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Effect of Vinsol Resin Air Entraining Agent on Strength and Durability of Concrete

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Abstract: ***Damage to reinforced concrete structures in cold environment is caused by freezing and thawing cycles which reduces durability of structures. In cold areas continuous freezing and thawing causes cracks to spread and weakens the concrete to the point of failure therefore frost damage is a contributing factor in the eventual rupture and erosion in concrete structures. In this experimental study mix proportion of Cement: Sand: Aggregate = 1:0.42:1.41 W/C ratio of 0.42 was used as reference sample. To this reference mix percentage of vinsol resin i.e. air entraining agent was increased from 0% to 2.5% by weight of cement. The freezing and thawing cycles were continued for 3days, 7days and 28days. The freezing was done at -15^{0}C ± 2 for 5 hrs while thawing was done at 25^{0}C ± 2 for 5 hrs. The compressive strength of cubes was compared at each percentage of AEA added before and after freeze thaw cycle after 3days, 7days and 28days. Also compressive strength of air entrained agent added sample was compared with reference samples for obtaining optimum dosage of vinsol air entraining agent for reference mix. It was found slump value increased with the increment of the air entraining agent, making concrete more workable. There was a sharp increase in strength after 3 days due to rapid increase in the hydration reaction; initially the hydration reaction rate was slow by the freezing of the water molecules. 1 to 1.5% of vinsol resin air entraining agent is effective for producing frost resistance concrete at this mix proportion.***

Keywords: Frost resistance, Vinsol resin, Compressive strength, Freeze Thaw Cycles, Air Voids, Porosity

1. Introduction

Many research works are found to deal with the durability of concrete, especially freeze-thaw resistance in cold areas[1-7]. Damage to reinforced concrete structures in cold environment is caused by freezing and thawing cycles which reduces durability of structures[1-5] .In cold areas continuous freezing and thawing causes cracks to spread and weaken the concrete to the point of failure therefore frost damage is a contributing factor in the eventual rupture and erosion in concrete structures. Several theories have been proposed to explain the frost damage mechanism. Freezing of water in the pores is responsible for the surplus pressure [8]. The repetitive process of freezing and thawing creates weak layers parallel to the cooling surface, which makes them more susceptible to the pressure created by the ice crystals which grow in the direction of heat flow. Their growth continues until either the available water is depleted or the freezing is impossible; the latter is the cause of pressure on the surface of the voids [8,9]. Air voids are only available space for water to freeze without damaging the structure. In order to reach this space, water must pass through the paste; if the pressure for water to travel a certain distance surpasses the tensile strength of the paste, it causes damage [8,10]. The water in capillary pores does not freeze in situ but when the temperature drops below 0^{0}C, water becomes super cooled and tends to travel to a surface to freeze which results in desiccation of the specimen. Damage is the result of the desorption process which happens when the concentration of water is much higher than it should be according to equilibrium. The air voids reduce the traveling distance to a freezing surface, thereby facilitating the process of desorption, permitting more water to leave the pores and protecting the specimen [8, 11]. These air voids have diameter of about 0.05mm and are typically spaced within 0.2mm of each other [34, 36, 37]. Hence pore refinement, transforming of larger voids into evenly distributed and smaller air voids contribute to the frost resistance of the concrete [8].

Resistance to alternate freeze thaw cycles is developed by using air entrained concrete. Air entrained concrete contains tiny air bubbles which are uniformly distributed throughout cement paste [8, 12-14]. In a cubic yard of concrete there may be 300 billion entrained air voids with a total air content of 4-6% by volume [34, 35]. Normal strength concrete requires total air content of 4-7% out of which, approximately 2% is entrapped air and the remaining 2–5% is entrained air [34, 38].

Besides creating weak layers parallel to the cooling surface as stated above continuous freezing and thawing also causes internal micro cracking. The resistance to internal micro cracking can be calculated by the standards mentioned in ASTM C666 [8, 15]. For assessing durability of frost resistance concrete ASTM C666 defines three factors: Relative dynamic modulus of elasticity (RDME), Durability factor (DF) and Length change in percent. These parameters are mainly influenced by content of additives used in fresh state of matrix.

The mechanism of additives is based on their of action such as (a) air entraining agents, (b) consolidation agents, (c) crack cross linking additives, and (d) hydrophobic agents. These additives first provide extra volume for ice expansion to decrease hydraulic water pressure; then reduce porosity and refine concrete pores to decrease water absorption; followed by bridging the cracks to prevent crack propagation, and finally alter concrete hydrophilicity to limit water presence [8].

Refining pores also make concrete freeze thaw resistant by reducing porosity. Micro and nano sized pozzolans and fillers are used to reduce porosity. These pozzolans produce more cement gel i.e calcium silicate hydrated (CSH) by reacting with $Ca(OH)_2$ [8,16-21].

Reduction of crack propagation by addition of micro fibers, nano tubes, and nano sheets control freeze thaw damage in concrete. These additives consume the energy from water expansion due to frost and bridge cracks therefore water plays important role in frost action [8, 22-29].

Hubert woods suggested concrete with water to cement ratio at or below 0.40 can be alternative air entrained concrete. This low w/c ratio ($w/c<0.40$) concrete does not contain excess water that would freeze. Also due low w/c permeability will be reduced which will prevent saturation of concrete [34,39]. Pigeon et al developed freeze-thaw durable mixtures at w/cm of 0.30 and lower [34, 45]. Hooton et al used silica fume and achieved good frost resistance at w/cm of 0.35 and lower [34,42]. Mokhtarzadeh et al developed frost resistant mixtures with w/cm of 0.29 and 0.31 while Li et al had acceptable freezing and thawing durability at w/cm of 0.24 and lower [35, 43,44]. Impermeable additives like silica fume can reduce need of air entrainment [34] . Silica fume has particles with size almost 100 times smaller than cement particles which lead to high specific surface area and less workability [8,20,30-33]. Silica fume is impermeable to water and would not allow to get concrete saturated in natural outdoor exposure as studied by cohen et al with low W/C ratio concrete simultaneously he also stated if there were probability of saturation air entrainment would be used [34,41]. Less than 20% silica fume by mass showed satisfactory frost resistance [8,30-33].

A. Gokce et. al. studied freezing and thawing resistance of air entrained concrete in which the coarse aggregate was produced by recycling air-entrained concrete and non-air-entrained concrete, respectively. They found recycled coarse aggregate produced from non-air-entrained concrete caused poor freezing and thawing resistance in concrete. Micro structural studies showed that non-air-entrained adhered mortar caused disintegration of the recycled coarse aggregate in itself and disrupted the surrounding new mortar after a limited number of freezing and thawing cycles [46]. B.B.Sabir et. al. studied behavior (strength and durability) of air-entrained CSF (condensed silica fume) concrete after freezing and thawing cycles in which CSF was used as an alternative to cement from 0-12% and W/C 0.4. It was found not only compressive strength of specimens after 7 and 28 days but flexural strength after 35 cycles of freezing and thawing cycles with increasing CSF content [47].

Study over air entrained concrete has been conducted using multi axial and uni- axial loads for tension and compression prior to freeze thaw cycles. Also weight loss, dynamic modulus of elasticity and strength under tensile load, cleavage load, and compressive load after different cycles of fast freeze thaw cycles has been studied. Even though thorough research has been conducted on air entrained concrete but main concern lies on dosage of additives to be added for entrapping air to make it frost resistant [1,6,7].

Various chemical substances can be used for air entraining which are by product of pulp processing, paper production and petroleum production. These are sodium salts of wood resin (e.g. sodium abietate, similar to Neutralized Vinsol resin) [46]. Vinsol resin is commonly available air entraining agent but the effect on workability due to addition of vinsol has not been fully evaluated.

Present work focused on the impact of freeze-thaw cycles on mechanical properties of air entrained concrete by adding vinsol resins at different percentage by weight of cement. Very little work is reported about the mechanical behavior of air entrained concrete produced by adding vinsol resin. The systemic experimental study of air entrained concrete by adding vinsol resins at different percentage by weight of cement is done in this paper. The compressive strength of cubes was compared at each percentage of AEA added before and after freeze thaw cycle after 3days, 7days and 28days.Varying amount of AEA added in samples is shown table 2. Also compressive strength of air entrained agent added sample was compared with reference samples for obtaining optimum dosage of vinsol air entraining agent for reference mix as shown in table 2.

2. Experimental Procedure

Raw materials In this study, local materials (1) Ordinary Portland cement (OPC-43 , Type-I) (2) locally available sand from Sind river Ganderbal having fineness modulus (3) coarse aggregate crushed stones of nominal size 20mm size. Table 1 shows the proportion of material used in reference samples. (4) Vinsol resin for air entraining. Table 2 shows percentage of air entraining agent added by weight of cement in each sample against 3,7,28 days. Ratio of mix proportion Cement: Sand: Aggregate = 1:0.42:1.41

Table 1: Mix proportion for reference sample without AEA

Material	Quantity
Cement	440.85kg/m^3
Sand	186 kg/m^3
Aggregate	640.87 kg/m^3
W/C	0.42

Table 2: Percentage of AEA (vinsol resin) added by weight of cement

Days				
Percentage of AEA	0	T1,T2	T13,T14	T25,T26
	0.5	T3,T4	T15,T16	T27,T28
	1	T5,T6	T17,T18	T29,T30
	1.5	T7,T8	T19,T20	T31,T32
	2	T9,T10	T21,T22	T33,T34
	2.5	T11,T12	T23,T24	T35,T36

3. Experimental Procedure

For compressive strength analysis cubes of size 150mm×150mm×150mm were casted. Casting of all the samples were done in the room temperature condition with 20±3^{0}C. The dry mixing of cement sand and aggregates was done for 1min in mixer, then water was added and mixture was thoroughly mixed in mixer for 8± 2 minutes. The slump was measured with slump cone apparatus . Air entraining agent by weight of cement was added into water at time of mixing. The cubes were demoulded after 24 hrs and placed into freezer set at-15^{0}C ± 2 for 5 hrs for freezing and kept at room temperature ie 25^{0}C$\pm$2 for 5 hrs for thawing. The freezing and thawing cycles were continued for 3, 7, and 28 days. The compressive strength was obtained in universal testing machine with which load was applied at 4000N/sec as shown in fig 1.

Figure 1: Compression in UTM

4. Result and Discussion

Workability increased with the increase of air entraining agent as shown in fig 2. It's because the air bubbles got introduced into the concrete matrix which increased slump making concrete more workable.

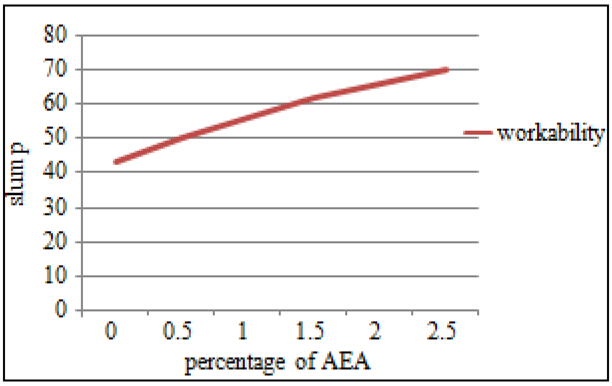

Figure 2: Increment in slump with increment of air entraining agent (AEA)

Compressive strength of concrete decreased after 3 days, 7 days and 28days freeze and thaw cycles compared to normal compressive strength as shown in fig 3. It's because the water in micro pores got frozen due freezing and melted due to thawing. This continuous process of freeze and thaw led to deterioration of concrete and resulted in decrease of strength. This can be due to formation ice crystals in air voids [8,9]. The dimension of voids increased due to expansion of ice crystals and led to surplus pressure weakening bonds at interfacial transition zone (ITZ).

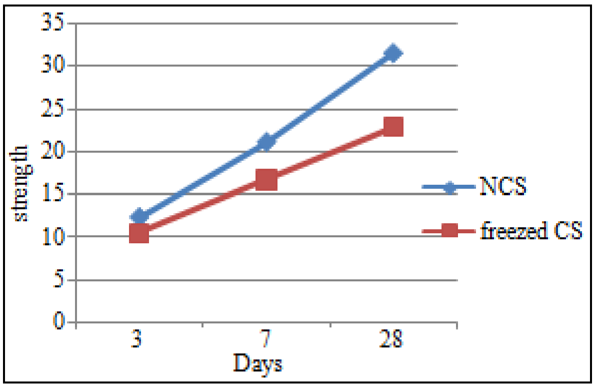

Figure 3: Normal compressive strength (NCS) versus Freezed Compressive strength (FCS)

When 0.5 % , 1,% 1.5%, 2%, ,2.5% AEA respectively, by weight of cement was added not only slump increased but compressive strength increased with increasing number of days before and after freeze thaw cycles as shown in fig 4, fig5,fig 6, fig7, and fig8 respectively. Even though entrapped air content kept water out from reach of cement particles but some water could hydrate it but less than reference samples, this can be reason for low strength. Also due to air entrapment from air entrainment agent compressive strength was less than normal compressive strength of reference sample. It's because porosity increased and density decreased. Initially the hydration of cement particles was incomplete due to freezing and thawing process but during thawing some water released was utilized for hydration , hence after 7days freeze thaw cycles sharp increase in strength was observed.

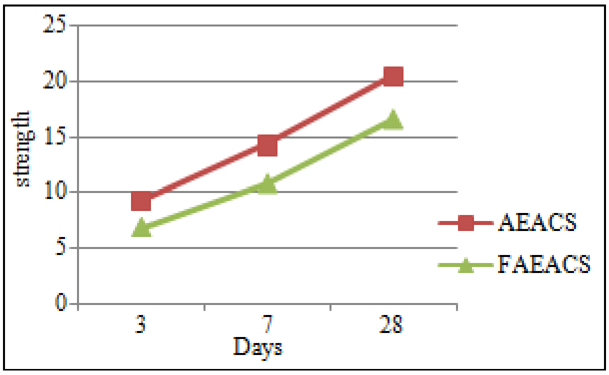

Figure 4: Effect of strength with 0.5% AEA before and after Freeze Thaw cycles

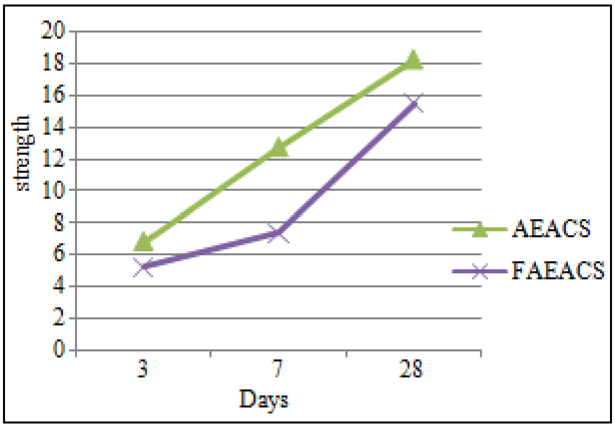

Figure 5: Effect of strength with 1 % AEA before and after Freeze Thaw cycles

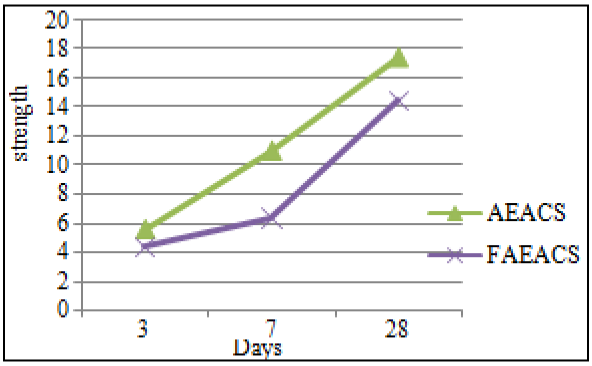

Figure 6: Effect of strength with 1.5% AEA before and after Freeze Thaw cycles

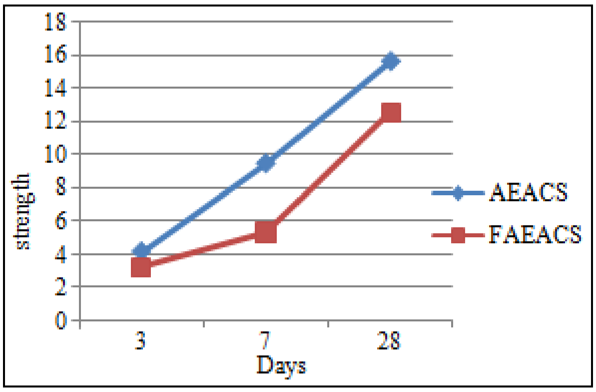

Figure 7: Effect of strength with 2% AEA before and after Freeze Thaw cycles

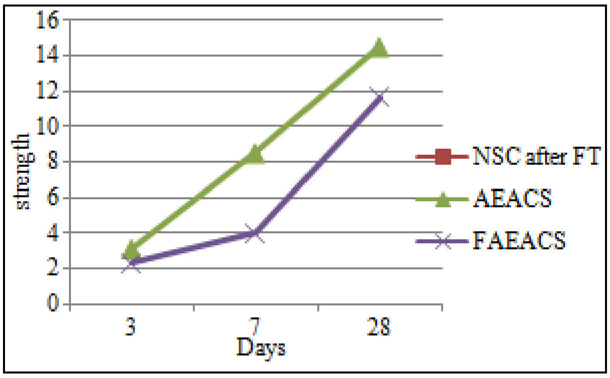

Figure 8: Effect of strength with 2.5% AEA before and after Freeze Thaw cycles

Over all compressive strength improved with time as shown in fig 9. Its because during thawing water from ice crystal melts which can be used for hydration of cement particles. From fig 2 it was observed the strength achieved was equal to target strength but due to hydrophilic and hydrophobic action of air entraining agents water could not reach to cement particle and couldn't hydrate it. Hence decrease in strength compared to reference strength was observed as shown in fig 2.

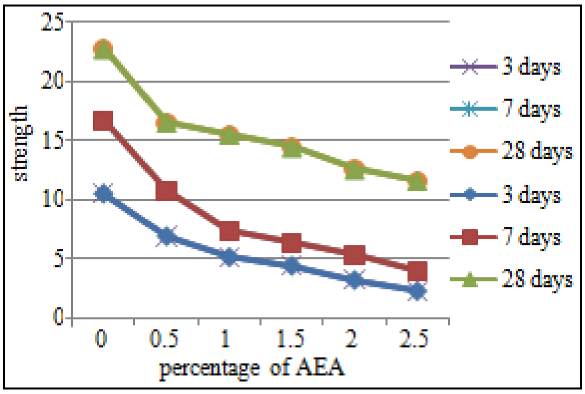

Figure 9: Effect on strength after 3days, 7 days and 28 days with the increment of AEA dosage after freeze thaw cycles

1% to 1.5% of AEA showed steady response in both cases before freeze thaw cycles after freeze thaw cycles as shown in fig 10, fig11 and fig 12. Its due to reason 2-5% of air is entrained as verified by W. Micah Hale et.al [38].

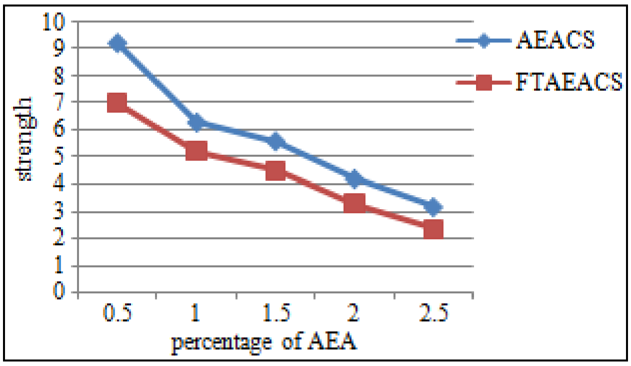

Figure 10: Strength 3 days sample before and after Freeze thaw cycles

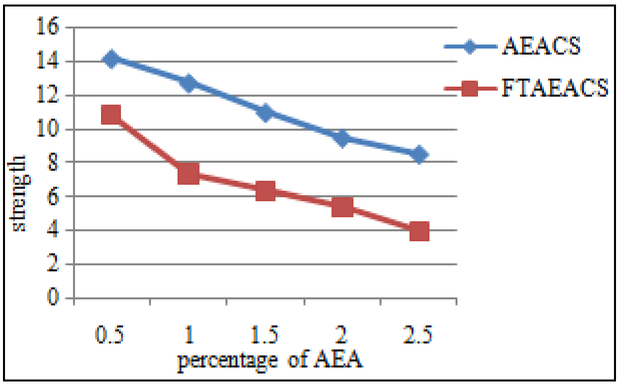

Figure 11: Strength 7 days sample before and after Freeze thaw cycles

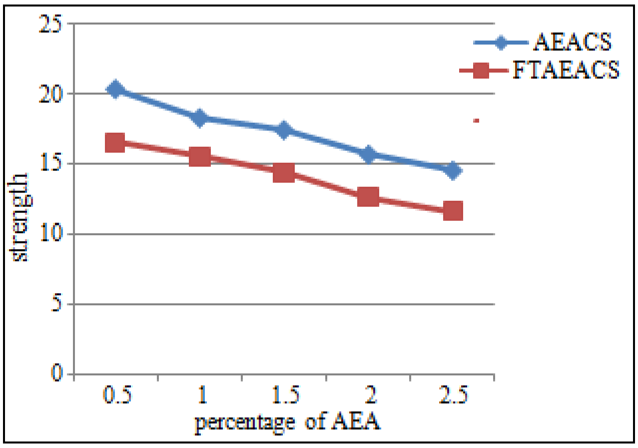

Figure 12: Strength 28 days sample before and after Freeze thaw cycles

5. Conclusion

Based upon the experimental work performed following conclusions could be made:

1) Slump value increased with the increment of the air entraining agent, making concrete more workable.
2) Porosity increased due to entrapment of air, decreasing the strength of concrete.
3) The size of the voids increased due to formation of ice crystals during freezing and thawing of water there by exerting surplus pressure on the concrete exceeding its tensile strength.
4) There was a sharp increase in strength after 3 days due to rapid increase in the hydration reaction as initially the reaction rate was slowed by the freezing of the water molecules.
5) Air voids are only the spaces which allow water to get entrapped into the specimen hence the rate of freeze and thaw cycle was increased, which can be reduced by adding filler materials.
6) It was found 1 to 1.5% of air entrain agent is effective for producing frost resistance concrete at mix proportion Cement: Sand: Aggregate = 1:0.42:1.41 and 0.42 W/C ratio.

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