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DIMENSIONAL STABILITY OF FLY ASH CONCRETE UNDER FREEZE-THAW ACTION IN SALINE WATER

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Abstract*- under Freezing Thawing actions, leaching of calcium hydroxide produced during the hydration of Portland cement, provides greater voids thereby aggravating the rate of deterioration. Upon freezing, water expands 9% in volume and generates high pressure inside concrete that provides easier paths for water to penetrate into the concrete, resulting in greater disintegration as freeze/thaw cycles continue. The performance of concrete with fly ash is found to be improved as compared to Portland cement concretes as fly ash combines with calcium hydroxide to produce additional cementitious materials, thereby reducing the amount of leachable calcium hydroxide. As a result, permeability and porosity are reduced and also fly ash fills the minute voids and creates a denser and less absorptive concrete. This Paper investigated dimensional stability i.e. visual examination, weight change and volume change properties of concrete with and without fly ash, with special focus on freeze/thaw resistance. Two different grades of concrete M28 and M38, each with five different cement replacement levels 0, 20, 30, 40 and 60% were studied in plain water as well as in saline water over 90 freeze-thaw cycles. Test results show that fly ash concrete has better resistance on dimensional stability in both ambient temperature conditions as well as under freeze-thaw action which may inhibit the penetration of aggressive species in concrete thereby increasing its durability.*

Keywords: Durability, Dimensional stability, Fly ash, Freeze/thaw, Saline water.

1. INTRODUCTION

Concrete deterioration for freeze-thaw cyclic action has been a major problem in cooler areas of different countries. Freeze-thaw deterioration begins when water enters into the voids of concrete. Leaching of calcium hydroxide, which is produced during the hydration of portland cement, provides greater voids for water to occupy, thereby aggravating the rate of deterioration. Freezing of water or salt solution in the concrete pores may cause severe deterioration and considerable reduction of service life. It is commonly known that plain water freezes at 0°C under normal atmospheric pressure. When water freezes, the volume increases by 9% as water turns to ice, generating high pressure in the adjacent concrete. However, water that is trapped within the capillary pores of concrete does not necessarily freeze at 0°C. The temperature at which water freezes in capillary pores is a function of the size of the pores and pore chemistry. As pore size decreases, the temperature required to freeze the water also decreases [1].

The marine environment is characterized by typical aggressive loading of various soluble salts in sea water. Typically, sea water contains about 3.5% soluble salts by weight [2]. The relative ionic concentrations are 18 gpl Cl^-, 12 gpl Na^+, 2.6 gpl $(SO_4)^{2-}$, 1.4 gpl Mg^{2+} and 0.5 gpl Ca^{2+}. Normally, pH of sea water is about 8. In a marine environment, in addition to its presence in original mix, the chloride ion penetrates into the concrete either from sea water or sea winds carrying sea salts and reacts with the hydrated cement products which produces complex compounds including Friedels salt which are leachable and expansive in nature. The chloride attacks also destroy the passivity of steel and lead to the initiation of rebar corrosion. On the other hand, the penetration of sulphate ions attack the hydrated cement matrix with the formation of gypsum and a complex compound known as calcium sulphoaluminate (ettringite).

In the region with cold climate, the freeze-thaw damage is the most important issue among the durability problems in concrete structures, such as dams, hydraulic and offshore structures, and bridges and highway pavements, during their service. One of the advances in concrete technology is the development of fly ash concrete and its use in it. Fly ash is a by-product from combustion of pulverized coal. As the coal is heated to high temperatures, it liquefies. It is thereafter cooled rapidly, which forms spherical particles. The fly ash consists mainly of silica (SiO_2), aluminium oxide (Al_2O_3), iron oxide (Fe_2O_3) and calcium oxide (CaO). Use of fly ash improves the workability of concrete slurry, reduce the heat of hydration of cement and increase the strength of concrete with age; therefore, it can improve the mechanical properties and durability of concrete [3].

Fly ash combines with calcium hydroxide to produce additional cementitious materials, thereby reducing the amount of calcium hydroxide that may be leached out of the concrete. Leaching of the calcium hydroxide increases concrete voids which can accelerate freeze-thaw damage. As a result, permeability and porosity are reduced. Fly ash also fills the minute voids creating a denser and less absorptive concrete. It reduces the amount of water required in the mix by approximately 2% to 10%, because the spherical shape of the fly ash particles reduces bleed channels and void spaces. Reduction of bleed channels limits the entrance of water; fewer void spaces mean less space for water to accumulate. High quality fly ash also produces more cohesive concrete which holds entrained air inside the concrete. Fly ash helps to produce higher compressive strengths in the long term that provide a strong concrete which resists the forces generated during the freezing of water in the voids. As a whole fly ash concrete is more stable, uniform, dense, less absorptive and less permeable—all factors which improve freeze-thaw durability. The performance of concrete with additions of fly ash is in many situations improved compared to that of concrete mixed with Portland cement only.

Penetration of chloride ions is also dependent on the permeability of the concrete; a more permeable concrete will lead to less resistance against penetration [4]. Concrete with fly ash has shown better resistance against chloride penetration than concrete with ordinary Portland cement. This is partly due to that fly ash creates a denser structure, which reduces the permeation and also concrete with fly ash binds the chloride ions better, thus leaving fewer ions free [5]. The active alumina (Al_2O_3), which exists in larger amounts in fly ash than in Portland cement, is able to bind the chloride ions. According to Dhir [5], the binding capacity was found to be at maximum at a replacement of fly ash of 50% of the cement, but optimum at about 30%. Concrete with fly ash replacing 33% of the cement, the binding capacity was four times larger than for ordinary Portland cement. Furthermore, the binding capacity increased with the concentrations of chloride ions. Replacement of the cement by 30% fly ash was found to improve the resistance against chloride ions with two to four times. A more mature concrete will be less permeable, thus more resistance regarding chloride ingress.

The key to prevention of sulfate attack is to tie up the free lime and calcium aluminates to eliminate the possibility of ongoing reactions. Increased sulfate resistance of concrete containing fly ash may be explained by the reaction of silica, alumina and ferric oxide found in fly ash with calcium hydroxide liberated during the hydration of Portland cement to form relatively stable cementitious compounds. Greater impermeability of such type of concrete reduces penetration of sulfate solutions and results in improved resistance to sulfate attack. Fly ash not only reduces the permeability of the concrete, but because of reaction of these materials with available alkalis, it removes that essential component required for Alkali Aggregate reaction (AAR) and thus it is an effective means of reduction the risk of AAR occurring.

2. STUDIES ON FREEZE-THAW ACTIONS

Naik et al. [6] investigated freezing and thawing resistance of high-volume Class C and Class F fly ash paving concretes. The concrete mixtures were proportioned with of 20 and 50% Class C fly ash, and 40% Class F fly ash. The 40% Class F fly ash concrete mixture exhibited the highest durability factor amongst all the three mixtures tested. The average durability factor for the 50 percent Class C fly ash mixture was 90.

Drahushak-Crow and von Fay [7] studied freezing and thawing durability of concretes made with three different fly ashes. Fly ash concrete mixtures were proportioned for five different cement replacement levels (10, 30, 50, 75, 100 %) with fly ash. The number of cycles to failure depended greatly upon type of fly ash, amount of cementitious content, and type of curing.

As per Schießl [8], air entrained concrete with 30% of the cement replaced with fly ash on a one-to-one basis, showed less good resistance regarding freeze/thaw on the surface than concrete without fly ash. However, the level of scaling was at an acceptable level. The resistance was further improved by prolonged curing.

Müller [9] tested air entrained concrete with different amount of fly ash in blended cement (0%, 20%, 30% and 35%). All mixtures had significantly less scaling at the surface than what is acceptable. The concretes with 0%, 20% and 30% showed similar behaviour, whereas the concrete with 35% showed slightly worse.

Bortz [10] studied the influence of source of fly ash on the durability regarding scaling under freeze/thaw. The source of the fly ash, which affects the properties of the fly ash, had high impact on the resistance of freeze/thaw scaling. The amount of fly ash was 67% of cement content and it replaced the cement on a one-to-one basis.

The freeze-thaw action on structural concrete in the splash/tidal zone has its own characteristics and is dependent on ambient air and sea water temperature. In addition, the chemical attack of the sea water on the cement constituents is found to lead to a more pronounced deterioration in the concrete structure. The major aim of this work is to evaluate the freezing and thawing durability of concrete made with Class F fly ash. The properties evaluated were the weight change, volume change, compressive strength, water permeability, RCPT and freezing and thawing resistance of concrete with or without fly ash. The results of this investigation would provide data for establishing appropriate mix proportions for concretes subjected to freezing and thawing resistance against sea water and deicer salts.

3. EXPERIMENTAL PROGRAM

The experimental program was planned to study the suitability of fly ash as partial replacement of cement in making structural concrete taking into consideration of dimensional stability of hardened concrete exposed to Freezing-Thawing environment in plain as well as sea water.

3.1 Materials Used

Concrete test specimens were cast using ASTM type-I Ordinary Portland cement (OPC), ASTM Class F Fly ash collected from Boropukuria Power Plant, Bangladesh, crushed gravel as coarse aggregate and natural river sand as fine aggregate. **Table 1** provides chemical compositions of the OPC and Boropukuria fly ash. 12.5 mm downgraded crushed stone, with fineness modulus 6.58 and specific gravity 2.70, was used as coarse aggregate. The fine aggregate was river sand with fineness modulus 2.58 and specific gravity 2.61.

Table 1 : Chemical composition (%) of ordinary portland cement and fly ash

Constituents	Compo-sition	OPC	FA
Calcium Oxide	CaO	65.18	0.65
Silicon Di-Oxide	SiO_2	20.80	51.49
Aluminum Oxide	Al_2O_3	5.22	31.60
Ferric Oxide	Fe_2O_3	3.15	2.80
Magnesium Oxide	MgO	1.16	0.28
Sulfur Tri-Oxide	SO_3	2.19	0.19
Sodium Oxide	Na_2O	--	0.18
Loss on Ignition	--	1.70	4.2
Insoluble Residue	--	0.6	--

-- = not measured items.

3.2 Mix Design and Sample Preparation

Two different grades of concrete namely M28 and M38 were used in the program. Five different mix proportions of cement fly ash (100:0, 80:20, 70:30, 60:40 and 40:60) were used as cementitious material. Thus the fly ash concrete means the concrete made by using cement and fly ash as cementitious material with sand, stone chips and water. Relevant information of different concrete mixes is given in **Table 2.** M38FA60 means grade of concrete is 38 and cement fly ash ratio is 40:60. Cubical specimens of 100 mm size were prepared according to the mix proportion as described. The specimens were demoulded after 24 hours of casting and cured in plain water at 27±2°C.

Table 2 : Mix proportions and properties of fresh concrete

Mixture constituent & properties (kg/m^3)	Grade of Concrete	
	M28	**M38**
Cement	435	500
Water	218	218
Sand	545	520
Stone Chips	1150	1120
w/(c+fa)	0.50	0.44
Slump (mm)	68	60
Air content %	1.3	1.1

3.3 Variables Studied

Plain water (PW) as well as artificially made sea water (SW) were used for curing the specimens. SW was made by mixing tap water with exact amount and proportion of principal salts found in natural sea water. Freezing-Thawing arrangement was created in a freeze-thaw chamber. In each freeze-thaw cycle, the temperature was varied from (-17.8^{0}C) to (+4.4^{0}C) over a total period of 24 hours (8+4 hours for freezing and thawing; 7+5 hours kept at two terminal temperatures) **(Refer to Plate No.1)**. 30 and 90 freeze-thaw cycles after 28 days of procuring in plain water.

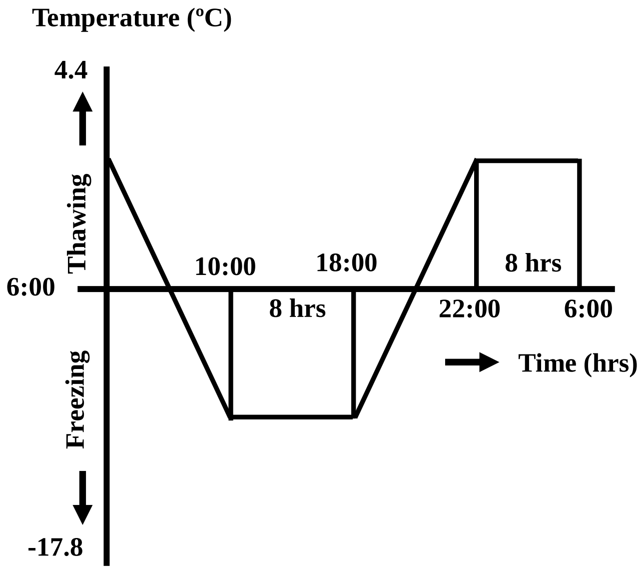

Plate no.1: Schematic Freeze-Thaw Cvcle

3.4 Experimental Procedures

In ASTM C 666, two procedures of freezing-thawing test are defined: Procedure A, rapid freezing and thawing in water, and Procedure B, rapid freezing in air and thawing in water. In this study, the Procedure A was used and according to this procedure, the temperature of the curing water condition concrete specimens was lowered from 4 to -17.8 °C and raised it from -17.8 to 4 °C in 4 hours. This Paper investigates about visual examination, weight change and volume change properties of concrete with and without fly ash, with special focus on freeze/thaw resistance

4. RESULTS AND DISCUSSION

Concrete specimens exposed in the sea water and plain water is taken out after specific cycles of freeze-thaw, for conducting various tests. The concrete specimens subjected upto 90 cycles of freeze-thaw actions in the submerged state of plain water and sea water are shown in **Plate No.2 to plate No.9.** A visual examination showed that most of the specimens exposed to sea water lost their dimensional stability with substantial erosion and tended to become uneven. Some changes in color from the original dark gray to lime gray of the specimens in sea water have also been observed which indicates either the salts deposition on the concrete surfaces or leaching out of portlandite, $Ca(OH)_2$. Also interior surfaces have indicted a higher level of saturation with increasing number of freeze-thaw cycles both in sea and plain water environments.

Plate no. 2: OPC Concrete specimens after 30 cycles of freezing and thawing in PW

Plate no. 3: FA Concrete specimens after 30 cycles of freezing and thawing in PW

Plate no. 4: OPC Concrete specimens after 30 cycles of freezing and thawing in SW

Plate no. 5: FA Concrete specimens after 30 cycles of freezing and thawing in SW

Plate no. 6: OPC Concrete specimens after 90 cycles of freezing and thawing in PW

Plate no. 7: FA Concrete specimens after 90 cycles of freezing and thawing in PW

Plate no. 8: OPC Concrete specimens after 90 cycles of freezing and thawing in SW

Plate no. 9: OPC Concrete specimens after 90 cycles of freezing and thawing in SW

4.1 Weight Change

The change in weight of the specimens of concrete grade M38 and M28 in different exposure conditions and for various freeze-thaw cycles have been illustrated in **Fig.1** and **Fig.2** respectively. A close examination reveals that at the end of 30 cycles of freeze-thaw, the specimens in sea water exhibit a higher percentage (nearly 1.1 to 2.6%) of weight gain as compared to the plain water cured specimens (nearly 0.9 to 2.2%). This increase in weight may be primarily due to the ingress of sea water or plain water into the concrete. After 90 cycles, a significant difference in the trend of weight change for the concrete specimens exposed to sea water has been found to occur as compared to that for the specimens placed in plain water. In this condition plain water cured specimen exhibit higher percentage of weight gain as compared to sea water cured concrete. After 90 cycles of freeze-thaw, a considerable change (loss) in the weight lying between 0.1 and 1.1% is observed for the concretes exposed to the plain water environment whereas for the similar specimens placed in sea water, this change is found to lie in the range of -0.8 to 1.4%. From the figure it is clear that higher grade concrete has better resistance against weight change compared to lower grade concrete in freeze-thaw action. Also it is seen that, fly ash concrete shows better resistance against weight change as compared to plain concrete particularly after long Freeze-Thaw loading. It may be due to the development of its resistance to water/salt ions penetration inside concrete as the rate of hydration of fly ash concrete in relatively slow.

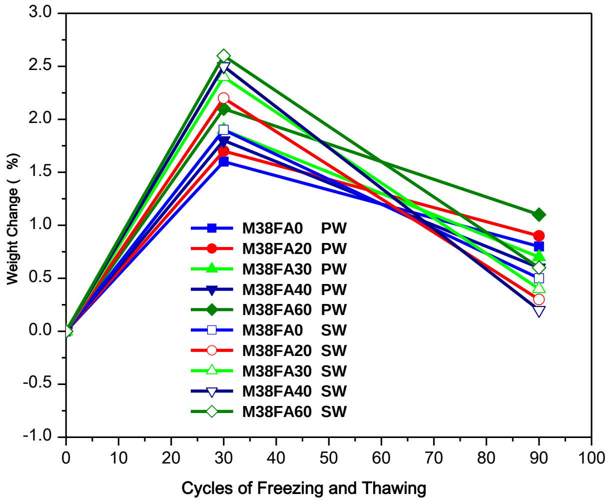

Fig.1: Weight Change - Freeze Thaw Relation for M38 Grade Concrete

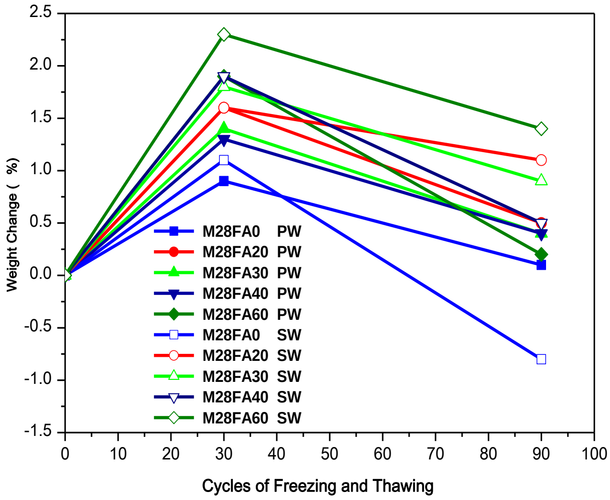

Fig.2: Weight Change - Freeze Thaw Relation for M28 Grade Concrete

4.2 Volume Change

The change in volume of fly ash concrete of grade M38 and M28 exposed to sea water and plain water for different period of freeze-thaw cycle are illustrated in **Fig.3** and **Fig.4** respectively. It is clear from these figures that the effect of sea water on the volume change of concrete specimens is relatively higher than that of plain water under Freeze-Thaw action. At the initial stage, i.e. after 30 cycles of freeze-thaw, volume of all the specimens are observed to be increased. It may be attributed due to hydration reaction of cement in presence of ingress of sea or plain water inside the concrete mass. At the end of 90 cycles, sea water cured concrete specimens have exhibited volumetric change of nearly -0.2 to -0.53%, whereas a volume change of -0.19 to 0.1% has been found in the specimens placed in the plain water. The volume change of the concrete specimens placed in sea water and plain water has been found to decrease due to surface erosion and splitting. The decrease in volume resulting from erosion/crumbling of outer surfaces of concrete may be attributed to the deposition of chemical compounds into the voids of concrete, the crystallization as well as their expansion due to freezing of the entrapped water inside the voids. Also from the figures it is clear that fly ash concrete shows much more resistance against volume change as compared to OPC concrete for relatively higher cycles of freeze-thaw.

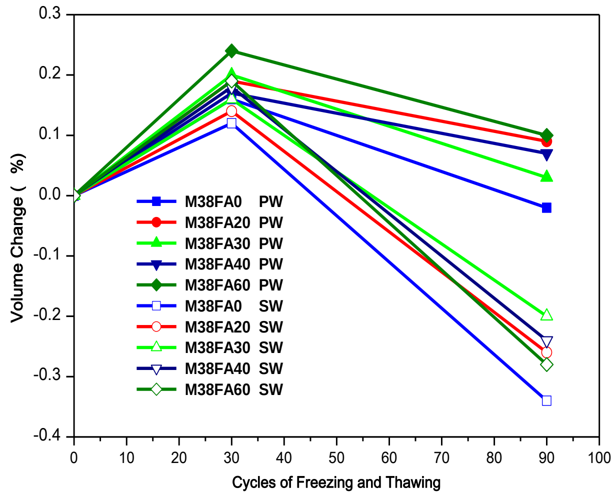

Fig.3: Volume Change - Freeze Thaw Relation for M38 Grade Concrete

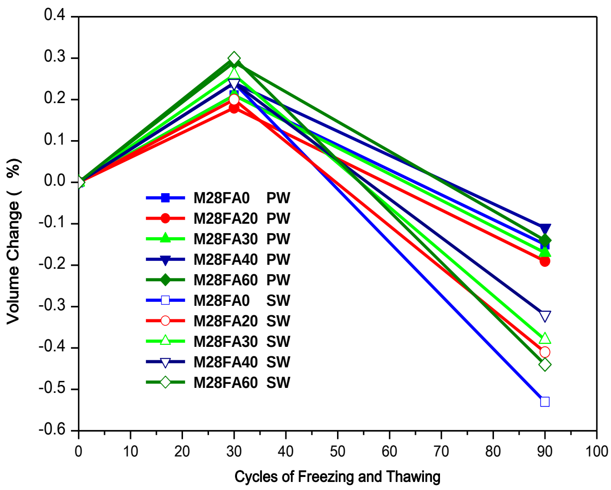

Fig.4: Volume Change - Freeze Thaw Relation for M28 Grade Concrete

5. CONCLUSION

The results of the Freeze-Thaw investigation carried out on concrete exposed to sea and plain water over 90 cycles have been critically analyzed and interpreted. Based on the limited number of tests and variables studied over the specific freeze-thaw cycles, the following conclusions are drawn:

(a) Concrete exposed to freeze-thaw cyclic loading in sea water is much more vulnerable to deterioration including erosion, splitting and crumbling than in plain water.

(b) The loss in weight of test specimens is found to the extent upto 2.6% in sea water and around 2.1% in plain water due to erosion and crumbling of concrete specimens in the freeze-thaw environment. Fly ash concrete shows better resistance against weight change as compared to OPC concrete.

(c) Concrete also shows a significant decrease in volume as much as 0.53% in sea water under freeze-thaw environment; whereas the specimens exposed to plain water show a decrease in volume of around 0.19%. Also it is observed that fly ash concrete has better resistance regarding dimensional instability as compared to OPC concrete.

(d) Higher grade concrete showed better resistance against dimensional instability as compared to lower grades of concrete.

(e) The use of fly ash in cement production reduces the problem of its disposal, saving the valuable fertile lands and the use of clinker, the production of which consumes a lot of energy and natural resources.

6. REFERENCES

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