PERFORMANCE OF CEMENT GROUT INCORPORATING SAND DUST UNDER VARIOUS TEMPERATURES

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ABSTRACT

The present research studies the addition of sand dust (SD) on the performance of cement grout. Cube specimens of 5 x 5 x 5 cm were made with different mixing temperature and compositions. The mixing temperatures were 15, 30, 45 and 60°C. It was observed that grout mixed at 60°C is not suitable for bonded post tensioned concrete structure because the efflux time of fluidity test is not within the allowable limit. Grout consisting of cement, sand dust and water shows better bond stress and resistance to salt attack than grout consisting of cement and water. On the other hand compressive strength of controlled sample shows higher values than the samples with sand dust. The rate of capillary suction is almost same for all the fresh grout mixed at different temperature and composition.

Keywords: cement grout, sand dust, salt crystallization, temperature.

INTRODUCTION

Grout is cement based fluid mixtures used to fill voids. The grout has two functions which are it prevents corrosion of the steel tendons and provides an efficient bond between the tendon and the structural member (Freedma, S., 1973). In particular, they are pumped into ducts in structural elements through which prestressing or post tensioning duct passes. Grouting is a process by means of which grout is injected into voids, fissures ,cavities in soil or rock formations in order to improve the properties, specifically to reduce permeability, to increase strength or to lessen the deformability of the formations (Anagnostopoulos, C. A. *et al*., 2004).

Grouting has a wide application in modern civil engineering such as to connect distinct structural elements in a homogeneous structure by injecting the seams between them with grout compounds, to fix reinforcing cables in precast and prestressed concrete structures, to lift and erect leaning structures and buildings, for rehabilitation and reinforcement of old defective masonry or historical buildings and many other applications (Nonveiller, E., 1989). Currently there is no single American Society for Testing and Materials (ASTM) or industry specification covering grouts for post tensioning tendons.

The purpose of grouting is to provide permanent protection to the post-tensioned steel against corrosion and to develop bond between the prestressing cables and the surrounding structural concrete. Cement grout is chemically basic and provides a passive environment around the post tensioning bars or strands. In addition grout serves to bond internal tendons to the structure. In the free length of external tendon the principal role of grout is to provide an alkaline environment inside the duct (Federal Highway Administration, 2008).

A high performance, non shrinkable cement grout should be used to achieved excellent result in post tensioned concrete. A common problem associated with the grouting of bonded post tensioning tendons is the segregation of water from the grout mixture. There are two forms of bleeding in one form, water rises to top of the duct and the heavier cement and aggregates settle to the bottom due to difference in unit weights. In the other form, when the tendons are made up of strands, bleeding is due to the filtering action of the strands, but solid particles do not (Reynolds, C. E. *et al*., 2008). Another critical characteristic of a grout is that it should remain pump-able for the anticipated time to fully inject the tendon. This may be significant for long tendons or where a group of several tendons is to be injected in one continuous operation. Some thixotropic grouts can have very low viscosity after agitation, becoming easy to pump. Consistency, fluidity, water retentivity and bleeding are the significant properties of new particulate grouts.

The compressive strength of the grout is a property that relates directly to the structure of the cement paste and provides a good indication of its quality (Neville, A. M., 2005). The addition of polypropylene fibre to the grout results in a reduction in compressive strength. This can be attributed to the weak planes formed at the interfaces between the fibre and grout matrix (Komonen, J. *et al*., 2003). At low water/solid ratios grouts containing bentonite exhibit comparable values of compressive strength to that controls. As the water/solid ratio increases, bentonite shows a decrease effect on the strength of the grout. This is because the addition of bentonite to the grout results in an increase in porosity especially at high water/solid ratios (Huang, W., 1997).

In this study, Sand dust is introduced to grout. Prestressing cables are widely used in huge constructions like buildings and bridges. Corrosion of prestressing steel is more dangerous than the corrosion of reinforcing steel in concrete. Stress corrosion is propagated due to corrosion initiation in prestressing steel under stressed condition. Corrosion resistance of the prestressing steel depends upon the grout material. So evaluation of the performance of this grout material is essential.

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Scope

In prestressed concrete structures, corrosion attack is generally protected by high alkalinity provided by cement based grout. Thus a passive layer on the steel surface provides adequate corrosion resistance. The long term durability of this resistance relies on the stability conditions necessary for the passive layer. In post-tensioning concrete structures the grout protecting the cables establishes the durability of the cables. The defects included in grout within the ducts, admixtures in the grout and other reactants causing the tendon to initiate localized corrosion leading to corrosion failure.

The durability of prestressed concrete bridges primarily depends on the steel wire cables. Several disorders in these bridges are well known, such as fracture of these cables by stress corrosion cracking due to water penetration in prestressing ducts. This water can contain various aggressive constituents with respect to corrosion (like chlorides). Its penetration inside the duct is due to the presence of sealing defects of the structure or in the concrete (like cracks). The second category of defects relates to the cement grout injection, which protects cables. This occur due to a degradation of the grout in contact with water (problems of bleeding and segregation) leading to brittle fracture of steels. So it is required to determine the properties of grout. One of the factors controlling the grout properties is temperature. Since temperature differs considerably with seasons and also varies in different places, different properties of grout may get changed with variation of temperature. This is why it is necessary to observe those changes. This study is focusing on the effect of sand dust on the properties of cement grout.

MATERIALS AND METHODS

Materials properties

Cement

In this research Ordinary Portland Cement (ASTM Type-1) (ASTM, 2003) was applied with specific surface 3415 cm^2/g, specific gravity 3.15gr/cm^3, initial setting time 124 minutes, final setting time 246 minutes and normal consistency 27.4% were used. Chemical composition of ordinary cement is reported in Table-1. Prior to use cement proportions were sieved to ensure that Portland cement used is free of unwanted lumps and debris. This will also help in the mixing process to be done later.

Table-1. Chemical composition of cement.

Compound	Percentage
SiO_2	24.45
AlO_3	4.33
Fe_2O_3	3.86
CaO	60.76
MgO	1.8
SO_3	1.48
LOI	1.78
IR	0.45
Free Lime	1.064

Water

Drinkable tap water is used in this research.

Sand dust

The river sand dust is used during this study is the mass passing through the No. 100 sieve (ASTM standard sieve). This Sand Dust (SD) is used as a partial replacement of cement. In this study two types of composition is prepared in which one sample is SD free and another one contains 30% of SD.

Mix design

Proportioning and mixing of grouts have been based on the ASTM C938-02, Standard Practice for Proportioning Grout Mixtures for Preplaced-Aggregate concrete (ASTM, 2002). For the experiments, two series of the mixture proportions according percentage of sand dust ratio adopted and are reported in Table-2. Hot water and cold water was added to maintain the desired temperature.

Table-2. Mixture proportion of concrete mixes.

Mix	Cement (kg)	Water (kg)	Water/ binder ratio	Sand dust (kg)
0% SD	10	20.8	0.48	0
30% SD	7	20.8	0.48	3

Experimental investigation

Mixing of grout at different temperature

Grouts are mixed in the laboratory using proportions of Ordinary Portland Cement, sand dust, and water (Figure-1).

Figure-1. Grout mixture machine.

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Mixing was done through the aid of mechanical mixtures. Mixture used must be cleaned and dampened prior to use. Minimum time of mixing was maintained at 3-4 minutes. Four mixing temperatures (15°, 30°, 45° and 60°) were maintained during this study. Temperatures of the mixtures are controlled using cold and hot water. To ensure the desired temperature trial mixing was carried out before the final mixing. Forty two specimens of size 5 x 5 x 5 cm were cast for each temperature. Among them six specimens were cast with a single bar embedded vertically along central axis of each specimen. Prior to casting the test specimen, the inside surface of the molds were coated with a thin film of mineral oil.

Flowability measurement

The fluidity of the grout, expressed in seconds, is a measure of the time necessary for a stated quantity of grout to pass through the orifice of the cone under stated condition (Figure-2).

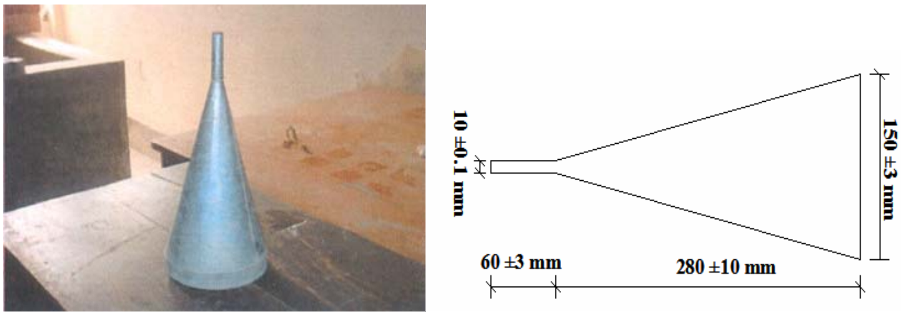

Figure-2. Flow cone and its dimensions.

This apparatus is used to determine the fluidity of cement grout by ASTM C940-98a (ASTM, 1998 and ASTM, 1997). Efflux time is recorder with respect to time to determine its fluidity.

At first the cone with its axis vertical and its largest diameter uppermost, was mounted. Then the cylinder was placed under the cone outlet. During test the cone was prevented from vibration and all surfaces of it was cleaned and dampened so that the surfaces are moist but without free water. The lower cone orifice was closed. The grout was poured to fill the conical section of the cone. Pouring was done slowly to prevent the build up of air in the grout in the cone. The lower cone orifice was opened and at the same time, the stop watch was started. The time was measured, taken to the nearest 0.5 seconds, to fill the cylinder to 1 litre. For suitability testing, two tests were carried out, the first immediately after mixing and another one after 30 minutes of mixing. The required efflux time was 9 to 20 seconds immediately after mixing and 35 seconds maximum with 30 minutes of mixing for grouts (ASTM, 2002 and ASTM, 1997).

Pull out test

When a reinforcing rod is embedded in concrete, the concrete adheres to its surface resisting any force that tends to pull or push the rod. This is called the bond between the concrete and the steel, the intensity of this adhesive force is called the bond stress or bond unit stress, in reality this bond is a resistance to shearing between the surface of the steel and the concrete away from the surface of the steel in direction parallel to the surface and lengthwise of the bar. Six specimens were cast placing 7 mm dia bar at the centre of the specimen for each temperature. After 56 days of curing bond pull out test was carried out using the pull out testing machine and failure load was recorded.

Figure-3. Pull out test equipment and specimens.

Capillary suction test

The capillary tests were conducted in accordance with British and European standard testing procedure for mortars and stone. The capillary suction of a grout is related to the size and number of internal pores and their degree of interconnection. In general, the narrower and better connected the pores the greater the suction, but also, the larger the number of pores the greater the overall amount of water that is absorbed. The specimens were placed on thin supports in a shallow water basin and their bases submerged to a depth of 3±1 mm. At the time intervals, each test specimens was removed from the basin, its base blotted dry and its mass noted to the nearest 0.01 g. Measurements were taken at 3, 10, 20, 30, 45, 90, 120 and 180 min.

Salt crystallization test

Salt crystallization cycling allows determination of the resistance of the mortars to salt attack. After each cycle, the conditions of the specimens were recorder and results reported in terms of weight loss and number of cycles required to induce failure. The sample was immersed in a 14% solution of sodium sulfate decahydrate ($Na_2SO_4.10H_2O$) for 4 hours. They were then removed and left to dry in an oven preheated to 105°C for a period of 15 hours later left to cool to room temperature for 6 hours. Their individual masses were noted before recommencement of the soaking in salt solution. The sample cubes were subjected to 20 such cycles expect in the event of failure or disintegration of the cubes occurring before completion (Doran, D. K. 1992).

RESULTS AND DISCUSSIONS

Fluidity measurement

It can be seen from Figure-4 that up to 45°C the efflux time maintain a constant value of around 6 seconds but increase rapidly when the temperature raised to 60°C. The results also indicates that the grout become harder rapidly when the mixing temperature more than 45°C. 0% SD and 30% SD mixes exhibits same nature for immediately after mixing. On the other hand, there was a slight decrease in efflux time up to 45°C in the 30 % SD* but in 0% SD* it exhibits reverse result. The grout becomes stiff in both cases at 60°C.

Table-3. Fluidity test results.

e r a	**Efflux time** (Second)			
	Immediately after mixing		**After 30 minutes of mixing**	
	0% SD	30% SD	0% SD*	30% SD*
15°C	6	7	7	16
30°C	5	5	7	10
45°C	5	5	11	9
60°C	12	13	Stiff	Stiff

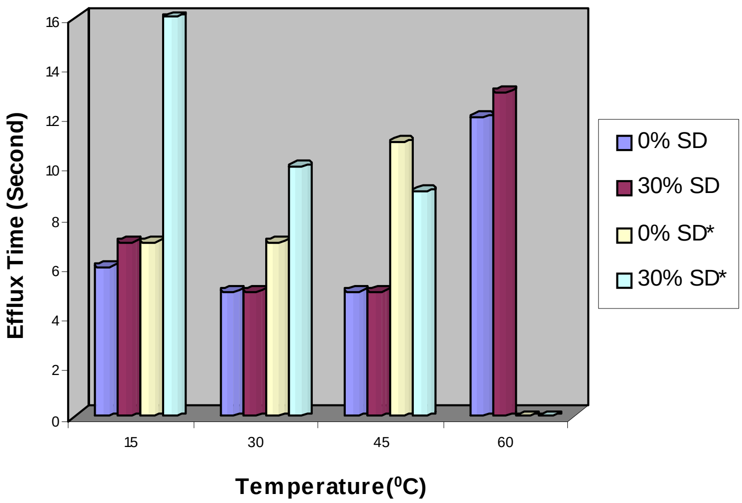

Figure-4. Flowability curve immediately and after 30 minutes of mixing.

Compressive strength

Table-6 indicates at an early age compressive strength increases after addition of SD but decreases for long times for 15°C of mixing temperature. The results also indicates that the compressive strength of 30°C samples have greater results than 15 samples.

Table-6. Compressive strength of the concrete mixes.

Temperat ure	**Compressive strength** (MPa)							
	1 day		**3 day**		**7 day**		**56 day**	
	0% SD	30% SD	0% SD	30% SD	0% SD	30% SD	0% SD	30% SD
15°C	6.09	6.55	14.10	10.24	23.58	16.62	39.61	31.72
30°C	6.72	7.17	14.82	11.03	22.24	15.51	46.47	38.82
45°C	6.69	6.14	17.52	12.41	26.89	15.58	52.57	51.37
60°C	7.72	6.31	18.27	10.34	24.82	12.58	42.26	42.13

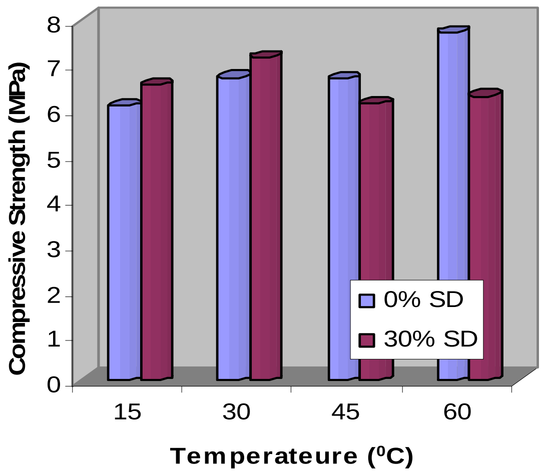

Figure-5. Compressive test results for day 1.

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Figure-5 indicates that at an early age, compressive strength exhibits similar result up to 45°C and then go up for the increase of temperature for 0% SD. But for 30% SD mix the compressive strength slightly fluctuated with increase of temperature. The compressive strength of 30% SD was increased for the increase of temperature up to 30°C than 0% SD samples but shows reverse results for 45 and 60°C of mixing temperature.

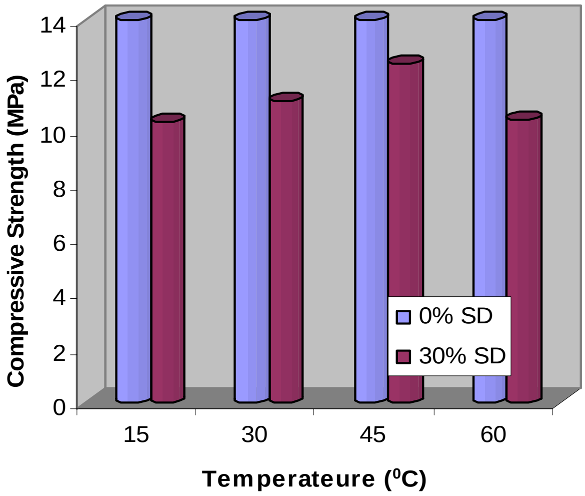

Figure-6. Compressive test results for day 3.

Figure-6 indicates that, for 0% SD, the compressive strength remains steady for various mixing temperature. But there was a slight fluctuation in compressive strength for 30% SD samples.

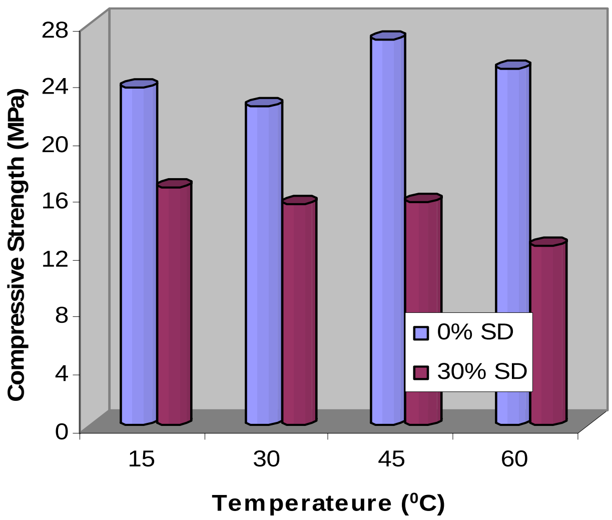

Figure-7. Compressive test results for day 7.

From Figure-7, 0% SD mixes shows better results with respect to 30% SD mixes for all mixing temperature. The compressive strength fluctuates slightly with increase of mixing temperature. There was a downward trend in compressive strength for 30% SD samples.

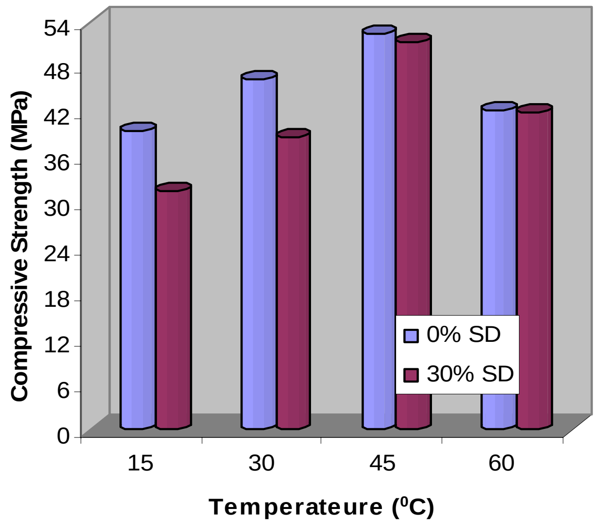

Figure-8. Compressive test results for day 56.

Figure-8 compares the change of compressive strength with the change of temperature between 15°C to 60°C for 56 days age sample. It can be clearly seen that the up to 45°C the compressive strength decrease and increase rapidly when the temperature raised to 60°C for 30% SD. But for 0% SD compressive strength decrease up to 30°C and then increase rapidly.

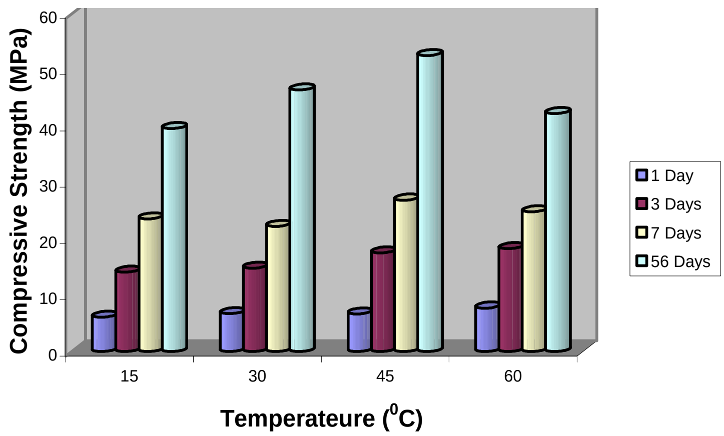

Figure-9. Compressive test results for 0% SD.

From Figure-9, the increasing rate of compressive strength is higher for 30°C and 45°C than for 15°C and 60°C mixing temperature. It was also observed that for 15°C, 30°C, 45°C and 60°C the increasing rate of compressive strength is 68%, 109%, 96% and 70% respectively at 56 days with compared to 7 days sample for 0% SD.

From Figure-10, the increasing rate of compressive strength is higher for 45°C and 60°C than for 15°C and 30°C mixing temperature. It was observed that for 15°C, 30°C, 45°C and 60°C the increasing rate of compressive strength is 91%, 150%, 234% and 229% respectively at 56 days with compared to 7 days sample for 0% SD.

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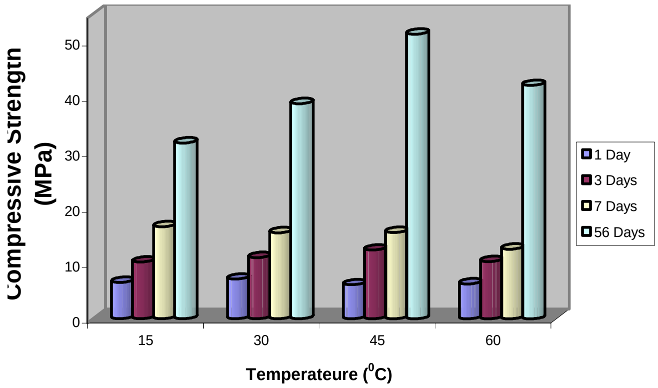

Figure-10. Compressive test results for 30% SD.

From Figure-9 and Figure-10 it is observed that the increment in compressive strength of 56 days samples at 45°C and 60°C is higher that 15°C and 30°C mixture than of 7 days samples in both cases i.e., 0% SD and 30% SD. For both 0% SD and 30% SD, the compressive strength of 56 days samples is more than twice with respect to that of 7 days samples.

From Figure-11 and Figure-12 it is found that 30°C and 45°C samples exhibits better compressive strength than 15°C and 60°C samples for both compositions.

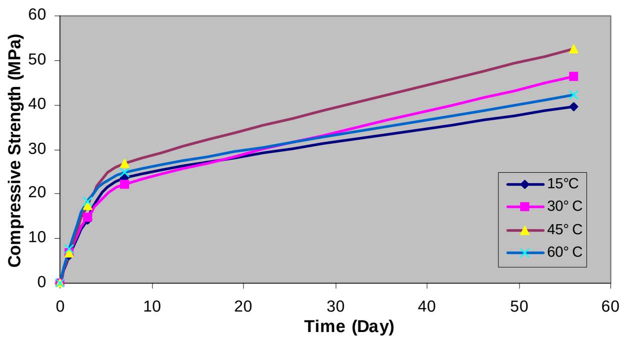

Figure-11. Compressive test results for 0% SD.

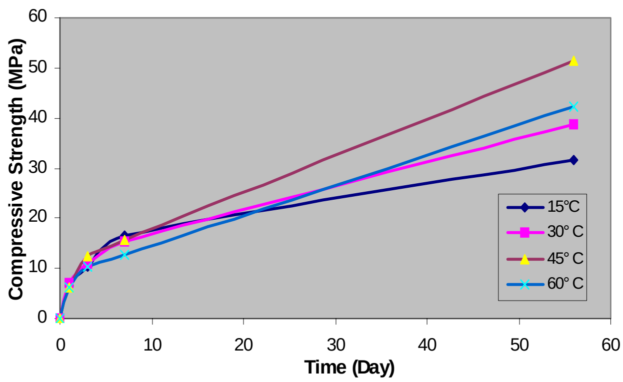

Figure-12. Compressive test results for 30% SD.

Bond stress measurement

Table-4 presents the results of the bond stress by Pull out test. It is verified that addition of sand dust increased the bond stress of grout mixes. It was also observed that the increasing rate of bond stress is higher for 15°C and 45°C than for 30°C and 60°C mixing temperature. The result indicates that, the bond stress for 30% SD at 15°C, 30°C, 45°C and 60°C is increased by 619%, 44%, 344% and 111% respectively than 0% SD.

Table-4. Results of the bond stress by pull out test.

Temperature (°C)	**Average bond stress** (MPa)		
	0% SD	30% SD	% Change
15	0.89	6.4	619%
30	4.05	5.84	44%
45	1.35	6	344%
60	2.7	5.7	111%

Figure-13 compares the change of efflux time with the change of temperature between 15°C to 60°C. It can be clearly seen that the up to 45°C the flowability remains around 6 but increase rapidly when the temperature raised to 60°C. The data also indicate improvements in bond stress for 30% SD grout compared to that of 30% SD. This is likely to be due to the addition of sand dust to grout. Sand dust gives a better resistance in bond failure than cement particles.

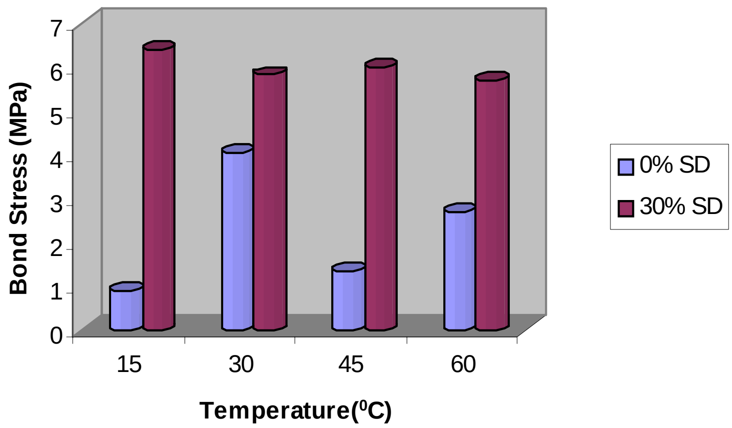

Figure-13. Variation of bond stress with temperature.

Capillary suction measurement

From Figure-14, the slope of the lines represents the rate of suction. The curves obtained from the capillary suction test for 0% SD is almost parallel to each other. So the slope of the capillary suction curves are remains constant with increase of temperature.

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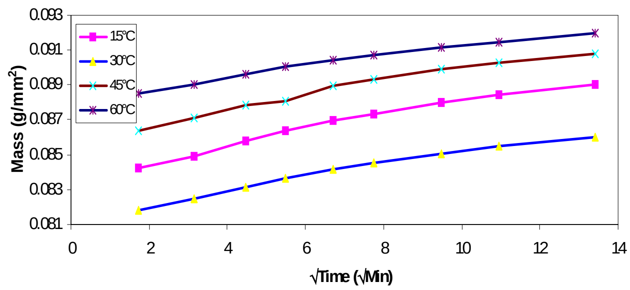

Figure-14. Capillary suction test results for 0% SD.

From Figure-15, for 30% SD, 15°C curve is nearly parallel to 30°C and other twos are also shows similar nature. Figure-14 and Figure-15 also furnished data related to capillary suction in four different mixing temperatures. The propagation of water for 0% SD is almost the same as propagation of water for 30% SD. The slope of the lines represents the rate of suction.

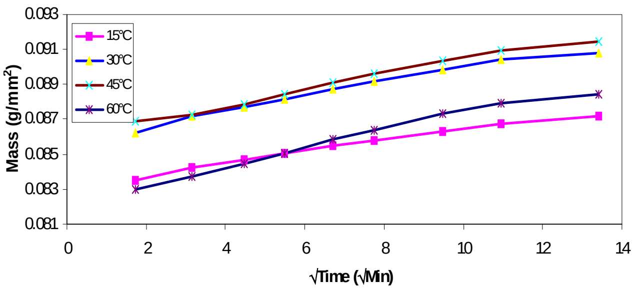

Figure-15. Capillary suction test results for 0% SD

Table-6 presents the best fit curve equation obtained from capillary suction test. Capillary action is caused by surface tension and by the comparative value of the adhesion between the water and the concrete to the cohesion of the water. The action of surface tension is to cause the water to rise within a small capillary that is partially immersed in the water. The rate of capillary suction of 0% SD is remained the same as 30% SD samples. R-squared values show good accuracy of the test.

Table-6. Capillary suction rate.

Temperature	0 % SD			30 % SD		
	Curve Equation	CSR**	R^2	Curve Equation	CSR**	R^2
15^0C	0.0004x+.0838	0.0004	0.9708	0.0003x+.0832	0.0003	0.9783
30^0C	.0004x+0.0815	0.0004	0.9738	.0004x+0.0861	0.0004	0.9852
45^0C	0.0004x+0.086	0.0004	0.9683	0.0004x+0.823	0.0004	0.9824
60^0C	.0003x+0.0882	0.0003	0.9745	.0004x+0.0859	0.0004	0.9763

*Capillary Suction Rate in mm/min$^{0.5}$

Salt crystallization measurement

From Figure-17, the 30% SD samples sustain 20 cycles before surface roughness appears and crack formed due to salt crystallization. So the durability of 30% SD is higher than 0% SD. Surface scaling of concrete is observed due to salt crystallization. The salts present on concrete as efflorescence or subflorescence are usually highly soluble in water. From this graph, it is observed that mass loss is almost same up to 3 cycles for various temperatures but then loss of mass is occurs rapidly in 30°C sample. The 0% SD samples sustain 7 cycles before surface roughness appears and crack formed due to salt crystallization.

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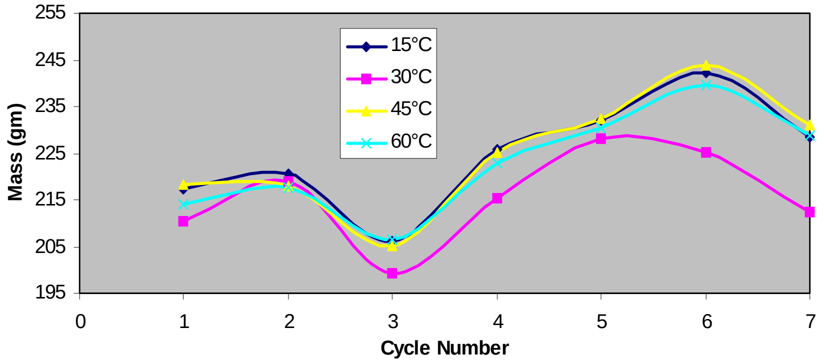

Figure-16. Salt crystallization results for 0% SD.

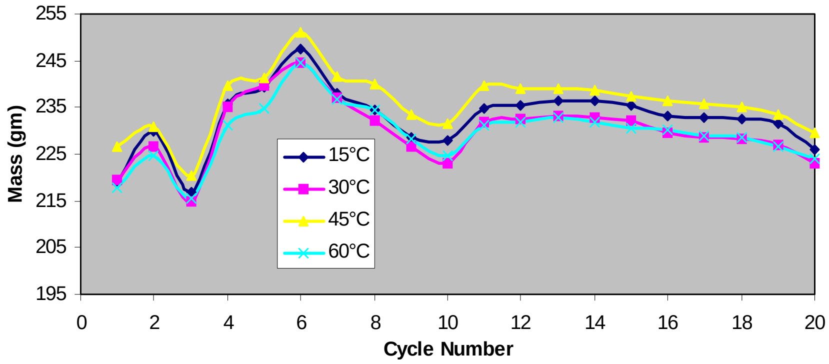

Figure-17. Salt crystallization results for 30% SD.

DISCUSSIONS

From fluidity test it was observed that 15, 30 and 45°C mixing temperature there is no significant change in efflux time in both composition. However efflux time increases for 60° temperature in both composition and it is stiff after 30 minute of mixing. All samples expect 60°C exhibits approximately double efflux time in case of immediate mixing and after 30 minutes of mixing.

Grout mixed at 15°C and 60°C gain highest compressive strength. And 0% SD gains better compressive strength than 30% SD. But both composition shows less compressive strength than the requirement which is 20 MPa at 3 days and 35 MPa at 28 days.

For 0% SD grout mixed at 30°C shows highest bond stress and 30% SD shows better bond stress than 0% SFD for all temperature combinations. In the graph of capillary suction, the slope of the line represents rate of capillary suction. From graph it was observed that the rate of capillary suction is almost same for different mixing temperature and compositions.

In salt crystallization test, 0% SD got damage after 7th cycle. On the other hand, 30% SD got damage after 20th cycle. So it can be said that 30% SD have better resistance to salt attack than 0% SD. From graph it can be seen that it follows zigzag pattern, when immersed in the salt solution, it underwent an increase in mass. This is due to the grout absorbing salt from solution, which later crystallized inside the structure during the drying phase. The increase was quickly followed by a rapid decline in mass as the cube began to suffer the effects of crypto-efflorescence within their pores.

It can be conclude that grout mixed at 60°C is not suitable for post tensioned concrete structure and grout containing a small amount of very fine sand has better resistance to salt attack and shows better bond stress than grout containing cement and water. Mixing temperature has no effect on bleeding and resistance to salt attack and a very little effect on rate of capillary suction.

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