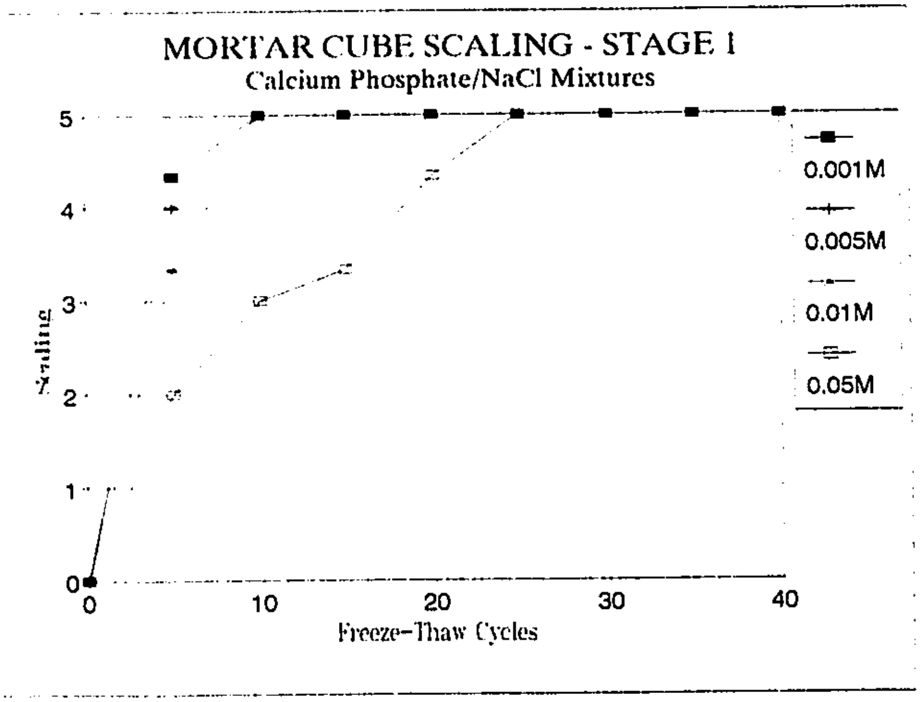
Calcium Phosphate/NaCl Mixtures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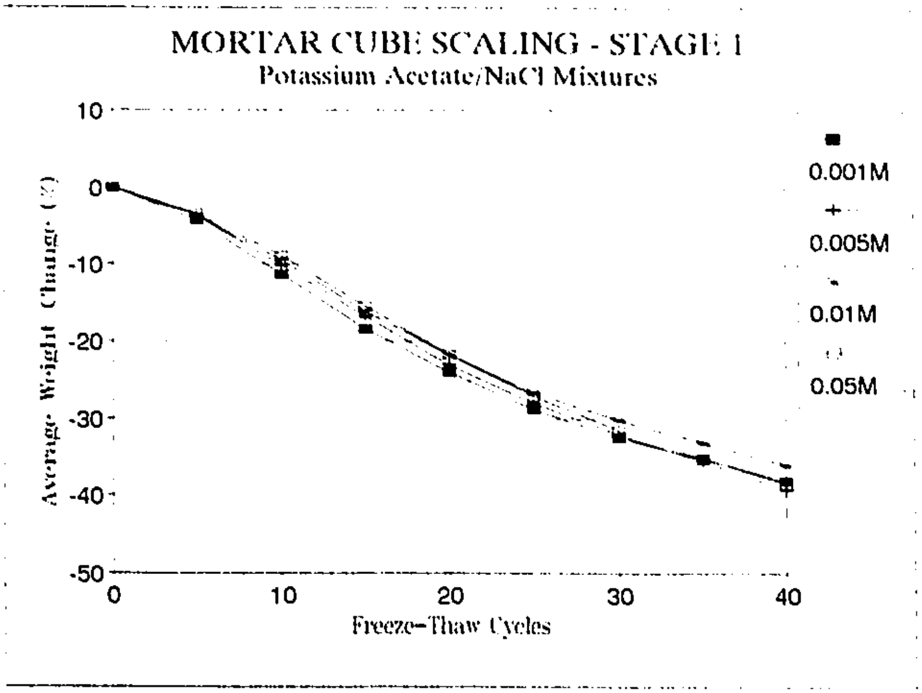
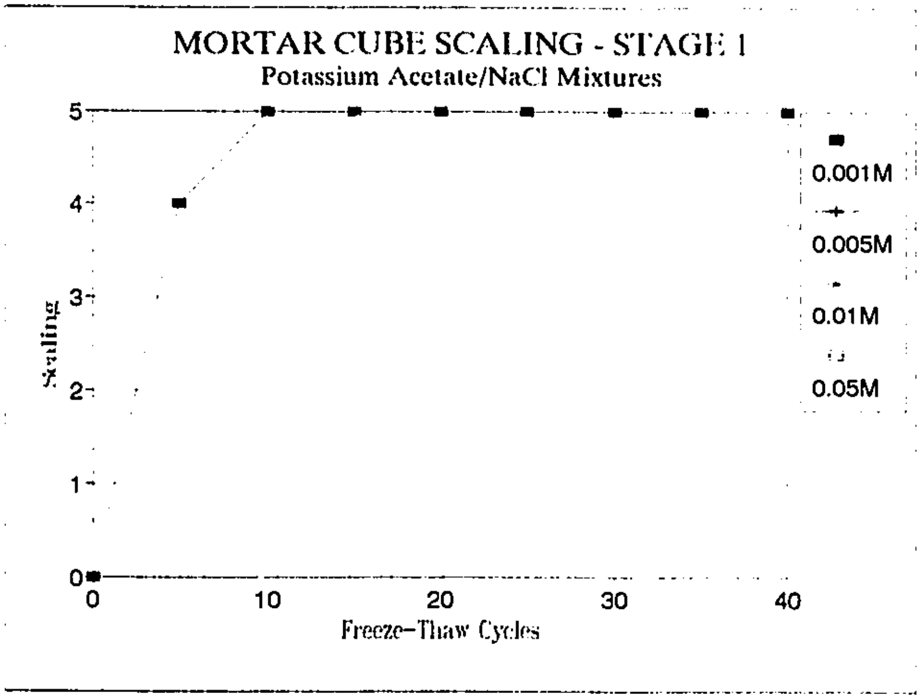
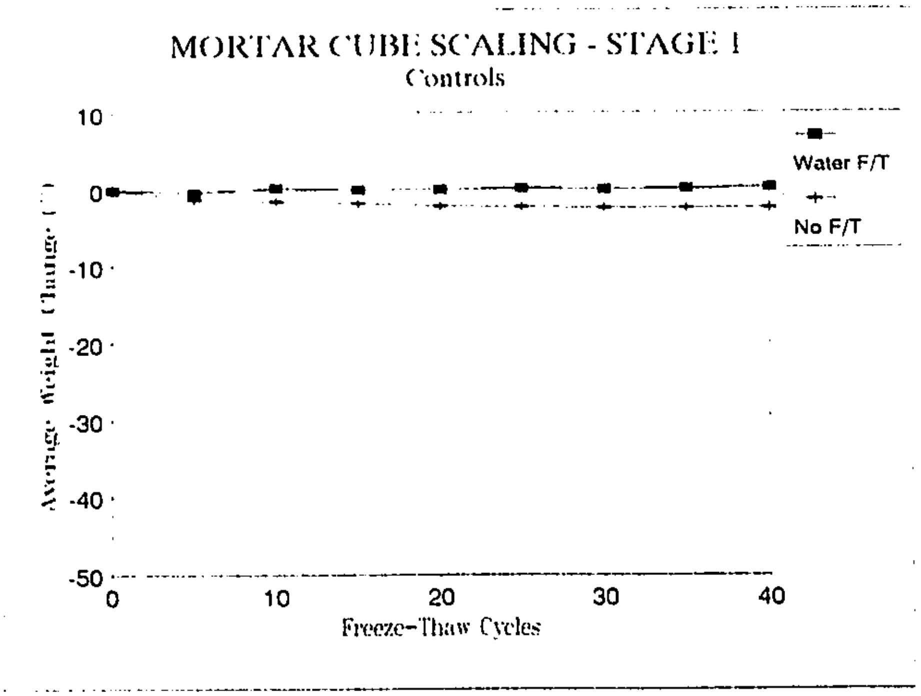
Calcium Phosphate/NaCl Mixtures

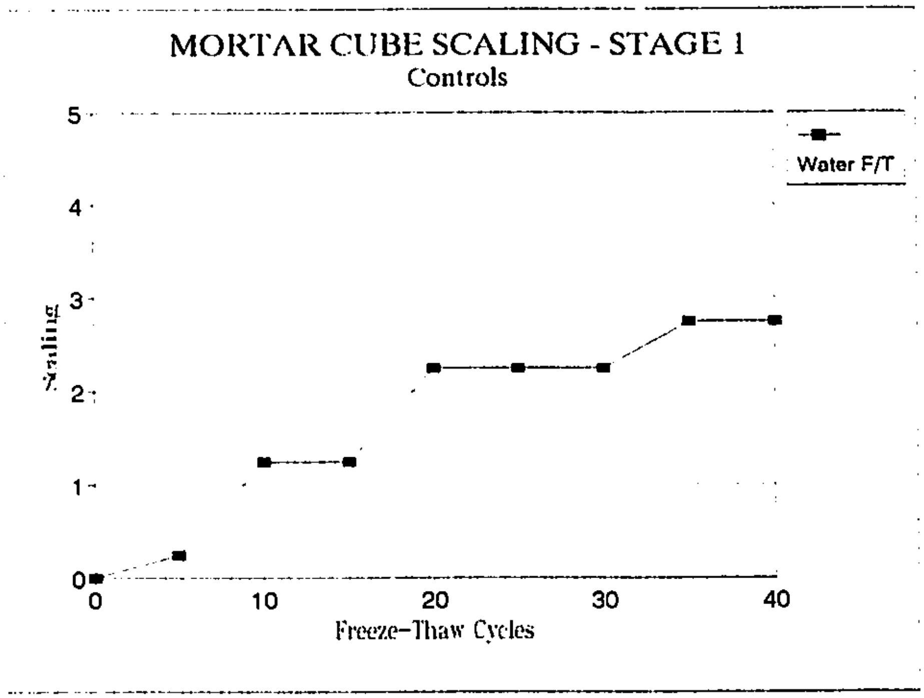


MORTAR CUBE SCALING - STAGE 1
Potassium Acetate/NaCl Mixtures



MORTAR CUBE SCALING - STAGE 1
Potassium Acetate/NaCl Mixtures


MORTAR CUBE SCALING - STAGE 1
Controls
Average Weight Change (%)
10
0
-10
-20
-30
-40
-50
0
10
20
30
40
Freeze-Thaw Cycles
Water F/T
No F/T


MORTAR CUBE SCALING - STAGE 1
Controls
Scaling
5
4
3
2
1
0
0
10
20
30
40
Freeze-Thaw Cycles
Water F/T

APPENDIX C

Compressive Strength Observations (Stage 1)

COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 1

Cube #	Dry Weight (g)		Weight Change (%)	Failure Force (lbs)	Planimeter Reading		Calculated Area (sq.in.)		Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
	Feb.23	May 6			Side 1	Side 2	Side 1	Side 2				
NaCl 0.2-1	271.34	195.03	-28.12	10300	0.321	0.303	1.68	1.59	6305	43.5		
NaCl 0.2-2	251.33	178.57	-28.95	6890	0.156	0.311	0.82	1.63	5636	38.9		
NaCl 0.2-3	272.95	201.77	-26.08	7800	0.273	0.378	1.43	1.98	4577	31.6	38.0	27.72
NaCl 0.5-1	278.51	179.75	-35.46	5520	0.310	0.270	1.62	1.41	3636	25.1		
NaCl 0.5-2	237.17	120.62	-49.14	3780	0.227	0.067	1.19	0.35	4911	33.9		
NaCl 0.5-3	273.18	173.68	-36.42	7580	0.280	0.225	1.47	1.18	5734	39.5	32.8	40.34
NaCl 2.0-1	275.02	273.37	-0.60	14190	0.439	0.496	2.30	2.60	5797	40.0		
NaCl 2.0-2	258.03	253.61	-1.71	12520	0.455	0.550	2.38	2.88	4759	32.8		
NaCl 2.0-3	265.92	259.08	-2.57	8670	0.430	0.480	2.25	2.51	3639	25.1	32.6	1.63
NaCl 3.5-1	276.55	284.43	2.85	13080	0.441	0.550	2.31	2.88	5042	34.8		
NaCl 3.5-2	254.80	262.44	3.00	15540	0.480	0.657	2.51	3.44	5221	36.0		
NaCl 3.5-3	263.67	271.51	2.97	11320	0.595	0.640	3.12	3.35	3501	24.1	31.6	-2.94
CaCl2 0.2-1	282.22	226.16	-19.86	11840	0.465	0.367	2.43	1.92	5436	37.5		
CaCl2 0.2-2	260.45	199.84	-23.27	9560	0.342	0.348	1.79	1.82	5293	36.5		
CaCl2 0.2-3	271.05	224.90	-17.03	12460	0.420	0.415	2.20	2.17	5700	39.3	37.8	20.05
CaCl2 0.5-1	272.78	224.58	-17.67	8740	0.295	0.296	1.54	1.55	5649	39.0		
CaCl2 0.5-2	255.84	202.20	-20.97	6410	0.290	0.240	1.52	1.26	4620	31.9		
CaCl2 0.5-3	256.66	202.67	-21.04	5240	0.194	0.254	1.02	1.33	4468	30.8	33.9	19.89
CaCl2 2.0-1	285.87	282.71	-1.11	17120	0.460	0.299	2.41	1.57	8616	59.4		
CaCl2 2.0-2	246.12	243.58	-1.03	11740	0.196	0.267	1.03	1.40	9686	66.8		
CaCl2 2.0-3	266.93	259.71	-2.70	13900	0.400	0.317	2.09	1.66	7406	51.1	59.1	1.61
CaCl2 3.5-1	278.23	282.39	1.50	14800	0.472	0.600	2.47	3.14	5274	36.4		
CaCl2 3.5-2	257.80	263.59	2.25	16130	0.396	0.455	2.07	2.38	7240	49.9		
CaCl2 3.5-3	270.78	276.02	1.94	16120	0.408	0.433	2.14	2.27	7322	50.5	45.6	-1.89
K-Ace 0.2-1	273.44	214.21	-21.66	10930	0.374	0.344	1.96	1.80	5815	40.1		
K-Ace 0.2-2	260.32	212.14	-18.51	10150	0.412	0.404	2.16	2.12	4752	32.8		
K-Ace 0.2-3	258.60	215.08	-16.83	11230	0.446	0.395	2.34	2.07	5101	35.2	36.0	19.00
K-Ace 0.5-1	280.72	198.26	-29.37	8860	0.382	0.373	2.00	1.95	4483	30.9		
K-Ace 0.5-2	257.92	174.51	-32.34	6290	0.223	0.234	1.17	1.23	5258	36.3		
K-Ace 0.5-3	271.86	202.17	-25.63	10070	0.369	0.393	1.93	2.06	5048	34.8	34.0	29.12
K-Ace 2.0-1	267.94	272.65	1.76	16450	0.703	0.647	3.68	3.39	4655	32.1		
K-Ace 2.0-2	251.12	254.61	1.39	13230	0.655	0.628	3.43	3.29	3939	27.2		
K-Ace 2.0-3	273.52	277.10	1.31	13630	0.725	0.660	3.80	3.46	3759	25.9	28.4	-1.49
K-Ace 3.5-1	279.60	286.23	2.37	15760	0.752	0.753	3.94	3.94	4000	27.6		
K-Ace 3.5-2	255.68	261.28	2.19	15180	0.594	0.688	3.11	3.60	4523	31.2		
K-Ace 3.5-3	263.28	269.49	2.36	14610	0.671	0.698	3.51	3.65	4077	28.1	29.0	-2.31
CMA 0.05-1	286.02	283.61	-0.84	20640	0.706	0.695	3.70	3.64	5628	38.8		
CMA 0.05-2	246.08	243.59	-1.01	15160	0.589	0.348	3.08	1.82	6180	42.6		
CMA 0.05-3	275.05	272.18	-1.04	19140	0.691	0.675	3.62	3.53	5352	36.9	39.4	0.97
CMA 0.1-1	282.82	280.83	-0.70	18650	0.593	0.704	3.10	3.69	5493	37.9		
CMA 0.1-2	253.29	251.94	-0.53	19380	0.572	0.636	2.99	3.33	6128	42.3		
CMA 0.1-3	274.71	272.82	-0.69	19330	0.671	0.640	3.51	3.35	5632	38.8	39.7	0.64
CMA 0.2-1	275.40	274.65	-0.27	21120	0.588	0.697	3.08	3.65	6278	43.3		
CMA 0.2-2	255.52	254.36	-0.45	19290	0.593	0.588	3.10	3.08	6239	43.0		
CMA 0.2-3	263.72	262.74	-0.37	19460	0.697	0.618	3.65	3.24	5653	39.0	41.8	0.37
CMA 0.5-1	281.90	281.32	-0.21	17080	0.640	0.601	3.35	3.15	5258	36.2		
CMA 0.5-2	259.24	258.60	-0.25	20310	0.600	0.528	3.14	2.76	6878	47.4		
CMA 0.5-3	272.65	271.29	-0.50	20280	0.707	0.665	3.70	3.48	5646	38.9	40.9	0.32

COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 1

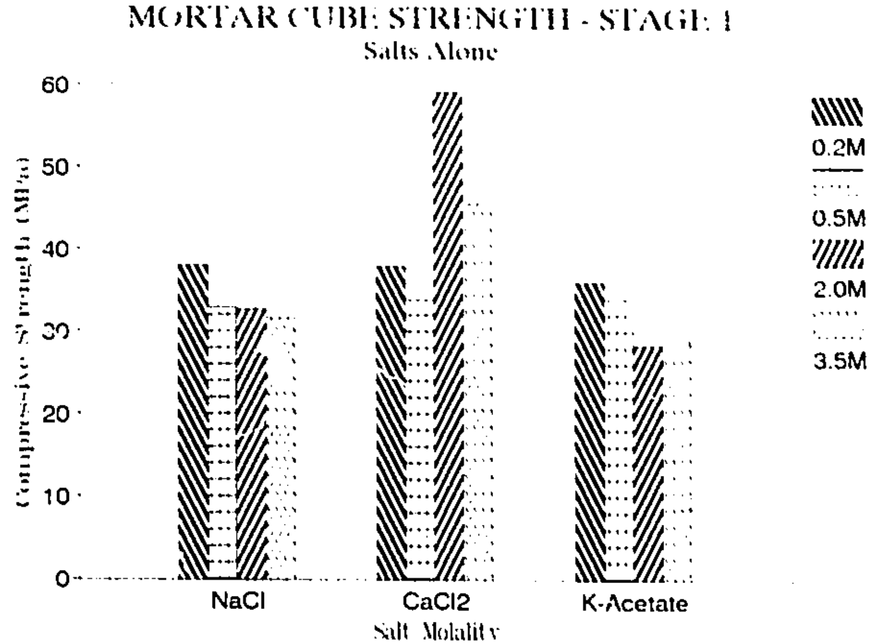
Cube #	Dry Weight (g) Feb.23	Dry Weight (g) May 6	Weight Change (%)	Failure Force (lbs)	Planimeter Reading Side 1	Planimeter Reading Side 2	Calculated Area (sq.in.) Side 1	Calculated Area (sq.in.) Side 2	Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
Na-Ph 0.001-1	273.47	159.47	-41.69	8300	0.296	0.198	1.55	1.04	6418	44.3		
Na-Ph 0.001-2	260.32	154.58	-40.62	5500	0.200	0.141	1.05	0.74	6161	42.5		
Na-Ph 0.001-3	260.76	166.07	-36.31	6410	0.268	0.214	1.40	1.12	5080	35.0	40.6	39.54
Na-Ph 0.005-1	279.13	172.54	-38.19	6240	0.167	0.266	0.87	1.39	5505	38.0		
Na-Ph 0.005-2	241.10	134.01	-44.42	4660	0.101	0.129	0.53	0.68	7740	53.4		
Na-Ph 0.005-3	268.94	175.60	-34.71	6890	0.285	0.245	1.49	1.28	4966	34.2	41.9	39.10
Na-Ph 0.01-1	277.24	173.62	-37.38	7900	0.125	0.235	0.65	1.23	8383	57.8		
Na-Ph 0.01-2	256.01	162.33	-36.59	5690	0.252	0.215	1.32	1.13	4654	32.1		
Na-Ph 0.01-3	269.03	172.91	-35.73	5940	0.196	0.160	1.03	0.84	6374	43.9	44.6	36.57
Na-Ph 0.05-1	280.31	278.65	-0.59	19780	0.677	0.595	3.54	3.12	5940	41.0		
Na-Ph 0.05-2	250.22	249.40	-0.33	18420	0.564	0.543	2.95	2.84	6356	43.8		
Na-Ph 0.05-3	268.53	267.19	-0.50	18610	0.552	0.643	2.89	3.37	5949	41.0	41.9	0.47
K-Ph 0.001-1	278.18	169.27	-39.15	5450	0.188	0.225	0.98	1.18	5041	34.8		
K-Ph 0.001-2	253.58	142.66	-43.74	5200	0.161	0.182	0.84	0.95	5791	39.9		
K-Ph 0.001-3	265.87	173.64	-34.69	6570	0.197	0.213	1.03	1.12	6121	42.2	39.0	39.19
K-Ph 0.005-1	278.22	169.74	-38.99	7050	0.302	0.264	1.58	1.38	4758	32.8		
K-Ph 0.005-2	259.87	162.27	-37.56	6890	0.233	0.225	1.22	1.18	5747	39.6		
K-Ph 0.005-3	273.77	184.12	-32.75	6690	0.196	0.263	1.03	1.38	5568	38.4	36.9	36.43
K-Ph 0.01-1	286.49	198.29	-30.79	8820	0.332	0.314	1.74	1.64	5216	36.0		
K-Ph 0.01-2	255.65	166.89	-34.72	5560	0.189	0.201	0.99	1.05	5446	37.5		
K-Ph 0.01-3	268.12	196.75	-26.62	7820	0.312	0.208	1.63	1.09	5745	39.6	37.7	30.71
K-Ph 0.05-1	278.01	273.39	-1.66	15800	0.582	0.587	3.05	3.07	5163	35.6		
K-Ph 0.05-2	255.42	254.26	-0.45	17460	0.522	0.596	2.73	3.12	5966	41.1		
K-Ph 0.05-3	258.93	245.66	-5.12	15250	0.540	0.448	2.83	2.35	5896	40.7	39.1	2.41
Ca-Ph 0.001-1	268.98	159.33	-40.77	6750	0.125	0.246	0.65	1.29	6950	47.9		
Ca-Ph 0.001-2	249.00	141.31	-43.25	4800	0.173	0.150	0.91	0.79	5677	39.1		
Ca-Ph 0.001-3	269.62	162.64	-39.68	6420	0.235	0.253	1.23	1.32	5025	34.6	40.6	41.23
Ca-Ph 0.005-1	280.53	171.02	-39.04	5700	0.255	0.235	1.34	1.23	4444	30.6		
Ca-Ph 0.005-2	250.35	148.19	-40.81	5850	0.214	0.234	1.12	1.23	4988	34.4		
Ca-Ph 0.005-3	270.11	184.07	-31.85	8280	0.320	0.213	1.68	1.12	5934	40.9	35.3	37.23
Ca-Ph 0.01-1	269.55	155.20	-42.42	6820	0.244	0.187	1.28	0.98	6045	41.7		
Ca-Ph 0.01-2	255.89	147.09	-42.52	6210	0.230	0.195	1.20	1.02	5582	38.5		
Ca-Ph 0.01-3	263.11	152.47	-42.05	5060	0.240	0.167	1.26	0.87	4749	32.7	37.6	42.33
Ca-Ph 0.05-1	281.31	209.39	-25.57	9640	0.332	0.348	1.74	1.82	5415	37.3		
Ca-Ph 0.05-2	257.86	188.94	-26.73	8960	0.286	0.272	1.50	1.42	6134	42.3		
Ca-Ph 0.05-3	266.53	189.86	-28.77	7800	0.260	0.246	1.36	1.29	5889	40.6	40.1	27.02
K-Na 0.001-1	275.76	171.20	-37.92	5140	0.113	0.297	0.59	1.55	4789	33.0		
K-Na 0.001-2	253.85	159.09	-37.33	6910	0.249	0.185	1.30	0.97	6082	41.9		
K-Na 0.001-3	263.48	171.80	-34.80	8790	0.252	0.289	1.32	1.51	6207	42.8	39.2	36.68
K-Na 0.005-1	280.33	164.54	-41.30	5800	0.242	0.254	1.27	1.33	4467	30.8		
K-Na 0.005-2	258.59	166.21	-35.72	8080	0.225	0.270	1.18	1.41	6235	43.0		
K-Na 0.005-3	275.01	175.62	-36.14	6030	0.365	0.134	1.91	0.70	4616	31.8	35.2	37.72
K-Na 0.01-1	278.62	169.88	-39.03	5840	0.217	0.220	1.14	1.15	5105	35.2		
K-Na 0.01-2	251.59	166.39	-33.86	8010	0.244	0.208	1.28	1.09	6770	46.7		
K-Na 0.01-3	273.19	186.98	-31.56	9320	0.247	0.251	1.29	1.31	7149	49.3	43.7	34.82
K-Na 0.05-1	275.81	167.73	-39.19	4470	0.258	0.177	1.35	0.93	3925	27.1		
K-Na 0.05-2	251.91	153.75	-38.97	4700	0.198	0.231	1.04	1.21	4185	28.9		
K-Na 0.05-3	273.87	183.74	-32.91	7790	0.261	0.267	1.37	1.40	5636	38.9	31.6	37.02

COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 1

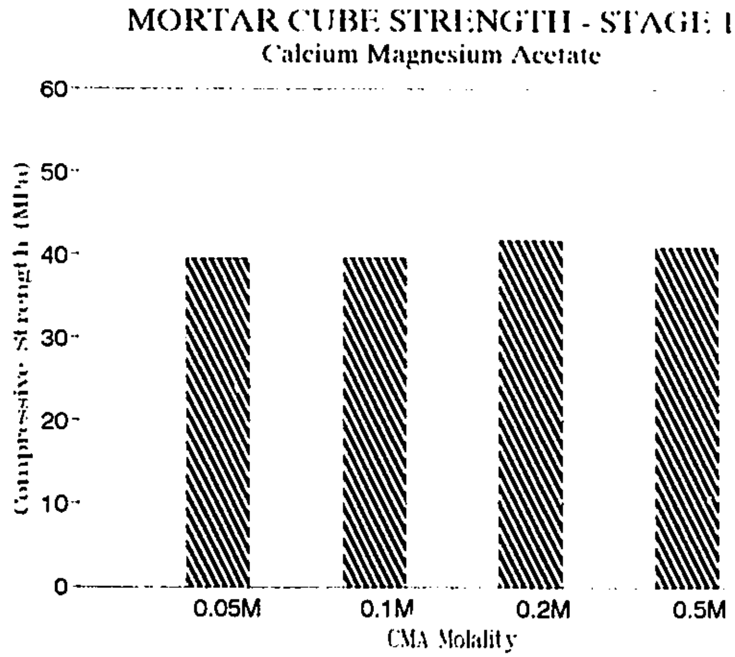
Cube #	Dry Weight (g)		Weight Change (%)	Failure Force (lbs)	Planimeter Reading		Calculated Area (sq.in.)		Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
	Feb.23	May 6			Side 1	Side 2	Side 1	Side 2				
Control 1	279.43	276.79	-0.94	21470	0.692	0.664	3.62	3.48	6048	41.7		
Control 2	243.80	241.00	-1.15	14920	0.600	0.575	3.14	3.01	4851	33.4		
Control 3	265.76	263.46	-0.87	16280	0.702	0.671	3.68	3.51	4529	31.2		
Control 4	271.81	269.20	-0.96	19190	0.727	0.717	3.81	3.75	5077	35.0	35.3	0.98
Control 5	276.98	273.25	-1.35	18660	0.721	0.716	3.77	3.75	4960	34.2		
Control 6	274.23	267.05	-2.62	15760	0.602	0.601	3.15	3.15	5004	34.5		
Control 7	245.42	238.58	-2.79	14900	0.644	0.618	3.37	3.24	4510	31.1		
Control 8	244.85	238.21	-2.71	16600	0.655	0.585	3.43	3.06	5114	35.3	33.8	2.37
Control 9	254.18	--	--	14920	--	--	3.51	3.97	3989	27.5		
Control 10	273.38	--	--	18500	--	--	4.05	4.00	4596	31.7		
Control 11	257.63	--	--	16260	--	--	3.98	3.71	4229	29.2		
Control 12	258.86	--	--	17500	--	--	3.95	3.72	4563	31.5	30.0	

Note: Solution abbreviations

K-Ace = potassium acetate
CMA = calcium magnesium acetate
Na-Ph = sodium phosphate/NaCl mixture
K-Ph = potassium phosphate/NaCl mixture
Ca-Ph = calcium phosphate/NaCl mixture
K-Na = potassium acetate/NaCl mixture
Control (1to4) = control cubes in deionized-distilled water with freeze-thaw cycling
Control (5to8) = control cubes drying in air with no freeze-thaw cycling
Control (9to12) = control cubes for initial compressive strength

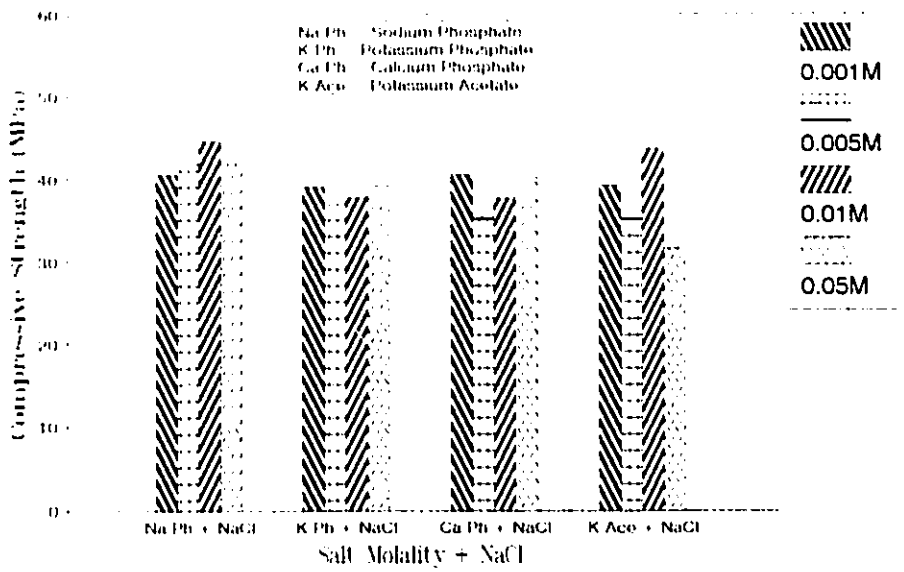

MORTAR CUBE STRENGTH - STAGE 1

Salts Alone

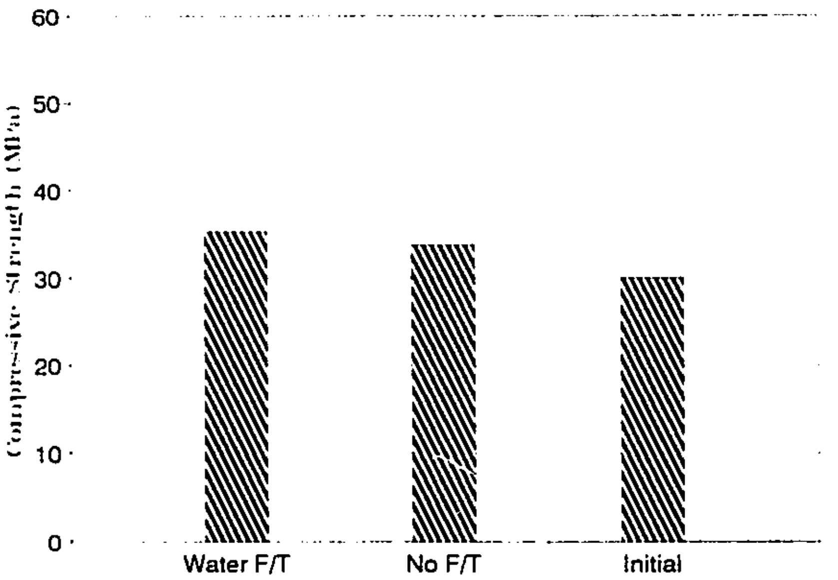

MORTAR CUBE STRENGTH - STAGE 1

Calcium Magnesium Acetate

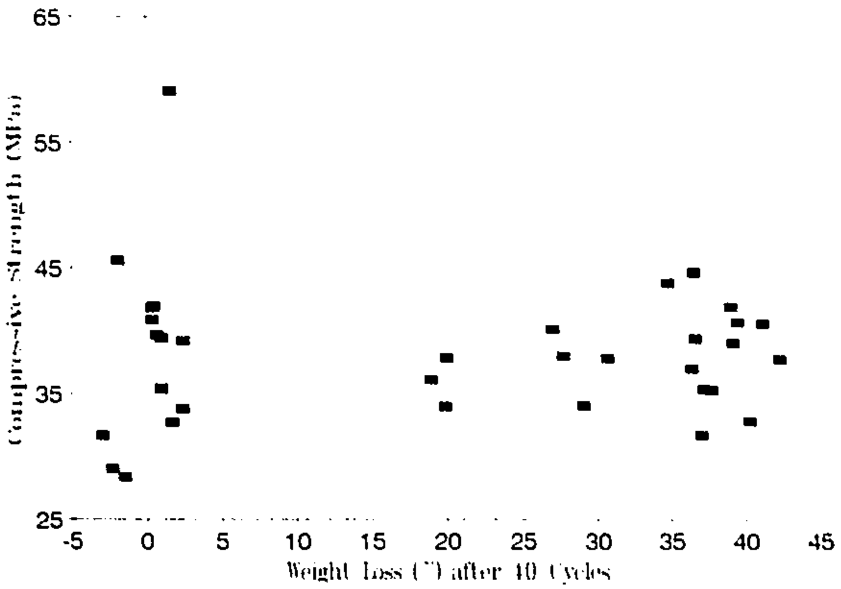
MORTAR CUBE STRENGTH - STAGE 1
Salt/Sodium Chloride Mixtures



MORTAR CUBE STRENGTH - STAGE 1
Controls



CUBE STRENGTH VS. WEIGHT LOSS - STAGE 1



APPENDIX D

Mortar Cube Scaling Observations (Stage 2)

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

Note: Solution abbreviations used

Na-Na = sodium phosphate/NaCl mixtures
Na-Ca = sodium phosphate/CaCl2 mixtures
KP-Na = potassium phosphate/NaCl mixtures
KP-Ca = potassium phosphate/CaCl2 mixtures
Ca-Ca = calcium phosphate/CaCl2 mixtures
CMA = calcium magnesium acetate/NaCl mixtures
Na-Pre = sodium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
K-Pre = potassium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Ca-Pre = calcium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
No-Pre = no phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Control(1-3) = deionized-distilled water freeze-thaw cycling
Control(4-6) = initial compressive strength cubes
Control(7-9) = air drying cubes, no freeze-thaw cycling
Moulded Cube = initial compressive strength moulded cubes

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Aug. 29 (dry - 0 cycles) Weight (g)			Sept. 5 (wet - 0 cycles) Weight (g)			Sept.12 (dry - 0 cycles) Weight (g)		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.01M Na-Na	281.79	309.23	310.69	290.65	319.29	319.12	280.62	308.93	308.27
0.02M Na-Na	289.11	303.89	309.49	297.57	313.90	318.37	287.41	303.36	307.65
0.03M Na-Na	280.98	308.48	300.87	289.63	317.71	309.93	279.73	307.33	299.50
0.04M Na-Na	302.92	302.05	295.66	311.79	310.99	304.10	301.06	300.65	293.75
0.05M Na-Na	289.96	297.51	313.52	298.85	306.87	322.48	288.05	296.48	311.28
0.01M Na-Ca	294.32	305.56	289.02	303.38	314.74	298.17	293.01	303.44	287.60
0.02M Na-Ca	293.62	309.12	300.19	301.54	318.42	308.56	291.29	307.75	298.29
0.03M Na-Ca	279.12	303.41	303.80	287.47	312.39	312.95	277.93	301.94	302.41
0.04M Na-Ca	291.81	297.82	286.72	300.63	306.09	295.02	290.56	296.07	285.35
0.05M Na-Ca	289.15	292.89	306.44	297.50	301.37	314.87	287.41	291.73	304.36
0.01M KP-Na	306.10	311.77	307.41	315.14	320.53	316.43	304.93	310.43	306.12
0.02M KP-Na	285.94	289.52	295.95	294.16	298.16	304.63	284.33	288.64	294.07
0.03M KP-Na	295.94	310.27	309.82	303.97	319.48	318.68	293.91	309.27	308.13
0.04M KP-Na	290.23	311.27	309.09	299.07	320.22	318.35	289.13	309.49	307.69
0.05M KP-Na	305.98	292.51	297.69	314.39	301.14	305.89	304.24	291.50	295.91
0.01M KP-Ca	296.30	302.81	312.13	305.08	311.40	322.03	294.83	300.90	311.17
0.02M KP-Ca	290.55	304.48	289.30	299.34	313.13	298.06	289.50	303.74	288.54
0.03M KP-Ca	298.63	312.08	309.26	306.84	321.63	317.90	296.87	311.35	307.33
0.04M KP-Ca	280.20	301.02	307.35	289.21	309.81	317.11	279.14	299.28	306.34
0.05M KP-Ca	291.91	300.19	304.35	300.23	309.74	312.73	290.59	299.29	302.49
0.01M Ca-Ca	283.66	308.97	304.82	291.87	317.69	313.11	282.23	307.71	302.87
0.05M Ca-Ca	296.93	298.66	304.73	305.35	307.10	314.50	295.40	297.14	304.01
0.1M Ca-Ca	298.98	293.75	310.64	307.14	302.12	318.98	297.41	293.05	308.76
0.2M Ca-Ca	295.37	306.44	286.90	304.06	315.57	295.82	294.11	305.26	286.03
0.4M Ca-Ca	289.47	314.01	310.21	298.33	323.12	319.48	288.52	312.55	309.27
0.001M CMA	299.41	312.55	308.85	307.66	321.27	317.67	298.06	311.33	307.33
0.005M CMA	288.66	307.40	292.46	297.65	316.22	301.19	287.89	306.06	291.46
0.01M CMA	291.29	292.78	303.78	299.76	301.75	312.29	289.59	292.05	301.96
0.05M CMA	287.83	298.27	308.55	296.73	306.53	318.36	286.42	296.78	307.71
Na-Pre	280.83	288.95	310.02	288.85	296.75	317.61	279.06	287.71	307.65
K-Pre	299.49	308.01	306.51	307.93	316.24	315.50	298.39	305.89	305.59
Ca-Pre	280.61	309.78	295.67	289.88	320.01	305.49	280.39	310.44	296.07
No-Pre	289.03	303.18	287.38	297.88	312.58	296.32	288.33	302.75	286.76
Control(1-3)	288.54	297.69	290.56	296.85	306.95	299.64	286.77	296.69	289.57
Control(4-6)	275.61	312.32	312.25	274.97	311.67	311.48			
Control(7-9)	295.32	284.76	292.83	294.47	284.32	291.98	290.52	281.54	288.08
Moulded Cube	289.39	284.16	288.92	288.84	283.72	288.47			

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Sept. 17 (5 cycles)						Sept. 23 (10 cycles)					
	Weight (g)			Scaling			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.01M Na-Na	285.63	313.72	313.23	3	2	3	279.46	305.26	309.91	3	3	4
0.02M Na-Na	294.48	310.34	313.85	2	2	2	293.21	309.72	313.46	2	2	3
0.03M Na-Na	287.01	314.92	306.36	2	1	1	286.98	315.79	307.21	2	2	2
0.04M Na-Na	309.08	308.42	301.26	1	1	2	310.00	309.19	302.04	1	2	2
0.05M Na-Na	295.75	304.19	319.20	2	1	2	296.67	305.46	320.27	2	1	2
0.01M Na-Ca	300.25	311.25	294.88	1	2	2	298.31	310.59	294.90	2	2	2
0.02M Na-Ca	298.18	315.10	305.21	2	1	2	297.36	315.39	305.02	2	1	2
0.03M Na-Ca	284.42	309.17	308.93	2	1	3	283.93	309.48	309.11	2	1	3
0.04M Na-Ca	297.97	303.05	292.35	1	2	2	298.71	304.53	293.52	1	2	2
0.05M Na-Ca	295.20	298.88	312.49	1	1	2	296.42	300.40	313.66	1	1	2
0.01M KP-Na	310.19	315.86	311.03	1	2	3	308.59	312.83	308.76	2	3	4
0.02M KP-Na	290.24	294.70	299.71	1	2	3	289.36	294.39	299.06	2	2	3
0.03M KP-Na	301.04	316.67	314.45	1	1	3	300.85	317.62	314.48	2	1	3
0.04M KP-Na	296.33	317.33	314.97	1	1	2	296.63	317.90	315.46	2	2	3
0.05M KP-Na	311.84	298.75	303.39	1	1	1	312.59	299.89	304.21	1	1	1
0.01M KP-Ca	302.16	308.39	318.78	1	1	2	299.52	307.35	318.73	2	2	3
0.02M KP-Ca	296.25	310.62	294.74	2	1	2	294.39	310.79	295.05	3	2	3
0.03M KP-Ca	304.45	319.20	315.11	1	1	2	303.49	319.81	315.20	2	2	2
0.04M KP-Ca	286.05	307.24	313.79	1	1	2	285.83	308.15	314.33	2	1	3
0.05M KP-Ca	298.29	307.17	310.29	1	1	1	299.03	308.28	311.55	1	1	1
0.01M Ca-Ca	289.69	315.54	310.13	1	1	2	289.74	316.41	310.57	2	2	3
0.05M Ca-Ca	303.50	304.58	312.71	0	1	1	304.72	306.22	313.40	1	1	2
0.1M Ca-Ca	304.43	299.71	316.62	1	1	1	305.87	301.01	317.83	1	1	2
0.2M Ca-Ca	300.54	311.89	292.45	1	1	0	302.06	313.60	294.09	1	1	1
0.4M Ca-Ca	294.19	319.04	315.77	0	0	0	295.55	320.55	317.28	0	0	0
0.001M CMA	301.51	314.46	310.42	3	3	4	289.71	302.54	300.61	4	4	4
0.005M CMA	291.95	311.21	296.17	4	3	3	281.13	300.41	290.60	5	4	4
0.01M CMA	293.04	297.03	306.45	4	2	3	279.81	288.08	298.89	5	3	4
0.05M CMA	293.56	303.76	314.70	2	1	2	292.78	304.25	315.12	2	2	3
Na-Pre	286.37	294.39	314.99	1	1	1	282.91	293.01	313.63	2	2	2
K-Pre	304.84	313.64	312.96	1	2	2	303.03	312.27	312.48	2	2	2
Ca-Pre	285.56	316.10	301.21	1	1	2	284.49	316.29	301.29	2	2	3
No-Pre	290.99	306.70	290.22	3	3	3	276.83	297.33	284.65	4	4	4
Control(1-3)	295.04	304.83	297.50	0	0	0	296.24	306.17	298.77	1	0	0
Control(4-6)												
Control(7-9)	289.96	280.85	287.50				289.38	279.83	286.43			
Moulded Cube												

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Sept. 28 (15 cycles)						Oct. 3 (20 cycles)					
	Weight (g)			Scaling			Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.01M Na-Na	270.78	293.17	304.48	4	4	4	259.24	279.95	296.72	5	5	5
0.02M Na-Na	291.88	308.88	312.89	2	2	4	288.91	307 22	312.32	3	3	4
0.03M Na-Na	286.19	315.88	307.59	2	2	2	284.55	315.46	307.48	3	2	2
0.04M Na-Na	310.13	309.60	302.55	1	2	2	309.95	309.67	302.67	2	2	2
0.05M Na-Na	296.89	306.10	320.74	2	1	2	296.33	306.31	320.72	2	1	2
0.01M Na-Ca	294.54	307.93	293.57	2	2	3	289.39	303.14	290.86	3	3	3
0.02M Na-Ca	294.37	314.14	303.55	3	2	3	289.18	311.36	300.84	4	3	3
0.03M Na-Ca	282.60	308.74	308.59	3	2	4	280.20	306.71	307.38	3	2	4
0.04M Na-Ca	298.98	304.87	294.05	1	2	2	298.08	304.86	294.45	1	2	2
0.05M Na-Ca	296.91	301.05	313.92	2	1	2	297.06	301.57	314.14	2	1	2
0.01M KP-Na	305.86	308.01	306.67	2	3	4	299.70	298.53	302.89	3	4	5
0.02M KP-Na	288.32	293.71	298.78	2	3	3	286.58	293.37	298.38	3	3	3
0.03M KP-Na	299.60	317.99	314.44	2	2	3	298.19	318.24	314.38	3	2	3
0.04M KP-Na	296.08	317.43	315.38	2	2	3	295.21	316.75	315.34	2	2	3
0.05M KP-Na	312.68	300.32	304.52	1	1	1	312.60	300.56	304.75	2	2	1
0.01M KP-Ca	294.90	304.58	317.42	3	2	3	289.55	300.49	314.90	4	3	4
0.02M KP-Ca	290.10	309.42	294.63	3	2	3	284.27	306.25	293.31	4	3	4
0.03M KP-Ca	301.62	319.12	314.43	2	2	3	297.71	316.89	312.49	3	3	3
0.04M KP-Ca	285.36	307.83	314.59	2	2	3	285.08	307.37	314.06	3	2	3
0.05M KP-Ca	299.59	308.92	312.08	2	2	1	299.10	308.45	311.98	2	2	1
0.01M Ca-Ca	288.50	316.48	310.71	3	2	3	284.65	315.83	309.11	3	2	3
0.05M Ca-Ca	305.46	307.20	314.09	1	1	2	305.62	307.68	314.19	1	1	2
0.1M Ca-Ca	306.87	301.97	318.68	1	1	2	307.39	302.53	319.08	1	1	2
0.2M Ca-Ca	302.69	314.42	294.74	1	1	1	303.01	314.64	294.92	1	1	1
0.4M Ca-Ca	296.32	321.23	317.94	1	1	1	296.61	321.53	318.23	1	1	1
0.001M CMA	277.17	286.34	289.63	4	4	5	263.01	271.67	279.82	5	5	5
0.005M CMA	269.25	287.51	283.52	5	4	4	258.90	276.81	275.35	5	5	4
0.01M CMA	266.95	276.59	289.91	5	4	5	253.46	263.85	279.50	5	4	5
0.05M CMA	290.71	303.61	315.03	3	2	3	287.60	302.72	314.78	3	2	3
Na-Pre	274.41	287.89	309.52	3	3	3	262.79	280.23	302.71	4	4	3
K-Pre	298.02	307.20	310.87	3	3	3	290.81	298.73	307.77	3	4	3
Ca-Pre	281.37	314.00	300.28	3	2	3	275.53	309.63	298.12	3	3	3
No-Pre	262.64	285.73	278.18	5	4	4	248.36	274.21	271.13	5	4	5
Control(1-3)	296.71	306.67	299.18	1	0	1	296.95	306.94	299.42	1	0	1
Control(4-6)												
Control(7-9)	289.48	279.44	286.02				289.26	279.02	285.55			
Moulded Cube												

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Oct. 8 (25 cycles)					
	Weight (g)			Scaling		
Salt Type	Cube 1	Cube 2	Cube 3	Cube 1	Cube 2	Cube 3
0.01M Na-Na	247.06	265.09	288.84	5	5	5
0.02M Na-Na	285.24	305.49	311.75	4	3	4
0.03M Na-Na	282.31	314.97	307.33	4	2	2
0.04M Na-Na	309.60	309.90	302.70	2	2	2
0.05M Na-Na	296.17	306.44	320.55	2	1	2
0.01M Na-Ca	284.75	299.32	288.69	3	3	4
0.02M Na-Ca	284.10	308.08	297.31	4	3	4
0.03M Na-Ca	277.16	304.25	305.57	4	3	4
0.04M Na-Ca	296.26	304.21	293.76	2	2	2
0.05M Na-Ca	296.20	301.57	313.98	2	1	2
0.01M KP-Na	291.61	287.27	298.09	4	5	5
0.02M KP-Na	284.72	292.71	297.72	3	3	4
0.03M KP-Na	294.84	318.38	314.05	4	2	3
0.04M KP-Na	291.76	315.00	315.05	3	2	3
0.05M KP-Na	311.98	300.47	304.37	2	2	2
0.01M KP-Ca	284.53	296.16	311.89	4	3	4
0.02M KP-Ca	278.07	302.46	291.52	4	4	5
0.03M KP-Ca	293.69	314.51	310.28	4	3	4
0.04M KP-Ca	283.75	306.45	314.12	3	2	3
0.05M KP-Ca	298.52	308.09	311.70	2	2	2
0.01M Ca-Ca	281.30	314.27	307.49	4	2	3
0.05M Ca-Ca	305.88	307.97	314.52	2	1	2
0.1M Ca-Ca	307.79	302.82	319.49	1	1	2
0.2M Ca-Ca	302.99	314.84	294.96	1	1	1
0.4M Ca-Ca	296.87	321.65	318.46	1	1	1
0.001M CMA	248.48	257.71	269.22	5	5	5
0.005M CMA	248.44	265.34	267.07	5	5	5
0.01M CMA	240.14	251.14	269.39	5	5	5
0.05M CMA	283.95	301.10	314.42	3	2	3
Na-Pre	249.32	270.90	294.81	5	5	3
K-Pre	282.00	287.50	304.87	4	4	4
Ca-Pre	267.53	302.67	294.99	4	3	4
No-Pre	235.14	262.00	264.07	5	5	5
Control(1-3)	297.05	307.01	299.55	1	0	1
Control(4-6)						
Control(7-9)	289.18	278.61	285.15			
Moulded Cube						

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Sept. 17 (5 cycles)					Sept. 23 (10 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.01M Na-Na	-1.73	-1.74	-1.85	-1.77	2.7	-3.85	-4.39	-2.89	-3.71	3.3
0.02M Na-Na	-1.04	-1.13	-1.42	-1.20	2.0	-1.47	-1.33	-1.54	-1.45	2.3
0.03M Na-Na	-0.90	-0.88	-1.15	-0.98	1.3	-0.91	-0.60	-0.88	-0.80	2.0
0.04M Na-Na	-0.87	-0.83	-0.93	-0.88	1.3	-0.57	-0.58	-0.68	-0.61	1.7
0.05M Na-Na	-1.04	-0.87	-1.02	-0.98	1.7	-0.73	-0.46	-0.69	-0.62	1.7
0.01M Na-Ca	-1.03	-1.11	-1.10	-1.08	1.7	-1.67	-1.32	-1.10	-1.36	2.0
0.02M Na-Ca	-1.11	-1.04	-1.09	-1.08	1.7	-1.39	-0.95	-1.15	-1.16	1.7
0.03M Na-Ca	-1.06	-1.03	-1.28	-1.13	2.0	-1.23	-0.93	-1.23	-1.13	2.0
0.04M Na-Ca	-0.88	-0.99	-0.91	-0.93	1.7	-0.64	-0.51	-0.51	-0.55	1.7
0.05M Na-Ca	-0.77	-0.83	-0.76	-0.79	1.3	-0.36	-0.32	-0.38	-0.36	1.3
0.01M KP-Na	-1.57	-1.46	-1.71	-1.58	2.0	-2.08	-2.40	-2.42	-2.30	3.0
0.02M KP-Na	-1.33	-1.16	-1.62	-1.37	2.0	-1.63	-1.26	-1.83	-1.57	2.3
0.03M KP-Na	-0.96	-0.88	-1.33	-1.06	1.7	-1.03	-0.58	-1.32	-0.98	2.0
0.04M KP-Na	-0.92	-0.90	-1.06	-0.96	1.3	-0.82	-0.72	-0.91	-0.82	2.3
0.05M KP-Na	-0.81	-0.79	-0.82	-0.81	1.0	-0.57	-0.42	-0.55	-0.51	1.0
0.01M KP-Ca	-0.96	-0.97	-1.01	-0.98	1.3	-1.82	-1.30	-1.02	-1.38	2.3
0.02M KP-Ca	-1.03	-0.80	-1.11	-0.98	1.7	-1.65	-0.75	-1.01	-1.14	2.7
0.03M KP-Ca	-0.78	-0.76	-0.88	-0.80	1.3	-1.09	-0.57	-0.85	-0.84	2.0
0.04M KP-Ca	-1.09	-0.83	-1.05	-0.99	1.3	-1.17	-0.54	-0.88	-0.86	2.0
0.05M KP-Ca	-0.65	-0.83	-0.78	-0.75	1.0	-0.40	-0.47	-0.38	-0.42	1.0
0.01M Ca-Ca	-0.75	-0.68	-0.95	-0.79	1.3	-0.73	-0.40	-0.81	-0.65	2.3
0.05M Ca-Ca	-0.61	-0.82	-0.57	-0.67	0.7	-0.21	-0.29	-0.35	-0.28	1.3
0.1M Ca-Ca	-0.88	-0.80	-0.74	-0.81	1.0	-0.41	-0.37	-0.36	-0.38	1.3
0.2M Ca-Ca	-1.16	-1.17	-1.14	-1.15	0.7	-0.66	-0.62	-0.58	-0.62	1.0
0.4M Ca-Ca	-1.39	-1.26	-1.16	-1.27	0.0	-0.93	-0.80	-0.69	-0.81	0.0
0.001M CMA	-2.00	-2.12	-2.28	-2.13	3.3	-5.83	-5.83	-5.37	-5.68	4.0
0.005M CMA	-1.92	-1.58	-1.67	-1.72	3.3	-5.55	-5.00	-3.52	-4.69	4.3
0.01M CMA	-2.24	-1.56	-1.87	-1.89	3.0	-6.66	-4.53	-4.29	-5.16	4.0
0.05M CMA	-1.07	-0.90	-1.15	-1.04	1.7	-1.33	-0.74	-1.02	-1.03	2.3
Na-Pre	-0.86	-0.80	-0.82	-0.83	1.0	-2.06	-1.26	-1.25	-1.52	2.0
K-Pre	-1.00	-0.82	-0.81	-0.88	1.7	-1.59	-1.26	-0.96	-1.27	2.0
Ca-Pre	-1.49	-1.22	-1.40	-1.37	1.3	-1.86	-1.16	-1.37	-1.47	2.3
No-Pre	-2.31	-1.88	-2.06	-2.08	3.0	-7.07	-4.88	-3.94	-5.29	4.0
Control(1-3)	-0.61	-0.69	-0.71	-0.67	0.0	-0.21	-0.25	-0.29	-0.25	0.3
Control(4-6)										
Control(7-9)	-1.53	-1.22	-1.53	-1.43		-1.73	-1.58	-1.90	-1.74	
Moulded Cube										

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Sept. 28 (15 cycles)					Oct. 3 (20 cycles)				
	Weight Change (%)			Avg.	Avg.	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.01M Na-Na	-6.84	-8.18	-4.59	-6.53	4.0	-10.81	-12.32	-7.02	-10.05	5.0
0.02M Na-Na	-1.91	-1.60	-1.72	-1.74	2.7	-2.91	-2.13	-1.90	-2.31	3.3
0.03M Na-Na	-1.19	-0.58	-0.76	-0.84	2.0	-1.75	-0.71	-0.79	-1.08	2.3
0.04M Na-Na	-0.53	-0.45	-0.51	-0.50	1.7	-0.59	-0.42	-0.47	-0.49	2.0
0.05M Na-Na	-0.66	-0.25	-0.54	-0.48	1.7	-0.84	-0.18	-0.55	-0.52	1.7
0.01M Na-Ca	-2.91	-2.16	-1.54	-2.21	2.3	-4.61	-3.69	-2.45	-3.58	3.0
0.02M Na-Ca	-2.38	-1.34	-1.62	-1.78	2.7	-4.10	-2.22	-2.50	-2.94	3.3
0.03M Na-Ca	-1.69	-1.17	-1.39	-1.42	3.0	-2.53	-1.82	-1.78	-2.04	3.0
0.04M Na-Ca	-0.55	-0.40	-0.33	-0.43	1.7	-0.85	-0.40	-0.19	-0.48	1.7
0.05M Na-Ca	-0.20	-0.11	-0.30	-0.20	1.7	-0.15	0.07	-0.23	-0.10	1.7
0.01M KP-Na	-2.94	-3.91	-3.08	-3.31	3.0	-4.90	-6.86	-4.28	-5.35	4.0
0.02M KP-Na	-1.99	-1.49	-1.92	-1.80	2.7	-2.58	-1.61	-2.05	-2.08	3.0
0.03M KP-Na	-1.44	-0.47	-1.33	-1.08	2.3	-1.90	-0.39	-1.35	-1.21	2.7
0.04M KP-Na	-1.00	-0.87	-0.93	-0.93	2.3	-1.29	-1.08	-0.95	-1.11	2.3
0.05M KP-Na	-0.54	-0.27	-0.45	-0.42	1.0	-0.57	-0.19	-0.37	-0.38	1.7
0.01M KP-Ca	-3.34	-2.19	-1.43	-2.32	2.7	-5.09	-3.50	-2.21	-3.60	3.7
0.02M KP-Ca	-3.09	-1.18	-1.15	-1.81	2.7	-5.03	-2.20	-1.59	-2.94	3.7
0.03M KP-Ca	-1.70	-0.78	-1.09	-1.19	2.3	-2.98	-1.47	-1.70	-2.05	3.0
0.04M KP-Ca	-1.33	-0.64	-0.79	-0.92	2.3	-1.43	-0.79	-0.96	-1.06	2.7
0.05M KP-Ca	-0.21	-0.26	-0.21	-0.23	1.7	-0.38	-0.42	-0.24	-0.34	1.7
0.01M Ca-Ca	-1.15	-0.38	-0.77	-0.77	2.7	-2.47	-0.59	-1.28	-1.45	2.7
0.05M Ca-Ca	0.04	0.03	-0.13	-0.02	1.3	0.09	0.19	-0.10	0.06	1.3
0.1M Ca-Ca	-0.09	-0.05	-0.09	-0.08	1.3	0.08	0.14	0.03	0.08	1.3
0.2M Ca-Ca	-0.45	-0.36	-0.37	-0.39	1.0	-0.35	-0.29	-0.30	-0.31	1.0
0.4M Ca-Ca	-0.67	-0.58	-0.48	-0.58	1.0	-0.58	-0.49	-0.39	-0.49	1.0
0.001M CMA	-9.91	-10.87	-8.83	-9.87	4.3	-14.51	-15.44	-11.91	-13.96	5.0
0.005M CMA	-9.54	-9.08	-5.87	-8.16	4.3	-13.02	-12.46	-8.58	-11.35	4.7
0.01M CMA	-10.95	-8.34	-7.17	-8.82	4.7	-15.45	-12.56	-10.50	-12.84	4.7
0.05M CMA	-2.03	-0.95	-1.05	-1.34	2.7	-3.08	-1.24	-1.12	-1.81	2.7
Na-Pre	-5.00	-2.99	-2.55	-3.51	3.0	-9.02	-5.57	-4.69	-6.43	3.7
K-Pre	-3.22	-2.86	-1.47	-2.51	3.0	-5.56	-5.54	-2.45	-4.52	3.3
Ca-Pre	-2.94	-1.88	-1.71	-2.17	2.7	-4.95	-3.24	-2.41	-3.54	3.0
No-Pre	-11.83	-8.59	-6.12	-8.85	4.3	-16.62	-12.28	-8.50	-12.47	4.7
Control(1-3)	-0.05	-0.09	-0.15	-0.10	0.7	0.03	-0.00	-0.07	-0.01	0.7
Control(4-6)										
Control(7-9) Moulded Cube	-1.69	-1.72	-2.04	-1.82		-1.77	-1.86	-2.20	-1.95	

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

	Oct. 8 (25 cycles)				
	Weight Change (%)			Avg.	Avg.
Salt Type	Cube 1	Cube 2	Cube 3	Wt.Chg.	Scale
0.01M Na-Na	-15.00	-16.98	-9.49	-13.82	5.0
0.02M Na-Na	-4.14	-2.68	-2.08	-2.97	3.7
0.03M Na-Na	-2.53	-0.86	-0.84	-1.41	2.7
0.04M Na-Na	-0.70	-0.35	-0.46	-0.50	2.0
0.05M Na-Na	-0.90	-0.14	-0.60	-0.55	1.7
0.01M Na-Ca	-6.14	-4.90	-3.18	-4.74	3.3
0.02M Na-Ca	-5.78	-3.25	-3.65	-4.23	3.7
0.03M Na-Ca	-3.59	-2.61	-2.36	-2.85	3.7
0.04M Na-Ca	-1.45	-0.61	-0.43	-0.83	2.0
0.05M Na-Ca	-0.44	0.07	-0.28	-0.22	1.7
0.01M KP-Na	-7.47	-10.38	-5.80	-7.88	4.7
0.02M KP-Na	-3.21	-1.83	-2.27	-2.44	3.3
0.03M KP-Na	-3.00	-0.34	-1.45	-1.60	3.0
0.04M KP-Na	-2.44	-1.63	-1.04	-1.70	2.7
0.05M KP-Na	-0.77	-0.22	-0.50	-0.50	2.0
0.01M KP-Ca	-6.74	-4.89	-3.15	-4.93	3.7
0.02M KP-Ca	-7.11	-3.41	-2.19	-4.24	4.3
0.03M KP-Ca	-4.29	-2.21	-2.40	-2.97	3.7
0.04M KP-Ca	-1.89	-1.08	-0.94	-1.31	2.7
0.05M KP-Ca	-0.57	-0.53	-0.33	-0.48	2.0
0.01M Ca-Ca	-3.62	-1.08	-1.79	-2.16	3.0
0.05M Ca-Ca	0.17	0.28	0.01	0.15	1.7
0.1M Ca-Ca	0.21	0.23	0.16	0.20	1.3
0.2M Ca-Ca	-0.35	-0.23	-0.29	-0.29	1.0
0.4M Ca-Ca	-0.49	-0.45	-0.32	-0.42	1.0
0.001M CMA	-19.24	-19.78	-15.25	-18.09	5.0
0.005M CMA	-16.53	-16.09	-11.33	-14.65	5.0
0.01M CMA	-19.89	-16.77	-13.74	-16.80	5.0
0.05M CMA	-4.31	-1.77	-1.24	-2.44	2.7
Na-Pre	-13.69	-8.71	-7.18	-9.86	4.3
K-Pre	-8.42	-9.09	-3.37	-6.96	4.0
Ca-Pre	-7.71	-5.42	-3.44	-5.52	3.7
No-Pre	-21.06	-16.18	-10.88	-16.04	5.0
Control(1-3)	0.07	0.02	-0.03	0.02	0.7
Control(4-6)					
Control(7-9)	-1.80	-2.01	-2.34	-2.05	
Moulded Cube					

MORTAR CUBE SCALING OBSERVATIONS - STAGE 2

Salt Type	0 Cycle Wt Chg	5 Cycle Wt Chg	10 Cycle Wt Chg	15 Cycle Wt Chg	20 Cycle Wt Chg	25 Cycle Wt Chg	0 Cycle Scale	5 Cycle Scale	10 Cycle Scale	15 Cycle Scale	20 Cycle Scale	25 Cycle Scale
0.01M Na-Na	0.00	-1.77	-3.71	-6.53	-10.05	-13.82	0.0	2.7	3.3	4.0	5.0	5.0
0.02M Na-Na	0.00	-1.20	-1.45	-1.74	-2.31	-2.97	0.0	2.0	2.3	2.7	3.3	3.7
0.03M Na-Na	0.00	-0.98	-0.80	-0.84	-1.08	-1.41	0.0	1.3	2.0	2.0	2.3	2.7
0.04M Na-Na	0.00	-0.88	-0.61	-0.50	-0.49	-0.50	0.0	1.3	1.7	1.7	2.0	2.0
0.05M Na-Na	0.00	-0.98	-0.62	-0.48	-0.52	-0.55	0.0	1.7	1.7	1.7	1.7	1.7
0.01M Na-Ca	0.00	-1.08	-1.36	-2.21	-3.58	-4.74	0.0	1.7	2.0	2.3	3.0	3.3
0.02M Na-Ca	0.00	-1.08	-1.16	-1.78	-2.94	-4.23	0.0	1.7	1.7	2.7	3.3	3.7
0.03M Na-Ca	0.00	-1.13	-1.13	-1.42	-2.04	-2.85	0.0	2.0	2.0	3.0	3.0	3.7
0.04M Na-Ca	0.00	-0.93	-0.55	-0.43	-0.48	-0.83	0.0	1.7	1.7	1.7	1.7	2.0
0.05M Na-Ca	0.00	-0.79	-0.36	-0.20	-0.10	-0.22	0.0	1.3	1.3	1.7	1.7	1.7
0.01M KP-Na	0.00	-1.58	-2.30	-3.31	-5.35	-7.88	0.0	2.0	3.0	3.0	4.0	4.7
0.02M KP-Na	0.00	-1.37	-1.57	-1.80	-2.08	-2.44	0.0	2.0	2.3	2.7	3.0	3.3
0.03M KP-Na	0.00	-1.06	-0.98	-1.08	-1.21	-1.60	0.0	1.7	2.0	2.3	2.7	3.0
0.04M KP-Na	0.00	-0.96	-0.82	-0.93	-1.11	-1.70	0.0	1.3	2.3	2.3	2.3	2.7
0.05M KP-Na	0.00	-0.81	-0.51	-0.42	-0.38	-0.50	0.0	1.0	1.0	1.0	1.7	2.0
0.01M KP-Ca	0.00	-0.98	-1.38	-2.32	-3.60	-4.93	0.0	1.3	2.3	2.7	3.7	3.7
0.02M KP-Ca	0.00	-0.98	-1.14	-1.81	-2.94	-4.24	0.0	1.7	2.7	2.7	3.7	4.3
0.03M KP-Ca	0.00	-0.80	-0.84	-1.19	-2.05	-2.97	0.0	1.3	2.0	2.3	3.0	3.7
0.04M KP-Ca	0.00	-0.99	-0.86	-0.92	-1.06	-1.31	0.0	1.3	2.0	2.3	2.7	2.7
0.05M KP-Ca	0.00	-0.75	-0.42	-0.23	-0.34	-0.48	0.0	1.0	1.0	1.7	1.7	2.0
0.01M Ca-Ca	0.00	-0.79	-0.65	-0.77	-1.45	-2.16	0.0	1.3	2.3	2.7	2.7	3.0
0.05M Ca-Ca	0.00	-0.67	-0.28	-0.02	0.06	0.15	0.0	0.7	1.3	1.3	1.3	1.7
0.1M Ca-Ca	0.00	-0.81	-0.38	-0.08	0.08	0.20	0.0	1.0	1.3	1.3	1.3	1.3
0.2M Ca-Ca	0.00	-1.15	-0.62	-0.39	-0.31	-0.29	0.0	0.7	1.0	1.0	1.0	1.0
0.4M Ca-Ca	0.00	-1.27	-0.81	-0.58	-0.49	-0.42	0.0	0.0	0.0	1.0	1.0	1.0
0.001M CMA	0.00	-2.13	-5.68	-9.87	-13.96	-18.09	0.0	3.3	4.0	4.3	5.0	5.0
0.005M CMA	0.00	-1.72	-4.69	-8.16	-11.35	-14.65	0.0	3.3	4.3	4.3	4.7	5.0
0.01M CMA	0.00	-1.89	-5.16	-8.82	-12.84	-16.80	0.0	3.0	4.0	4.7	4.7	5.0
0.05M CMA	0.00	-1.04	-1.03	-1.34	-1.81	-2.44	0.0	1.7	2.3	2.7	2.7	2.7
Na-Pre	0.00	-0.83	-1.52	-3.51	-6.43	-9.86	0.0	1.0	2.0	3.0	3.7	4.3
K-Pre	0.00	-0.88	-1.27	-2.51	-4.52	-6.96	0.0	1.7	2.0	3.0	3.3	4.0
Ca-Pre	0.00	-1.37	-1.47	-2.17	-3.54	-5.52	0.0	1.3	2.3	2.7	3.0	3.7
No-Pre	0.00	-2.08	-5.29	-8.85	-12.47	-16.04	0.0	3.0	4.0	4.3	4.7	5.0
Control(1-3)	0.00	-0.67	-0.25	-0.10	-0.01	0.02	0.0	0.0	0.3	0.7	0.7	0.7
Control(4-6)	0.00						0.0					
Control(7-9)	0.00	-1.43	-1.74	-1.82	-1.95	-2.05	0.0					
Moulded Cube	0.00						0.0					

CUBE WEIGHT LOSS LINEAR REGRESSION ANALYSIS - STAGE 2
(Force lines through zero)

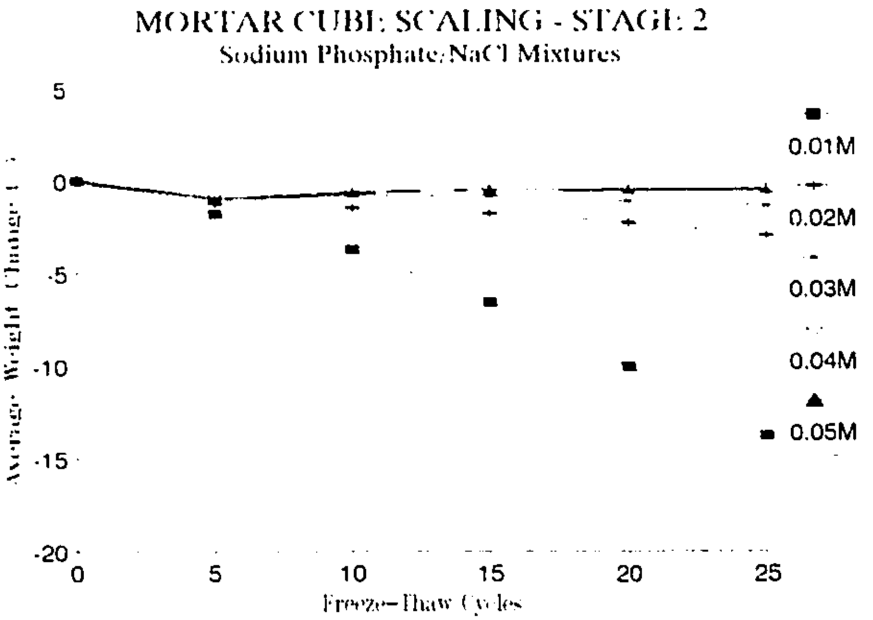
Salt / Chloride Mixture	Constant	Std Err of Y Est	R Squared	# of Observ.	Degrees of Freedom	X Coef.	Std Err of Coef.	Rank
0.05M Ca(H2PO4)2*H2O + 0.45M CaCl2	0	0.3310	-0.2045	6	5	0.0010	0.0089	1
0.1M Ca(H2PO4)2*H2O + 0.4M CaCl2	0	0.4110	-0.2270	6	5	0.0017	0.0111	2
Deionized-Distilled Water (Control)	0	0.3119	-0.3819	6	5	0.0052	0.0084	3
0.05M NaH2PO4 + 0.45M CaCl2	0	0.3480	-0.5931	6	5	0.0131	0.0094	4
0.05M KH2PO4 + 0.45M CaCl2	0	0.3084	-0.4991	6	5	0.0219	0.0083	5
0.2M Ca(H2PO4)2*H2O + 0.3M CaCl2	0	0.5173	-0.7287	6	5	0.0229	0.0140	6
0.05M KH2PO4 + 0.45M NaCl	0	0.3369	-0.6644	6	5	0.0258	0.0091	7
0.04M NaH2PO4 + 0.46M NaCl	0	0.3734	-0.7257	6	5	0.0294	0.0101	8
0.05M NaH2PO4 + 0.45M NaCl	0	0.4067	-0.7008	6	5	0.0309	0.0110	9
0.4M Ca(H2PO4)2*H2O + 0.1M CaCl2	0	0.5737	-0.8350	6	5	0.0315	0.0155	10
0.04M NaH2PO4 + 0.46M CaCl2	0	0.3650	-0.2254	6	5	0.0341	0.0098	11
0.04M KH2PO4 + 0.46M CaCl2	0	0.3466	0.3982	6	5	0.0590	0.0093	12
0.03M NaH2PO4 + 0.47M NaCl	0	0.3240	0.5270	6	5	0.0599	0.0087	13
0.04M KH2PO4 + 0.46M NaCl	0	0.3073	0.6868	6	5	0.0667	0.0083	14
0.03M KH2PO4 + 0.47M NaCl	0	0.3559	0.5522	6	5	0.0694	0.0096	15
0.01M Ca(H2PO4)2*H2O + 0.49M CaCl2	0	0.2815	0.8569	6	5	0.0763	0.0076	16
0.05M CMA + 0.45M NaCl	0	0.2610	0.8995	6	5	0.0967	0.0070	17
Air (Control)	0	0.5829	0.4162	6	5	0.1032	0.0157	18
0.03M KH2PO4 + 0.47M CaCl2	0	0.2789	0.9293	6	5	0.1057	0.0075	19
0.03M NaH2PO4 + 0.47M CaCl2	0	0.2898	0.9091	6	5	0.1093	0.0078	20
0.02M KH2PO4 + 0.48M NaCl	0	0.4545	0.7099	6	5	0.1106	0.0123	21
0.02M NaH2PO4 + 0.48M NaCl	0	0.2920	0.9171	6	5	0.1215	0.0079	22
0.02M KH2PO4 + 0.48M CaCl2	0	0.3517	0.9465	6	5	0.1514	0.0095	23
0.02M NaH2PO4 + 0.48M CaCl2	0	0.3661	0.9408	6	5	0.1514	0.0099	24
0.01M NaH2PO4 + 0.49M CaCl2	0	0.3181	0.9666	6	5	0.1762	0.0086	25
0.01M KH2PO4 + 0.49M CaCl2	0	0.3180	0.9692	6	5	0.1809	0.0086	26
0.05M Ca(H2PO4)2*H2O Pretreatment	0	0.5456	0.9207	6	5	0.1912	0.0147	27
0.05M KH2PO4 Pretreatment	0	0.8340	0.8981	6	5	0.2321	0.0225	28
0.01M KH2PO4 + 0.49M NaCl	0	0.6175	0.9523	6	5	0.2797	0.0167	29
0.05M NaH2PO4 Pretreatment	0	1.3031	0.8822	6	5	0.3251	0.0351	30
0.01M NaH2PO4 + 0.49M NaCl	0	0.9863	0.9645	6	5	0.5022	0.0266	31
0.005M CMA + 0.495M NaCl	0	0.7063	0.9845	6	5	0.5609	0.0190	32
No Pretreatment	0	0.6825	0.9877	6	5	0.6156	0.0184	33
0.01M CMA + 0.49M NaCl	0	0.9416	0.9789	6	5	0.6327	0.0254	34
0.001M CMA + 0.499M NaCl	0	0.9148	0.9829	6	5	0.6886	0.0247	35

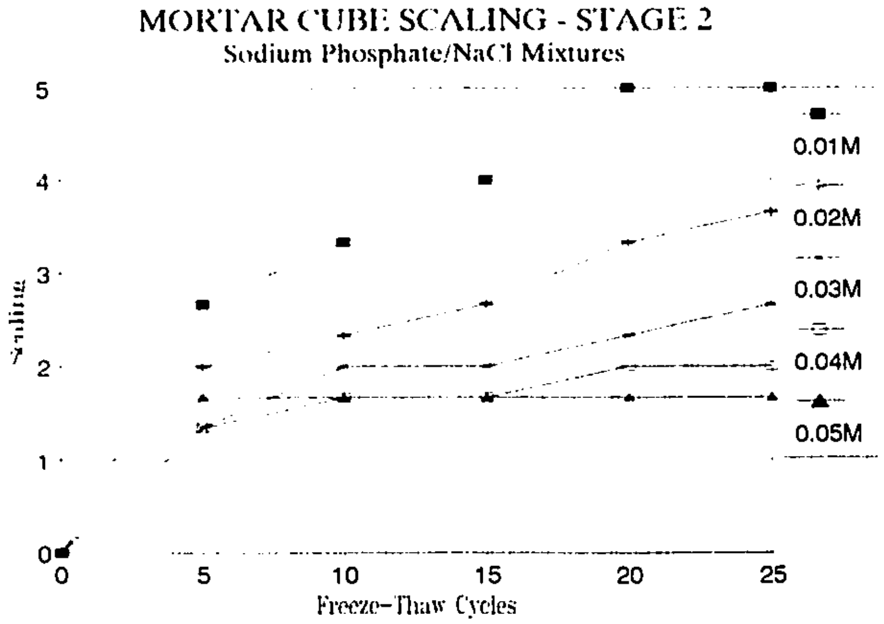
Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Squared = Correlation coefficient squared

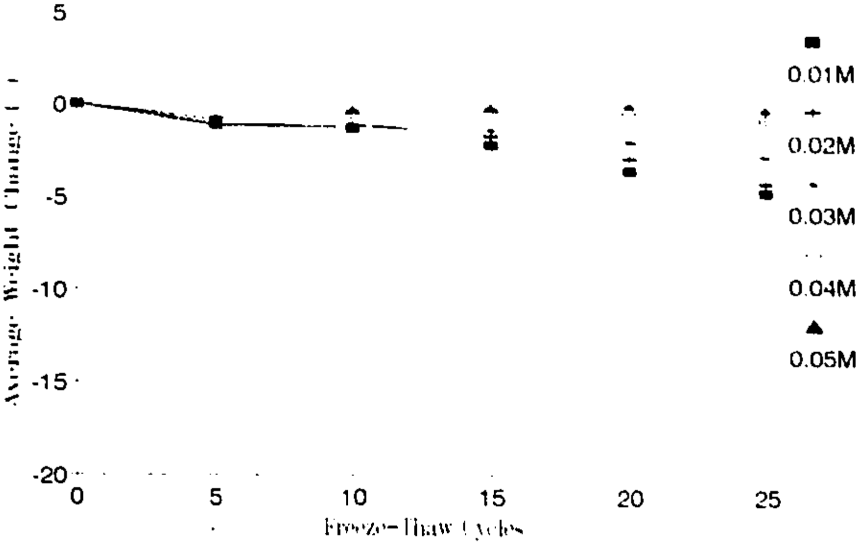
MORTAR CUBE VISUAL OBSERVATIONS - STAGE 2

Solution	After 1 Cycles		After 2 Cycles				After 4 Cycles
	Unfrozen Solution	Saturation of Cubes (%)	Unfrozen Solution	Saturation of Cubes (%)	Explosions	Scaling	Saturation of Cubes (%)
0.01M Na-Na						Visible	70
0.02M Na-Na						Visible	80
0.03M Na-Na						Visible	85
0.04M Na-Na						Visible	90
0.05M Na-Na						Visible	90
0.01M Na-Ca	Minor		Minor		Minor	Minor	90
0.02M Na-Ca	Minor		Minor		Minor	Minor	80
0.03M Na-Ca	Minor		Minor		Minor	Minor	80
0.04M Na-Ca	Minor		Minor		Minor	Minor	80
0.05M Na-Ca	Minor		Minor		Minor	Minor	90
0.01M KP-Na					Minor	Minor	95
0.02M KP-Na					Minor	Minor	90
0.03M KP-Na					Minor	Minor	90
0.04M KP-Na					Minor	Minor	95
0.05M KP-Na					Minor	Minor	95
0.01M KP-Ca					Minor	Minor	90
0.02M KP-Ca					Minor	Minor	95
0.03M KP-Ca					Minor	Minor	95
0.04M KP-Ca					Minor	Minor	95
0.05M KP-Ca					Minor	Minor	95
0.01M Ca-Ca							98
0.05M Ca-Ca	Minor		Minor				95
0.1M Ca-Ca	Minor		Minor				90
0.2M Ca-Ca							
0.4M Ca-Ca							
0.001M CMA					Minor	Minor	
0.005M CMA					Minor	Minor	
0.01M CMA							
0.05M CMA							
Na-Pre		80		90		Visible	90
K-Pre		90		95			98
Ca-Pre		100		100		Visible	100
No-Pre		50		50	Minor	Minor	90
Control(1-3)							

Note: 1) Mortar cube observations listed were taken immediately after removal from the freezer.
2) Unfrozen solution is melt water present in the container.
3) Explosions are scaled material which have been ejected from the cube surface over 1cm away.
4) Saturation of cube refers to the height at which the cube side appears damp.
5) Solution abbreviations used:
Na-Na = sodium phosphate/NaCl mixture
Na-Ca = sodium phosphate/CaCl2 mixture
KP-Na = potassium phosphate/NaCl mixture
KP-Ca = potassium phosphate/CaCl2 mixture
Ca-Ca = calcium phosphate/CaCl2 mixture
CMA = calcium magnesium acetate/NaCl mixture
Na-Pre = sodium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
K-Pre = potassium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Ca-Pre = calcium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
No-Pre = no phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Control(1-3) = deionized-distilled water freeze-thaw cycling

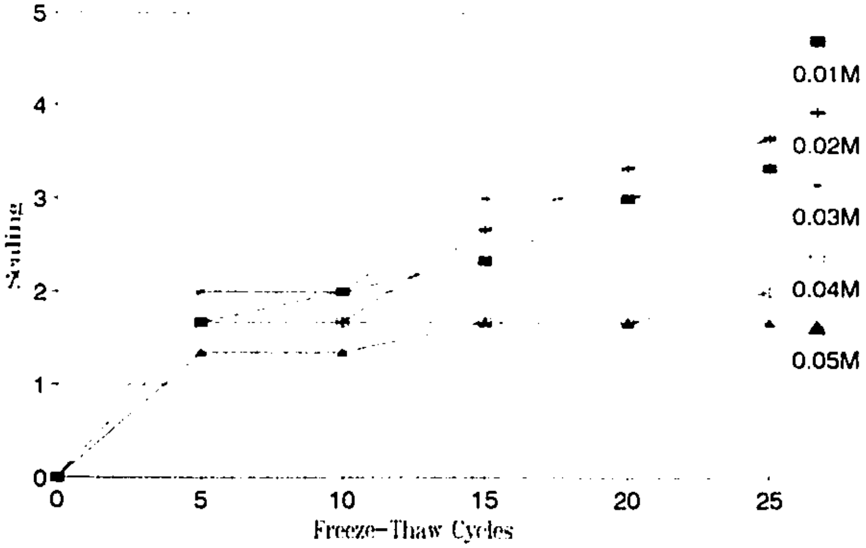

MORTAR CUBE SCALING - STAGE 2
Sodium Phosphate/NaCl Mixtures
Average Weight Change
5
0
-5
-10
-15
-20
0
5
10
15
20
25
Freeze–Thaw Cycles
0.01M
0.02M
0.03M
0.04M
0.05M


MORTAR CUBE SCALING - STAGE 2
Sodium Phosphate/NaCl Mixtures
Scaling
5
4
3
2
1
0
0
5
10
15
20
25
Freeze–Thaw Cycles
0.01M
0.02M
0.03M
0.04M
0.05M



MORTAR CUBE SCALING - STAGE 2

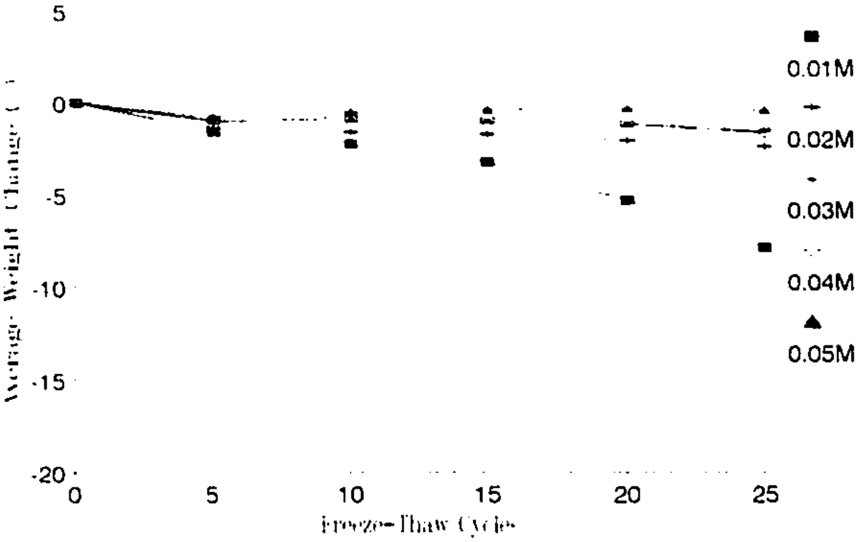
Sodium Phosphate/CaCl2 Mixtures



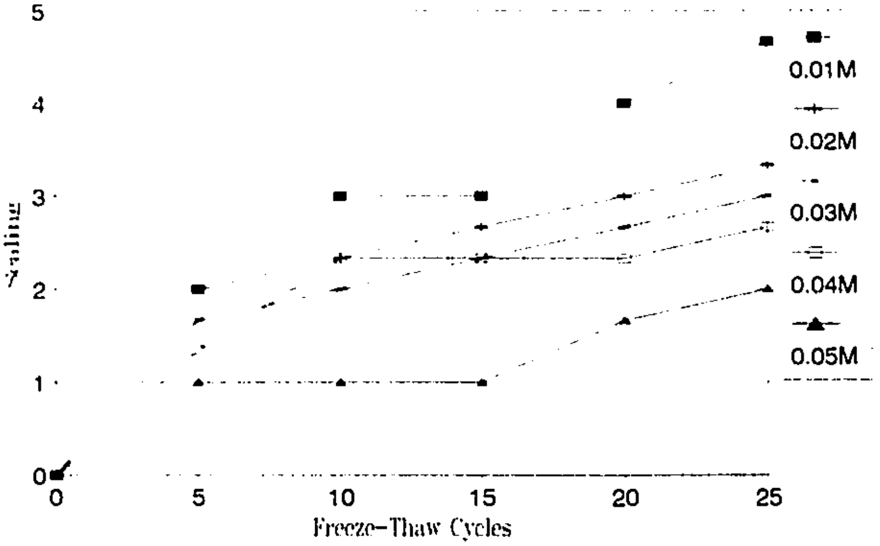
MORTAR CUBE SCALING - STAGE 2

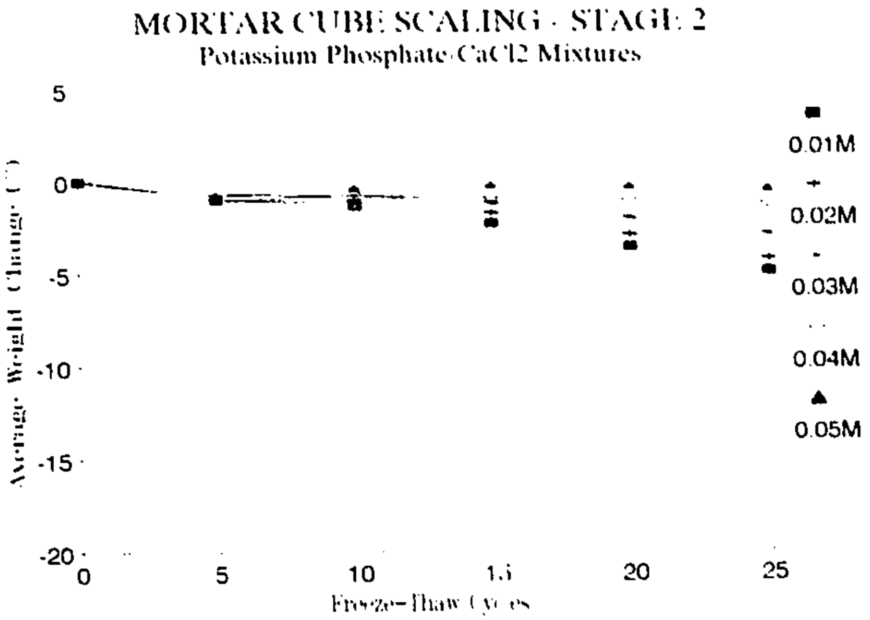
Sodium Phosphate/CaCl2 Mixtures

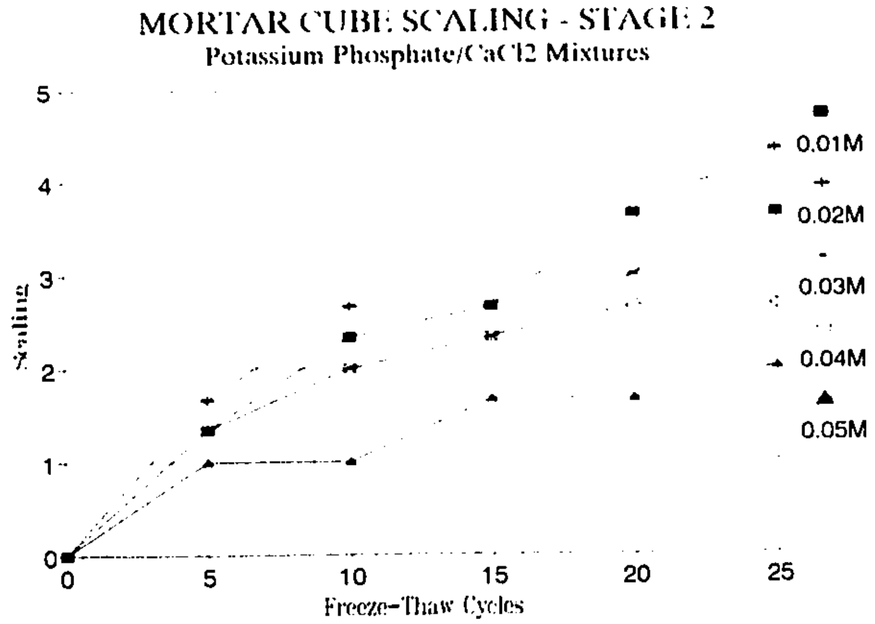
MORTAR CUBE SCALING - STAGE 2
Potassium Phosphate/NaCl Mixtures

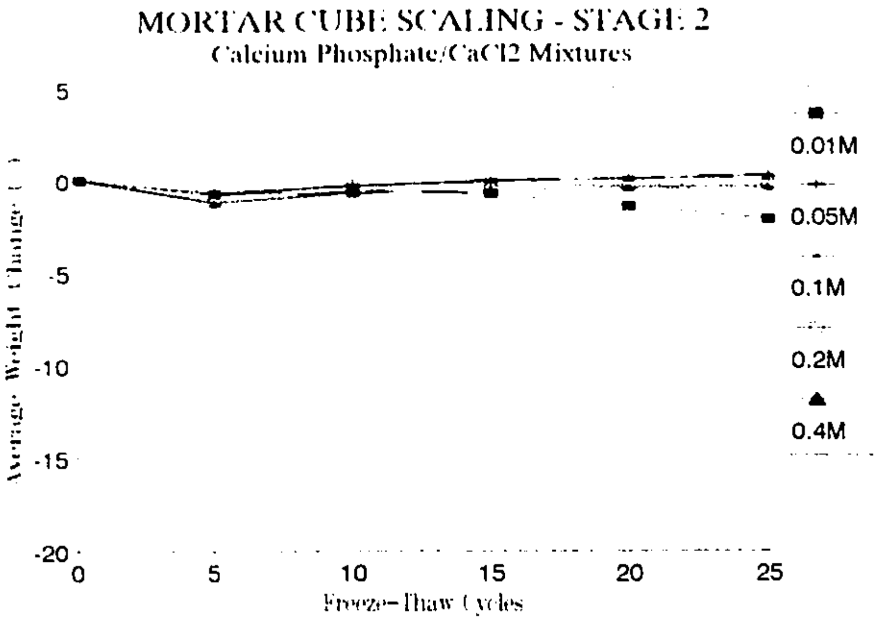


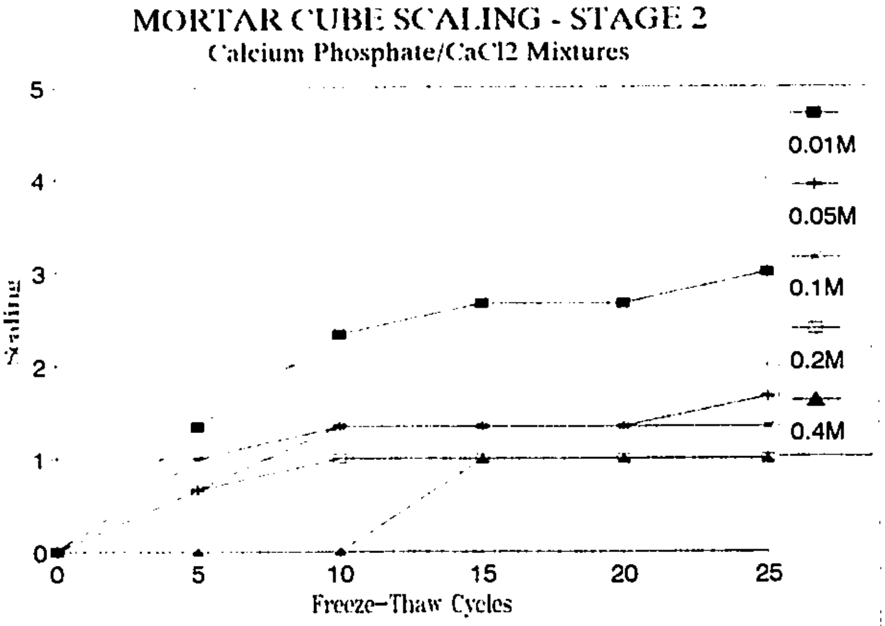
MORTAR CUBE SCALING - STAGE 2
Potassium Phosphate/NaCl Mixtures

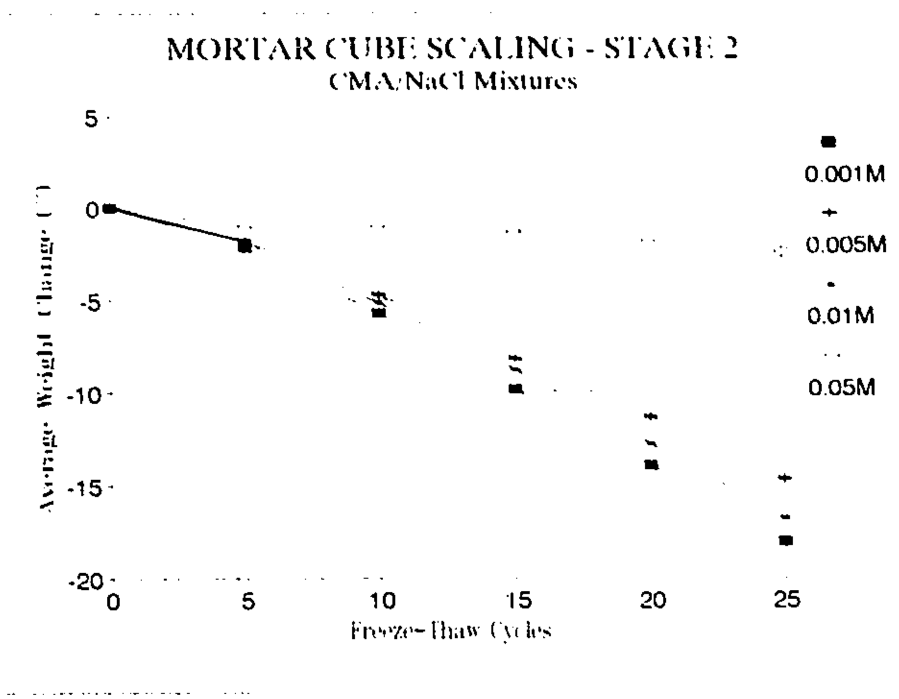


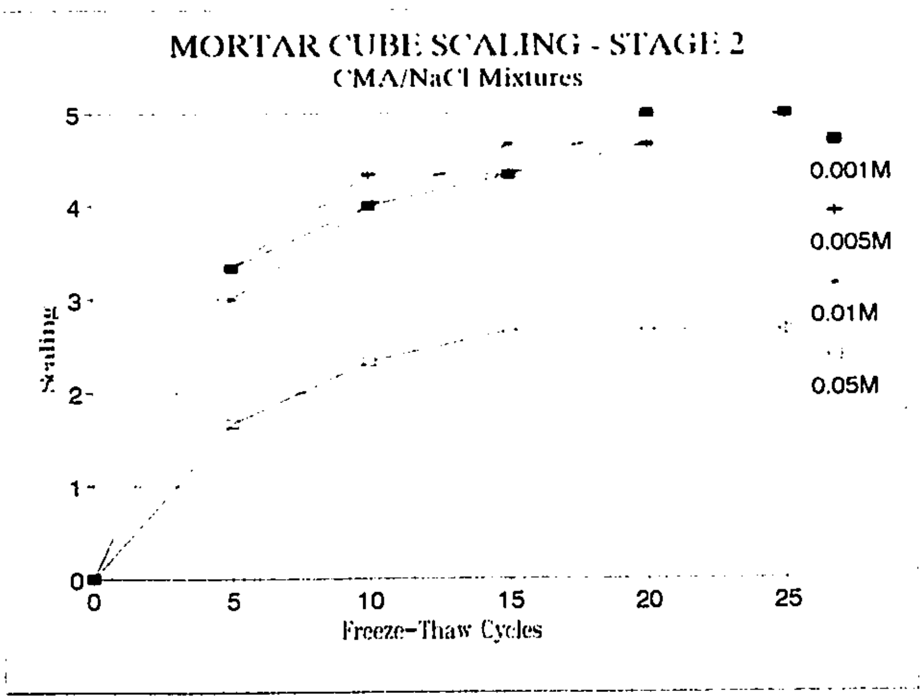

MORTAR CUBE SCALING - STAGE 2
Potassium Phosphate/CaCl2 Mixtures

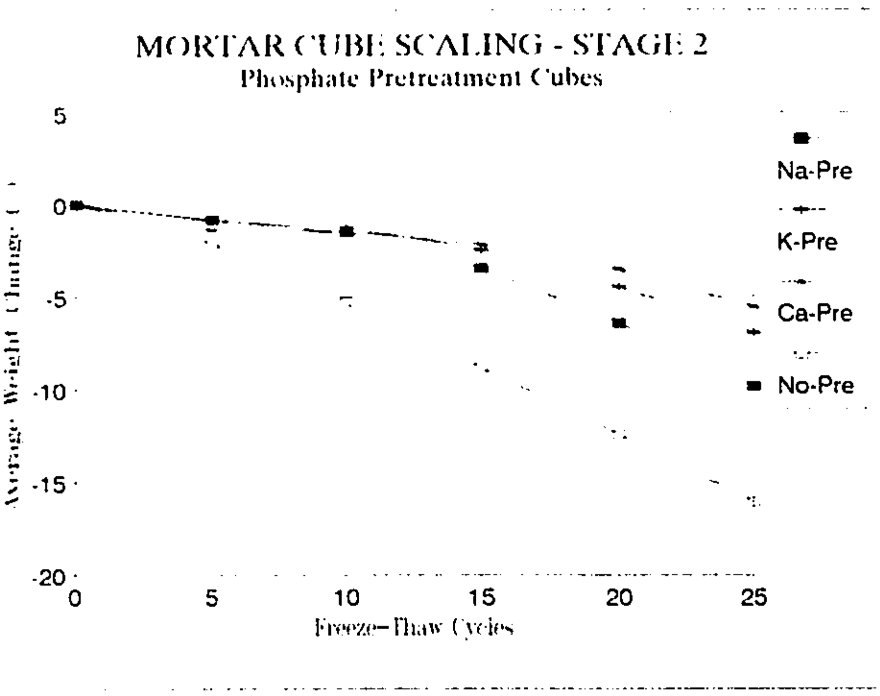

MORTAR CUBE SCALING - STAGE 2
Potassium Phosphate/CaCl2 Mixtures

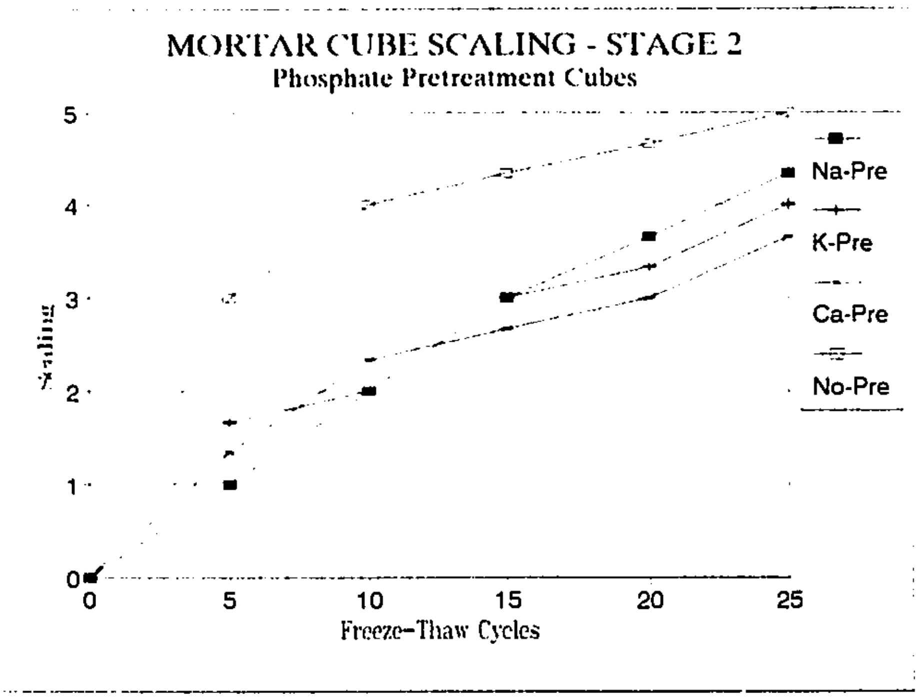

MORTAR CUBE SCALING - STAGE 2
Calcium Phosphate/CaCl2 Mixtures
Average Weight Change (%)
5
0
-5
-10
-15
-20
0
5
10
15
20
25
Freeze–Thaw Cycles
0.01M
0.05M
0.1M
0.2M
0.4M

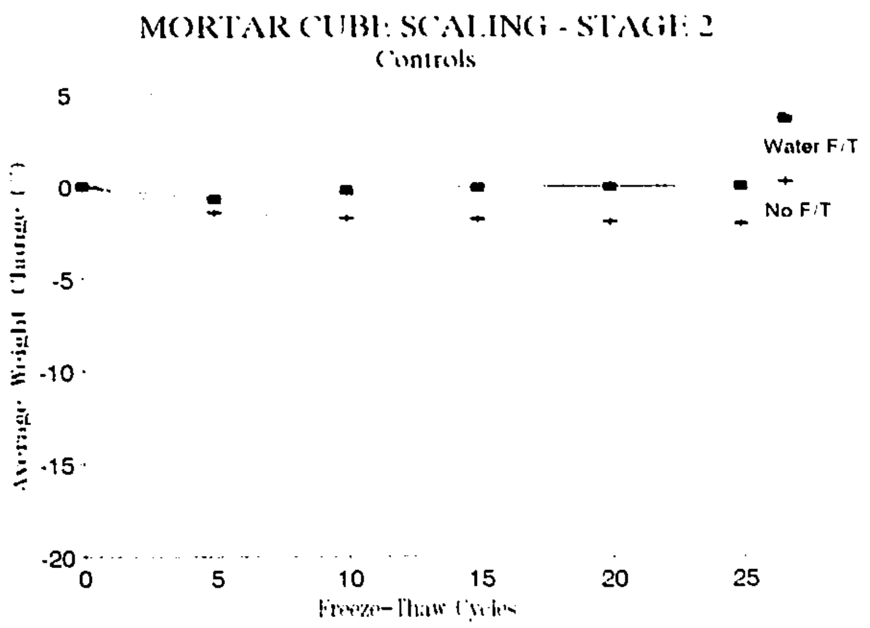

MORTAR CUBE SCALING - STAGE 2
Calcium Phosphate/CaCl2 Mixtures
Scaling
5
4
3
2
1
0
0
5
10
15
20
25
Freeze–Thaw Cycles
0.01M
0.05M
0.1M
0.2M
0.4M

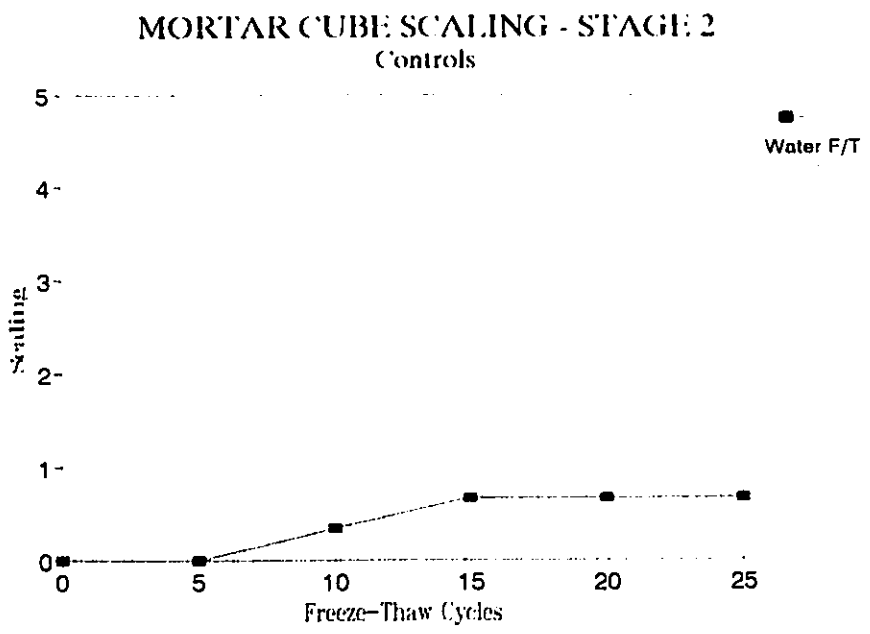

MORTAR CUBE SCALING - STAGE 2
CMA/NaCl Mixtures
Average Weight Change ( )
5
0
-5
-10
-15
-20
0
5
10
15
20
25
Freeze-Thaw Cycles
0.001M
0.005M
0.01M
0.05M


MORTAR CUBE SCALING - STAGE 2
CMA/NaCl Mixtures
Scaling
5
4
3
2
1
0
0
5
10
15
20
25
Freeze-Thaw Cycles
0.001M
0.005M
0.01M
0.05M


MORTAR CUBE SCALING - STAGE 2
Phosphate Pretreatment Cubes


MORTAR CUBE SCALING - STAGE 2
Phosphate Pretreatment Cubes


MORTAR CUBE SCALING - STAGE 2
Controls
Average Weight Change (%)
5
0
-5
-10
-15
-20
0
5
10
15
20
25
Freeze-Thaw Cycles
Water F/T
No F/T


MORTAR CUBE SCALING - STAGE 2
Controls
Scaling
5
4
3
2
1
0
0
5
10
15
20
25
Freeze-Thaw Cycles
Water F/T

APPENDIX E

Compressive Strength Observations (Stage 2)

COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 2

Cube #	Dry Weight (g) Sept.12	Dry Weight (g) Oct.26	Weight Change (%)	Failure Force (lbs)	Planimeter Reading Side 1	Planimeter Reading Side 2	Calculated Area (sq.in.) Side 1	Calculated Area (sq.in.) Side 2	Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
Na-Na 0.01-1	281.79	235.60	-16.39	11460	0.357	0.350	1.87	1.83	6192	42.7		
Na-Na 0.01-2	309.23	252.32	-18.40	12210	0.352	0.388	1.84	2.03	6303	43.5		
Na-Na 0.01-3	310.69	275.00	-11.49	15390	0.623	0.596	3.26	3.12	4823	33.3	39.8	15.43
Na-Na 0.02-1	289.11	271.85	-5.97	19050	0.617	0.488	3.23	2.55	6586	45.4		
Na-Na 0.02-2	303.89	291.49	-4.08	18590	0.678	0.623	3.55	3.26	5458	37.6		
Na-Na 0.02-3	309.49	297.09	-4.01	24260	0.683	0.679	3.58	3.55	6804	46.9	43.3	4.69
Na-Na 0.03-1	280.98	268.79	-4.34	20350	0.661	0.657	3.46	3.44	5898	40.7		
Na-Na 0.03-2	308.48	300.35	-2.64	18750	0.740	0.715	3.87	3.74	4923	33.9		
Na-Na 0.03-3	300.87	293.07	-2.59	20790	0.707	0.667	3.70	3.49	5780	39.9	38.2	3.19
Na-Na 0.04-1	302.92	294.85	-2.66	21740	0.686	0.711	3.59	3.72	5945	41.0		
Na-Na 0.04-2	302.05	295.32	-2.23	19590	0.631	0.728	3.30	3.81	5507	38.0		
Na-Na 0.04-3	295.66	288.64	-2.37	21380	0.667	0.744	3.49	3.90	5788	39.9	39.6	2.42
Na-Na 0.05-1	289.96	282.13	-2.70	21070	0.674	0.600	3.53	3.14	6318	43.6		
Na-Na 0.05-2	297.51	292.55	-1.67	23100	0.713	0.666	3.73	3.49	6399	44.1		
Na-Na 0.05-3	313.52	305.78	-2.47	23480	0.745	0.714	3.90	3.74	6148	42.4	43.4	2.28
Na-Ca 0.01-1	294.32	273.52	-7.07	10680	0.546	0.397	2.86	2.08	4326	29.8		
Na-Ca 0.01-2	305.56	287.21	-6.01	17290	0.516	0.484	2.70	2.53	6605	45.5		
Na-Ca 0.01-3	289.02	277.35	-4.04	20150	0.601	0.588	3.15	3.08	6474	44.6	40.0	5.70
Na-Ca 0.02-1	293.62	272.34	-7.25	15250	0.494	0.448	2.59	2.35	6184	42.6		
Na-Ca 0.02-2	309.12	295.07	-4.55	17330	0.550	0.610	2.88	3.19	5707	39.3		
Na-Ca 0.02-3	300.19	284.88	-5.10	17950	0.443	0.517	2.32	2.71	7143	49.2	43.7	5.63
Na-Ca 0.03-1	279.12	265.46	-4.89	15450	0.514	0.551	2.69	2.88	5542	38.2		
Na-Ca 0.03-2	303.41	291.34	-3.98	19530	0.664	0.617	3.48	3.23	5824	40.2		
Na-Ca 0.03-3	303.80	292.98	-3.56	18010	0.459	0.606	2.40	3.17	6460	44.5	41.0	4.14
Na-Ca 0.04-1	291.81	283.61	-2.81	21350	0.575	0.545	3.01	2.85	7282	50.2		
Na-Ca 0.04-2	297.82	291.42	-2.15	20030	0.696	0.708	3.64	3.71	5450	37.6		
Na-Ca 0.04-3	286.32	282.14	-1.46	20390	0.610	0.619	3.19	3.24	6338	43.7	43.8	2.14
Na-Ca 0.05-1	289.15	283.54	-1.94	24030	0.651	0.688	3.41	3.60	6855	47.3		
Na-Ca 0.05-2	292.89	289.44	-1.18	23120	0.695	0.644	3.64	3.37	6596	45.5		
Na-Ca 0.05-3	306.44	300.67	-1.88	20220	0.721	0.543	3.77	2.84	6111	42.1	45.0	1.67
KP-Na 0.01-1	306.10	278.29	-9.09	18290	0.391	0.458	2.05	2.40	8229	56.7		
KP-Na 0.01-2	311.77	273.61	-12.24	14980	0.477	0.473	2.50	2.48	6024	41.5		
KP-Na 0.01-3	307.41	284.10	-7.58	16950	0.454	0.480	2.38	2.51	6932	47.8	48.7	9.64
KP-Na 0.02-1	285.94	271.15	-5.17	19850	0.541	0.573	2.83	3.00	6807	46.9		
KP-Na 0.02-2	289.52	278.75	-3.72	17670	0.615	0.602	3.22	3.15	5546	38.2		
KP-Na 0.02-3	295.95	283.47	-4.22	16730	0.561	0.615	2.94	3.22	5434	37.5	40.9	4.37
KP-Na 0.03-1	295.94	280.49	-5.22	17410	0.573	0.523	3.00	2.74	6068	41.8		
KP-Na 0.03-2	310.27	303.49	-2.19	26360	0.637	0.674	3.34	3.53	7681	53.0		
KP-Na 0.03-3	309.82	298.69	-3.59	22200	0.656	0.667	3.43	3.49	6410	44.2	46.3	3.67
KP-Na 0.04-1	290.23	277.78	-4.29	24990	0.678	0.570	3.55	2.98	7649	52.7		
KP-Na 0.04-2	311.27	299.79	-3.69	24070	0.680	0.662	3.56	3.47	6852	47.2		
KP-Na 0.04-3	309.09	300.28	-2.85	20710	0.655	0.632	3.43	3.31	6147	42.4	47.5	3.61
KP-Na 0.05-1	305.98	297.04	-2.92	26180	0.647	0.632	3.39	3.31	7819	53.9		
KP-Na 0.05-2	292.51	286.21	-2.15	22240	0.687	0.647	3.60	3.39	6369	43.9		
KP-Na 0.05-3	297.69	289.74	-2.67	20150	0.574	0.605	3.01	3.17	6529	45.0	47.6	2.58

COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 2

Cube #	Dry Weight (g)		Weight Change (%)	Failure Force (lbs)	Planimeter Reading		Calculated Area (sq.in.)		Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
	Sept.12	Oct.26			Side 1	Side 2	Side 1	Side 2				
KP-Ca 0.01-1	296.30	272.24	-8.12	15510	0.452	0.432	2.37	2.26	6702	46.2		
KP-Ca 0.01-2	302.81	283.77	-6.29	16020	0.492	0.528	2.58	2.76	6000	41.4		
KP-Ca 0.01-3	312.13	298.49	-4.37	20140	0.566	0.704	2.96	3.69	6058	41.8	43.1	6.26
KP-Ca 0.02-1	290.55	265.28	-8.70	12940	0.246	0.478	1.29	2.50	6827	47.1		
KP-Ca 0.02-2	304.48	289.41	-4.95	24750	0.645	0.620	3.38	3.25	7474	51.5		
KP-Ca 0.02-3	289.30	279.28	-3.46	19790	0.592	0.666	3.10	3.49	6009	41.4	46.7	5.70
KP-Ca 0.03-1	298.63	280.90	-5.94	20110	0.511	0.635	2.68	3.32	6703	46.2		
KP-Ca 0.03-2	312.08	301.26	-3.47	21630	0.675	0.632	3.53	3.31	6322	43.6		
KP-Ca 0.03-3	309.26	297.08	-3.94	20760	0.618	0.496	3.24	2.60	7119	49.1	46.3	4.45
KP-Ca 0.04-1	280.20	271.34	-3.16	18270	0.499	0.498	2.61	2.61	7000	48.3		
KP-Ca 0.04-2	301.02	293.10	-2.63	23110	0.584	0.652	3.06	3.41	7142	49.2		
KP-Ca 0.04-3	307.35	299.79	-2.46	20780	0.632	0.692	3.31	3.62	5995	41.3	46.3	2.75
KP-Ca 0.05-1	291.91	285.34	-2.25	20060	0.597	0.607	3.13	3.18	6365	43.9		
KP-Ca 0.05-2	300.19	294.70	-1.83	18710	0.643	0.655	3.37	3.43	5506	38.0		
KP-Ca 0.05-3	304.35	298.36	-1.97	22120	0.675	0.672	3.53	3.52	6273	43.3	41.7	2.02
Ca-Ca 0.01-1	283.66	270.33	-4.70	17830	0.450	0.586	2.36	3.07	6574	45.3		
Ca-Ca 0.01-2	308.97	301.53	-2.41	20850	0.715	0.545	3.74	2.85	6321	43.6		
Ca-Ca 0.01-3	304.82	295.20	-3.16	19310	0.665	0.559	3.48	2.93	6026	41.6	43.5	3.42
Ca-Ca 0.05-1	296.93	292.38	-1.53	19670	0.695	0.670	3.64	3.51	5505	38.0		
Ca-Ca 0.05-2	298.66	294.80	-1.29	21870	0.766	0.757	4.01	3.96	5485	37.8		
Ca-Ca 0.05-3	304.73	301.00	-1.22	22000	0.770	0.745	4.03	3.90	5547	38.2	38.0	1.35
Ca-Ca 0.1-1	298.98	294.36	-1.55	27430	0.747	0.722	3.91	3.78	7133	49.2		
Ca-Ca 0.1-2	293.75	289.63	-1.40	22960	0.747	0.718	3.91	3.76	5987	41.3		
Ca-Ca 0.1-3	310.64	305.34	-1.71	23640	0.762	0.760	3.99	3.98	5933	40.9	43.8	1.55
Ca-Ca 0.2-1	295.37	291.23	-1.40	26230	0.743	0.735	3.89	3.85	6779	46.7		
Ca-Ca 0.2-2	306.44	301.97	-1.46	22280	0.794	0.787	4.16	4.12	5383	37.1		
Ca-Ca 0.2-3	286.90	283.64	-1.14	24760	0.724	0.742	3.79	3.88	6452	44.5	42.8	1.33
Ca-Ca 0.4-1	289.47	285.75	-1.29	24120	0.710	0.719	3.72	3.76	6448	44.5		
Ca-Ca 0.4-2	314.01	309.07	-1.57	23800	0.786	0.775	4.12	4.06	5824	40.2		
Ca-Ca 0.4-3	310.21	306.32	-1.25	24940	0.778	0.763	4.07	3.99	6182	42.6	42.4	1.37
CMA 0.001-1	299.41	236.63	-20.97	12500	0.396	0.310	2.07	1.62	6763	46.6		
CMA 0.001-2	312.55	245.41	-21.48	10380	0.329	0.371	1.72	1.94	5665	39.1		
CMA 0.001-3	308.85	256.45	-16.97	13150	0.377	0.410	1.97	2.15	6383	44.0	43.2	19.81
CMA 0.005-1	288.66	237.30	-17.79	12750	0.384	0.330	2.01	1.73	6821	47.0		
CMA 0.005-2	307.40	253.24	-17.62	14020	0.323	0.385	1.69	2.02	7564	52.2		
CMA 0.005-3	292.46	254.90	-12.84	12110	0.341	0.400	1.79	2.09	6243	43.0	47.4	16.08
CMA 0.01-1	291.29	228.65	-21.50	8500	0.309	0.248	1.62	1.30	5829	40.2		
CMA 0.01-2	292.78	239.41	-18.23	12580	0.362	0.348	1.90	1.82	6768	46.7		
CMA 0.01-3	303.78	256.95	-15.42	13650	0.395	0.393	2.07	2.06	6617	45.6	44.2	18.38
CMA 0.05-1	287.83	271.16	-5.79	17090	0.536	0.565	2.81	2.96	5930	40.9		
CMA 0.05-2	298.27	288.27	-3.35	22780	0.633	0.618	3.31	3.24	6956	48.0		
CMA 0.05-3	308.55	300.89	-2.48	24120	0.667	0.685	3.49	3.59	6815	47.0	45.3	3.88

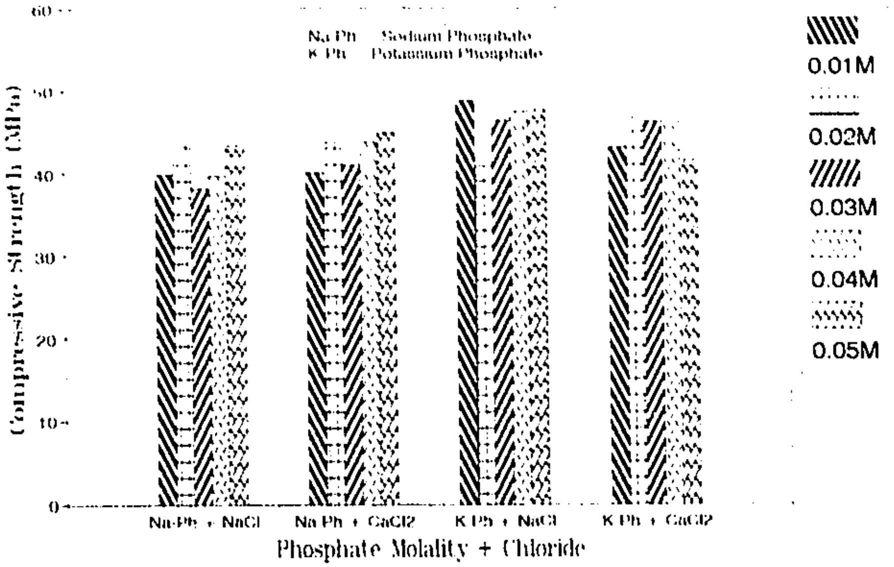
COMPRESSIVE STRENGTH OBSERVATIONS AND TOTAL WEIGHT LOSS - STAGE 2

Cube #	Dry Weight (g) Sept.12	Dry Weight (g) Oct.26	Weight Change (%)	Failure Force (lbs)	Planimeter Reading Side 1	Planimeter Reading Side 2	Calculated Area (sq.in.) Side 1	Calculated Area (sq.in.) Side 2	Compress Strength (psi)	Compress Strength (MPa)	Avg.Com. Strength (MPa)	Avg.Tot. Wt.Loss (%)
Na-Pre 1	280.83	237.77	-15.33	15460	0.413	0.443	2.16	2.32	6899	47.6		
Na-Pre 2	288.95	259.06	-10.34	17030	0.526	0.464	2.75	2.43	6571	45.3		
Na-Pre 3	310.02	281.55	-9.18	21030	0.582	0.651	3.05	3.41	6515	44.9	45.9	11.62
K-Pre 1	299.49	269.82	-9.91	18550	0.533	0.584	2.79	3.06	6344	43.7		
K-Pre 2	308.01	274.47	-10.89	14330	0.497	0.542	2.60	2.84	5269	36.3		
K-Pre 3	306.51	291.79	-4.80	18620	0.662	0.605	3.47	3.17	5614	38.7	39.6	8.53
Ca-Pre 1	280.61	254.75	-9.22	13150	0.684	0.365	3.58	1.91	4789	33.0		
Ca-Pre 2	309.78	288.12	-6.99	18930	0.615	0.555	3.22	2.91	6181	42.6		
Ca-Pre 3	295.67	281.34	-4.85	20010	0.627	0.664	3.28	3.48	5921	40.8	38.8	7.02
No-Pre 1	289.03	223.33	-22.73	10220	0.268	0.226	1.40	1.18	7903	54.5		
No-Pre 2	303.18	248.70	-17.97	13090	0.351	0.502	1.84	2.63	5862	40.4		
No-Pre 3	287.38	251.19	-12.59	15860	0.427	0.451	2.24	2.36	6900	47.6	47.5	17.76
Control 1	288.54	282.89	-1.96	23110	0.742	0.751	3.88	3.93	5913	40.8		
Control 2	297.69	292.46	-1.76	25180	0.761	0.793	3.98	4.15	6190	42.7		
Control 3	290.56	285.42	-1.77	20790	0.737	0.743	3.86	3.89	5366	37.0	40.1	1.83
Control 4	275.61	--	--	20020	0.715	0.766	3.74	4.01	5164	35.6		
Control 5	312.32	--	--	24900	0.845	0.817	4.42	4.28	5723	39.5		
Control 6	312.25	--	--	22650	0.798	0.808	4.18	4.23	5387	37.1	37.4	--
Control 7	295.32	286.95	-2.83	25320	0.769	0.747	4.03	3.91	6380	44.0		
Control 8	284.76	276.96	-2.74	19090	0.732	0.732	3.83	3.83	4981	34.3		
Control 9	292.83	283.42	-3.21	21510	0.775	0.762	4.06	3.99	5346	36.9	38.4	2.93
Moulded Cube1	289.39	--	--	29440	0.703	0.733	3.68	3.84	7832	54.0		
Moulded Cube2	284.16	--	--	26880	0.705	0.736	3.69	3.85	7126	49.1		
Moulded Cube3	288.92	--	--	26920	0.744	0.720	3.90	3.77	7024	48.4	50.5	--

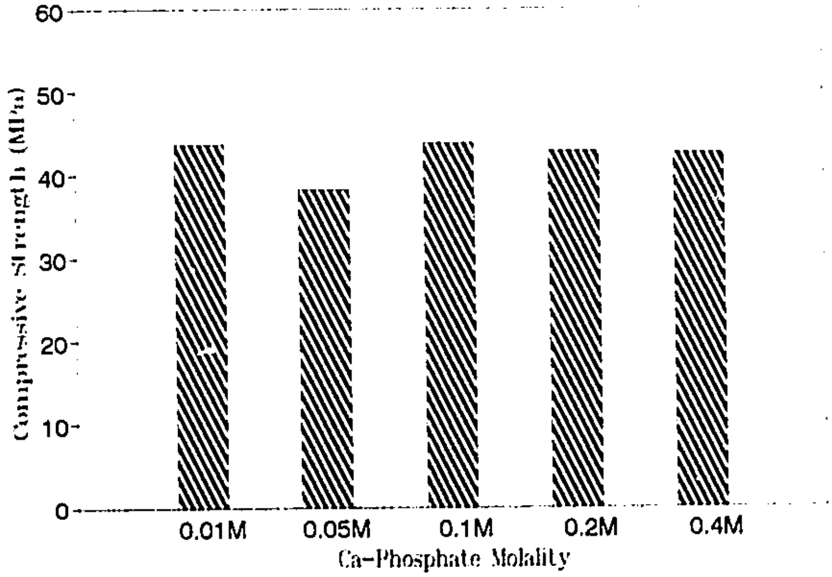
Note: Solution abbreviations used

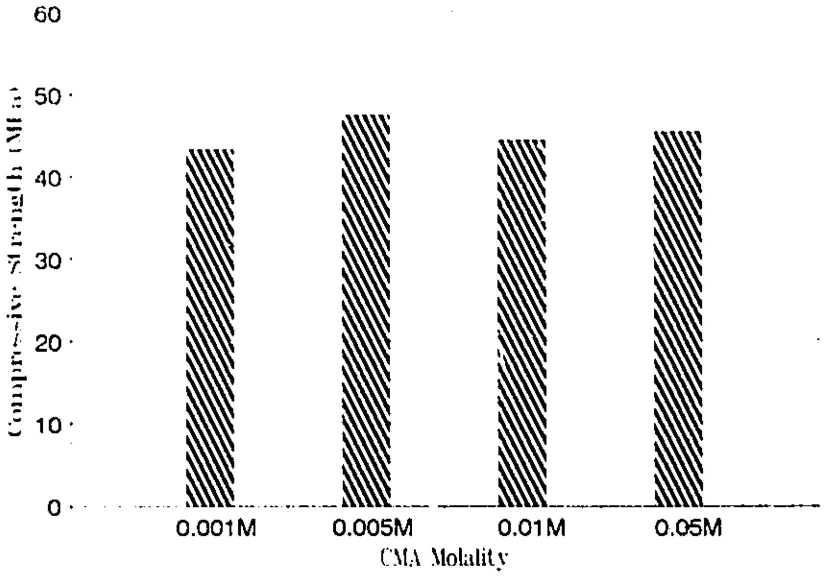
Na-Na = sodium phosphate/NaCl mixtures
Na-Ca = sodium phosphate/CaCl2 mixtures
KP-Na = potassium phosphate/NaCl mixtures
KP-Ca = potassium phosphate/CaCl2 mixtures
Ca-Ca = calcium phosphate/CaCl2 mixtures
CMA = calcium magnesium acetate/NaCl mixtures
Na-Pre = sodium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
K-Pre = potassium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Ca-Pre = calcium phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
No-Pre = no phosphate pretreatment with 0.5M NaCl freeze-thaw cycling
Control(1-3) = deionized-distilled water freeze-thaw cycling
Control(4-6) = initial compressive strength cubes
Control(7-9) = air drying cubes, no freeze-thaw cycling
Moulded Cube = initial compressive strength moulded cubes

MORTAR CUBE STRENGTH - STAGE 2
Phosphate/Chloride Mixtures



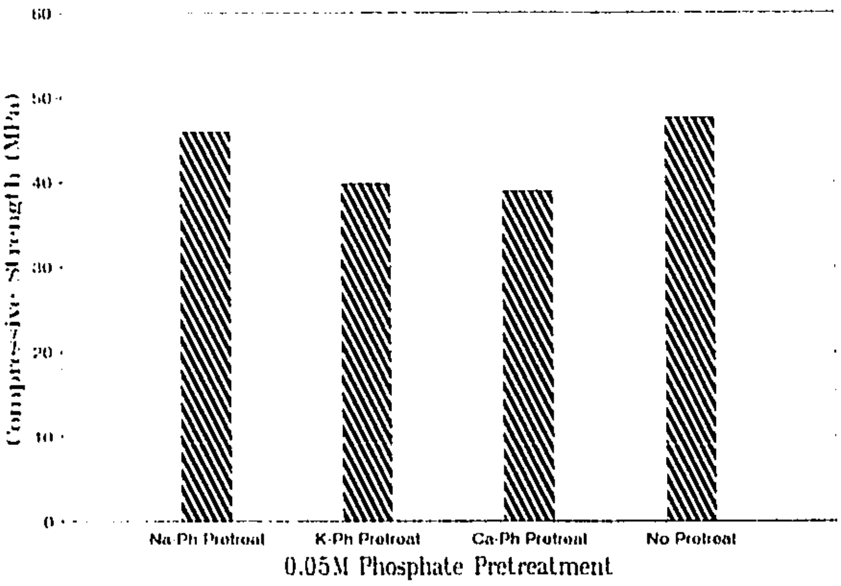
MORTAR CUBE STRENGTH - STAGE 2
Ca-Phosphate/Calcium Chloride Mixtures





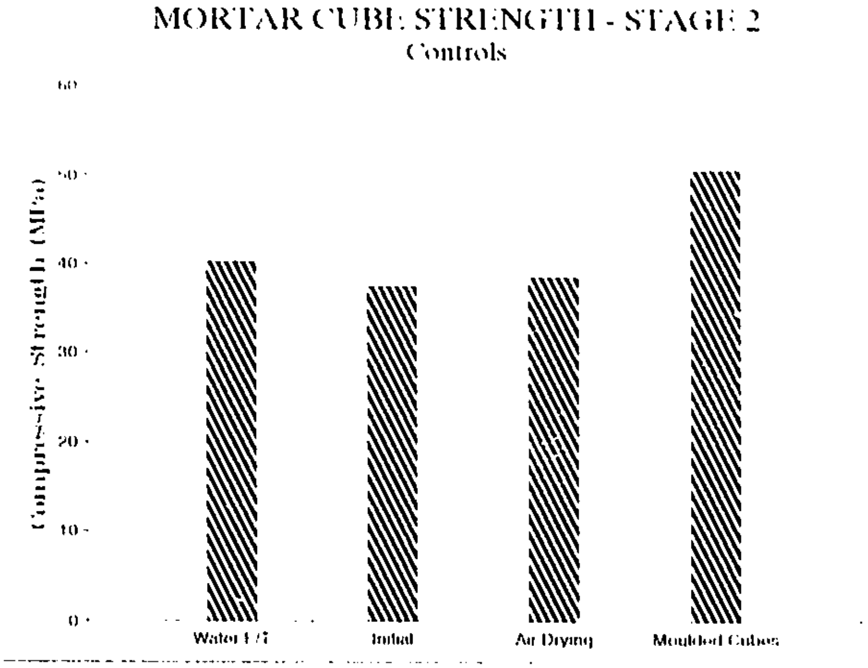
MORTAR CUBE STRENGTH - STAGE 2

CMA/Sodium Chloride Mixtures

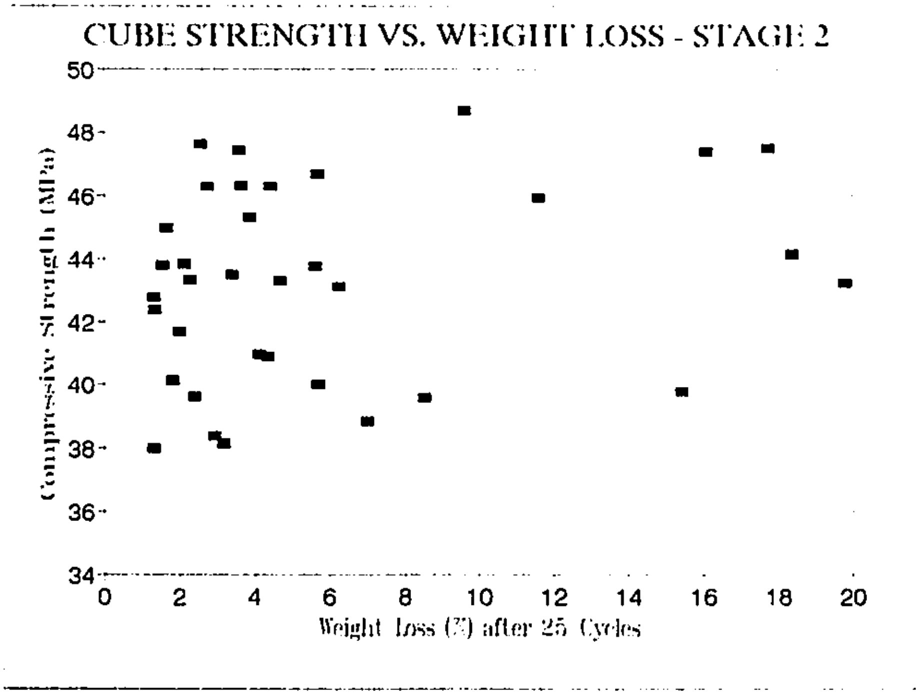


MORTAR CUBE STRENGTH - STAGE 2

Phosphate Pretreatment Cubes



MORTAR CUBE STRENGTH - STAGE 2
Controls



CUBE STRENGTH VS. WEIGHT LOSS - STAGE 2

APPENDIX F

Student t Test Analysis for Compressive Strengths of Cubes

STUDENT T TEST FOR COMPRESSIVE STRENGTH OF CUBES

Group Mean t Test Between Stage 1 and 2 Cube Strength Values

Stage 1 Salt Type	Salt Molality (M)	X1 Average Strength (MPa)	Stage 2 Salt Type	Salt Molality (M)	X2 Average Strength (MPa)	$(X1-\bar{X}1)^2$	$(X2-\bar{X}2)^2$
NaCl	0.2	38.0	Na-Ph + NaCl	0.01	39.8	0.014	12.159
CaCl2	0.2	37.8	Na-Ph + CaCl2	0.01	40.0	0.007	10.802
K-Acetate	0.2	36.0	K-Ph + NaCl	0.01	48.7	3.372	29.181
NaCl	0.5	32.8	K-Ph + CaCl2	0.01	43.1	25.237	0.030
CaCl2	0.5	33.9	Na-Ph + NaCl	0.02	43.3	15.797	0.001
K-Acetate	0.5	34.0	Na-Ph + CaCl2	0.02	43.7	14.871	0.209
NaCl	2.0	32.6	K-Ph + NaCl	0.02	40.9	27.239	5.795
CaCl2	2.0	59.1	K-Ph + CaCl2	0.02	46.7	451.108	11.504
K-Acetate	2.0	28.4	Na-Ph + NaCl	0.03	38.2	89.376	26.365
NaCl	3.5	31.6	Na-Ph + CaCl2	0.03	41.0	38.572	5.382
CaCl2	3.5	45.6	K-Ph + NaCl	0.03	46.3	59.979	9.258
K-Acetate	3.5	29.0	K-Ph + CaCl2	0.03	46.3	78.966	9.050
CMA	0.05	39.4	Na-Ph + NaCl	0.04	39.6	2.544	13.447
CMA	0.1	39.7	Na-Ph + CaCl2	0.04	43.8	3.272	0.290
CMA	0.2	41.8	K-Ph + NaCl	0.04	47.5	15.342	17.357
CMA	0.5	40.9	K-Ph + CaCl2	0.04	46.3	9.139	8.968
Na-Ph + NaCl	0.001	40.6	Na-Ph + NaCl	0.05	43.4	7.517	0.005
K-Ph + NaCl	0.001	39.0	Na-Ph + CaCl2	0.05	45.0	1.252	2.793
Ca-Ph + NaCl	0.001	40.6	K-Ph + NaCl	0.05	47.6	7.427	18.698
K-Ace + NaCl	0.001	39.2	K-Ph + CaCl2	0.05	41.7	1.972	2.522
Na-Ph + NaCl	0.005	41.9	Ca-Ph + CaCl2	0.01	43.5	16.066	0.040
K-Ph + NaCl	0.005	36.9	Ca-Ph + CaCl2	0.05	38.0	0.821	27.884
Ca-Ph + NaCl	0.005	35.3	Ca-Ph + CaCl2	0.1	43.8	6.398	0.251
K-Ace + NaCl	0.005	35.2	Ca-Ph + CaCl2	0.2	42.8	6.962	0.257
Na-Ph + NaCl	0.01	44.6	Ca-Ph + CaCl2	0.4	42.4	45.789	0.765
K-Ph + NaCl	0.01	37.7	CMA + NaCl	0.001	43.2	0.019	0.003
Ca-Ph + NaCl	0.01	37.6	CMA + NaCl	0.005	47.4	0.044	16.997
K-Ace + NaCl	0.01	43.7	CMA + NaCl	0.01	44.2	34.533	0.763
Na-Ph + NaCl	0.05	41.9	CMA + NaCl	0.05	45.3	16.714	3.957
K-Ph + NaCl	0.05	39.1	Na-Ph Pretreat		45.9	1.647	6.995
Ca-Ph + NaCl	0.05	40.1	K-Ph Pretreat		39.6	4.982	13.668
K-Ace + NaCl	0.05	31.6	Ca-Ph Pretreat		38.8	39.086	19.980
Water F/T		35.3	No Pretreat		47.5	6.252	17.697
No F/T		33.8	Water F/T		40.1	16.642	9.860
Initial		30.0	Initial		37.4	62.266	34.631
			No F/T		38.4		23.913
			Moulded Cubes		50.5		52.294
	Sum(X1)	1324.6		Sum(X2)	1601.6	1111.2	413.8
	Count(X1)	35		Count(X2)	37		
	Avg(X1)	37.8		Avg(X2)	43.3		

STUDENT T TEST FOR COMPRESSIVE STRENGTH OF CUBES

F Test Check for Variance

F = 2.84
v1 = 34
v2 = 36
Sign. 5% = 3.52
Sign. 1% = 2.25
Therefore variance difference not significant above 5%

t Test for Group Means

t = 4.946
Deg. Free. = 70
Sign. 1% = 2.653
Sign. 0.1% = 3.446
Therefore group mean difference significant below 0.1%

Paired Mean t Test Between Stage 1 and 2 Cube Strength Values

Stage 1 Salt Type	Salt Molality (M)	X1 Average Strength (MPa)	Stage 2 Salt Type	Salt Molality (M)	X2 Average Strength (MPa)	Y (X2-X1)	$(Y-\bar{Y})^2$
NaCl	0.5	32.8	No Pretreat		47.5	14.7	76.0
Na-Ph + NaCl	0.01	44.6	Na-Ph + NaCl	0.01	39.8	-4.8	115.9
K-Ph + NaCl	0.01	37.7	K-Ph + NaCl	0.01	48.7	11.0	25.3
Na-Ph + NaCl	0.05	41.9	Na-Ph + NaCl	0.05	43.4	1.4	20.5
K-Ph + NaCl	0.05	39.1	K-Ph + NaCl	0.05	47.6	8.5	6.4
Water F/T		35.3	Water F/T		40.1	4.8	1.3
No F/T		33.8	No F/T		38.4	4.6	1.7
Initial		30.0	Initial		37.4	7.4	2.2
					Sum(Y) =	47.6	249.5
					Count(Y)=	8	

t Test for Paired Means

t = 2.821
Deg. Free. = 7
Sign. 5% = 2.365
Sign. 1% = 3.499
Therefore paired mean difference for mortar mix was significant below 5%
but not significant above 1%

STUDENT T TEST FOR COMPRESSIVE STRENGTH OF CUBES

Paired Mean t Test Between NaCl and CaCl2 Cube (Stage 2) Strength Values

NaCl Mixture Salt Type	Salt Molality (M)	X1 Average Strength (MPa)	CaCl2 Mixture Salt Type	Salt Molality (M)	X2 Average Strength (MPa)	Y (X2-X1)	$(Y-Y)^2$
Na-Ph + NaCl	0.01	39.8	Na-Ph + CaCl2	0.01	40.0	0.2	0.0
K-Ph + NaCl	0.01	48.7	K-Ph + CaCl2	0.01	43.1	-5.6	33.8
Na-Ph + NaCl	0.02	43.3	Na-Ph + CaCl2	0.02	43.7	0.4	0.0
K-Ph + NaCl	0.02	40.9	K-Ph + CaCl2	0.02	46.7	5.8	31.0
Na-Ph + NaCl	0.03	38.2	Na-Ph + CaCl2	0.03	41.0	2.8	6.7
K-Ph + NaCl	0.03	46.3	K-Ph + CaCl2	0.03	46.3	-0.0	0.1
Na-Ph + NaCl	0.04	39.6	Na-Ph + CaCl2	0.04	43.8	4.2	15.8
K-Ph + NaCl	0.04	47.5	K-Ph + CaCl2	0.04	46.3	-1.2	2.0
Na-Ph + NaCl	0.05	43.4	Na-Ph + CaCl2	0.05	45.0	1.6	1.9
K-Ph + NaCl	0.05	47.6	K-Ph + CaCl2	0.05	41.7	-5.9	37.8

Sum(Y) = 2.4 128.9
Count(Y)= 10

t Test for Paired Means

t = 0.197
Deg. Free. = 9
Sign. 10% = 1.833
Sign. 5% = 2.262
Therefore paired mean difference for chloride type was not significant above 10%

APPENDIX G

Metal Bar Corrosion Observations

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

Note: Solution abbreviations used:

K-Ace = potassium acetate
CMA = calcium magnesium acetate
Na-Ph = sodium phosphate/NaCl mixture
K-Ph = potassium phosphate/NaCl mixture
Ca-Ph = calcium phosphate/NaCl mixture
K-Na = potassium acetate/NaCl mixture
Control = deionized-distilled water
Air = bar not exposed to a solution

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

	Feb. 28 (dry - 0 days)			Mar. 6 (7 days)					
							Observations		
Salt Type	Black Bar	Red Bar	Blue Bar	Black Bar	Red Bar	Blue Bar	Salt Deposits	Bar Corrosion	Solution Colour
0.2M NaCl	12.21	12.13	12.13	12.18	12.09	12.09	yes	below liquid	orange
0.5M NaCl	12.14	12.05	12.09	12.10	12.01	12.05	yes	below liquid	orange
2.0M NaCl	12.12	12.09	12.25	12.09	12.07	12.22	abundant	below liquid	orange
3.5M NaCl	12.18	12.13	12.08	12.15	12.10	12.05	yes		orange
0.2M CaCl2	12.13	12.16	12.18	12.10	12.13	12.16		above & below liquid	orange
0.5M CaCl2	12.16	12.17	12.17	12.13	12.14	12.14		above & below liquid	orange
2.0M CaCl2	12.22	12.03	12.15	12.20	12.01	12.13		above & below liquid	orange
3.5M CaCl2	12.14	12.16	12.18	12.12	12.14	12.16		above & below liquid	orange
0.2M K-Ace	12.11	12.20	12.20	12.10	12.19	12.19			colourless
0.5M K-Ace	12.11	12.08	12.20	12.10	12.07	12.19			colourless
2.0M K-Ace	12.07	12.12	12.11	12.06	12.11	12.10			colourless
3.5M K-Ace	12.13	12.03	12.15	12.12	12.02	12.14			colourless
0.05M CMA	12.14	12.21	12.11	12.13	12.20	12.09			slightly cloudy
0.1M CMA	12.06	12.17	12.19	12.05	12.16	12.18	minor		slightly cloudy
0.2M CMA	12.13	12.09	12.15	12.12	12.08	12.14	minor		slightly cloudy
0.5M CMA	12.19	12.07	11.98	12.18	12.06	11.98	yes		slightly cloudy
0.001M Na-Ph	12.07	12.15	12.10	12.05	12.13	12.08	minor	above & below liquid	orange
0.005M Na-Ph	12.06	12.18	12.15	12.04	12.17	12.14	minor	below liquid	light yellow
0.01M Na-Ph	12.03	12.22	12.10	12.02	12.21	12.08	minor	below liquid	light yellow
0.05M Na-Ph	12.03	12.09	12.07	12.02	12.08	12.05	yes	above & below liquid	slightly cloudy
0.001M K-Ph	12.08	12.08	12.09	12.05	12.06	12.07	yes	below liquid	orange
0.005M K-Ph	12.10	12.08	12.23	12.09	12.07	12.22		below liquid	light yellow
0.01M K-Ph	12.11	12.07	12.14	12.10	12.06	12.12		below liquid	light yellow
0.05M K-Ph	12.01	12.11	12.19	12.01	12.10	12.19	yes	above & below liquid	light yellow
0.001M Ca-Ph	12.18	12.13	12.13	12.15	12.10	12.09	yes	below liquid	orange
0.005M Ca-Ph	12.01	12.19	12.18	12.00	12.18	12.17	minor	above & below liquid	colourless
0.01M Ca-Ph	12.21	12.04	12.11	12.20	12.03	12.09	minor	below liquid	colourless
0.05M Ca-Ph	12.11	12.03	12.15	12.10	12.02	12.14	minor	below liquid	colourless
0.001M K-Na	12.14	12.16	12.15	12.10	12.13	12.12		above & below liquid	orange
0.005M K-Na	12.12	12.12	12.09	12.08	12.09	12.06	minor	below liquid	orange
0.01M K-Na	12.11	12.07	12.21	12.08	12.04	12.17		below liquid	orange
0.05M K-Na	12.06	12.05	12.05	12.01	12.00	12.02		below liquid	orange
Control	12.10	12.06	12.12	12.09	12.04	12.10		below liquid	orange
Air	12.18			12.18					

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

Mar. 13 (14 days)

	Observations		
	Bar		Solution
Salt Type	Salt Deposits	Corrosion	Colour
0.2M NaCl	yes	below liquid	orange
0.5M NaCl	yes	above & below liquid	orange
2.0M NaCl	yes	above & below liquid	orange
3.5M NaCl	abundant	below liquid	orange
0.2M CaCl2		above & below liquid	orange
0.5M CaCl2		above & below liquid	orange
2.0M CaCl2		above & below liquid	orange
3.5M CaCl2		above & below liquid	orange
0.2M K-Ace			colourless
0.5M K-Ace			colourless
2.0M K-Ace			colourless
3.5M K-Ace			colourless
0.05M CMA			slight cloudy
0.1M CMA	minor		slight cloudy
0.2M CMA	minor		slight cloudy
0.5M CMA	yes		slight cloudy
0.001M Na-Ph	minor	above & below liquid	orange
0.005M Na-Ph	minor	below liquid	light yellow
0.01M Na-Ph	minor	above & below liquid	light yellow
0.05M Na-Ph	minor	above & below liquid	slight cloudy
0.001M K-Ph	minor	above & below liquid	orange
0.005M K-Ph	minor	above & below liquid	light yellow
0.01M K-Ph	minor	above & below liquid	light yellow
0.05M K-Ph	yes	above & below liquid	slight cloudy
0.001M Ca-Ph	minor	below liquid	orange
0.005M Ca-Ph	minor	above & below liquid	light yellow
0.01M Ca-Ph	minor	below liquid	light yellow
0.05M Ca-Ph	yes	above & below liquid	light yellow
0.001M K-Na	yes	above & below liquid	orange
0.005M K-Na	minor	above & below liquid	orange
0.01M K-Na	minor	above & below liquid	orange
0.05M K-Na	minor	above & below liquid	orange
Control		below liquid	orange
Air			

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

Mar. 20 (21 days)

Salt Type	Black Bar	Red Bar	Blue Bar	Observations Salt Deposits	Bar Corrosion	Solution Colour
0.2M NaCl	12.13	12.04	12.04	yes	above & below liquid	orange
0.5M NaCl	12.06	11.98	12.02	yes	above & below liquid	orange
2.0M NaCl	12.08	12.06	12.21	yes	above & below liquid	orange
3.5M NaCl	12.14	12.10	12.05	abundant	above & below liquid	orange
0.2M CaCl2	12.09	12.12	12.15		above & below liquid	orange
0.5M CaCl2	12.12	12.14	12.13		above & below liquid	orange
2.0M CaCl2	12.20	12.02	12.13		above & below liquid	orange
3.5M CaCl2	12.14	12.16	12.18		above & below liquid	orange
0.2M K-Ace	12.07	12.16	12.16		below liquid	orange
0.5M K-Ace	12.10	12.08	12.19			colourless
2.0M K-Ace	12.06	12.11	12.11			colourless
3.5M K-Ace	12.13	12.03	12.15			colourless
0.05M CMA	12.11	12.18	12.09	minor	below liquid	orange
0.1M CMA	12.05	12.18	12.19	minor		slight cloudy
0.2M CMA	12.12	12.08	12.14	yes		slight cloudy
0.5M CMA	12.19	12.07	11.99	yes		slight cloudy
0.001M Na-Ph	12.03	12.10	12.07	minor	above & below liquid	orange
0.005M Na-Ph	12.04	12.17	12.14	minor	above & below liquid	light yellow
0.01M Na-Ph	12.02	12.21	12.09	minor	above & below liquid	light yellow
0.05M Na-Ph	12.02	12.09	12.06	yes	above & below liquid	colourless
0.001M K-Ph	12.03	12.03	12.06	minor	above & below liquid	orange
0.005M K-Ph	12.09	12.07	12.22	minor	above & below liquid	light yellow
0.01M K-Ph	12.10	12.06	12.12	yes	above & below liquid	light yellow
0.05M K-Ph	12.01	12.12	12.19	yes	above & below liquid	light yellow
0.001M Ca-Ph	12.12	12.08	12.07	yes	above & below liquid	orange
0.005M Ca-Ph	12.01	12.19	12.18	minor	above & below liquid	light yellow
0.01M Ca-Ph	12.21	12.04	12.10	minor	above & below liquid	light yellow
0.05M Ca-Ph	12.12	12.03	12.16	yes	above & below liquid	light yellow
0.001M K-Na	12.07	12.11	12.10	minor	above & below liquid	orange
0.005M K-Na	12.06	12.06	12.03		above & below liquid	orange
0.01M K-Na	12.05	12.01	12.13		above & below liquid	orange
0.05M K-Na	11.97	11.96	11.97		above & below liquid	orange
Control	12.05	12.01	12.07		below liquid	orange
Air	12.18					

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

	Mar. 27 (28 days)			Apr. 3 (35 days)		
	Observations			Observations		
	Bar		Solution	Bar		Solution
Salt Type	Salt Deposits	Corrosion	Colour	Salt Deposits	Corrosion	Colour
0.2M NaCl		above & below liquid	orange	yes	above & below liquid	orange
0.5M NaCl		above & below liquid	orange	yes	above & below liquid	orange
2.0M NaCl	minor	above & below liquid	orange	yes	above & below liquid	orange
3.5M NaCl	abundant	above & below liquid	orange	abundant	above & below liquid	orange
0.2M CaCl2		above & below liquid	orange		above & below liquid	orange
0.5M CaCl2		above & below liquid	orange		above & below liquid	orange
2.0M CaCl2		above & below liquid	orange		above & below liquid	orange
3.5M CaCl2		above & below liquid	orange		above & below liquid	light orange
0.2M K-Ace		above liquid	colourless		above liquid	colourless
0.5M K-Ace		above liquid	colourless			colourless
2.0M K-Ace			colourless			colourless
3.5M K-Ace			colourless			colourless
0.05M CMA	minor	below liquid	orange	minor	below liquid	orange
0.1M CMA	minor		cloudy	minor		cloudy
0.2M CMA	minor		cloudy	minor		cloudy
0.5M CMA	yes		cloudy	yes		cloudy
0.001M Na-Ph	minor	above & below liquid	orange	minor	above & below liquid	orange
0.005M Na-Ph	minor	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.01M Na-Ph	minor	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.05M Na-Ph	yes	above & below liquid	colourless	yes	above & below liquid	colourless
0.001M K-Ph		above & below liquid	orange	minor	above & below liquid	orange
0.005M K-Ph		above & below liquid	light yellow	minor	above & below liquid	light yellow
0.01M K-Ph	yes	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.05M K-Ph	yes	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.001M Ca-Ph	yes	above & below liquid	orange		above & below liquid	orange
0.005M Ca-Ph		above & below liquid	light yellow	minor	above & below liquid	light yellow
0.01M Ca-Ph	yes	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.05M Ca-Ph	yes	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.001M K-Na	minor	above & below liquid	orange	minor	above & below liquid	orange
0.005M K-Na		above & below liquid	orange		above & below liquid	orange
0.01M K-Na		above & below liquid	orange		above & below liquid	orange
0.05M K-Na		above & below liquid	orange		above & below liquid	orange
Control		below liquid	orange		below liquid	orange
Air						

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

Apr. 10 (42 days)

Observations

Salt Type	Black Bar	Red Bar	Blue Bar	Salt Deposits	Bar Corrosion	Solution Colour
0.2M NaCl	12.04	11.97	11.96	yes	above & below liquid	orange
0.5M NaCl	12.02	11.92	11.97		above & below liquid	orange
2.0M NaCl	12.05	12.02	12.17	yes	above & below liquid	orange
3.5M NaCl	12.12	12.08	12.03	abudant	above & below liquid	orange
0.2M CaCl2	12.04	12.08	12.10		above & below liquid	orange
0.5M CaCl2	12.09	12.10	12.10		above & below liquid	orange
2.0M CaCl2	12.19	12.00	12.12		above & below liquid	orange
3.5M CaCl2	12.14	12.15	12.18		above & below liquid	light orange
0.2M K-Ace	12.06	12.16	12.15		above liquid	colourless
0.5M K-Ace	12.10	12.08	12.19		above liquid	colourless
2.0M K-Ace	12.06	12.11	12.11			colourless
3.5M K-Ace	12.12	12.03	12.15			colourless
0.05M CMA	12.08	12.15	12.06	minor	below liquid	orange
0.1M CMA	12.05	12.17	12.19	minor	above liquid	cloudy
0.2M CMA	12.13	12.09	12.15	minor		cloudy
0.5M CMA	12.19	12.07	11.98	minor		cloudy
0.001M Na-Ph	12.01	12.08	12.04	yes	above & below liquid	orange
0.005M Na-Ph	12.06	12.17	12.14	yes	above & below liquid	light yellow
0.01M Na-Ph	12.03	12.22	12.10	yes	above & below liquid	light yellow
0.05M Na-Ph	12.03	12.10	12.08	yes	above & below liquid	colourless
0.001M K-Ph	12.03	12.03	12.04	yes	above & below liquid	orange
0.005M K-Ph	12.10	12.07	12.22	yes	above & below liquid	light yellow
0.01M K-Ph	12.12	12.08	12.14	yes	above & below liquid	light yellow
0.05M K-Ph	12.01	12.11	12.19	minor	above & below liquid	light yellow
0.001M Ca-Ph	12.08	12.03	12.02	minor	above & below liquid	orange
0.005M Ca-Ph	12.01	12.18	12.17	yes	above & below liquid	light yellow
0.01M Ca-Ph	12.21	12.04	12.10	yes	above & below liquid	light yellow
0.05M Ca-Ph	12.12	12.04	12.15	yes	above & below liquid	light yellow
0.001M K-Na	12.03	12.07	12.07	minor	above & below liquid	orange
0.005M K-Na	12.00	12.02	11.98		above & below liquid	orange
0.01M K-Na	11.99	11.96	12.09	minor	above & below liquid	orange
0.05M K-Na	11.89	11.89	11.88		above & below liquid	orange
Control	12.00	11.95	12.01		below liquid	orange
Air	12.18					

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

	Apr. 17 (49 days) Observations			Apr. 24 (56 days) Observations		
Salt Type	Bar Salt Deposits	Bar Corrosion	Solution Colour	Bar Salt Deposits	Bar Corrosion	Solution Colour
0.2M NaCl	minor	above & below liquid	orange	minor	above & below liquid	orange
0.5M NaCl	yes	above & below liquid	orange	minor	above & below liquid	orange
2.0M NaCl	yes	above & below liquid	orange	yes	above & below liquid	orange
3.5M NaCl	abundant	above & below liquid	orange	yes	above & below liquid	orange
0.2M CaCl2		above & below liquid	orange		above & below liquid	orange
0.5M CaCl2		above & below liquid	orange		above & below liquid	orange
2.0M CaCl2		above & below liquid	orange		above & below liquid	orange
3.5M CaCl2		above & below liquid	light orange		above & below liquid	light orange
0.2M K-Ace		above liquid	colourless		above liquid	colourless
0.5M K-Ace		above liquid	colourless		above liquid	colourless
2.0M K-Ace			colourless			colourless
3.5M K-Ace			colourless			colourless
0.05M CMA		below liquid	orange		below liquid	orange
0.1M CMA		above liquid	cloudy		above liquid	slightly cloudy
0.2M CMA	minor		cloudy			slightly cloudy
0.5M CMA	minor		cloudy	minor		slightly cloudy
0.001M Na-Ph		above & below liquid	orange	minor	above & below liquid	orange
0.005M Na-Ph	yes	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.01M Na-Ph	yes	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.05M Na-Ph	yes	above & below liquid	colourless	minor	above & below liquid	colourless
0.001M K-Ph	minor	above & below liquid	orange		above & below liquid	orange
0.005M K-Ph	minor	above & below liquid	light yellow		above & below liquid	light yellow
0.01M K-Ph	minor	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.05M K-Ph	minor	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.001M Ca-Ph	yes	above & below liquid	orange	yes	above & below liquid	orange
0.005M Ca-Ph	yes	above & below liquid	light yellow	yes	above & below liquid	light yellow
0.01M Ca-Ph	yes	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.05M Ca-Ph	yes	above & below liquid	light yellow	minor	above & below liquid	light yellow
0.001M K-Na		above & below liquid	orange	minor	above & below liquid	orange
0.005M K-Na	minor	above & below liquid	orange	minor	above & below liquid	orange
0.01M K-Na		above & below liquid	orange		above & below liquid	orange
0.05M K-Na		above & below liquid	orange		above & below liquid	orange
Control		below liquid	orange		below liquid	orange
Air						

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

May 1 (63 days)

Observations

Salt Type	Black Bar	Red Bar	Blue Bar	Salt Deposits	Bar Corrosion	Solution Colour
0.2M NaCl	11.98	11.92	11.91	minor	above & below liquid	orange
0.5M NaCl	11.97	11.89	11.93	minor	above & below liquid	orange
2.0M NaCl	12.14	11.99	12.01	yes	above & below liquid	orange
3.5M NaCl	12.10	12.05	12.00	yes	above & below liquid	orange
0.2M CaCl2	12.00	12.04	12.07		above & below liquid	orange
0.5M CaCl2	12.05	12.07	12.07		above & below liquid	orange
2.0M CaCl2	12.18	11.99	12.11		above & below liquid	orange
3.5M CaCl2	12.15	12.16	12.18		above & below liquid	light orange
0.2M K-Ace	12.06	12.15	12.15		above liquid	colourless
0.5M K-Ace	12.10	12.07	12.18		above liquid	colourless
2.0M K-Ace	12.06	12.10	12.10			colourless
3.5M K-Ace	12.12	12.02	12.15			colourless
0.05M CMA	12.05	12.12	12.04	minor	below liquid	orange
0.1M CMA	12.05	12.17	12.18		above liquid	slightly cloudy
0.2M CMA	12.13	12.08	12.15			cloudy orange
0.5M CMA	12.19	12.06	11.98	minor	below liquid	cloudy orange
0.001M Na-Ph	11.97	12.04	12.00	minor	above & below liquid	orange
0.005M Na-Ph	12.04	12.15	12.13	minor	above & below liquid	light yellow
0.01M Na-Ph	12.02	12.21	12.08	yes	above & below liquid	light yellow
0.05M Na-Ph	12.03	12.10	12.07	yes	above & below liquid	colourless
0.001M K-Ph	12.01	12.01	12.02	minor	above & below liquid	orange
0.005M K-Ph	12.09	12.07	12.21	minor	above & below liquid	light yellow
0.01M K-Ph	12.11	12.07	12.13	minor	above & below liquid	light yellow
0.05M K-Ph	12.00	12.10	12.18	minor	above & below liquid	light yellow
0.001M Ca-Ph	12.03	11.97	11.96	minor	above & below liquid	orange
0.005M Ca-Ph	12.00	12.17	12.16	yes	above & below liquid	light yellow
0.01M Ca-Ph	12.20	12.03	12.09	yes	above & below liquid	light yellow
0.05M Ca-Ph	12.11	12.03	12.15	yes	above & below liquid	light yellow
0.001M K-Na	11.99	12.04	12.03	minor	above & below liquid	orange
0.005M K-Na	11.96	11.97	11.94	minor	above & below liquid	orange
0.01M K-Na	11.95	11.93	12.05	minor	above & below liquid	orange
0.05M K-Na	11.82	11.82	11.81		above & below liquid	orange
Control	11.95	11.90	11.95		below liquid	orange
Air	12.18					

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

	Mar. 6 (7 days) Weight Change (%)				Mar. 20 (21 days) Weight Change (%)			
Salt Type	Black Bar	Red Bar	Blue Bar	Avg. Wt Chg	Black Bar	Red Bar	Blue Bar	Avg. Wt Chg
0.2M NaCl	-0.25	-0.33	-0.33	-0.30	-0.66	-0.74	-0.74	-0.71
0.5M NaCl	-0.33	-0.33	-0.33	-0.33	-0.66	-0.58	-0.58	-0.61
2.0M NaCl	-0.25	-0.17	-0.24	-0.22	-0.33	-0.25	-0.33	-0.30
3.5M NaCl	-0.25	-0.25	-0.25	-0.25	-0.33	-0.25	-0.25	-0.27
0.2M CaCl2	-0.25	-0.25	-0.16	-0.22	-0.33	-0.33	-0.25	-0.30
0.5M CaCl2	-0.25	-0.25	-0.25	-0.25	-0.33	-0.25	-0.33	-0.30
2.0M CaCl2	-0.16	-0.17	-0.16	-0.16	-0.16	-0.08	-0.16	-0.14
3.5M CaCl2	-0.16	-0.16	-0.16	-0.16	0.00	0.00	0.00	0.00
0.2M K-Ace	-0.08	-0.08	-0.08	-0.08	-0.33	-0.33	-0.33	-0.33
0.5M K-Ace	-0.08	-0.08	-0.08	-0.08	-0.08	0.00	-0.08	-0.05
2.0M K-Ace	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	0.00	-0.06
3.5M K-Ace	-0.08	-0.08	-0.08	-0.08	0.00	0.00	0.00	0.00
0.05M CMA	-0.08	-0.08	-0.17	-0.11	-0.25	-0.25	-0.17	-0.22
0.1M CMA	-0.08	-0.08	-0.08	-0.08	-0.08	0.08	0.00	-0.00
0.2M CMA	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
0.5M CMA	-0.08	-0.08	0.00	-0.05	0.00	0.00	0.08	0.03
0.001M Na-Ph	-0.17	-0.16	-0.17	-0.17	-0.33	-0.41	-0.25	-0.33
0.005M Na-Ph	-0.17	-0.08	-0.08	-0.11	-0.17	-0.08	-0.08	-0.11
0.01M Na-Ph	-0.08	-0.08	-0.17	-0.11	-0.08	-0.08	-0.08	-0.08
0.05M Na-Ph	-0.08	-0.08	-0.17	-0.11	-0.08	0.00	-0.08	-0.06
0.001M K-Ph	-0.25	-0.17	-0.17	-0.19	-0.41	-0.41	-0.25	-0.36
0.005M K-Ph	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
0.01M K-Ph	-0.08	-0.08	-0.16	-0.11	-0.08	-0.08	-0.16	-0.11
0.05M K-Ph	0.00	-0.08	0.00	-0.03	0.00	0.08	0.00	0.03
0.001M Ca-Ph	-0.25	-0.25	-0.33	-0.27	-0.49	-0.41	-0.49	-0.47
0.005M Ca-Ph	-0.08	-0.08	-0.08	-0.08	0.00	0.00	0.00	0.00
0.01M Ca-Ph	-0.08	-0.08	-0.17	-0.11	0.00	0.00	-0.08	-0.03
0.05M Ca-Ph	-0.08	-0.08	-0.08	-0.08	0.08	0.00	0.08	0.05
0.001M K-Na	-0.33	-0.25	-0.25	-0.27	-0.58	-0.41	-0.41	-0.47
0.005M K-Na	-0.33	-0.25	-0.25	-0.28	-0.50	-0.50	-0.50	-0.50
0.01M K-Na	-0.25	-0.25	-0.33	-0.27	-0.50	-0.50	-0.66	-0.55
0.05M K-Na	-0.41	-0.41	-0.25	-0.36	-0.75	-0.75	-0.66	-0.72
Control	-0.08	-0.17	-0.17	-0.14	-0.41	-0.41	-0.41	-0.41
Air	0.00			0.00	0.00			0.00

METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

	Apr. 10 (42 days)				May 1 (63 days)			
	Weight Change (%)				Weight Change (%)			
Salt Type	Black Bar	Red Bar	Blue Bar	Avg. Wt Chg	Black Bar	Red Bar	Blue Bar	Avg. Wt Chg
0.2M NaCl	-1.39	-1.32	-1.40	-1.37	-1.88	-1.73	-1.81	-1.81
0.5M NaCl	-0.99	-1.08	-0.99	-1.02	-1.40	-1.33	-1.32	-1.35
2.0M NaCl	-0.58	-0.58	-0.65	-0.60	0.17	-0.83	-1.96	-0.87
3.5M NaCl	-0.49	-0.41	-0.41	-0.44	-0.66	-0.66	-0.66	-0.66
0.2M CaCl2	-0.74	-0.66	-0.66	-0.69	-1.07	-0.99	-0.90	-0.99
0.5M CaCl2	-0.58	-0.58	-0.58	-0.58	-0.90	-0.82	-0.82	-0.85
2.0M CaCl2	-0.25	-0.25	-0.25	-0.25	-0.33	-0.33	-0.33	-0.33
3.5M CaCl2	0.00	-0.08	0.00	-0.03	0.08	0.00	0.00	0.03
0.2M K-Ace	-0.41	-0.33	-0.41	-0.38	-0.41	-0.41	-0.41	-0.41
0.5M K-Ace	-0.08	0.00	-0.08	-0.05	-0.08	-0.08	-0.16	-0.11
2.0M K-Ace	-0.08	-0.08	0.00	-0.06	-0.08	-0.17	-0.08	-0.11
3.5M K-Ace	-0.08	0.00	0.00	-0.03	-0.08	-0.08	0.00	-0.06
0.05M CMA	-0.49	-0.49	-0.41	-0.47	-0.74	-0.74	-0.58	-0.69
0.1M CMA	-0.08	0.00	0.00	-0.03	-0.08	0.00	-0.08	-0.05
0.2M CMA	0.00	0.00	0.00	0.00	0.00	-0.08	0.00	-0.03
0.5M CMA	0.00	0.00	0.00	0.00	0.00	-0.08	0.00	-0.03
0.001M Na-Ph	-0.50	-0.58	-0.50	-0.52	-0.83	-0.91	-0.83	-0.85
0.005M Na-Ph	0.00	-0.08	-0.08	-0.05	-0.17	-0.25	-0.16	-0.19
0.01M Na-Ph	0.00	0.00	0.00	0.00	-0.08	-0.08	-0.17	-0.11
0.05M Na-Ph	0.00	0.08	0.08	0.06	0.00	0.08	0.00	0.03
0.001M K-Ph	-0.41	-0.41	-0.41	-0.41	-0.58	-0.58	-0.58	-0.58
0.005M K-Ph	0.00	-0.08	-0.08	-0.05	-0.08	-0.08	-0.16	-0.11
0.01M K-Ph	0.08	0.08	0.00	0.06	0.00	0.00	-0.08	-0.03
0.05M K-Ph	0.00	0.00	0.00	0.00	-0.08	-0.08	-0.08	-0.08
0.001M Ca-Ph	-0.82	-0.82	-0.91	-0.85	-1.23	-1.32	-1.40	-1.32
0.005M Ca-Ph	0.00	-0.08	-0.08	-0.05	-0.08	-0.16	-0.16	-0.14
0.01M Ca-Ph	0.00	0.00	-0.08	-0.03	-0.08	-0.08	-0.17	-0.11
0.05M Ca-Ph	0.08	0.08	0.00	0.06	0.00	0.00	0.00	0.00
0.001M K-Na	-0.91	-0.74	-0.66	-0.77	-1.24	-0.99	-0.99	-1.07
0.005M K-Na	-0.99	-0.83	-0.91	-0.91	-1.32	-1.24	-1.24	-1.27
0.01M K-Na	-0.99	-0.91	-0.98	-0.96	-1.32	-1.16	-1.31	-1.26
0.05M K-Na	-1.41	-1.33	-1.41	-1.38	-1.99	-1.91	-1.99	-1.96
Control	-0.83	-0.91	-0.91	-0.88	-1.24	-1.33	-1.40	-1.32
Air	0.00			0.00	0.00			0.00

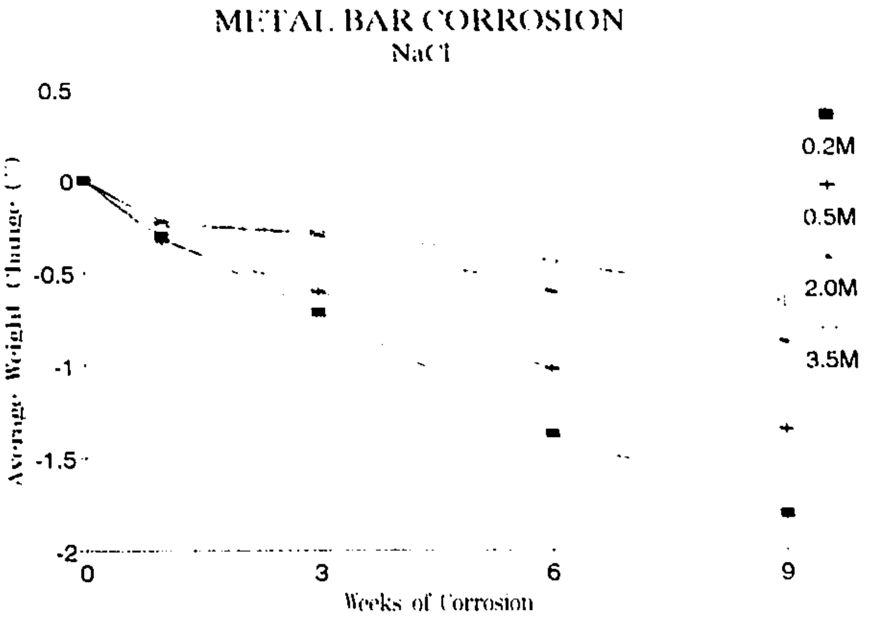
METAL BAR CORROSION OBSERVATIONS AND WEIGHTS (g)

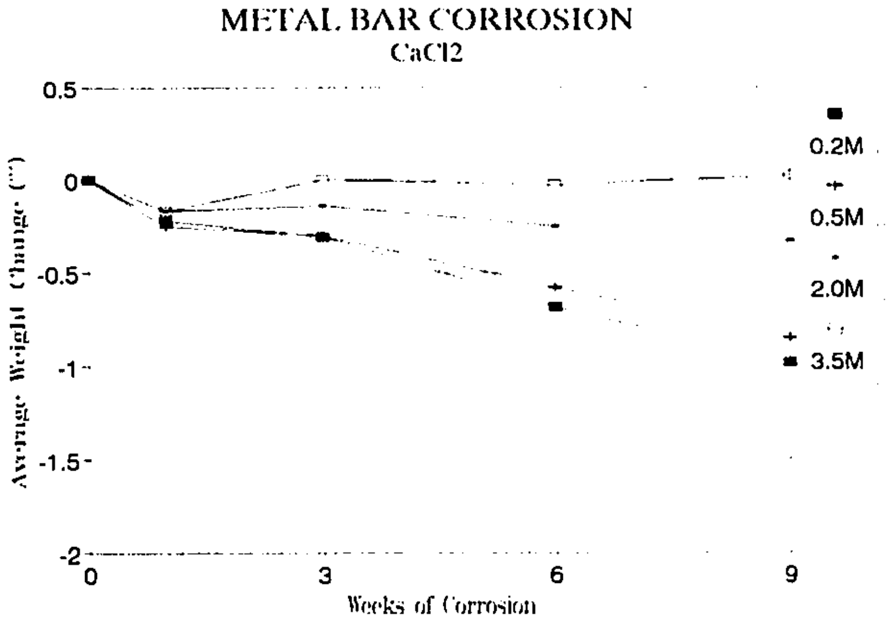
Salt Type	0 Weeks Wt Chg	1 Weeks Wt Chg	3 Weeks Wt Chg	6 Weeks Wt Chg	9 Weeks Wt Chg
0.2M NaCl	0.00	-0.30	-0.71	-1.37	-1.81
0.5M NaCl	0.00	-0.33	-0.61	-1.02	-1.35
2.0M NaCl	0.00	-0.22	-0.30	-0.60	-0.87
3.5M NaCl	0.00	-0.25	-0.27	-0.44	-0.66
0.2M CaCl2	0.00	-0.22	-0.30	-0.69	-0.99
0.5M CaCl2	0.00	-0.25	-0.30	-0.58	-0.85
2.0M CaCl2	0.00	-0.16	-0.14	-0.25	-0.33
3.5M CaCl2	0.00	-0.16	0.00	-0.03	0.03
0.2M K-Ace	0.00	-0.08	-0.33	-0.38	-0.41
0.5M K-Ace	0.00	-0.08	-0.05	-0.05	-0.11
2.0M K-Ace	0.00	-0.08	-0.06	-0.06	-0.11
3.5M K-Ace	0.00	-0.08	0.00	-0.03	-0.06
0.05M CMA	0.00	-0.11	-0.22	-0.47	-0.69
0.1M CMA	0.00	-0.08	-0.00	-0.03	-0.05
0.2M CMA	0.00	-0.08	-0.08	0.00	-0.03
0.5M CMA	0.00	-0.05	0.03	0.00	-0.03
0.001M Na-Ph	0.00	-0.17	-0.33	-0.52	-0.85
0.005M Na-Ph	0.00	-0.11	-0.11	-0.05	-0.19
0.01M Na-Ph	0.00	-0.11	-0.08	0.00	-0.11
0.05M Na-Ph	0.00	-0.11	-0.06	0.06	0.03
0.001M K-Ph	0.00	-0.19	-0.36	-0.41	-0.58
0.005M K-Ph	0.00	-0.08	-0.08	-0.05	-0.11
0.01M K-Ph	0.00	-0.11	-0.11	0.06	-0.03
0.05M K-Ph	0.00	-0.03	0.03	0.00	-0.08
0.001M Ca-Ph	0.00	-0.27	-0.47	-0.85	-1.32
0.005M Ca-Ph	0.00	-0.08	0.00	-0.05	-0.14
0.01M Ca-Ph	0.00	-0.11	-0.03	-0.03	-0.11
0.05M Ca-Ph	0.00	-0.08	0.05	0.06	0.00
0.001M K-Na	0.00	-0.27	-0.47	-0.77	-1.07
0.005M K-Na	0.00	-0.28	-0.50	-0.91	-1.27
0.01M K-Na	0.00	-0.27	-0.55	-0.96	-1.26
0.05M K-Na	0.00	-0.36	-0.72	-1.38	-1.96
Control	0.00	-0.14	-0.41	-0.88	-1.32
Air	0.00	0.00	0.00	0.00	0.00

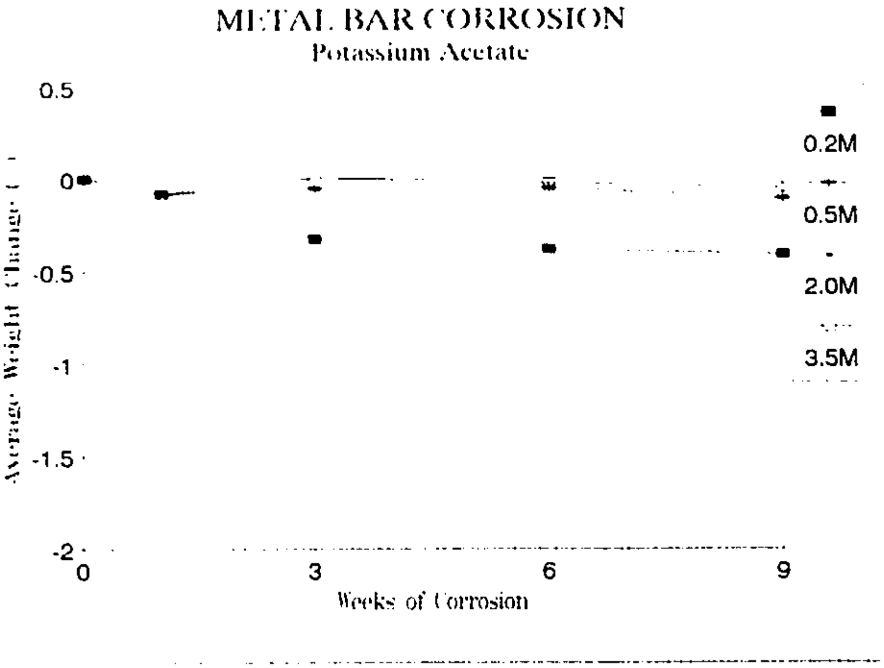
METAL BAR CORROSION WEIGHT LOSS LINEAR REGRESSION ANALYSIS

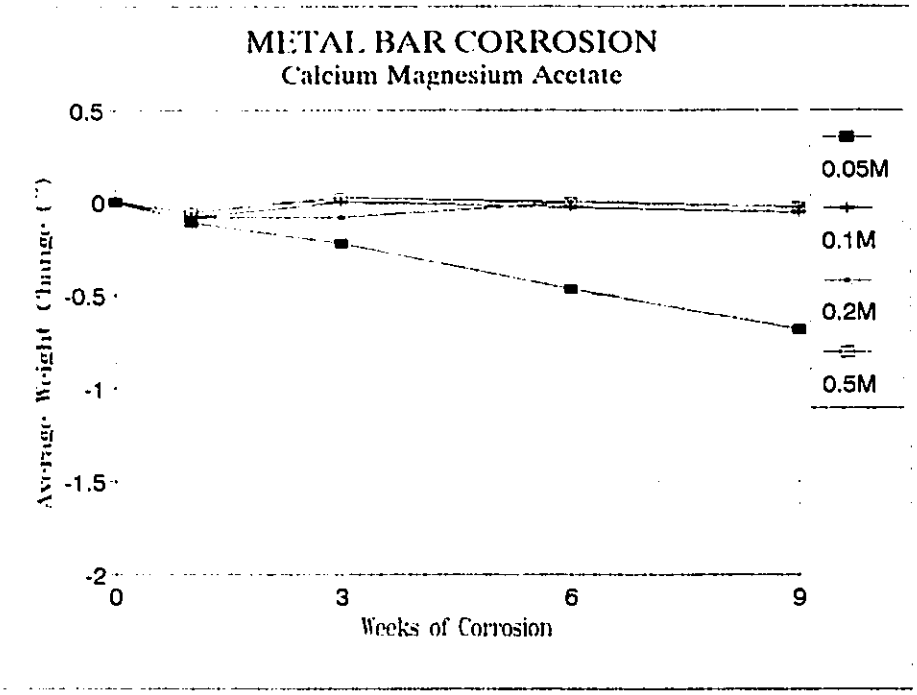
Salt / Chloride Mixture	Constant	Std Err of Y Est	R Squared	# of Observ.	Degrees of Freedom	X Coef.	Std Err of Coef.	Rank
0.05M NaH2PO4 + 0.45M NaCl	0.0595	0.0598	0.3944	5	3	-0.0113	0.0081	1
3.5M CaCl2	0.0705	0.0770	0.2324	5	3	-0.0099	0.0104	2
0.01M KH2PO4 + 0.49M NaCl	0.0645	0.0776	0.1243	5	3	-0.0068	0.0105	3
0.05M Ca(H2PO4)2*H2O + 0.45M NaCl	0.0159	0.0606	0.1366	5	3	-0.0056	0.0082	4
0.2M CMA	0.0492	0.0466	0.0619	5	3	-0.0028	0.0063	5
Air (Control)	0.0000	0.0000	1.0000	5	3	0.0000	0.0000	6
0.5M CMA	0.0101	0.0363	0.0007	5	3	0.0002	0.0049	7
0.1M CMA	0.0250	0.0403	0.0479	5	3	0.0021	0.0054	8
3.5M KC2H3O2	0.0250	0.0405	0.0476	5	3	0.0021	0.0055	9
0.01M NaH2PO4 + 0.49M NaCl	0.0468	0.0633	0.0563	5	3	0.0036	0.0085	10
0.01M Ca(H2PO4)2*H2O + 0.49M NaCl	0.0340	0.0545	0.1578	5	3	0.0055	0.0074	11
0.05M KH2PO4 + 0.45M NaCl	-0.0095	0.0384	0.3670	5	3	0.0068	0.0052	12
0.005M KH2PO4 + 0.495M NaCl	0.0385	0.0369	0.4096	5	3	0.0072	0.0050	13
0.5M KC2H3O2	0.0315	0.0340	0.4778	5	3	0.0076	0.0046	14
2.0M KC2H3O2	0.0316	0.0340	0.4790	5	3	0.0076	0.0046	15
0.005M Ca(H2PO4)2*H2O + 0.495M NaCl	0.0131	0.0481	0.4891	5	3	0.0110	0.0065	16
0.005M NaH2PO4 + 0.495M NaCl	0.0432	0.0605	0.4656	5	3	0.0132	0.0082	17
2.0M CaCl2	0.0588	0.0559	0.8472	5	3	0.0308	0.0075	18
0.2M KC2H3O2	0.0686	0.0954	0.8054	5	3	0.0454	0.0129	19
0.001M KH2PO4 + 0.499M NaCl	0.0943	0.0829	0.8945	5	3	0.0565	0.0112	20
3.5M NaCl	0.0826	0.0768	0.9261	5	3	0.0636	0.0104	21
0.05M CMA	0.0114	0.0182	0.9968	5	3	0.0749	0.0025	22
0.5M CaCl2	0.0651	0.0681	0.9673	5	3	0.0867	0.0092	23
0.001M NaH2PO4 + 0.499M NaCl	0.0373	0.0452	0.9860	5	3	0.0887	0.0061	24
2.0M NaCl	0.0518	0.0550	0.9806	5	3	0.0915	0.0074	25
0.2M CaCl2	0.0375	0.0583	0.9836	5	3	0.1056	0.0079	26
0.001M KC2H3O2 + 0.499M NaCl	0.0919	0.0725	0.9774	5	3	0.1115	0.0098	27
0.005M KC2H3O2 + 0.495M NaCl	0.0748	0.0612	0.9889	5	3	0.1353	0.0083	28
0.01M KC2H3O2 + 0.49M NaCl	0.0912	0.0788	0.9821	5	3	0.1365	0.0107	29
0.001M Ca(H2PO4)2*H2O + 0.499M NaCl	0.0562	0.0608	0.9895	5	3	0.1383	0.0082	30
0.5M NaCl	0.1168	0.0952	0.9764	5	3	0.1433	0.0129	31
Deionized-Distilled Water (Control)	-0.0106	0.0133	0.9996	5	3	0.1479	0.0018	32
0.2M NaCl	0.0756	0.0840	0.9905	5	3	0.2009	0.0113	33
0.05M KC2H3O2 + 0.45M NaCl	0.0757	0.0644	0.9950	5	3	0.2130	0.0087	34

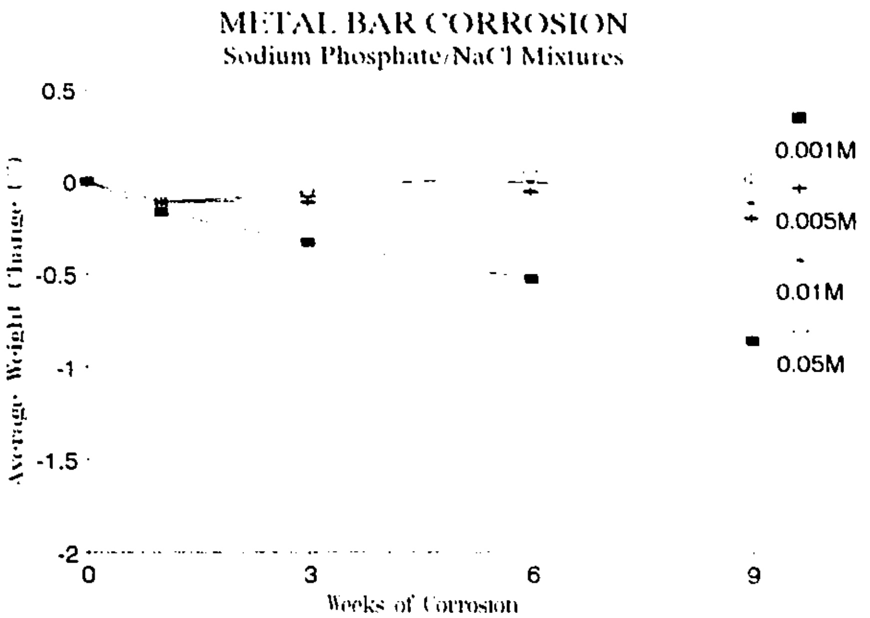
Note: 1) X Coef. = Slope of the weight loss versus time plots
2) R Squared = Correlation coefficient squared


METAL BAR CORROSION
NaCl


METAL BAR CORROSION
CaCl2

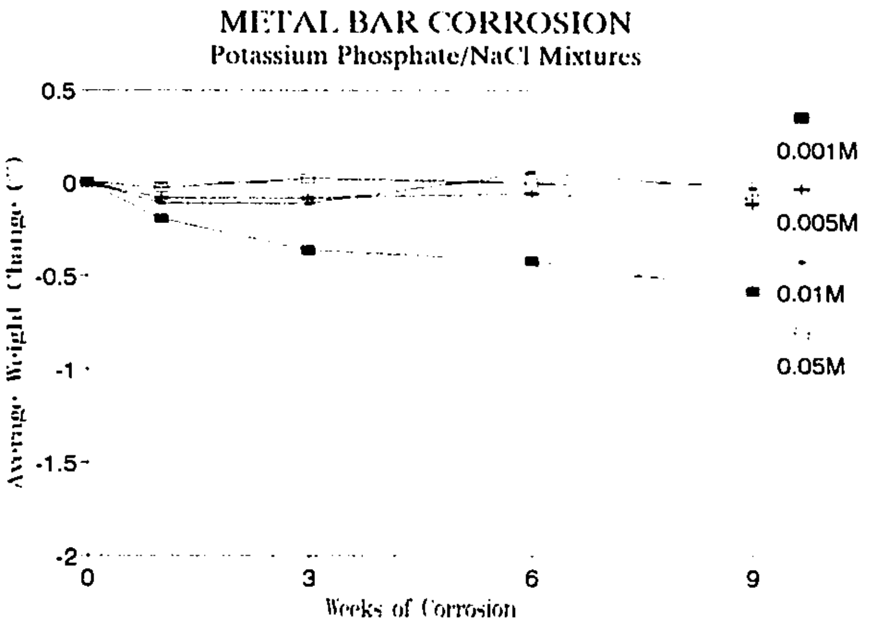

METAL BAR CORROSION
Potassium Acetate
Average Weight Change (%)
0.5
0
-0.5
-1
-1.5
-2
0
3
6
9
Weeks of Corrosion
0.2M
0.5M
2.0M
3.5M


METAL BAR CORROSION
Calcium Magnesium Acetate
Average Weight Change (%)
0.5
0
-0.5
-1
-1.5
-2
0
3
6
9
Weeks of Corrosion
0.05M
0.1M
0.2M
0.5M



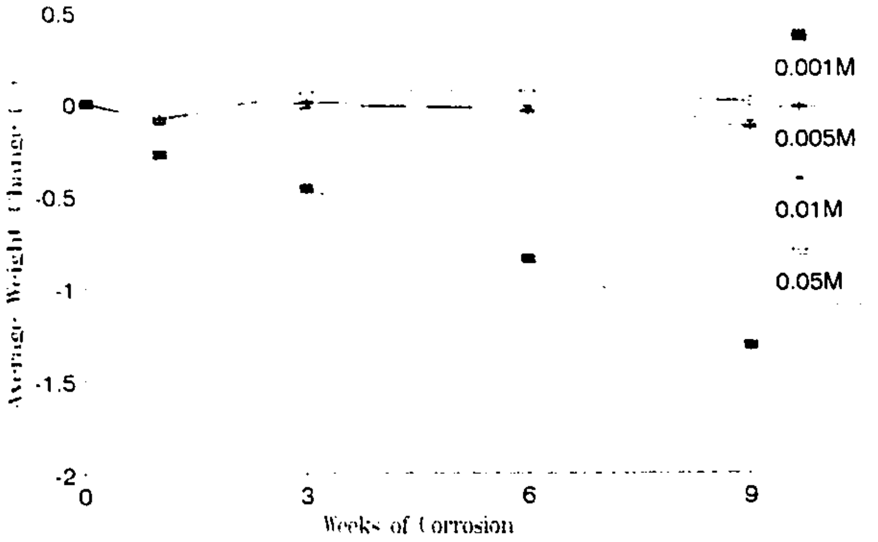
METAL BAR CORROSION

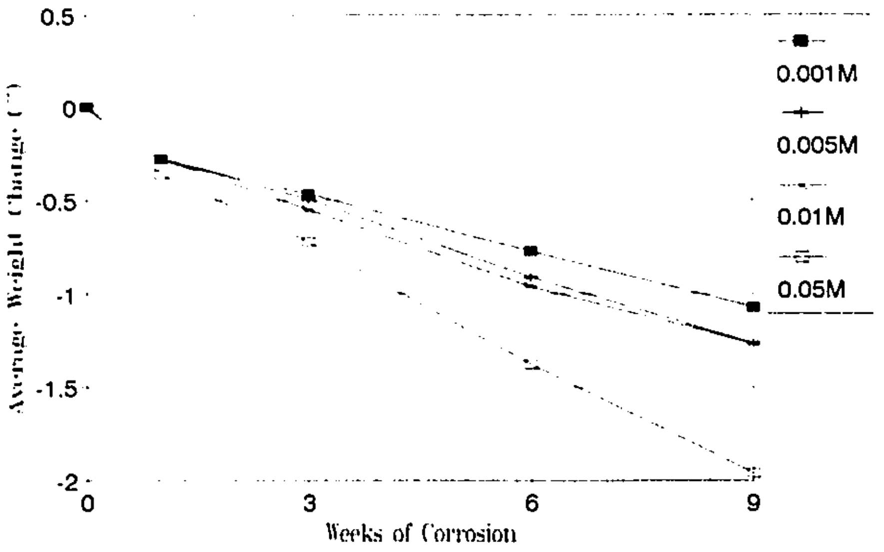
Sodium Phosphate/NaCl Mixtures

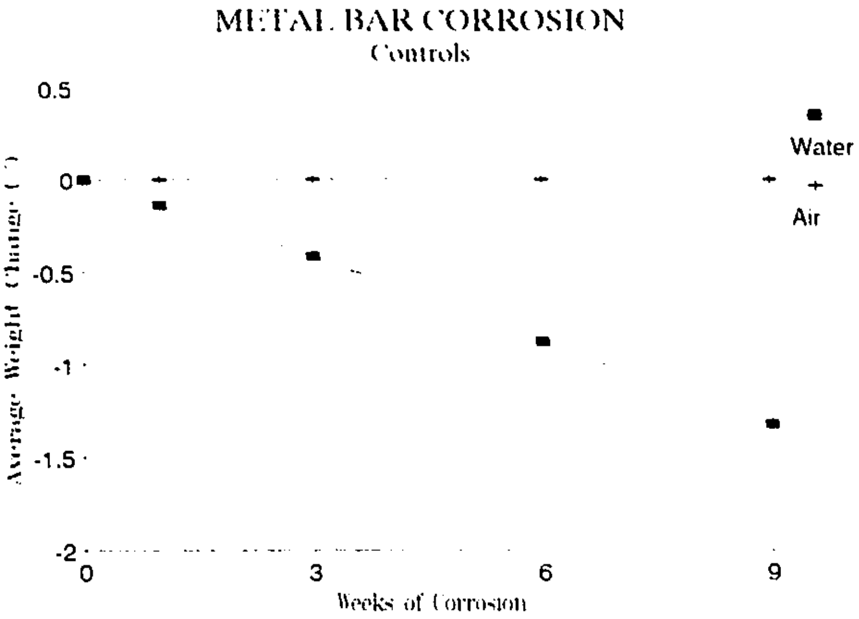


METAL BAR CORROSION

Potassium Phosphate/NaCl Mixtures


METAL BAR CORROSION
Calcium Phosphate/NaCl Mixtures


METAL BAR CORROSION
Potassium Acetate/NaCl Mixtures


METAL BAR CORROSION
Controls
0.5
0
-0.5
-1
-1.5
-2
Average Weight Change (%)
0
3
6
9
Weeks of Corrosion
Water
Air

APPENDIX H

Ice Melting Observations

ICE MELTING OBSERVATIONS

Solution: 0.2M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#35	#36	#38	#35	#36	#38		
0	49.76	50.75	48.87	0.00	0.00	0.00	0.00	0.00
30	40.00	40.07	38.28	20.56	22.06	22.73	21.78	21.78
60	36.90	36.74	34.84	27.09	28.94	30.11	28.71	28.71
90	34.54	34.40	32.30	32.06	33.77	35.57	33.80	33.80
120	32.27	32.13	29.67	36.84	38.46	41.21	38.84	38.84
150	30.25	29.70	27.38	41.10	43.48	46.13	43.57	43.57
180	28.54	28.11	25.43	44.70	46.77	50.31	47.26	47.26
210	26.30	25.90	23.03	49.42	51.33	55.46	52.07	52.07
240	23.98	23.40	20.56	54.31	56.50	60.76	57.19	57.19
stick wt.	2.29	2.34	2.28					

Solution: 0.5M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#37	#43	#25	#37	#43	#25		
0	45.15	45.27	43.07	0.00	0.00	0.00	0.00	0.00
30	36.15	35.52	33.79	20.97	22.65	22.77	22.13	22.13
60	30.40	29.57	27.77	34.37	36.47	37.54	36.13	36.13
90	25.40	24.20	22.41	46.03	48.94	50.69	48.55	48.55
120	20.26	19.10	17.29	58.01	60.79	63.25	60.68	60.68
150	15.85	14.46	12.50	68.28	71.57	75.00	71.62	71.62
180	11.33	10.15	8.17	78.82	81.58	85.62	82.01	82.01
210	7.13	5.82	3.95	88.60	91.64	95.98	92.07	92.07
240	3.66	2.87	2.39	96.69	98.49	99.80	98.33	98.33
stick wt.	2.24	2.22	2.31					

Solution: 2.0M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#44	#41	#48	#44	#41	#48		
0	50.66	48.01	49.26	0.00	0.00	0.00	0.00	0.00
30	20.26	18.78	20.98	62.89	63.88	60.23	62.33	62.33
60	6.22	6.25	8.17	91.93	91.26	87.52	90.24	90.24
90	2.42	2.32	2.82	99.79	99.85	98.91	99.52	99.52
120	2.38	2.26	2.31	99.88	99.98	100.00	99.95	99.95
150	--	--	--	--	--	--	100.00	100.00
180	--	--	--	--	--	--	100.00	100.00
210	--	--	--	--	--	--	100.00	100.00
240	--	--	--	--	--	--	100.00	100.00
stick wt.	2.32	2.25	2.31					

ICE MELTING OBSERVATIONS

Solution: Deionized-Distilled Water

Melting Time (mins.)	Popsicle Weight (g) #19	#70	#68	Weight Loss (%) #19	#70	#68	Average Weight Loss (%)	Corrected Weight Loss (%)
0	49.25	42.50	46.70	0.00	0.00	0.00	0.00	0.00
30	48.30	41.49	45.53	2.02	2.51	2.64	2.39	2.39
60	49.69	42.60	46.85	-0.94	-0.25	-0.34	-0.51	-0.51
90	49.97	43.24	47.33	-1.53	-1.84	-1.42	-1.60	-1.60
120	50.16	43.20	47.31	-1.94	-1.74	-1.38	-1.68	-1.68
150	50.01	43.10	47.10	-1.62	-1.49	-0.90	-1.34	-1.34
180	49.86	43.06	47.05	-1.30	-1.39	-0.79	-1.16	-1.16
210	49.89	43.20	46.92	-1.36	-1.74	-0.50	-1.20	-1.20
240	50.06	43.39	46.97	-1.72	-2.21	-0.61	-1.52	-1.52
stick wt.	2.24	2.30	2.35					

Solution: 0.02M KH2PO4 + 0.48M NaCl

Melting Time (mins.)	Popsicle Weight (g) #8	#12	#9	Weight Loss (%) #8	#12	#9	Average Weight Loss (%)	Corrected Weight Loss (%)
0	49.38	47.24	52.69	0.00	0.00	0.00	0.00	0.00
30	28.58	26.62	30.16	44.06	45.87	44.73	44.89	44.89
60	21.77	20.32	22.60	58.48	59.89	59.74	59.37	59.37
90	17.45	16.29	18.25	67.63	68.85	68.37	68.29	68.29
120	14.27	13.48	14.94	74.37	75.11	74.95	74.81	74.81
150	11.38	10.73	11.75	80.49	81.22	81.28	81.00	81.00
180	8.54	8.04	9.10	86.51	87.21	86.54	86.75	86.75
210	6.19	5.08	6.55	91.48	93.79	91.60	92.29	92.29
240	4.54	3.63	4.43	94.98	97.02	95.81	95.94	95.94
stick wt.	2.17	2.29	2.32					

Solution: 0.05M KH2PO4 + 0.45M NaCl

Melting Time (mins.)	Popsicle Weight (g) #23	#10	#53	Weight Loss (%) #23	#10	#53	Average Weight Loss (%)	Corrected Weight Loss (%)
0	50.89	48.91	48.26	0.00	0.00	0.00	0.00	0.00
30	48.09	46.12	44.79	5.75	5.98	7.55	6.43	6.43
60	45.84	44.01	42.74	10.37	10.50	12.02	10.96	10.96
90	43.86	42.57	41.16	14.43	13.59	15.45	14.49	14.49
120	42.01	41.11	39.99	18.23	16.72	18.00	17.65	17.65
150	40.36	39.64	38.24	21.61	19.87	21.81	21.10	21.10
180	38.81	38.34	37.03	24.79	22.65	24.44	23.96	23.96
210	37.36	37.03	35.61	27.77	25.46	27.54	26.92	26.92
240	36.12	35.84	34.55	30.32	28.01	29.84	29.39	29.39
stick wt.	2.17	2.25	2.32					

ICE MELTING OBSERVATIONS

Solution: 0.02M KH2PO4 + 0.48M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#63	#72	#69	#63	#72	#69		
0	50.45	50.09	49.94	0.00	0.00	0.00	0.00	0.00
30	40.38	42.02	41.42	20.92	16.96	17.88	18.59	18.59
60	33.74	36.52	36.28	34.71	28.51	28.67	30.63	30.63
90	29.04	32.69	32.40	44.47	36.56	36.81	39.28	39.28
120	24.35	28.68	28.61	54.22	44.99	44.76	47.99	47.99
150	20.43	25.02	24.82	62.36	52.68	52.72	55.92	55.92
180	17.02	21.19	20.60	69.44	60.73	61.57	63.91	63.91
210	13.58	17.59	16.58	76.59	68.29	70.01	71.63	71.63
240	11.47	14.14	12.73	80.97	75.54	78.09	78.20	78.20
stick wt.	2.31	2.50	2.29					

Solution: 0.05M KH2PO4 + 0.45M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#42	#65	#71	#42	#65	#71		
0	47.87	44.72	48.03	0.00	0.00	0.00	0.00	0.00
30	32.75	31.29	34.30	33.17	31.63	30.04	31.61	31.61
60	25.88	25.24	27.75	48.23	45.88	44.38	46.16	46.16
90	20.21	20.60	22.55	60.67	56.81	55.75	57.74	57.74
120	15.14	16.09	17.55	71.79	67.43	66.70	68.64	68.64
150	9.62	11.30	12.02	83.90	78.71	78.80	80.47	80.47
180	4.79	6.69	6.55	94.49	89.57	90.77	91.61	91.61
210	2.91	3.33	2.86	98.62	97.48	98.84	98.31	98.31
240	2.30	2.26	2.33	99.96	100.00	100.00	99.99	99.99
stick wt.	2.28	2.26	2.33					

Solution: 0.02M Ca(H2PO4)2*H2O + 0.48M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#29	#28	#31	#29	#28	#31		
0	46.73	49.69	48.23	0.00	0.00	0.00	0.00	0.00
30	43.85	46.93	45.48	6.49	5.83	5.98	6.10	6.10
60	41.60	44.57	43.38	11.55	10.82	10.55	10.97	10.97
90	39.82	42.65	41.67	15.56	14.87	14.27	14.90	14.90
120	37.96	40.86	39.80	19.75	18.66	18.34	18.91	18.91
150	35.89	39.14	37.98	24.41	22.29	22.30	23.00	23.00
180	34.00	37.17	36.03	28.66	26.45	26.54	27.22	27.22
210	32.02	35.31	34.19	33.12	30.38	30.54	31.35	31.35
240	30.39	33.70	32.64	36.79	33.78	33.91	34.83	34.83
stick wt.	2.32	2.36	2.26					

ICE MELTING OBSERVATIONS

Solution: 0.05M Ca(H2PO4)2*H2O + 0.45M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#24	#27	#16	#24	#27	#16		
0	49.53	50.06	47.17	0.00	0.00	0.00	0.00	0.00
30	44.61	45.07	41.23	10.42	10.43	13.22	11.36	11.36
60	40.32	40.10	36.39	19.50	20.83	24.00	21.44	21.44
90	36.18	35.96	32.29	28.27	29.49	33.13	30.29	30.29
120	32.36	31.56	28.30	36.36	38.69	42.01	39.02	39.02
150	28.51	27.29	24.43	44.52	47.62	50.62	47.58	47.58
180	24.79	23.11	20.83	52.39	56.36	58.64	55.80	55.80
210	21.09	19.11	17.19	60.23	64.72	66.74	63.90	63.90
240	17.51	15.25	13.79	67.81	72.79	74.31	71.64	71.64
stick wt.	2.31	2.24	2.25					

Solution: 0.02M Ca(H2PO4)2*H2O + 0.48M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#11	#14	#13	#11	#14	#13		
0	48.82	47.96	47.89	0.00	0.00	0.00	0.00	0.00
30	41.43	40.41	40.95	15.87	16.60	15.28	15.92	15.92
60	37.09	36.51	36.75	25.19	25.18	24.53	24.96	24.96
90	33.91	33.54	33.67	32.02	31.71	31.31	31.68	31.68
120	31.14	30.75	31.04	37.96	37.84	37.10	37.63	37.63
150	28.21	28.10	28.17	44.26	43.67	43.42	43.78	43.78
180	25.76	25.41	25.55	49.52	49.58	49.19	49.43	49.43
210	23.05	22.86	23.03	55.34	55.19	54.73	55.09	55.09
240	20.84	20.62	20.22	60.08	60.11	60.92	60.37	60.37
stick wt.	2.25	2.48	2.47					

Solution: 0.05M Ca(H2PO4)2*H2O + 0.45M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#2	#3	#5	#2	#3	#5		
0	44.73	45.91	48.95	0.00	0.00	0.00	0.00	0.00
30	36.30	37.77	40.54	19.88	18.65	18.03	18.85	18.85
60	31.33	32.92	35.48	31.60	29.76	28.88	30.08	30.08
90	27.32	28.83	31.50	41.05	39.13	37.41	39.20	39.20
120	23.98	25.50	27.85	48.93	46.76	45.24	46.98	46.98
150	20.92	22.08	24.10	56.14	54.59	53.28	54.67	54.67
180	17.85	18.88	20.75	63.38	61.92	60.46	61.92	61.92
210	14.46	15.87	17.42	71.37	68.82	67.60	69.27	69.27
240	11.54	12.83	14.09	78.26	75.78	74.74	76.26	76.26
stick wt.	2.32	2.26	2.31					

ICE MELTING OBSERVATIONS

Solution: 0.2M KC2H3O2

Melting Time (mins.)	Popsicle Weight (g) #7	#65	#69	Weight Loss (%) #7	#65	#69	Average Weight Loss (%)	Corrected Weight Loss (%)
0	46.31	53.05	53.32	0.00	0.00	0.00	0.00	0.00
30	29.89	34.41	34.75	37.29	36.71	36.40	36.80	36.80
60	26.13	30.04	29.75	45.83	45.31	46.20	45.78	45.78
90	22.83	26.00	25.36	53.33	53.27	54.80	53.80	53.80
120	19.99	22.75	21.81	59.78	59.67	61.76	60.40	60.40
150	17.40	19.88	18.35	65.66	65.32	68.54	66.51	66.51
180	15.04	17.18	15.51	71.02	70.64	74.11	71.92	71.92
210	12.42	13.98	12.04	76.97	76.94	80.91	78.27	78.27
240	9.77	11.18	9.15	82.99	82.45	86.57	84.01	84.01
stick	2.28	2.27	2.30					

Solution: 0.5M KC2H3O2

Melting Time (mins.)	Popsicle Weight (g) #66	#63	#67	Weight Loss (%) #66	#63	#67	Average Weight Loss (%)	Corrected Weight Loss (%)
0	54.93	60.26	55.95	0.00	0.00	0.00	0.00	0.00
30	50.30	55.82	51.93	8.79	7.66	7.49	7.98	7.98
60	48.00	53.52	49.92	13.15	11.63	11.24	12.01	12.01
90	46.06	51.51	48.21	16.83	15.10	14.42	15.45	15.45
120	44.05	49.76	46.32	20.65	18.12	17.94	18.90	18.90
150	42.32	47.83	44.66	23.93	21.45	21.04	22.14	22.14
180	40.38	45.91	42.65	27.61	24.77	24.78	25.72	25.72
210	38.63	43.88	40.75	30.94	28.27	28.32	29.18	29.18
240	36.26	41.92	38.88	35.43	31.65	31.81	32.96	32.96
stick	2.24	2.32	2.28					

Solution: 2.0M KC2H3O2

Melting Time (mins.)	Popsicle Weight (g) #61	#46	#64	Weight Loss (%) #61	#46	#64	Average Weight Loss (%)	Corrected Weight Loss (%)
0	55.87	55.90	59.52	0.00	0.00	0.00	0.00	0.00
30	29.33	30.21	33.34	49.50	47.79	45.67	47.65	48.89
60	14.53	16.39	18.59	77.10	73.49	71.39	74.00	97.77
90	5.75	7.82	9.71	93.47	89.43	86.88	89.93	100.00
120	2.54	2.28	4.24	99.46	99.74	96.42	98.54	100.00
150	2.32	2.23	2.27	99.87	99.83	99.86	99.85	100.00
180	--	--	--	--	--	--	100.00	100.00
210	--	--	--	--	--	--	100.00	100.00
240	--	--	--	--	--	--	100.00	100.00
stick	2.25	2.14	2.19					

ICE MELTING OBSERVATIONS

Solution: 0.02M $\mathrm{NaH_2PO_4}$ + 0.48M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#32	#30	#55	#32	#30	#55		
0	49.85	47.71	48.55	0.00	0.00	0.00	0.00	0.00
30	42.54	41.98	44.19	15.37	12.65	9.44	12.49	20.34
60	37.76	38.08	41.22	25.42	21.25	15.87	20.85	33.97
90	33.99	34.56	38.69	33.35	29.02	21.35	27.91	45.47
120	30.00	31.10	36.07	41.74	36.66	27.02	35.14	57.26
150	26.51	27.60	33.00	49.07	44.38	33.67	42.37	69.05
180	23.20	24.14	30.29	56.03	52.02	39.53	49.20	80.16
210	19.45	20.24	27.04	63.92	60.63	46.57	57.04	92.94
240	15.87	16.84	23.75	71.45	68.13	53.69	64.42	100.00
stick wt.	2.29	2.40	2.36					

Solution: 0.05M $\mathrm{NaH_2PO_4}$ + 0.45M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#26	#22	#58	#26	#22	#58		
0	53.70	51.89	47.14	0.00	0.00	0.00	0.00	0.00
30	51.34	50.18	46.73	4.58	3.44	0.91	2.98	4.86
60	50.01	49.52	46.00	7.16	4.77	2.54	4.83	7.86
90	49.08	48.92	45.52	8.97	5.98	3.61	6.19	10.08
120	48.40	48.37	45.00	10.29	7.09	4.77	7.38	12.03
150	48.04	47.90	44.59	10.99	8.04	5.68	8.23	13.42
180	47.19	47.30	44.07	12.64	9.24	6.84	9.57	15.60
210	46.20	46.98	43.51	14.56	9.89	8.09	10.85	17.67
240	45.69	46.30	--	15.55	11.26	--	13.40	21.84
stick wt.	2.19	2.24	2.25					

Solution: 0.02M $\mathrm{NaH_2PO_4}$ + 0.48M $\mathrm{CaCl_2}$

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#1	#17	#6	#1	#17	#6		
0	50.70	51.36	50.32	0.00	0.00	0.00	0.00	0.00
30	42.86	45.17	43.57	16.19	12.60	14.05	14.28	23.27
60	38.34	41.36	40.05	25.53	20.36	21.38	22.42	36.54
90	34.88	38.48	36.96	32.67	26.22	27.81	28.90	47.09
120	32.20	36.20	34.08	38.21	30.86	33.81	34.29	55.88
150	29.97	33.96	31.79	42.81	35.42	38.57	38.94	63.45
180	27.59	31.81	29.69	47.73	39.80	42.94	43.49	70.87
210	25.76	29.76	27.27	51.51	43.97	47.98	47.82	77.92
240	23.89	27.94	25.39	55.37	47.68	51.89	51.65	84.16
stick wt.	2.28	2.24	2.28					

ICE MELTING OBSERVATIONS

Solution: 0.05M NaH_2PO_4 + 0.45M $CaCl_2$

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#18	#15	#59	#18	#15	#59		
0	50.74	48.66	48.48	0.00	0.00	0.00	0.00	0.00
30	38.83	36.17	37.28	24.58	26.92	24.34	25.28	41.20
60	32.54	29.55	30.71	37.56	41.19	38.61	39.12	63.75
90	27.31	24.71	25.40	48.36	51.63	50.15	50.05	81.55
120	22.90	20.10	20.87	57.46	61.56	60.00	59.67	97.24
150	18.48	15.99	16.98	66.58	70.42	68.45	68.49	100.00
180	14.56	12.45	12.86	74.67	78.06	77.40	76.71	100.00
210	10.96	8.79	9.14	82.11	85.95	85.48	84.51	100.00
240	7.87	5.92	5.98	88.48	92.13	92.35	90.99	100.00
stick wt.	2.29	2.27	2.46					

Solution: 0.02M Calcium Magnesium Acetate + 0.48M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#64	#62	#66	#64	#62	#66		
0	47.22	48.24	47.21	0.00	0.00	0.00	0.00	0.00
30	45.91	47.07	45.93	2.91	2.54	2.85	2.76	4.50
60	45.08	46.79	45.39	4.75	3.15	4.05	3.98	6.49
90	44.70	46.24	44.97	5.60	4.34	4.98	4.97	8.10
120	44.43	45.94	44.62	6.19	4.99	5.76	5.65	9.20
150	43.06	44.99	43.70	9.24	7.05	7.81	8.03	13.09
180	41.47	43.61	42.38	12.77	10.05	10.74	11.18	18.23
210	39.97	42.19	41.21	16.10	13.13	13.34	14.19	23.12
240	38.85	41.47	40.20	18.58	14.69	15.59	16.29	26.54
stick wt.	2.18	2.16	2.24					

Solution: 0.05M Calcium Magnesium Acetate + 0.45M NaCl

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#67	#61	#46	#67	#61	#46		
0	48.27	44.78	48.67	0.00	0.00	0.00	0.00	0.00
30	42.89	39.53	43.11	11.70	12.34	11.95	12.00	19.55
60	39.29	35.90	39.71	19.52	20.88	19.25	19.88	32.40
90	36.94	33.54	36.99	24.63	26.43	25.10	25.39	41.37
120	34.30	30.91	34.53	30.37	32.61	30.38	31.12	50.71
150	30.72	27.79	31.21	38.15	39.95	37.52	38.54	62.80
180	27.97	24.79	27.73	44.13	47.00	44.99	45.38	73.94
210	25.65	22.40	25.04	49.17	52.62	50.77	50.86	82.87
240	23.23	19.86	22.25	54.43	58.59	56.77	56.60	92.23
stick wt.	2.27	2.25	2.13					

ICE MELTING OBSERVATIONS

Solution: 0.02M Calcium Magnesium Acetate + 0.48M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#45	#39	#40	#45	#39	#40		
0	46.37	43.99	43.87	0.00	0.00	0.00	0.00	0.00
30	37.04	34.22	35.39	21.18	23.36	20.37	21.64	35.26
60	30.02	27.88	29.35	37.12	38.52	34.88	36.84	60.03
90	24.66	22.87	23.95	49.28	50.50	47.85	49.21	80.19
120	19.88	18.44	19.42	60.14	61.10	58.73	59.99	97.75
150	15.22	14.43	14.89	70.72	70.68	69.61	70.34	100.00
180	11.20	10.90	11.09	79.84	79.12	78.74	79.24	100.00
210	7.65	7.74	7.48	87.90	86.68	87.41	87.33	100.00
240	4.66	4.99	4.68	94.69	93.26	94.14	94.03	100.00
stick wt.	2.32	2.17	2.24					

Solution: 0.05M Calcium Magnesium Acetate + 0.45M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#20	#34	#33	#20	#34	#33		
0	44.86	44.50	47.34	0.00	0.00	0.00	0.00	0.00
30	38.05	38.06	42.74	15.96	15.21	10.21	13.79	22.47
60	34.18	34.43	39.69	25.02	23.78	16.97	21.93	35.73
90	30.83	31.47	37.22	32.87	30.77	22.45	28.70	46.77
120	28.11	29.06	35.10	39.25	36.47	27.16	34.29	55.88
150	25.81	26.72	33.18	44.63	41.99	31.42	39.35	64.12
180	23.41	24.47	31.02	50.26	47.31	36.21	44.59	72.66
210	21.28	22.43	29.13	55.25	52.13	40.40	49.26	80.27
240	19.21	20.39	27.35	60.10	56.94	44.35	53.80	87.66
stick wt.	2.18	2.16	2.27					

Solution: 0.2M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#4	#49	#50	#4	#49	#50		
0	47.90	48.69	47.68	0.00	0.00	0.00	0.00	0.00
30	45.65	46.52	45.75	4.94	4.68	4.25	4.62	4.62
60	44.76	45.82	44.72	6.89	6.19	6.52	6.53	6.53
90	43.42	44.67	43.53	9.83	8.68	9.14	9.21	9.21
120	42.02	43.29	42.06	12.90	11.65	12.38	12.31	12.31
150	40.83	42.23	41.14	15.51	13.94	14.40	14.62	14.62
180	39.75	41.03	40.04	17.88	16.53	16.82	17.08	17.08
210	38.75	39.97	39.27	20.07	18.82	18.52	19.14	19.14
240	37.68	38.93	37.98	22.42	21.06	21.36	21.61	21.61
stick wt.	2.32	2.35	2.27					

ICE MELTING OBSERVATIONS

Solution: 0.5M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#54	#52	#47	#54	#52	#47		
0	51.35	50.00	49.76	0.00	0.00	0.00	0.00	0.00
30	42.47	41.25	39.99	18.14	18.36	20.58	19.02	19.02
60	37.53	36.94	35.85	28.23	27.40	29.30	28.31	28.31
90	33.75	34.02	32.76	35.96	33.52	35.80	35.09	35.09
120	30.10	31.01	29.62	43.41	39.84	42.42	41.89	41.89
150	26.66	28.07	26.72	50.44	46.00	48.53	48.32	48.32
180	23.34	25.17	23.77	57.22	52.09	54.74	54.68	54.68
210	20.09	22.47	21.07	63.86	57.75	60.43	60.68	60.68
240	16.65	19.62	18.29	70.89	63.73	66.28	66.97	66.97
stick wt.	2.40	2.33	2.28					

Solution: 2.0M CaCl2

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#51	#70	#19	#51	#70	#19		
0	48.90	56.51	55.20	0.00	0.00	0.00	0.00	0.00
30	14.38	22.01	19.97	74.06	63.64	66.52	68.07	100.00
60	2.35	7.24	2.51	99.87	90.89	99.49	96.75	100.00
90	2.29	2.38	2.30	100.00	99.85	99.89	99.91	100.00
120	--	--	--	--	--	--	100.00	100.00
150	--	--	--	--	--	--	100.00	100.00
180	--	--	--	--	--	--	100.00	100.00
210	--	--	--	--	--	--	100.00	100.00
240	--	--	--	--	--	--	100.00	100.00
stick wt.	2.29	2.30	2.24					

Solution: 0.1M Calcium Magnesium Acetate

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
0				ERR	ERR	ERR	ERR	
30				ERR	ERR	ERR	ERR	
60				ERR	ERR	ERR	ERR	
90				ERR	ERR	ERR	ERR	
120				ERR	ERR	ERR	ERR	
150				ERR	ERR	ERR	ERR	
180				ERR	ERR	ERR	ERR	
210				ERR	ERR	ERR	ERR	
240				ERR	ERR	ERR	ERR	
stick wt.								

ICE MELTING OBSERVATIONS

Solution: 0.2M Calcium Magnesium Acetate

Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
0				ERR	ERR	ERR	ERR	
30				ERR	ERR	ERR	ERR	
60				ERR	ERR	ERR	ERR	
90				ERR	ERR	ERR	ERR	
120				ERR	ERR	ERR	ERR	
150				ERR	ERR	ERR	ERR	
180				ERR	ERR	ERR	ERR	
210				ERR	ERR	ERR	ERR	
240				ERR	ERR	ERR	ERR	
stick wt.								

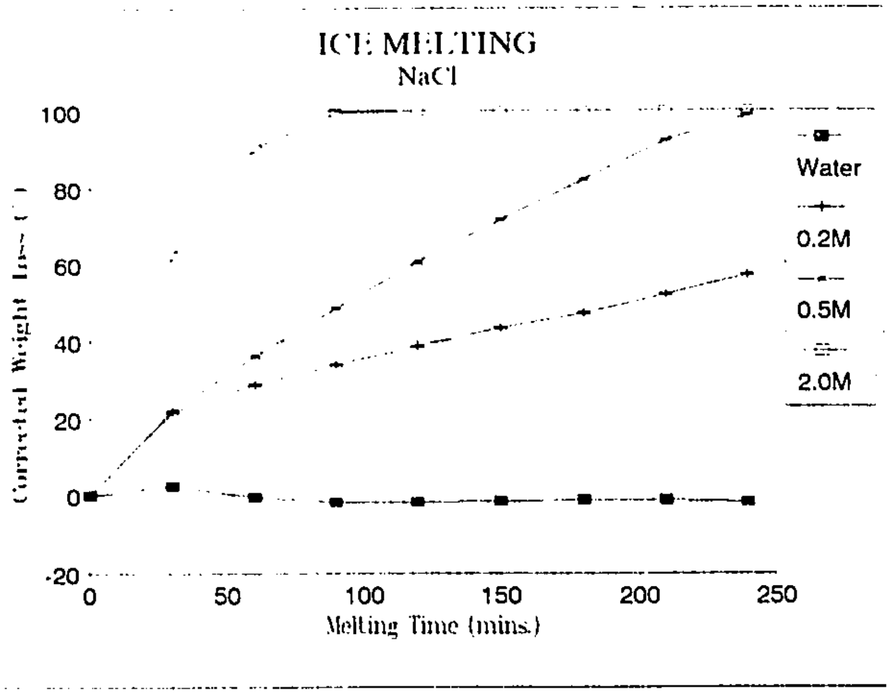
Solution: 0.5M Calcium Magnesium Acetate

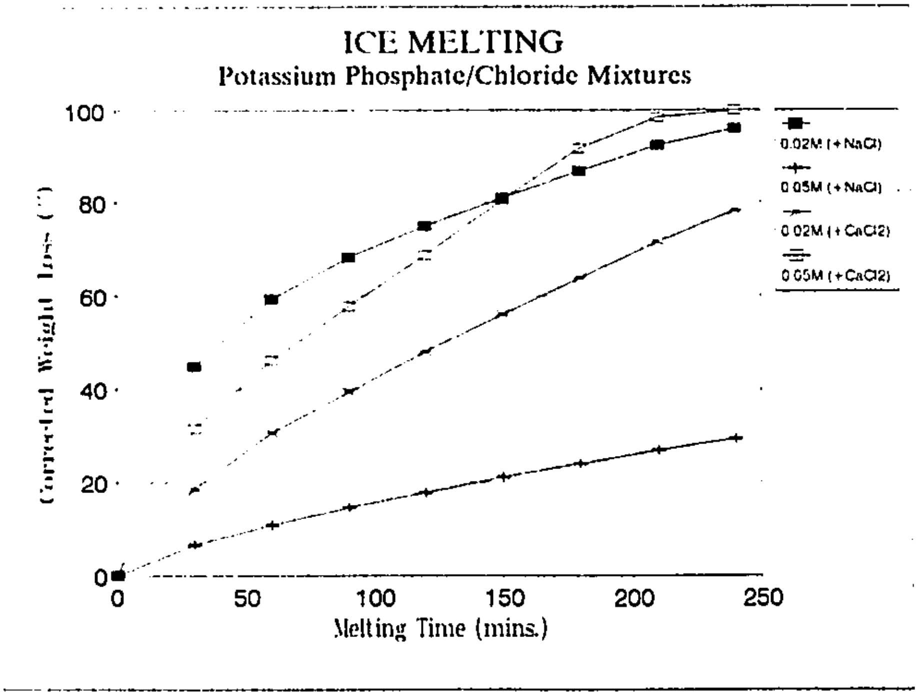
Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#29	#68	#62	#29	#68	#62		
0	54.05	58.19	56.25	0.00	0.00	0.00	0.00	0.00
30	45.82	51.65	51.11	15.91	11.71	9.50	12.38	20.17
60	40.00	46.97	46.42	27.16	20.10	18.17	21.81	35.54
90	35.37	42.90	42.86	36.11	27.39	24.76	29.42	47.94
120	31.97	39.53	38.81	42.68	33.42	32.24	36.12	58.85
150	28.52	35.71	34.42	49.35	40.27	40.36	43.33	70.60
180	25.21	31.88	29.99	55.75	47.13	48.55	50.47	82.25
210	21.75	28.44	25.62	62.44	53.29	56.63	57.45	93.62
240	18.20	24.36	21.02	69.30	60.59	65.13	65.01	100.00
stick wt.	2.32	2.36	2.16					

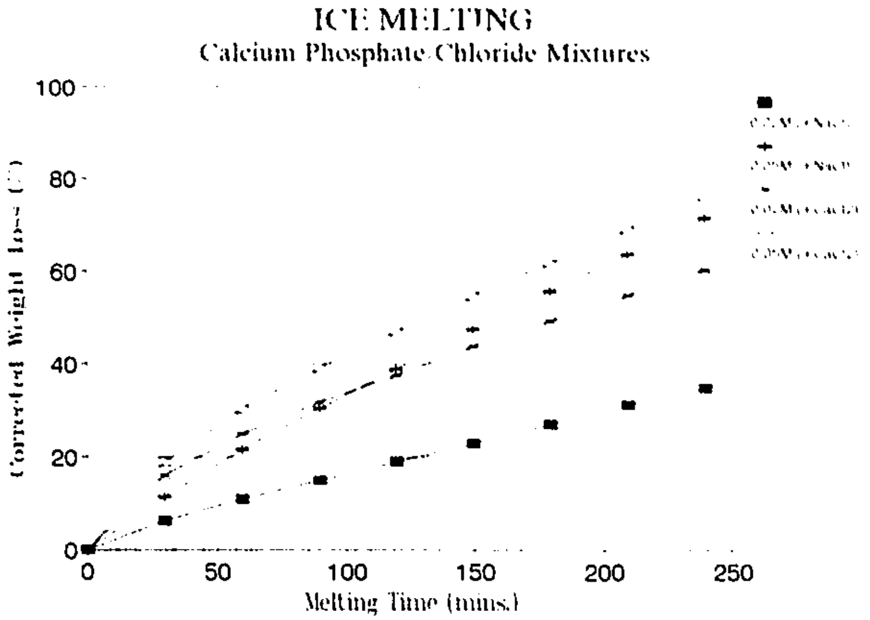
ICE MELTING LINEAR REGRESSION ANALYSIS

Salt / Chloride Mixture	Constant	Std Err of Y Est	R Squared	# of Observ.	Degrees of Freedom	X Coef.	Std Err of Coef.	Container	Freeze Over	Rank
2.0M CaCl2	0.000		1.000	2		3.333		square	no	1
2.0M KC2H3O2	-0.000	0.000	1.000	3	1	1.630	0.000	square	no	2
2.0M NaCl	5.738	14.056	0.954	3	1	1.504	0.331	cylinder3	no	3
0.02M CMA + 0.48M CaCl2	16.398	2.570	0.994	4	2	0.692	0.038	square	no	4
0.05M NaH2PO4 + 0.45M CaCl2	24.452	2.464	0.993	4	2	0.620	0.037	square	no	5
0.5M CMA	10.360	1.380	0.998	7	5	0.401	0.009	square	no	6
0.02M NaH2PO4 + 0.48M NaCl	9.349	0.661	0.999	7	5	0.397	0.004	square	no	7
0.05M KH2PO4 + 0.45M CaCl2	21.327	1.130	0.998	6	4	0.394	0.009	cylinder2	no	8
0.5M NaCl	12.648	1.587	0.997	7	5	0.386	0.010	cylinder2	no	9
0.05M CMA + 0.45M NaCl	10.326	1.137	0.998	8	6	0.346	0.006	square	no	10
0.05M CMA + 0.45M CaCl2	17.214	2.369	0.990	8	6	0.304	0.012	square	no	11
0.05M Ca(H2PO4)2*H2O + 0.45M NaCl	4.096	0.811	0.999	8	6	0.285	0.004	cylinder2	no	12
0.02M NaH2PO4 + 0.48M CaCl2	19.252	2.767	0.985	8	6	0.283	0.014	square	no	13
0.02M KH2PO4 + 0.48M CaCl2	13.048	1.675	0.994	8	6	0.279	0.009	cylinder1	no	14
0.05M Ca(H2PO4)2*H2O + 0.45M CaCl2	13.564	1.599	0.994	8	6	0.267	0.008	cylinder2	no	15
0.02M KH2PO4 + 0.48M NaCl	44.155	3.636	0.962	8	6	0.232	0.019	cylinder2	yes	16
0.5M CaCl2	14.229	1.063	0.996	8	6	0.223	0.005	cylinder3	no	17
0.2M KC2H3O2	32.541	1.455	0.993	8	6	0.220	0.007	cylinder2	yes	18
0.02M Ca(H2PO4)2*H2O + 0.48M CaCl2	11.936	1.268	0.994	8	6	0.207	0.007	cylinder3	no	19
0.2M NaCl	18.454	0.915	0.995	8	6	0.163	0.005	cylinder1	no	20
0.02M Ca(H2PO4)2*H2O + 0.48M NaCl	2.480	0.311	0.999	8	6	0.137	0.002	cylinder1	no	21
0.5M KC2H3O2	4.752	0.204	1.000	8	6	0.117	0.001	cylinder3	no	22
0.05M KH2PO4 + 0.45M NaCl	4.268	0.676	0.994	8	6	0.108	0.003	cylinder1	no	23
0.02M CMA + 0.48M NaCl	-0.895	1.970	0.950	8	6	0.108	0.010	square	no	24
0.2M CaCl2	2.006	0.313	0.998	8	6	0.082	0.002	cylinder1	yes	25
0.05M NaH2PO4 + 0.45M NaCl	2.961	0.750	0.984	8	6	0.074	0.004	square	no	26
Distilled-Deionized Water	-0.982	0.409	0.110	7	5	-0.002	0.003	cylinder3	yes	27

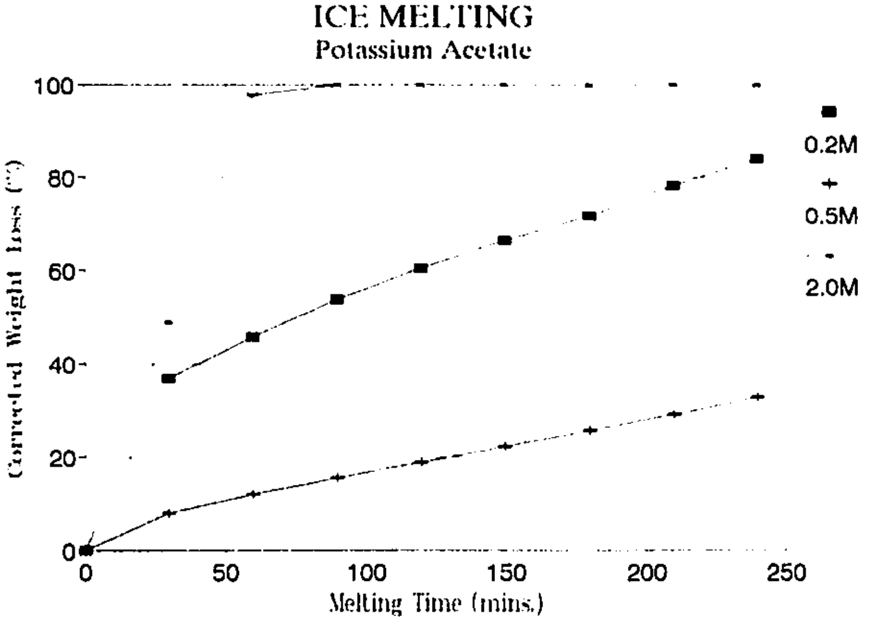
Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Squared = Correlation coefficient squared


ICE MELTING
NaCl
Corrected Weight Loss (%)
100
80
60
40
20
0
-20
0
50
100
150
200
250
Melting Time (mins.)
Water
0.2M
0.5M
2.0M

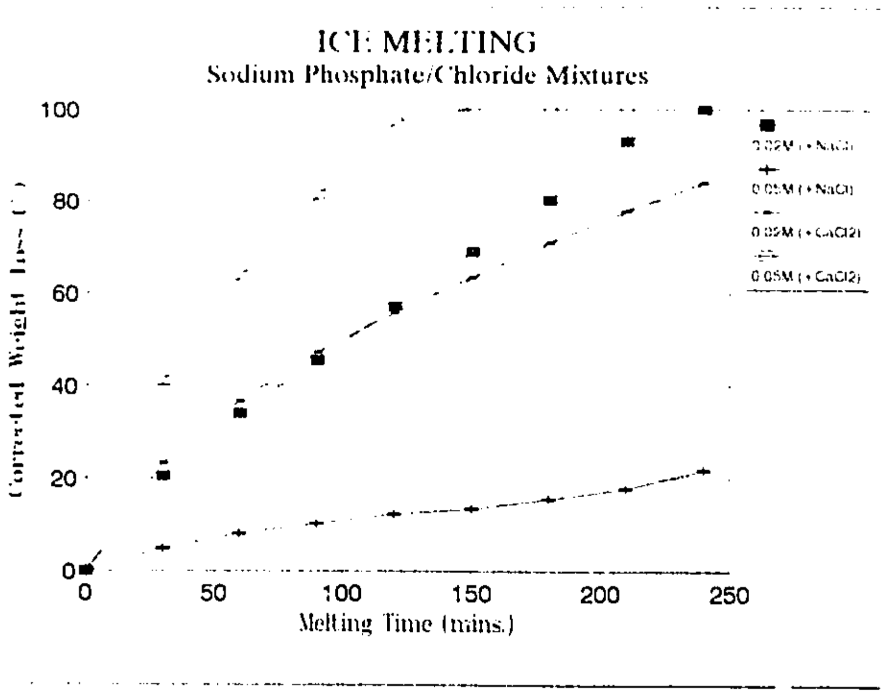

ICE MELTING
Potassium Phosphate/Chloride Mixtures
Corrected Weight Loss (%)
100
80
60
40
20
0
0
50
100
150
200
250
Melting Time (mins.)
0.02M (+NaCl)
0.05M (+NaCl)
0.02M (+CaCl2)
0.05M (+CaCl2)

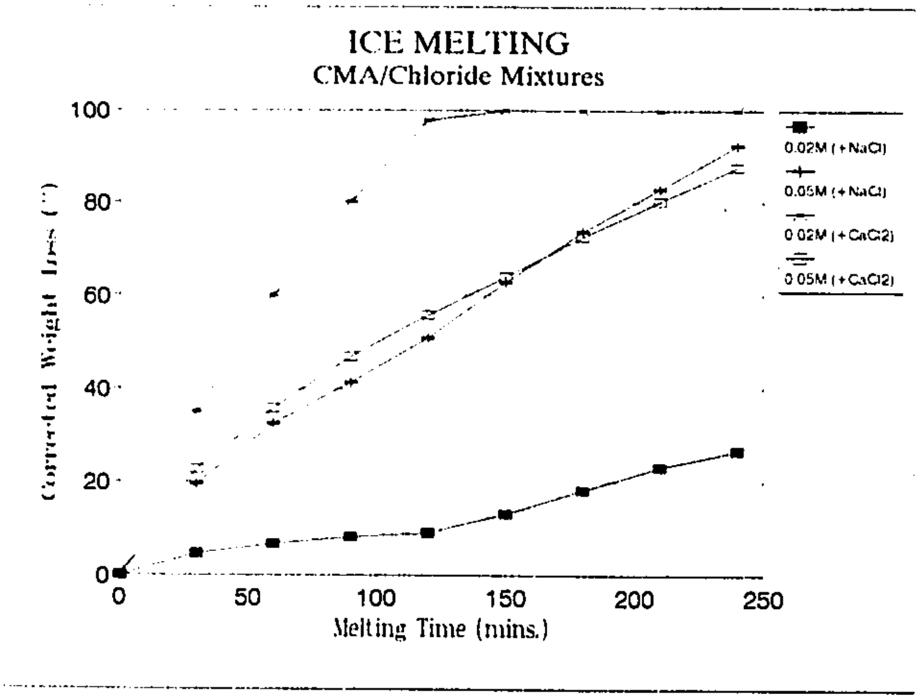

ICE MELTING

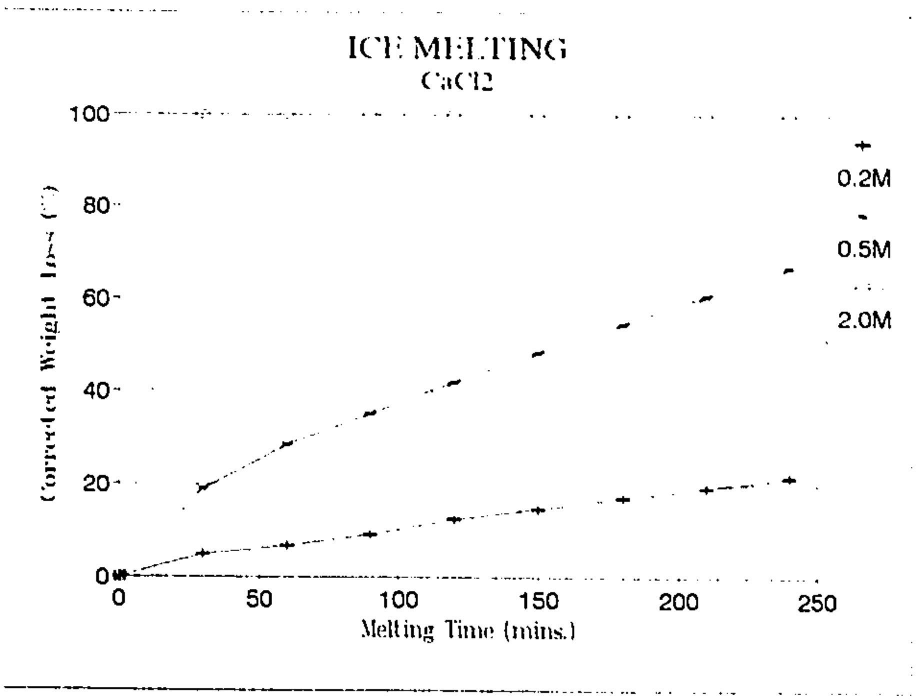
Calcium Phosphate/Chloride Mixtures

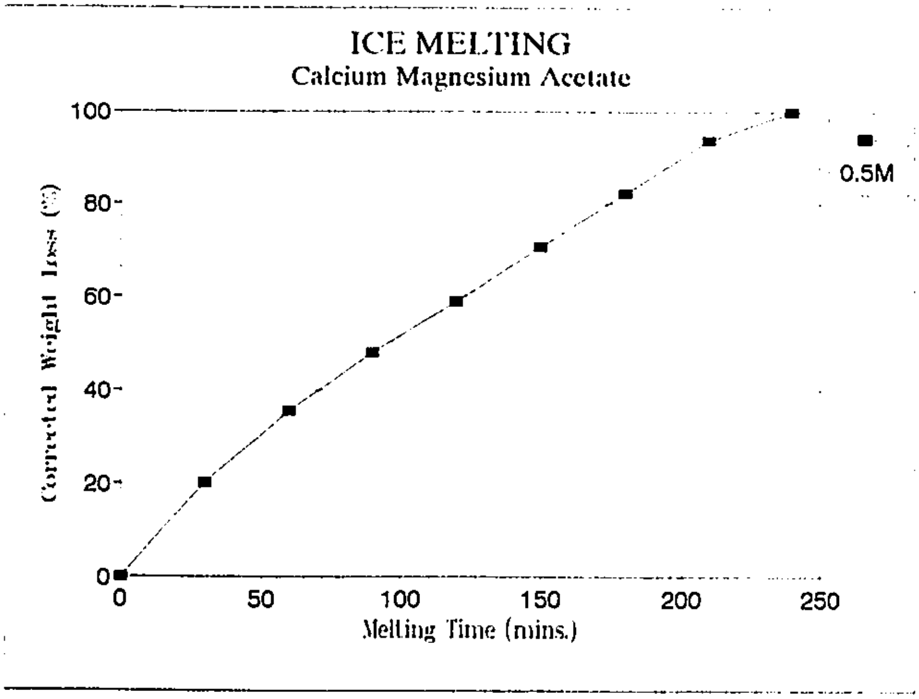

ICE MELTING

Potassium Acetate


ICE MELTING
Sodium Phosphate/Chloride Mixtures
Corrected Weight Loss (%)
100
80
60
40
20
0
0
50
100
150
200
250
Melting Time (mins.)
0.02M (+NaCl)
0.05M (+NaCl)
0.02M (+CaCl2)
0.05M (+CaCl2)


ICE MELTING
CMA/Chloride Mixtures
Corrected Weight Loss (%)
100
80
60
40
20
0
0
50
100
150
200
250
Melting Time (mins.)
0.02M (+NaCl)
0.05M (+NaCl)
0.02M (+CaCl2)
0.05M (+CaCl2)


ICE MELTING
CaCl2
Corrected Weight Loss (%)
0
20
40
60
80
100
0
50
100
150
200
250
Melting Time (mins.)
0.2M
0.5M
2.0M


ICE MELTING
Calcium Magnesium Acetate
Corrected Weight Loss (%)
0
20
40
60
80
100
0
50
100
150
200
250
Melting Time (mins.)
0.5M

APPENDIX I

Ice Melting Reproduciblity Experiment Observations

ICE MELTING OBSERVATIONS (0.5M NACL RETRIAL)

Container: Cylinder (1)

Melting Time (mins.)	Popsicle Weight (g) #39	#20	#27	Weight Loss (%) #39	#20	#27	Average Weight Loss (%)
0	54.85	53.99	50.48	0.00	0.00	0.00	0.00
30	48.55	48.12	45.33	11.96	11.33	10.68	11.32
60	44.72	44.48	41.63	19.23	18.36	18.35	18.65
90	41.64	41.62	38.80	25.08	23.88	24.21	24.39
120	38.14	38.21	35.72	31.73	30.46	30.60	30.93
150	35.05	35.35	32.57	37.59	35.98	37.13	36.90
180	31.87	32.26	29.19	43.63	41.95	44.13	43.24
210	28.68	29.44	26.00	49.69	47.39	50.75	49.28
240	25.94	26.58	23.06	54.89	52.92	56.84	54.88
stick wt.	2.18	2.19	2.24				

Container: Square (1)

Melting Time (mins.)	Popsicle Weight (g) #40	#3	#59	Weight Loss (%) #40	#3	#59	Average Weight Loss (%)	Corrected Weight Loss (%)
0	50.88	53.97	57.35	0.00	0.00	0.00	0.00	0.00
30	47.09	50.16	54.11	7.79	7.37	5.90	7.02	11.44
60	44.44	47.57	52.03	13.24	12.38	9.69	11.77	19.18
90	41.99	44.96	49.94	18.28	17.42	13.50	16.40	26.73
120	39.58	42.92	47.79	23.24	21.37	17.42	20.67	33.69
150	37.07	40.35	45.44	28.40	26.34	21.70	25.48	41.52
180	35.20	38.18	43.35	32.24	30.54	25.51	29.43	47.95
210	33.04	35.86	40.93	36.69	35.02	29.91	33.87	55.20
240	31.14	33.85	39.13	40.59	38.91	33.19	37.57	61.21
stick wt.	2.25	2.26	2.46					

Container: Cylinder (2)

Melting Time (mins.)	Popsicle Weight (g) #34	#54	#42	Weight Loss (%) #34	#54	#42	Average Weight Loss (%)
0	54.59	53.32	54.02	0.00	0.00	0.00	0.00
30	48.85	47.85	49.04	10.95	10.74	9.63	10.44
60	44.55	43.58	45.05	19.15	19.13	17.34	18.54
90	40.28	39.49	41.22	27.29	27.16	24.74	26.40
120	36.09	35.62	37.23	35.29	34.76	32.46	34.17
150	31.78	31.38	33.17	43.51	43.09	40.31	42.30
180	28.01	27.98	29.90	50.70	49.76	46.63	49.03
210	24.15	24.43	26.29	58.06	56.74	53.61	56.13
240	20.81	21.37	23.21	64.43	62.75	59.56	62.24
stick wt.	2.16	2.40	2.29				

ICE MELTING OBSERVATIONS (0.5M NACL RETRIAL)

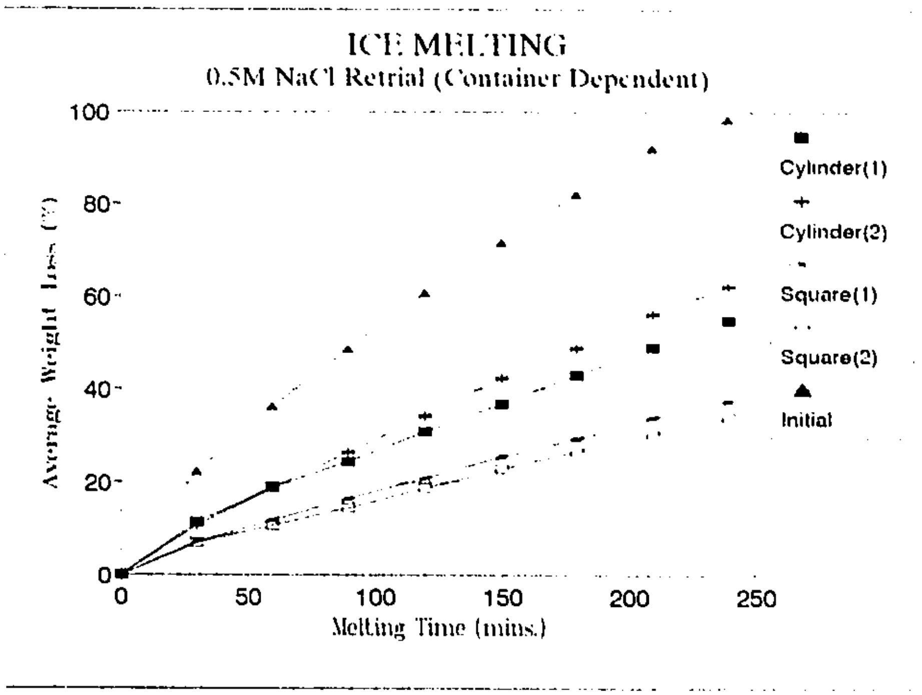
Container: Square (2)

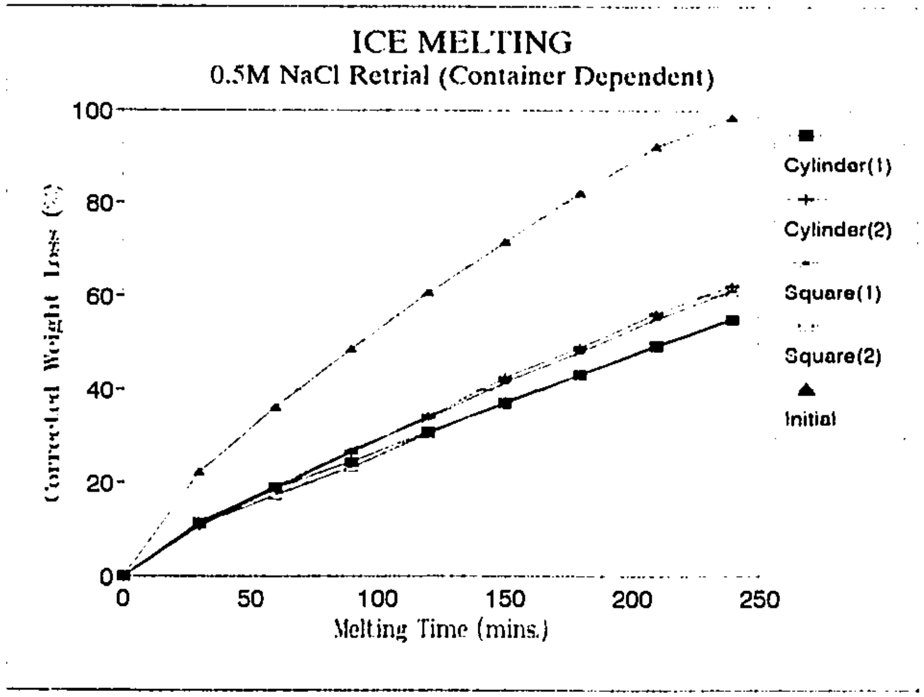
Melting Time (mins.)	Popsicle Weight (g)			Weight Loss (%)			Average Weight Loss (%)	Corrected Weight Loss (%)
	#33	#17	#10	#33	#17	#10		
0	50.99	54.91	56.22	0.00	0.00	0.00	0.00	0.00
30	47.94	50.84	52.66	6.26	7.73	6.60	6.86	11.18
60	46.21	48.61	50.78	9.81	11.96	10.08	10.62	17.30
90	44.18	46.69	48.98	13.98	15.61	13.42	14.33	23.36
120	42.07	44.17	47.01	18.31	20.39	17.07	18.59	30.29
150	39.83	41.86	44.90	22.91	24.78	20.98	22.89	37.29
180	37.98	39.83	43.19	26.70	28.63	24.15	26.49	43.17
210	36.01	37.68	41.28	30.75	32.71	27.69	30.38	49.51
240	34.37	35.58	39.55	34.11	36.70	30.89	33.90	55.24
stick wt.	2.27	2.24	2.26					

ICE MELTING (0.5M NACL RETRIAL) LINEAR REGRESSION

Container	Constant	Std Err of Y Est	R Squared	# of Observ.	Degrees of Freedom	X Coef.	Std Err of Coef.
Cylinder (1)	6.3972	0.2460	0.9997	7	5	0.2033	0.0015
Cylinder (2)	4.5721	0.7693	0.9980	7	5	0.2446	0.0048
Square (1)	3.4056	0.3224	0.9990	7	5	0.1441	0.0020
Square (2)	2.8413	0.2807	0.9991	7	5	0.1308	0.0016
Initial NaCl	14.9027	1.0327	0.9981	6	4	0.3724	0.0082

Note: 1) X Coef. = Slope of the weight loss versus time graph
2) R Squared = Correlation coefficient squared


ICE MELTING
0.5M NaCl Retrial (Container Dependent)
Average Weight Loss (%)
100
80
60
40
20
0
0
50
100
150
200
250
Melting Time (mins.)
Cylinder(1)
Cylinder(2)
Square(1)
Square(2)
Initial


ICE MELTING
0.5M NaCl Retrial (Container Dependent)
Corrected Weight Loss (%)
100
80
60
40
20
0
0
50
100
150
200
250
Melting Time (mins.)
Cylinder(1)
Cylinder(2)
Square(1)
Square(2)
Initial

APPENDIX J

Superphosphate Analysis

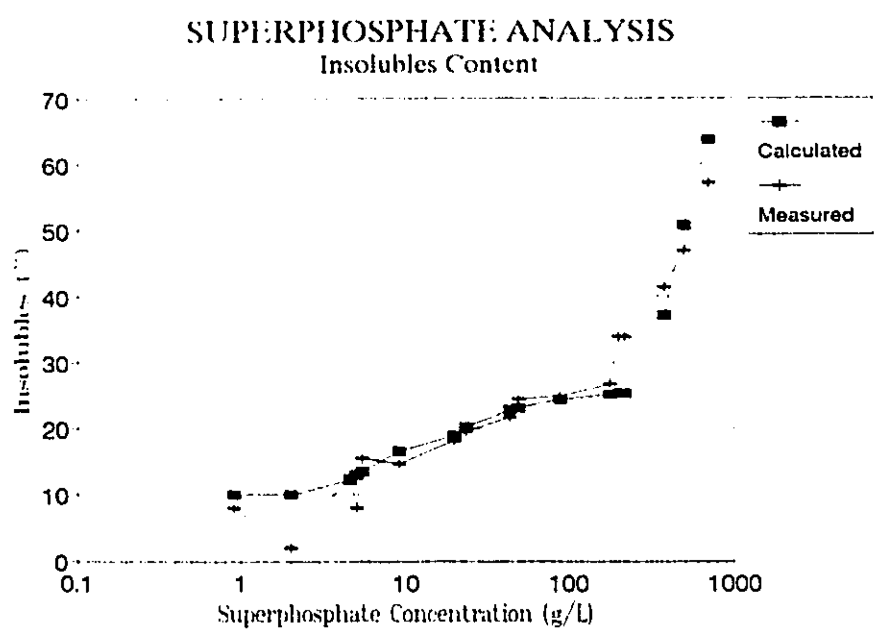
SUPERPHOSPHATE ANALYSIS

Chemical	Soluble (g/L)	Proport. (%)	0.9 g/L sample	Insoluble (g/L)	2 g/L sample	Insoluble (g/L)	4.6 g/L sample	Insoluble (g/L)	5 g/L sample	Insoluble (g/L)	5.4 g/L sample	Insoluble (g/L)
Ca(H2PO4)2*H2O	215	68	0.612	0.000	1.360	0.000	3.128	0.000	3.400	0.000	3.672	0.000
CaSO4	1	5	0.045	0.000	0.100	0.000	0.230	0.000	0.250	0.000	0.270	0.000
CaHPO4	0.4	11	0.099	0.000	0.220	0.000	0.506	0.106	0.550	0.150	0.594	0.194
SiO2	0	10	0.090	0.090	0.200	0.200	0.460	0.460	0.500	0.500	0.540	0.540
H2O	--	6	0.054	0.000	0.120	0.000	0.276	0.000	0.300	0.000	0.324	0.000
Total		100	0.9	0.090	2	0.200	4.6	0.566	5	0.650	5.4	0.734
Calc. Insol.(%)				10.00		10.00		12.30		13.00		13.59
Meas. Insol.(%)				8.00		2.00		12.80		8.00		15.56

Chemical	Soluble (g/L)	Proport. (%)	9.2 g/L sample	Insoluble (g/L)	20 g/L sample	Insoluble (g/L)	23.6 g/L sample	Insoluble (g/L)	44.6 g/L sample	Insoluble (g/L)	50 g/L sample	Insoluble (g/L)
Ca(H2PO4)2*H2O	215	68	6.256	0.000	13.600	0.000	16.048	0.000	30.328	0.000	34.000	0.000
CaSO4	1	5	0.460	0.000	1.000	0.000	1.180	0.180	2.230	1.230	2.500	1.500
CaHPO4	0.4	11	1.012	0.612	2.200	1.800	2.596	2.196	4.906	4.506	5.500	5.100
SiO2	0	10	0.920	0.920	2.000	2.000	2.360	2.360	4.460	4.460	5.000	5.000
H2O	--	6	0.552	0.000	1.200	0.000	1.416	0.000	2.676	0.000	3.000	0.000
Total		100	9.2	1.532	20	3.800	23.6	4.736	44.6	10.196	50	11.600
Calc. Insol.(%)				16.65		19.00		20.07		22.86		23.20
Meas. Insol.(%)				14.80		18.20		19.60		21.76		24.32

Chemical	Soluble (g/L)	Proport. (%)	89.3 g/L sample	Insoluble (g/L)	179 g/L sample	Insoluble (g/L)	200 g/L sample	Insoluble (g/L)	220 g/L sample	Insoluble (g/L)	381 g/L sample	Insoluble (g/L)
Ca(H2PO4)2*H2O	215	68	60.724	0.000	121.720	0.000	136.000	0.000	149.600	0.000	259.080	44.080
CaSO4	1	5	4.465	3.465	8.950	7.950	10.000	9.000	11.000	10.000	19.050	18.050
CaHPO4	0.4	11	9.823	9.423	19.690	19.290	22.000	21.600	24.200	23.800	41.910	41.510
SiO2	0	10	8.930	8.930	17.900	17.900	20.000	20.000	22.000	22.000	38.100	38.100
H2O	--	6	5.358	0.000	10.740	0.000	12.000	0.000	13.200	0.000	22.860	0.000
Total		100	89.3	21.818	179	45.140	200	50.600	220	55.800	381	141.740
Calc. Insol.(%)				24.43		25.22		25.30		25.36		37.20
Meas. Insol.(%)				24.96		26.70		33.86		33.93		41.50

Chemical	Soluble (g/L)	Proport. (%)	500 g/L sample	Insoluble (g/L)	714 g/L sample	Insoluble (g/L)
Ca(H2PO4)2*H2O	215	68	340.000	125.000	485.520	270.520
CaSO4	1	5	25.000	24.000	35.700	34.700
CaHPO4	0.4	11	55.000	54.600	78.540	78.140
SiO2	0	10	50.000	50.000	71.400	71.400
H2O	--	6	30.000	0.000	42.840	0.000
Total		100	500	253.600	714	454.760
Calc. Insol.(%)				50.72		63.69
Meas. Insol.(%)				46.74		57.12


SUPERPHOSPHATE ANALYSIS
Insolubles Content
Insolubles (%)
70
60
50
40
30
20
10
0
0.1
1
10
100
1000
Superphosphate Concentration (g/L)
Calculated
Measured

APPENDIX K

Mortar Cube Drying Rate Observations

MORTAR CUBE OBSERVATIONS

Drying Rate of Cubes

Cube	Nov.12 Wet Wt. (g)	Nov.13 Dry Wt. (g)	Nov.16 Dry Wt. (g)	Nov.17 Dry Wt. (g)	Nov.18 Dry Wt. (g)	Nov.20 Dry Wt. (g)	Nov.23 Dry Wt. (g)	Nov.30 Dry Wt. (g)	Dec. 7 Dry Wt. (g)	Dec.14 Dry Wt. (g)	Feb.26 Dry Wt. (g)	Mar.22 Dry Wt. (g)
a1	273.93	268.38	264.22	263.42	262.89	261.99	261.06	258.86	257.59	256.80	253.92	253.70
a2	277.83	272.84	268.15	267.24	266.66	265.67	264.74	262.50	261.23	260.49	257.50	257.30
a3	277.78	273.01	268.20	267.29	266.69	265.67	264.72	262.49	261.19	260.45	257.33	257.16
a4	280.19	275.22	270.50	269.62	269.00	267.98	267.01	264.76	263.45	262.70	259.46	259.26
a5	281.44	276.12	271.57	270.71	270.13	269.12	268.19	265.98	264.68	263.94	260.66	260.46
a6	279.21	273.31	269.10	268.32	267.79	266.86	265.99	263.89	262.64	261.93	258.73	258.54
b1	278.09	273.05	268.68	267.75	267.14	266.16	265.17	262.91	261.61	260.85	257.79	257.51
b2	280.85	276.78	271.70	270.70	270.01	268.93	267.90	265.59	264.29	263.54		
b3	282.45	278.36	273.10	272.16	271.48	270.38	269.35	267.03	265.70	264.93	261.67	261.45
b4	282.72	278.30	273.51	272.56	271.88	270.77	269.75	267.47	266.15	265.38	262.10	261.88
b5	283.16	278.33	273.90	272.95	272.31	271.23	270.23	267.99	266.66	265.90		
b6	280.13	274.63	270.37	269.57	269.01	268.05	267.13	264.97	263.68	262.95	259.66	259.45
c1	283.14	277.84	273.33	272.50	271.90	270.92	269.93	267.65	266.32	265.57	262.42	262.12
c2	286.84	282.14	277.18	276.29	275.61	274.58	273.53	271.16	269.81	269.03	265.75	265.49
c3	288.39	283.78	278.71	277.81	277.16	276.09	275.05	272.70	271.36	270.59		
c4	291.13	286.24	281.41	280.50	279.84	278.72	277.68	275.30	273.93	273.15		
c5	290.36	285.32	280.67	279.76	279.09	277.99	276.98	274.67	273.31	272.53	269.09	268.86
c6	283.64	278.33	273.82	273.01	272.44	271.46	270.53	268.33	267.04	266.30		
d1	275.69	270.14	265.87	265.10	264.56	263.67	262.75	260.59	259.32	258.60	255.51	255.21
d2	280.60	275.55	270.99	270.13	269.51	268.49	267.50	265.22	263.92	263.18	260.05	259.82
d3	280.88	276.05	271.48	270.64	270.00	268.94	267.93	265.65	264.34	263.59		
d4	282.23	277.27	272.80	271.96	271.35	270.30	269.30	267.04	265.73	264.97		
d5	281.39	276.53	271.89	271.09	270.49	269.46	268.48	266.26	264.95	264.20		
d6	280.30	275.02	270.38	269.61	269.06	268.09	267.16	265.02	263.75	263.03	259.73	259.51
e1	273.36	267.68	263.46	262.71	262.20	261.30	260.41	258.30	257.04	256.34		
e2	278.26	273.21	268.62	267.78	267.19	266.21	265.28	263.10	261.83	261.10	257.94	257.71
e3	281.92	277.16	272.61	271.78	271.18	270.14	269.14	266.88	265.55	264.79	261.50	261.26
e4	282.82	277.68	273.31	272.48	271.88	270.83	269.84	267.56	266.24	265.49	262.17	261.95
e5	282.16	277.09	272.64	271.85	271.26	270.21	269.23	267.01	265.70	264.49		
e6	283.88	278.34	273.88	273.08	272.51	271.52	270.61	268.46	267.18	266.44	263.07	262.90
f1	274.66	268.96	264.89	264.16	263.66	262.81	261.94	259.89	258.67	257.96	254.71	254.40
f2	280.06	274.71	270.19	269.42	268.88	267.98	267.07	264.97	263.72	263.00		
f3	283.13	277.85	273.18	272.38	271.83	270.89	269.96	267.83	266.54	265.81	262.51	262.24
f4	285.14	279.49	275.12	274.41	273.82	272.84	271.89	269.74	268.46	267.72	264.35	264.12
f5	285.18	279.46	275.14	274.43	273.81	272.81	271.89	269.73	268.46	267.73	264.43	264.17
f6	285.79	279.77	275.51	274.71	274.17	273.22	272.33	270.21	268.94	268.20		

MORTAR CUBE OBSERVATIONS

Drying Rate of Cubes

Cube	0 Days Wt.Loss (%)	1 Day Wt.Loss (%)	4 Days Wt.Loss (%)	5 Days Wt.Loss (%)	6 Days Wt.Loss (%)	8 Days Wt.Loss (%)	11 Days Wt.Loss (%)	18 Days Wt.Loss (%)	25 Days Wt.Loss (%)	32 Days Wt.Loss (%)	106 Days Wt.Loss (%)	130 Days Wt.Loss (%)
a1	0.00	2.03	3.54	3.84	4.03	4.36	4.70	5.50	5.97	6.25	7.30	7.39
a2	0.00	1.80	3.48	3.81	4.02	4.38	4.71	5.52	5.97	6.24	7.32	7.39
a3	0.00	1.72	3.45	3.78	3.99	4.36	4.70	5.50	5.97	6.24	7.36	7.42
a4	0.00	1.77	3.46	3.77	3.99	4.36	4.70	5.51	5.97	6.24	7.40	7.47
a5	0.00	1.89	3.51	3.81	4.02	4.38	4.71	5.49	5.96	6.22	7.38	7.45
a6	0.00	2.11	3.62	3.90	4.09	4.42	4.73	5.49	5.93	6.19	7.33	7.40
b1	0.00	1.81	3.38	3.72	3.94	4.29	4.65	5.46	5.93	6.20	7.30	7.40
b2	0.00	1.45	3.26	3.61	3.86	4.24	4.61	5.43	5.90	6.16		
b3	0.00	1.45	3.31	3.64	3.88	4.27	4.64	5.46	5.93	6.20	7.36	7.43
b4	0.00	1.56	3.26	3.59	3.83	4.23	4.59	5.39	5.86	6.13	7.29	7.37
b5	0.00	1.71	3.27	3.61	3.83	4.21	4.57	5.36	5.83	6.10		
b6	0.00	1.96	3.48	3.77	3.97	4.31	4.64	5.41	5.87	6.13	7.31	7.38
c1	0.00	1.87	3.46	3.76	3.97	4.32	4.67	5.47	5.94	6.21	7.32	7.42
c2	0.00	1.64	3.37	3.68	3.92	4.27	4.64	5.47	5.94	6.21	7.35	7.44
c3	0.00	1.60	3.36	3.67	3.89	4.27	4.63	5.44	5.91	6.17		
c4	0.00	1.68	3.34	3.65	3.88	4.26	4.62	5.44	5.91	6.18		
c5	0.00	1.74	3.34	3.65	3.88	4.26	4.61	5.40	5.87	6.14	7.33	7.40
c6	0.00	1.87	3.46	3.75	3.95	4.29	4.62	5.40	5.85	6.11		
d1	0.00	2.01	3.56	3.84	4.04	4.36	4.69	5.48	5.94	6.20	7.32	7.43
d2	0.00	1.80	3.42	3.73	3.95	4.32	4.67	5.48	5.94	6.21	7.32	7.41
d3	0.00	1.72	3.35	3.65	3.87	4.25	4.61	5.42	5.89	6.16		
d4	0.00	1.76	3.34	3.64	3.86	4.23	4.58	5.38	5.85	6.12		
d5	0.00	1.73	3.38	3.66	3.87	4.24	4.59	5.38	5.84	6.11		
d6	0.00	1.88	3.54	3.81	4.01	4.36	4.69	5.45	5.90	6.16	7.34	7.42
e1	0.00	2.08	3.62	3.90	4.08	4.41	4.74	5.51	5.97	6.23		
e2	0.00	1.81	3.46	3.77	3.98	4.33	4.66	5.45	5.90	6.17	7.30	7.39
e3	0.00	1.69	3.30	3.60	3.81	4.18	4.53	5.33	5.81	6.08	7.24	7.33
e4	0.00	1.82	3.36	3.66	3.87	4.24	4.59	5.40	5.86	6.13	7.30	7.38
e5	0.00	1.80	3.37	3.65	3.86	4.24	4.58	5.37	5.83	6.26		
e6	0.00	1.95	3.52	3.80	4.01	4.35	4.67	5.43	5.88	6.14	7.33	7.39
f1	0.00	2.08	3.56	3.82	4.00	4.31	4.63	5.38	5.82	6.08	7.26	7.38
f2	0.00	1.91	3.52	3.80	3.99	4.31	4.64	5.39	5.83	6.09		
f3	0.00	1.86	3.51	3.80	3.99	4.32	4.65	5.40	5.86	6.12	7.28	7.38
f4	0.00	1.98	3.51	3.76	3.97	4.31	4.65	5.40	5.85	6.11	7.29	7.37
f5	0.00	2.01	3.52	3.77	3.99	4.34	4.66	5.42	5.86	6.12	7.28	7.37
f6	0.00	2.11	3.60	3.88	4.07	4.40	4.71	5.45	5.90	6.15		
Avg.	0.00	1.82	3.44	3.74	3.95	4.31	4.65	5.44	5.90	6.17	7.32	7.40

Ca-Phosphate Absorption by Cubes

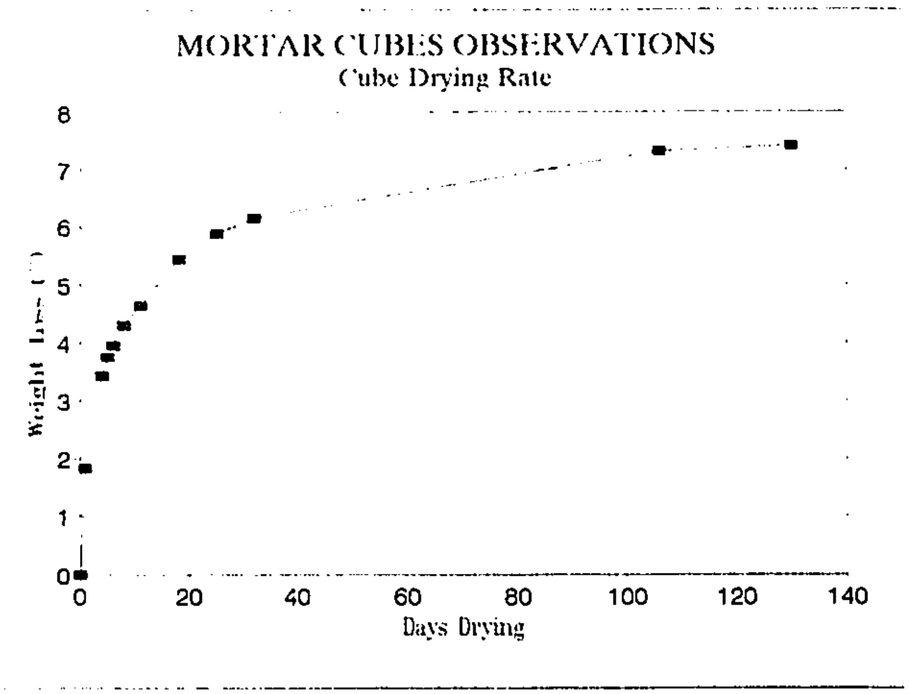
Solution	Cube	Dry Cube Weight (g)	Saturated Cube Wt. (g)	Solution Sorbed Wt. (g)	Contain. Wt. (g)	Solution + Contain. Wt. (g)	Dish Wt. (g)	Solution + Dish Wt. (g)	Remain. Solution Wt. (g)	No. of Solution Drops Used	Drops Wt. (g)
0.001-1	b2	263.09	281.07	17.98	29.82	147.13	64.15	64.95	118.11	46	1.11
0.001-2	d4	264.50	282.47	17.97	30.01	147.22	66.88	67.32	117.65	46	1.11
0.001-3	c6	265.83	283.73	17.90	29.80	147.15	64.02	64.96	118.29	46	1.11
0.01-1	c3	270.10	288.65	18.55	29.98	146.69	79.97	80.91	117.65	46	1.11
0.01-2	e5	264.49	282.79	18.30	29.53	146.94	65.33	66.36	118.44	46	1.11
0.01-3	f6	267.77	286.26	18.49	29.67	146.30	71.29	72.64	117.98	46	1.11
0.05-1	b5	265.43	285.16	19.73	30.03	146.92	64.22	64.74	117.41	46	1.11
0.05-2	f2	262.56	282.19	19.63	30.00	145.72	64.49	66.17	117.40	46	1.11
0.05-3	d3	263.14	282.81	19.67	30.00	146.67	63.60	64.39	117.46	46	1.11
0.1-1	e1	255.90	276.49	20.59	29.79	144.74	82.37	83.95	116.53	46	1.11
0.1-2	c4	272.65	293.89	21.24	29.80	144.91	63.95	65.20	116.36	46	1.11
0.1-3	d5	263.72	284.32	20.60	29.82	146.85	76.34	77.32	118.01	46	1.11

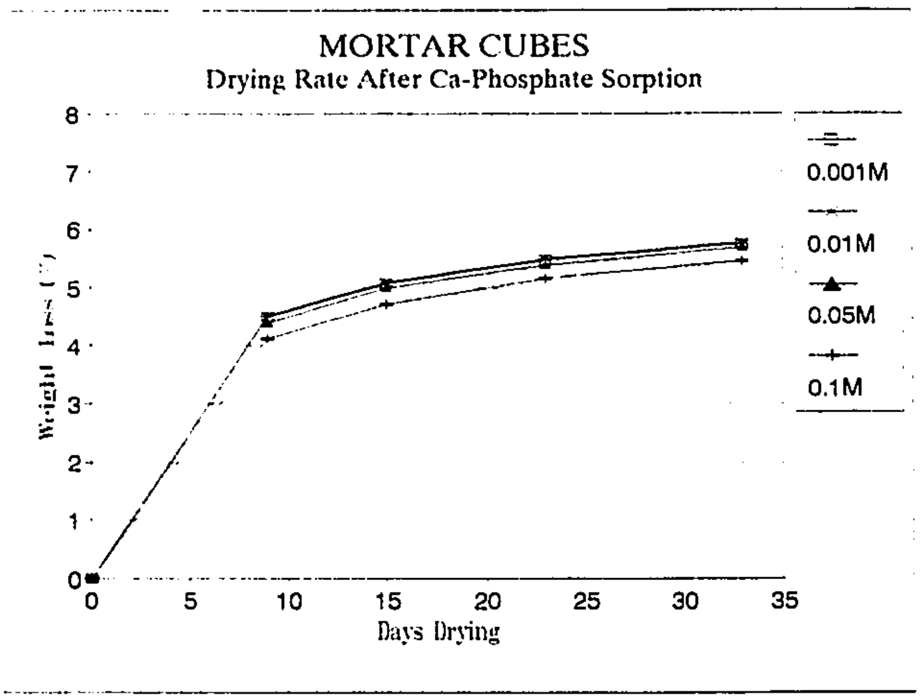
Solution	Cube	Total Solution Accounted Wt. (g)	Initial Solution Wt. (g)	Total Solution Missing Wt. (g)	Diff. of Sorbed Vs. Missing Wt. (g)
0.001-1	b2	119.22	139.44	20.22	-2.24
0.001-2	d4	118.76	139.44	20.68	-2.71
0.001-3	c6	119.40	139.44	20.04	-2.14
0.01-1	c3	118.76	140.00	21.24	-2.69
0.01-2	e5	119.55	140.00	20.45	-2.15
0.01-3	f6	119.09	140.00	20.91	-2.42
0.05-1	b5	118.52	140.98	22.46	-2.73
0.05-2	f2	118.51	140.98	22.47	-2.84
0.05-3	d3	118.57	140.98	22.41	-2.74
0.1-1	e1	117.64	142.52	24.88	-4.29
0.1-2	c4	117.47	142.52	25.05	-3.81
0.1-3	d5	119.12	142.52	23.40	-2.80

Ca-Phosphate Absorption - Cube Drying Rate

Solution	Cube	Dec.18 Dry Cube Weight (g)	Feb.17 Saturated Cube Wt. (g)	Feb.26 Dry Wt. (g)	Mar.4 Dry Wt. (g)	Mar.12 Dry Wt. (g)	Mar.22 Dry Wt. (g)
0.001-1	b2	263.09	281.07	268.36	266.72	265.64	264.85
0.001-2	d4	264.50	282.47	269.76	268.10	267.00	266.20
0.001-3	c6	265.83	283.73	271.08	269.43	268.31	267.52
0.01-1	c3	270.10	288.65	275.74	274.00	272.86	272.04
0.01-2	e5	264.49	282.79	270.13	268.38	267.22	266.37
0.01-3	f6	267.77	286.26	273.14	271.71	270.55	269.69
0.05-1	b5	265.43	285.16	272.67	270.90	269.78	268.95
0.05-2	f2	262.56	282.19	269.91	268.13	267.00	266.12
0.05-3	d3	263.14	282.81	270.36	268.66	267.51	266.68
0.1-1	e1	255.90	276.49	264.83	263.11	261.97	261.18
0.1-2	c4	272.65	293.89	281.84	280.22	278.79	277.87
0.1-3	d5	263.72	284.32	272.72	271.01	269.83	268.94

Solution	Cube	36 Days Sat.Wt. Gain(%)	0 Days Wt.Loss (%)	9 Days Wt.Loss (%)	15 Days Wt.Loss (%)	23 Days Wt.Loss (%)	33 Days Wt.Loss (%)
0.001-1	b2	6.83	0.00	4.52	5.11	5.49	5.77
0.001-2	d4	6.79	0.00	4.50	5.09	5.48	5.76
0.001-3	c6	6.73	0.00	4.46	5.04	5.43	5.71
0.01-1	c3	6.87	0.00	4.47	5.08	5.47	5.75
0.01-2	e5	6.92	0.00	4.48	5.10	5.51	5.81
0.01-3	f6	6.91	0.00	4.58	5.08	5.49	5.79
0.05-1	b5	7.43	0.00	4.38	5.00	5.39	5.68
0.05-2	f2	7.48	0.00	4.35	4.98	5.38	5.69
0.05-3	d3	7.48	0.00	4.40	5.00	5.41	5.70
0.1-1	e1	8.05	0.00	4.22	4.84	5.25	5.54
0.1-2	c4	7.79	0.00	4.10	4.65	5.14	5.45
0.1-3	d5	7.81	0.00	4.08	4.68	5.10	5.41
0.001M	average	6.79	0.00	4.49	5.08	5.47	5.75
0.01M	average	6.90	0.00	4.51	5.08	5.49	5.78
0.05M	average	7.46	0.00	4.38	5.00	5.40	5.69
0.1M	average	7.88	0.00	4.13	4.72	5.16	5.47


MORTAR CUBES OBSERVATIONS
Cube Drying Rate
Weight Loss (%)
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
Days Drying


MORTAR CUBES
Drying Rate After Ca-Phosphate Sorption
Weight Loss (%)
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30
35
Days Drying
0.001M
0.01M
0.05M
0.1M

APPENDIX L

Calcium Phosphate Absorption Analysis

CALCIUM PHOSPHATE ABSORPTION ANALYSIS

Time	RRI (%) for Distilled-Deionized Water		Relative Refractive Index (%) 0.001M			0.01M			0.05M			0.1M		
(sec)	Initial	Final	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3	Trial1	Trial2	Trial3
0	-0.4	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1	-0.1	1.2	1.2	1.3	2.7	2.7	2.7
20	-0.4	-0.4	-0.4	-0.4	-0.4	0.0	0.0	0.0	1.3	1.4	1.4	2.8	2.8	2.9
100	-0.4	-0.4	-0.4	-0.4	-0.4	0.0	0.0	0.0	1.3	1.3	1.3	2.8	2.8	2.7
1000	-0.4	-0.4	-0.4	-0.4	-0.4	-0.1	-0.1	0.0	1.3	1.3	1.2	2.7	2.7	2.7
5000	-0.4	-0.4	-0.3	-0.3	-0.2	0.1	0.1	0.1	1.3	1.3	1.3	2.8	2.8	2.7
10000	-0.3	-0.3	-0.3	-0.3	-0.3	0.0	0.0	0.0	1.2	1.2	1.2	2.7	2.6	2.7
40000	-0.2	-0.6	-0.3	-0.5	-0.5	-0.4	-0.4	-0.4	0.5	0.5	0.6	2.2	2.2	2.2
100000	-0.2	-0.6	-0.3	-0.3	-0.3	-0.3	-0.3	-0.4	0.5	0.5	0.5	2.1	1.9	1.9
210000	0.0	-0.6	-0.3	-0.3	-0.4	-0.4	-0.4	-0.4	0.1	0.1	0.1	1.6	1.6	1.6
450000	-0.2	-0.7	-0.4	-0.4	-0.5	-0.5	-0.5	-0.5	-0.1	0.0	-0.1	1.3	1.3	1.3
850000	-0.2	-0.7	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.2	-0.2	-0.1	1.1	1.0	1.1
1500000	0.0	-0.6	0.0	-0.1	-0.1	-0.1	-0.2	-0.2	0.1	0.1	0.1	0.8	0.7	0.8
2500000	-0.4	-0.8	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3	0.0	0.0	-0.1	0.4	0.4	0.5
5000000	-0.7	-0.8	-0.4	-0.4	-0.3	-0.2	-0.2	-0.2	-0.1	-0.1	0.0	0.3	0.3	0.3

Time	Average Corrected Relative Refractive Index (%)				Concentration (M) Variation over Time				pH Variation over Time			
(sec)	0.001M	0.01M	0.05M	0.1M	0.001M	0.01M	0.05M	0.1M	0.001M	0.01M	0.05M	0.1M
0	0.00	0.30	1.63	3.10	0.0010	0.010	0.056	0.107	4	3.5	2.5	2.5
20	0.00	0.40	1.77	3.23	0.0010	0.014	0.061	0.111				
100	0.00	0.40	1.70	3.17	0.0010	0.014	0.059	0.109				
1000	0.00	0.33	1.67	3.10	0.0010	0.011	0.057	0.107				
5000	0.13	0.50	1.70	3.17	0.0046	0.017	0.059	0.109				
10000	0.00	0.30	1.50	2.97	0.0010	0.010	0.052	0.102				
40000	-0.17	-0.05	0.98	2.74	0.0000	0.000	0.034	0.094				
100000	-0.04	0.02	0.95	2.51	0.0000	0.001	0.033	0.086				
210000	-0.24	-0.17	0.47	2.11	0.0000	0.000	0.016	0.073				
450000	-0.16	-0.11	0.44	1.92	0.0000	0.000	0.015	0.066				
850000	0.04	0.03	0.34	1.69	0.0015	0.001	0.012	0.058				
1500000	0.03	0.06	0.47	1.27	0.0009	0.002	0.016	0.044	10	9	5.5	4.5
2500000	0.16	0.25	0.61	1.17	0.0056	0.009	0.021	0.040	11	10	8	4.5
5000000	0.35	0.54	0.69	1.08	0.0120	0.019	0.024	0.037				

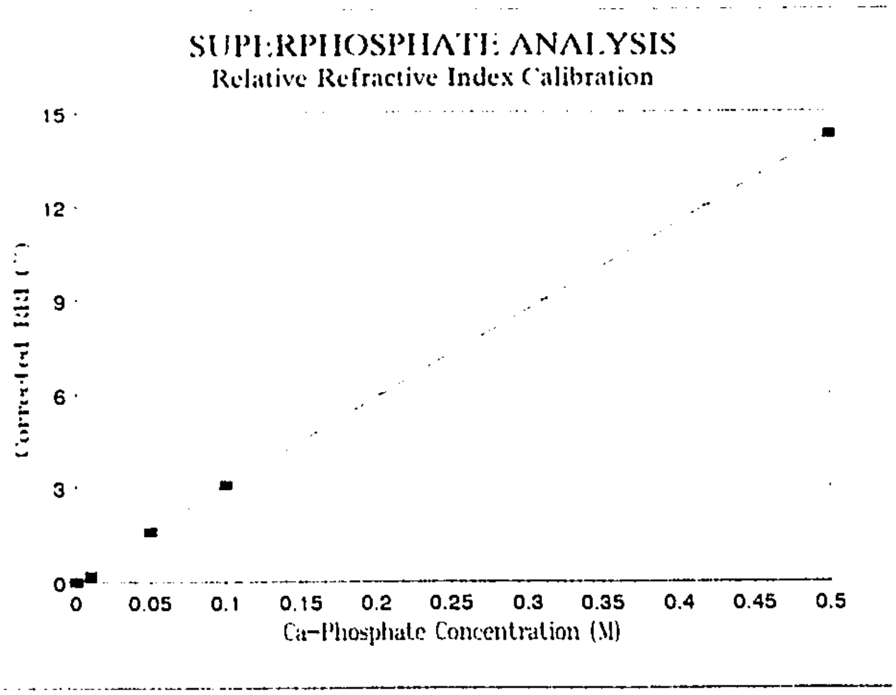
CALCIUM PHOSPHATE ABSORPTION ANALYSIS

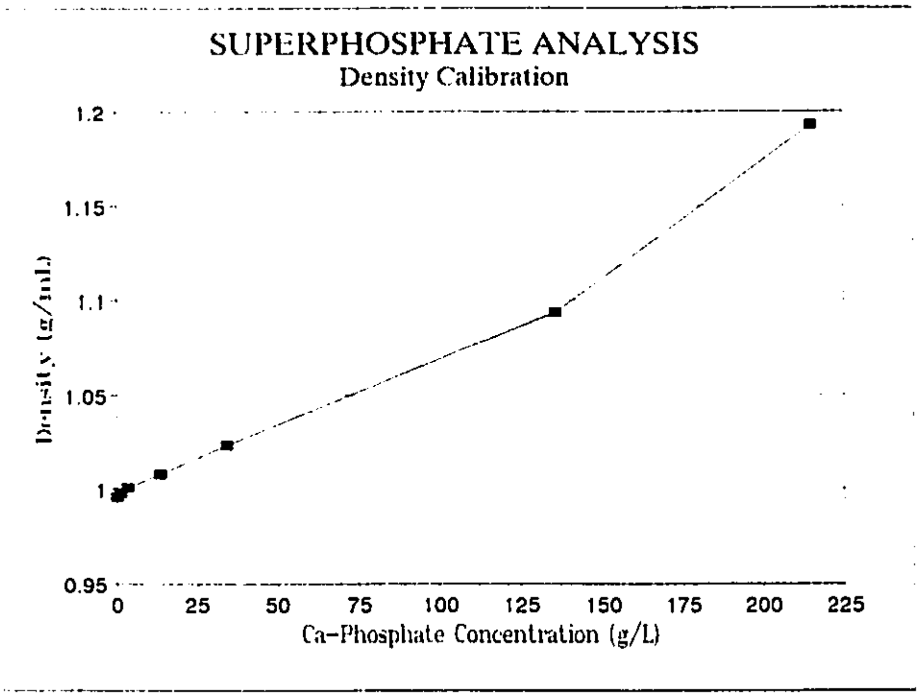
RRI Calibration

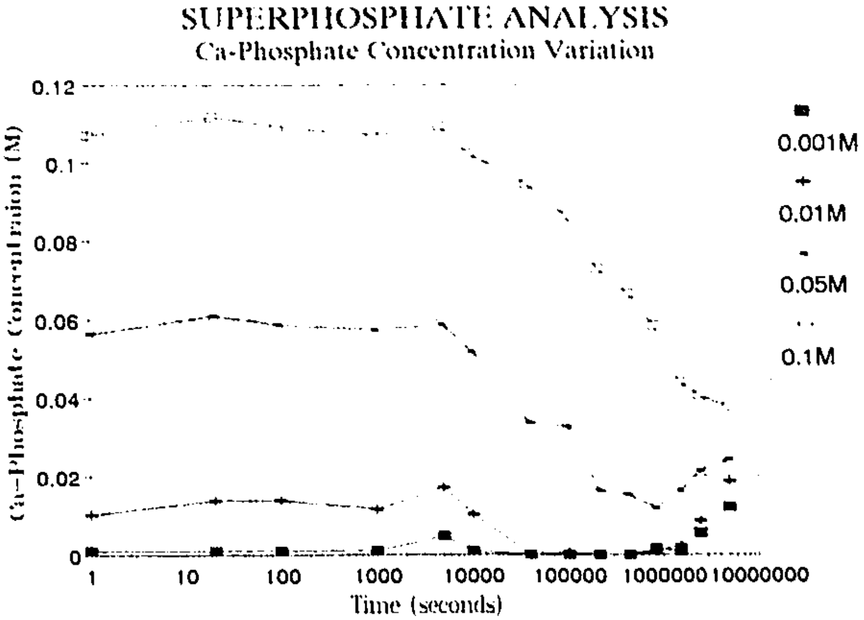
Ca-Phosphate Concentraion (M)	RRI (%)			Avg. RRI(%)	Correct Avg. RRI(%)
	Trial 1	Trial 2	Trial 3		
0	-0.6	-0.6	-0.6	-0.6	0.0
0.0001	-0.6	-0.6	-0.6	-0.6	0.0
0.001	-0.6	-0.6	-0.6	-0.6	0.0
0.01	-0.4	-0.4	-0.4	-0.4	0.2
0.05	1.0	1.0	1.0	1.0	1.6
0.1	2.5	2.5	2.5	2.5	3.1
0.5	13.8	13.6	13.6	13.7	14.3

Ca-Phosphate Density Calibration

Ca-Phosphate Concentraion (g/L)	Density (g/mL)
0	0.996
1.36	0.998
3.4	1.001
13.6	1.008
34	1.023
136	1.093
215	1.193


SUPERPHOSPHATE ANALYSIS
Relative Refractive Index Calibration
Corrected RRI (°)
15
12
9
6
3
0
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Ca-Phosphate Concentration (M)


SUPERPHOSPHATE ANALYSIS
Density Calibration
Density (g/mL)
1.2
1.15
1.1
1.05
1
0.95
0
25
50
75
100
125
150
175
200
225
Ca-Phosphate Concentration (g/L)


SUPERPHOSPHATE ANALYSIS
Ca-Phosphate Concentration Variation
Ca-Phosphate Concentration (M)
0.12
0.1
0.08
0.06
0.04
0.02
0
1
10
100
1000
10000
100000
1000000
10000000
Time (seconds)
■ 0.001M
+ 0.01M
- 0.05M
· · 0.1M

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