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Effect of hot water curing and hot air oven curing on admixed concrete

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Abstract: Cement production became an intense energy consumptive activity which produces green house gases and finding a suitable substitute is an important research task in the present scenario. It is also to be noted that temperature also plays a vital role in rate of strength gain. Hence in this paper an attempt has been made to study the effect of thermal curing on strength characteristics of GGBFS based concrete. Concrete with characteristic compressive strength of 20 MPa was chosen for the present study. Concrete specimens were cast with 20%, 30% and 40% replacement of cement with GGBFS and were cured under different curing conditions like hot water and hot air oven. The specimens were exposed to three different temperatures, namely 40˚C, 50˚C and 60˚C for four hours in hot water curing. Compression test and split tensile test were conducted on concrete cubes and cylinders respectively. From the results it was inferred that higher percentage replacement of cement with GGBFS yielded considerable increase in both tensile and compressive strength of the resulting concrete. It was found that replacement of cement with 40% of GGBFS under hot water curing at 60˚C temperature has yielded maximum compressive and tensile strength of concrete.
Keywords: GGBFS, compressive strength, tensile strength, hot water curing, hot air oven curing.

INTRODUCTION

A concrete element is expected to serve for its designated period without any problem to resist structural loading, fatigue, weathering, abrasion, and chemical attack. The duration and type of curing plays a big role in determining the required materials necessary to achieve the high level of quality. Curing is the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. The result was increased strength and decreased permeability. Curing is also a key player in mitigating cracks in the concrete, which severely impacts durability. Cracks allow open access for harmful materials to bypass the low permeability concrete near the surface. Good curing can help mitigate the appearance of unplanned cracking. Being practical, curing methods can enhance sustainability of concrete by reducing the need for resource intensive conditioning treatments. Curing conditions affect the strength development rate, as strength gain is significant in the curing phase. Improper curing leads to carbonation at early stage and reduces pH levels. In this regard, certain measures have to be introduced to ensure better quality of curing process in order to secure high quality of concrete. The three main functions of curing are retaining water in concrete during the early hardening process, reducing the loss of water from the surface of the concrete and most importantly accelerating strength gain using heat and additional moisture. It was found that thermal curing concrete increases rate of strength gain. Some of the literatures in the area of thermal curing of is explained in the following paragraphs:

Effects of dry and wet curing on compressive strength of silica fume based concrete was studied and it was found that the silica based concrete was more influenced by dry curing condition than on control concrete. Increase in the ratio of water and binder; influence the concrete to be more sensitive in dry curing conditions. Dry and wet curing conditions has shown a linear relationship between control concrete and silica fume based concrete [1].

Influence of curing methods on the strength and permeability of GGBFS concrete in a simulated arid climate was done and the development of strength and permeability of Ordinary Portland cement (OPC) and GGBFS modified concrete was compared. It was concluded that 50% replacement of cement with GGBFS cured under wet burlap method at 20°C gave high strength [2].

Strength, Economic and Sustainability Characteristics of Coal Ash –GGBS Based Geopolymer Concrete was analyzed and the feasibility of production of geopolymer concrete using coarser bottom ash was evaluated [3]. Additionally, the effect of replacement of fly ash with bottom ash at varying percentage on strength of Geopolymer concrete was also studied. The effect of curing methodology on strength of fly ash-GGBS based geopolymer concrete has also been evaluated. Economic impact and sustainability studies were conducted on both OPC based concrete and geopolymer concrete. Comparison studies shows that geopolymer concrete could be prepared at comparable cost with that of OPC concrete while they offer huge reduction in carbon dioxide emission.

Effects of curing conditions on properties of concrete using slag as replacer for cement was studied with autoclaving and steam curing conditions [4]. The replacement of cement with slag was varied as 25%, 50% and 75%. They reported that steam curing reduces the compressive strength compared to the other types of curing. Chloride permeability and penetrability significantly decreased with increase of slag replacement except for autoclave curing, which was least sensitive with respect to slag replacement and the addition of slag reduces the continuous pore diameter.

Effect of curing regime and temperature on the compressive strength of cement-slag mortar was investigated and found that higher strength could be achieved for OPC and OPC-slag mortars using lower binder content, provided the specimens are cured in water without heating. For slag mortars the highest strengths could be only achieved using more slag content and water curing without heating. The results have shown that curing regime and its duration had a significant effect on strength improvement of all groups of mortars [5]. Effect of different curing conditions on the mechanical and physical properties of concretes with mineral admixtures of silica fume and blast furnace slag was studied and concluded that the presence of mineral admixtures improve the compressive strength, ultrasonic pulse velocity, capillarity coefficient and appearing porosity [6].

Effect of thermal curing condition on mechanical and micro structural development was researched and found that unsuitable curing conditions may lead to speedy carbonation and concomitantly lower pH levels in the system, in turn occasioning significant declines in the rate of ash activation and mechanical strength development. Carbonation could only be prevented by subjecting the paste to high environmental humidity throughout the curing process [7]. Effect of curing at higher temperature on compressive strength and carbonation depth of pozzolanic structural lightweight concretes and Pulverized Fuel Ash- and Silica Fumes incorporated lightweight concrete was investigated. Concrete with PFA and SF as a cement substitute up to a percentage of 70 were compared. PFA- and SF-incorporated concrete had greater strength under accelerated curing condition than under normal curing condition, but OPC mixes showed a different result that they gain higher strength under normal curing and lower strength under accelerated curing when compared with the former [8].

Examination of compressive strength and electrical properties of concrete with white Portland cement and blast-furnace slag was done [9]. They tested the compressive strength of concrete cylinders and the electrical conductivity of the pore solution and found that larger amounts of slag resulted in increased electrical resistivity and decreases in the electrical conductivity of the pore solution, when compared to the controlled concretes which indicates that white Portland cement can be partially substituted by blast-furnace slag.

A comparative study was done on strength parameter for different standards and proposed a strength predicting exemplar for GGBFS based concrete. They concluded that compressive strength of control concrete has found to be higher when compared to GGBFS based concrete for all percentage replacement and ages. They also found that 40% replacement of GGBFS with cement attains more compressive strength when compared to 20% and 60% replacement of GGBFS .60% replacement of GGBFS gives less strength when compared to 20% and 40% replacement of GGBFS. For different percentage replacement of cement by GGBFS, the ratio of cylinder to cube compressive strength was clearly explained [10].

Effect of curing temperature on the thermal expansion and phase composition of hydrated limestone-slag cement was performed and concluded that increase in curing temperature yield an important increase in compressive strength of slag cement indicating the higher reactivity of slag arises from the pozzolanic activity point of view [11]. A research on effect of curing temperature and type of cement on early-age shrinkage of high-performance concrete was performed and they found that higher temperatures do not lead to higher deformations in the observed period, but generally cause a faster shrinkage and a faster development of self-induced stresses [12]. Engineering and durability properties of concretes based on alkali-activated granulated blast furnace slag/met kaolin blends was studied and concluded that at high activator concentration, compressive strengths and flexural strength at early age are enhanced by the inclusion of met kaolin in the binder. Increased met kaolin contents and higher activator concentrations leads to reduced water sorptivity and lower chloride permeability [13]. Cement paste containing GGBFS and the effects of elevated temperature was evaluated and concluded that under higher temperature of 1050 ˚C, cracking happens when 10% or lesser percentage of GGBFS content in all three W/B ratios. The crack was significantly reduced by increasing in GGBFS content up to 20% or above. A clear trend of GGBFS content for fire resistance is 50 - 80% was found in W/B ratio of 0.23. Inclusion of GGBFS increases the elastic modulus at higher temperature and the fire resistance of HPC was also greatly improved when the cement is replaced with GGBFS [14].

EXPERİMENTAL INVESTİGATİONS

Materials Used

The cement used for the study was Ordinary Portland Cement. The specific gravity of the cement was to be 3.15. The Coarse Aggregate used was broken stone. The Specific Gravity and Water absorption of broken stone are 2.76 and 0.78 % respectively. Size of coarse aggregate used here was 16 mm downsize. The fine aggregate used was river sand. To determine the specific gravity of coarse aggregate, wire basket method and it was ascertained to be 2.65. The Specific Gravity of river sand is 2.67. Ground granulated blast furnace slag (GGBFS) has been acquired from Salem. Fig 1 shows a photograph of GGBFS. It is obtained by quenching molten iron slag (a by-product of iron and steel-making).It is a glassy, granular product which is then dried and ground into a fine powder. An immersion water heater attached with thermostat was used for thermal curing. Thermostat is a device that automatically controls heating in such a way as to maintain a temperature at a constant level. This setup was designed in such a way that, when the temperature of water reaches the desired value, the thermostat automatically will be switched off and when the temperature falls down below the desired value it will be switched on.

Fig 1 : Appearance of Slag

Methodology

Specimens were cast and tested with different percentages of LDPE to study the effect of LDPE, different magnitudes of temperature to study the effect of temperature, different duration of thermal curing to arrive the optimum duration and different medium to study the resistance against sulphate and acid attack. The Mix proportion arrived was 1:1.44:3.19 to get a characteristic compressive strength of 20 MPa. The target mean strength was obtained to be 25.8 MPa. The water cement ratio adopted was 0.50 which was obtained from the Slump Cone test. Concrete cubes of size 100 mm x 100 mm x 100 mm were cast for different combinations of concrete with 20%, 30%, and 40% of GGBFS. The specimens were under thermal curing (hot water and hot air oven) for duration of 4 hours with temperatures of 40, 50 and 60°C to understand the effect of magnitude of temperature on strength of concrete (Fig.2).

Fig 2 : Specimens under thermal curing

Characterization of Ground Granulated Blast Furnace Slag

Chemical composition of Ground Granulated Blast Furnace Slag is obtained by XRF analysis of the sample. Table 1 shows the main elements (expressed as oxides) present in Ground Granulated Blast Furnace Slag. CaO is the major component in ash, following by SiO_2, Al_2O_3, MgO, Fe_2O_3 and SO_3 in concentrations of 34.01, 16.62, 9.11, 1.71 and 1.55 respectively. It is found that only traces of TiO2, Na2O, K2O, MnO, BaO, P2O5, SrO, Cl, ZrO2 and As2O3 are present. Since GGBFS contains all these constituents, it is now used as a cement substitute.

Table 1. Chemical Composition of GGBFS

Element	Concentration (%)	Element	Concentration (%)	Element	Concentration (%)
CaO	34.85	TiO_2	0.69	SrO	0.04
SiO_2	34.01	Na_2O	0.48	Cl	0.03
Al_2O_3	16.62	K_2O	0.46	ZrO_2	0.03
MgO	9.11	MnO	0.27	As_2O_3	37 ppm
Fe_2O_3	1.71	BaO	0.10		
SO_3	1.55	P_2O_5	0.04		

Compression Test Results

The results of the compression test for control concrete and concrete with 20%, 30% and 40% GGBFS for various curing conditions like hot water curing and hot air oven curing at temperatures of 40˚C, 50˚C and 60˚C respectively are presented in the table 2. The results revealed that the compressive strength of control concrete at the age of 28 days in normal curing was found to be 29.09 MPa which was greater than the designed target mean strength of 25.8 MPa.. Due to the effect of 4 hours curing in hot water and hot air oven, there was smaller increase in strength values compared to control concrete cured in normal water. It was observed that the rate of strength gain was in ascending trend from 40 to 50 ˚C temperature and further increase of temperature to 60˚C has shown a reverse trend in the case of hot water curing. Though the compressive strength results of control concrete cured in hot air oven curing yielded similar results, rate of strength gain was continuously in ascending trend from 40 to 60 ˚C. Comparing the results of hot water curing and hot air oven curing, former yielded better results than the later. It might be due to effective reach and distribution of temperature into the specimen when it was subjected to hot water curing.

Compressive strength of concrete increased for all percentages of replacement of cement with GGBFS. It was applicable for normal water, hot water and hot air oven curing. The compressive strength of GGBFS admixed concrete was found to be 29.53, 29.91 and 30.09 MPa for 20, 30 and 40% addition of GGBFS under normal curing conditions.

Though the rate of strength gain was found to be small (in the range of 2 to 3%), replacement of cement with GGBFS to an extent of 40% not only minimize the use of cement and disposal problem of waste product from steel industry but also saves cost that too without compromising strength. This rate of strength gain was also on ascending trend when GGBFS admixed concrete was subjected to either hot water or hot air oven curing. Comparing the results of admixed concrete subjected to thermal curing with control concrete and admixed concrete cured in normal water curing it was ranging from 4 to 15%. Lower strength gain was observed for specimens subjected to thermal curing with lower temperatures and higher strength gain was observed in specimens with higher temperatures.

Similar trend also was applicable when results were compared with control and admixed concrete. Results revealed that more strength gain between control concrete in normal water curing and admixed concrete in hot water /hot air oven was observed which gives an idea about the effect of admixture, effect of thermal curing and effect of admixed concrete on thermal curing.

Table 2. Compressive Strength Test Results

S. No	Combination	Average Load (kN)	Area (mm²)	Average Compressive Strength (MPa)
1	CC W	290.80	10000	29.09
2	CC H 40	306.15	10000	30.60
3	CC H 50	310.80	10000	31.01
4	CC H 60	298.00	10000	29.80
5	CC O 40	286.55	10000	28.65
6	CC O 50	295.40	10000	29.54
7	CC O 60	303.30	10000	30.33
8	S 20% W	295.30	10000	29.53
9	S 20% H 40	307.30	10000	30.73
10	S 20% H 50	311.20	10000	31.12
11	S 20% H 60	320.30	10000	32.03
12	S 20% O 40	302.00	10000	30.20
13	S 20% O 50	307.10	10000	30.71
14	S 20% O 60	313.50	10000	31.35
15	S 30% W	299.10	10000	29.91
16	S 30% H 40	308.00	10000	30.80
17	S 30% H 50	313.00	10000	31.30
18	S 30% H 60	322.70	10000	32.27
19	S 30% O 40	305.20	10000	30.52
20	S 30% O 50	307.50	10000	30.75
21	S 30% O 60	314.00	10000	31.40
22	S 40% W	300.90	10000	30.09
23	S 40% H 40	313.80	10000	31.38
24	S 40% H 50	319.60	10000	31.96
25	S 40% H 60	337.30	10000	33.73
26	S 40% O 40	306.50	10000	30.65
27	S 40% O 50	311.70	10000	31.17
28	S 40% O 60	323.20	10000	32.32

Split Tensile Test Results

The results of the split tensile strength test for control concrete and concrete with 20%, 30% and 40% GGBFS for various curing conditions such as hot water curing and hot air oven curing at temperatures of 40˚C, 50˚C and 60˚C respectively are presented in the table 3. The results revealed that the tensile strength of control concrete at the age of 28 days in normal curing was found to be 1.9 MPa. Due to the effect of 4 hours curing in hot water and hot air oven there was considerable increase in tensile strength values compared to control concrete cured in normal water. It was observed that the rate of strength gain was in ascending trend from 40 to 60 ˚C temperature in the case of hot water curing and hot air oven curing. Though the compressive strength results of control concrete cured in hot air oven curing yielded similar results, rate of strength gain was little bit lesser than specimens cured in hot water curing as seen in compressive strength results.

Tensile strength of concrete increased when cement was replaced with GGBFS irrespective of percentage. Increase of GGBFS addition also increased tensile strength. It was applicable for normal water, hot water and hot air oven curing. The tensile strength of GGBFS admixed concrete was found to be 1.94, 2.01 and 2.18 MPa for 20, 30 and 40% addition of GGBFS under normal curing conditions.

Comparing the results of admixed concrete subjected to thermal curing with control and admixed concrete cured in normal water curing it was ranging from 4 to 50%. Lower strength gain was observed for specimens subjected to thermal curing with lower temperatures and higher strength gain was observed in specimens with higher temperatures. Similar trend also was applicable when results were compared with control and admixed concrete. Results revealed that more strength gain between control concrete in normal water curing and admixed concrete in hot water /hot air oven was observed which gives an idea about the effect of admixture, effect of thermal curing and effect of admixed concrete on thermal curing as seen in compressive strength results. Comparing the results due to the effect thermal curing on compressive strength and tensile strength on control concrete and admixed concrete, tensile strength had significant improvement than compressive strength.

Table 3. Split Tensile Test Results

S.No	Combination	Average Load (kN)	Area (mm^2)	Tensile Strength (N/mm^2)
1	CC W	59.69	62832	1.9
2	CC H 40	66.6	62832	2.12
3	CC H 50	68.49	62832	2.18
4	CC H 60	74.14	62832	2.36
5	CC O 40	61.88	62832	1.97
6	CC O 50	65.65	62832	2.09
7	CC O 60	71.31	62832	2.27
8	S 20% W	60.94	62832	1.94
9	S 20% H 40	68.8	62832	2.19
10	S 20% H 50	69.11	62832	2.2
11	S 20% H 60	85.44	62832	2.72
12	S 20% O 40	64.4	62832	2.05
13	S 20% O 50	66.91	62832	2.13
14	S 20% O 60	74.76	62832	2.38
15	S 30% W	63.14	62832	2.01
16	S 30% H 40	69.74	62832	2.22
17	S 30% H 50	70.36	62832	2.24
18	S 30% H 60	88.9	62832	2.83
19	S 30% O 40	66.28	62832	2.11
20	S 30% O 50	70.36	62832	2.24
21	S 30% O 60	75.39	62832	2.4
22	S 40% W	68.49	62832	2.18
23	S 40% H 40	71	62832	2.26
24	S 40% H 50	71.94	62832	2.29
25	S 40% H 60	91.73	62832	2.92

26	S 40% O 40	68.79	62832	2.19
27	S 40% O 50	72.25	62832	2.3
28	S 40% O 60	79.47	62832	2.53

CONCLUSIONS

From the experimental investigations carried out on control concrete and GGBFS admixed concrete to study the effect of thermal curing following conclusions were drawn:

- Cement replacement with GGBFS yielded better results on compressive strength and tensile strength irrespective of its percentage to an extent of 16 % and 54% respectively..
- Test results indicated that, higher strength was obtained from few hours of thermal curing before normal curing when compared with specimens subjected to only normal curing.
- Effect of thermal curing was more effective on tensile strength than that of compressive strength of control concrete and GGBFS admixed concrete.
- Among two methods of thermal curing, it was found that hot water curing was more effective than hot air oven curing.
- From the results it was found that, specimen with 40% percentage GGBFS under hot water curing at 60˚C has yielded maximum compressive strength and tensile strength.
- Another advantage of using GGBFS as partial substitute to was substantial cost reduction of concrete. With an optimum amount of GGBFS substitution; cost incurred for cement could be reduced to 10-15% of the original cost. Furthermore, with the subsequent reduction in use of cement, there will be a reduction in the amount of CO_2 liberated into the atmosphere. Thus the optimum usage of GGBFS as a mineral admixture also minimizes the environmental problem.

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