Effect of Temperature on Durability of High Volumes of Slag Concrete

T. Vijaya Gowri[1], P.Sravana[2], P.Srinivasa Rao[3]

[1] *Asst. Professor, BVRIT (Autonomous), Narsapur, Medak,India*
[2] *Professor in Civil Engineering Department, JNTUH University, Hyderabad, India.*
[3] *Professor in Civil Engineering Department, JNTUH University, Hyderabad, India.*

Abstract

Concrete is an important material used in constructions like buildings, pavements, bridges etc. often subjected to environmental impact loads. The durability of concrete and strength of concrete are affected when the concrete is exposed to fire accidents in the buildings and at high temperature in case of concrete pavements. This paper presents the results of experimental studies conducted on performance of High Volumes of Slag Concrete (HVSC) exposed to elevated temperatures up to 600°C. In HVSC, 50% of cement is replaced with Ground Granulated Blast Furnace Slag (GGBS). In this experimental studies, HVSC of 100 mm cubes are cast and tested for various water/binder ratios ranging from 0.55 to 0.27. The specimens are exposed to elevated temperatures of 200°C, 400°C and 600°C for 4, 8, 12 hours. Result of compressive strengths and weights of cubes after expose to high temperature are estimated. Percentage loss in compressive strengths and weights are also evaluated. The results illustrate that the loss in compressive strength and weights are more for higher temperatures for longer duration for higher water/binder ratios.

Keywords — *High Volumes of Slag Concrete, Ground Granulated Blast Furnace Slag, elevated temperatures.*

I. INTRODUCTION

There is a need to pay attention while choosing the materials for structures like nuclear power plants, pavements, high rise buildings which are accidentally exposed to elevated temperatures in the form of fire. The constructions which are exposed to high temperatures are missile launching pads, aircraft engine test cells, turbo jet runways, extra-ordinary condition structures like storage tanks for coal gasification, crude oil, hot water, liquefaction vessels used in petro-chemical industries, foundation for blast furnace, coke industries, furnace walls, industrial chimney etc. Indeed, high temperature affects the thermo-mechanical properties which cause cracking. Thereby the concrete allows the ingress of water which causes corrosion of reinforcement and reduces strength of concrete. High temperatures cause drying of gel pores, difference in pore pressure, cracking due to high thermal variations, spalling and micro-cracking.

II. LITERATURE

G.V.Rama Rao et al.(2015)(1), The materials like pozzalonas may be natural, and artificial like industrial wastes or by-products which require less energy to make fine particles. These materials exhibit cementitious properties and combine with calcium hydroxide producing cementitious material. R. Sri Ravindrarajah et al., (2002)(2) stated that concrete consists of discrete and interconnected pores of variety of sizes and shapes and their distribution depend on the binder material type. The refinement of pore size as well as grain size of concrete is attained by the use of fly ash, slag and silica fume due to its fineness, pozzolanic and cementitious property. Free water in the gel causes capillary cavities and combined water in hardened cement paste improves the hydration process. Combined water can be dehydrated at 1000°C only due to its stability. Albert Noumowé, (2009)(3), mentioned that thermal gradients were very significant and generating high compressive stresses at the specimen surface during the heating for tests at 210°C and 310°C. This thermal loading cause stresses which are accompanied by the degradations of cement paste due to abrupt changes in volume further it leads to a damage of the concrete. Contrasting conditions observed while cooling the temperature in the Centre of specimen are more than the surface. This condition causes compressive stresses at Centre and tensile stresses on the surface. Compressive strength is decreased with the increase in temperature. However, losses were very less between 20°C and 110°C. There was appreciable reduction in the strength above 210 °C and loss in compressive strength was 8% whereas loss in compressive strength was 36% at 310 °C. P.Srinivasa Rao et al,(2006)(4) stated that the structural elements are exposed to solar radiation, thermal gradient in the elements are influenced by degree of humidity. In that way the elements of structures undergo one thermal cycle per day and also exposed to peak value of heating period and cooling period. F. Falade,(2010)(5), concluded that the compressive strength of concrete is reduced with increase in water/cement ratio and increase in temperature but increased with increase in curing period. The bond between the concrete within matrix decreases as the temperature increases. The loss in strength of specimens is in between 24 and 40% at the maximum temperature of 800^{o}C/hr, which is influenced by the mix proportion and curing age. Lightweight concrete consists of periwinkle shells which are the only appropriate material for structures that will be exposed to temperature lower than 300^{o}C. Rafat Siddique et al. (2011)(6), concluded that concrete with GGBFS can be used in constructions exposed to elevated temperatures. The degradation of mechanical properties of concrete is less between 27 and 100 ^{o}C. The values of compressive strength, split tensile strength and modulus of elasticity are reduced lower than 40% after exposing to a temperature more than 350 ^{o}C. The loss in mass is not very important at temperatures between 200 and 350 ^{o}C. GGBFS may contribute to some extent to the residual compressive strength of concrete at elevated temperatures. Similar findings were observed by Xiao and Falkner. M.A.Pathan et al., (2012)(7) stated that in practice, at the temperature 250 ^{o}C, calcium hydroxide starts to dehydrate generating more amount of water vapour. Further, significant reduction in their compressive strength was observed at temperatures in range of 300 ^{o}C and 600 ^{o}C. Seshagiri Rao M V et al., (2013)(8) stated that a considerable change in physical structure and chemical composition appears when concrete is exposed to high temperature. Above 100^{o}C, dehydration of water in C-S-H gel is important. This is added to thermal expansion of aggregates which causes increase in internal stresses at 300 ºC, further micro-cracks are developed. $Ca(OH)_2$, the product of hydration of cement paste, separates into CaO and H_2O at 400-600 °C subsequently; shrinkage of concrete occurs. H. Shehab El – Din et al., (2013)(9) concluded that the compressive strength values are lowered when concrete is exposed to increased temperature from 0 ^{o}C to 200 ^{o}C. However the lowest decrease in compressive strength observed is approximately 20.52 % in case of wrapped with 3 strips. When the specimen area wrapped with Carbon Fiber Reinforced Polymer (CFRP), an appreciable increase in compressive strengths is observed. The percentages of increase are about 248.56 % and 121.45 % in cases of totally wrapping and wrapped with 3 strips respectively than without wrapping at 200 ^{o}C. Saeed Ahmed Al.Sheikh, (2011)(10) concluded that the weight loss of high performance concrete increases with a temperature at a decreasing rate at 1000 ^{o}C; weight loss was about 12%. Above 200 ^{o}C, high performance concrete exhibited degradation in its properties and loss in compressive strength and tensile strength was around 69% and 73% respectively. Loss in strength for high performance concrete was found due to sudden cooling. A Farhat Bingol et al., (2004)(11), There are no significant losses in compressive strength of light weight aggregate concrete observed between 150 ^{o}C to 300 ^{o}C. The initial strength loss is important for all mix groups at 750 ^{o}C. The heating duration does not affect the strength loss significantly but high temperature is a significant parameter of strength loss. Stephen S. Szoke,(2006)(12), The degradation of pavement color resembles degradation of cement paste properties. Color of siliceous or limestone aggregate concrete change from pink or red to gray at about 600°C (1112°F). The concrete buffs at about 900°C (1652°F). Thermal and mechanical behavior of concrete is understood by temperature regime-structural behavior models, further helping in specification and design against the extremes of fire and for applications like nuclear reactors. S.H. Chowdhury, (2014)(13) stated that at high temperatures, loss in compressive strength and tensile strength was observed for all three concrete mixes of 100 MPa, 80 MPa and 40 MPa. The loss in strength for 80 MPa mix was about 44% when exposed to 400°C for 12 hrs. At 60°C, the loss in tensile strength for 80 MPa mix was about 18% for 72hrs exposure. A non-linear relationship was observed between weight loss and maximum temperature but loss was least in the case of highest strength mix for every temperature and duration of high temperature exposure. An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it.

III. RESEARCH SIGNIFICANCE

One of the most recommended materials for different types of constructions is concrete. The rate of cement consumption is also increasing constantly and the production of cement causes environmental impacts. Ground Granulated Blast Furnace Slag (GGBS) is the waste by-product which consists of cementitious properties and pozzolanic properties. This improves the properties of fresh concrete as well as durability of hardened concrete. In the present investigations, 10mm cubes of High Volumes of Slag Concrete are cast and tested for temperature resistance. The cubes are exposed to elevated temperatures of 200 ^{0}C, 400 ^{0}C and 600 ^{0}C for duration of 4, 8 and 12 hours. The Compressive strengths and weights of cubes are evaluated before testing and after testing in the laboratory**.** The percentage losses in strengths and weights of HVSC are evaluated.

IV. EXPERIMENTAL INVESTIGATION

A. Cement:

Locally available 53 grade of Ordinary Portland Cement (Ultratech Brand.) confirming to IS: 12269 was used in the investigations. The cement is tested for various properties like Normal consistency, specific gravity, Fineness, Soundness, Compressive Strength , and Specific Surface area were found to be 28%, 3.10, 4%, 0.5 mm, 53Mpa and 3100 cm^2/g in accordance with IS:12269-1987.

B. GGBS:

GGBS which is available in local was procured from Steel Plant, Visakhapatnam (Dt), Andhra Pradesh. The physical requirements in accordance with IS 1727- 1967 (Reaffirmed2008) and chemical requirements in accordance with IS: 12089 – 1987 (Reaffirmed 2008). The GGBFS is tested for various properties like Specific gravity and Fineness were found to be 2.86 and 3500 cm^2/g.

C. Super Plasticizer:

The Super plasticizer utilized was supplied by internationally reputed admixture manufactures. Endure flowcon04 was manufactured by Johnson. Endure flowcon04 is dark brown colored liquid and it is based as sulphonated naphthalene formaldehyde (SNF) super plasticizer. It complies with IS: 9103-1999, BS5075, ASTM C-494 was used. The super plasticizer is tested for properties like density and pH were found to be 1.2 and minimum 6.

D. Fine Aggregate:

The locally available river sand is used as fine aggregate in the present investigation. The sand is free from clay, silt, and organic impurities. The sand is tested for various properties like specific gravity, water absorption and fineness modulus of fine aggregate were found to be 2.55, 1.72 and 2.74 in accordance with IS:2386-1963.

E. Coarse Aggregate:

Machine crushed angular granite metal of 20mm nominal size from the local source is used as coarse aggregate. It is free from impurities such as dust, clay particles and organic matter etc., the coarse aggregate is also tested for its various properties. The specific gravity, water absorption and bulk density and fineness modulus of coarse aggregate were found to be 2.60, 0.38, 1490 kg/m^3 and 7.16 respectively.

F. Water:

Locally available water used for mixing and curing which is potable, shall be clean and free from injurious amounts of oils, acids, alkalis, salts, sugar, organic materials or other substances that may be deleterious to concrete or steel. entire document should be in Times New Roman or Times font. Type 3 fonts must not be used. Other font types may be used if needed for special purposes.

Table.1 : Quantities of Material required per One Cu. m. of High Volumes of Slag Concrete

w/b ratio	Water (Lts)	Cement (kg)	GGBS (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Super Plasticizer (ml)	Slump Values (mm)
0.55	176	160	160	763	990	0	75
0.50	176	176	176	749	971	0	80
0.45	176	196	196	715	966	0	65
0.40	176	220	220	662	971	1732	90
0.36	176	244	244	625	961	2122	100
0.32	176	275	275	587	936	3873	120
0.30	176	293	293	529	959	3882	130
0.27	176	326	326	477	945	4698	140

V. TEST PROCEDURE

To study the compressive strength of High Volumes of Slag Concrete when subjected to elevated temperatures of 200 °C, 400 °C and 600 °C , it was planned to be carried out through an experimental program on concrete specimens of size 100 mm cubes for various water/binder ratios of Ordinary and High Volumes of Slag Concrete. The test specimens were demoulded after 24 hours of air cooling and kept in water for curing for 28 days. The standard specimens after curing period were placed in electric muffle furnace at requisite temperature of 200 °C, 400 °C and 600 °C at 4 hours, 8 hours, and 12 hours duration. After the specimens were removed from the furnace, the specimens were allowed to cool in air for 24 hours. Then the specimens were tested for change in compressive strength and change in weight. The results are tabulated in Table 2 to Table 10.

VI. TEST RESULTS

Table 2 : Percentage Loss in Weight of High Volumes of Slag Concrete at 200 °C at 4, 8 and 12 Hours Duration with Reference to 28 Days weight

S. No.	w/b ratio	Loss in Weight (%) Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	4.23	6.23	7.34
2	0.50	4.12	6.17	6.30
3	0.45	4.06	5.81	6.07
4	0.40	3.05	5.36	5.99
5	0.36	2.50	4.89	5.77
6	0.32	2.48	4.26	5.27
7	0.30	2.12	3.94	5.26
8	0.27	2.00	3.15	5.04

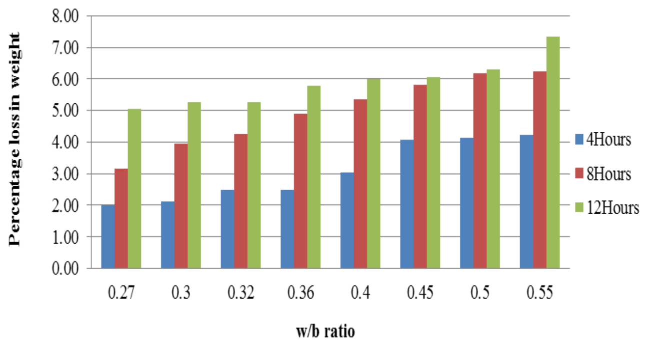

Fig. 1 Percentage Loss In Weight Of High Volumes Of Slag Concrete At 200 °c At 4, 8 And 12 Hours Duration

Table 3 : Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 200 °C for 4, 8 and 12 Hours Duration

S.No.	w/b ratio	Compressive Strength (MPa)			
		Duration			
		At Room Temperature	4 Hours	8 Hours	12 Hours
1	0.55	29.09	24.61	23.01	21.99
2	0.50	30.60	27.09	24.28	23.77
3	0.45	33.93	30.37	28.84	26.94
4	0.40	37.31	34.56	32.46	30.81
5	0.36	42.08	39.54	36.86	35.71
6	0.32	45.39	42.75	40.09	39.37
7	0.30	45.47	43.05	40.84	40.09
8	0.27	54.00	51.56	49.67	47.91

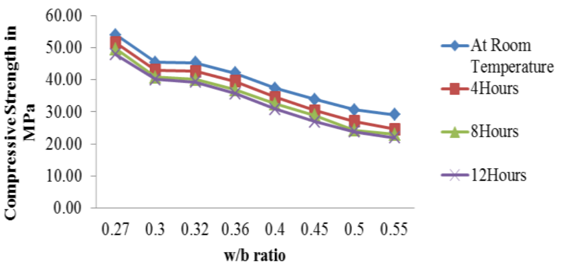

Fig. 2 Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 200 °C for 4, 8 and 12 Hours Duration

Table 4 : Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 200 °C at 4, 8, 12 Hours Duration

S. No.	w/b ratio	Loss in Compressive Strength (%)		
		Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	15.42	20.92	24.41
2	0.50	11.48	20.66	22.33
3	0.45	10.50	15.01	20.60
4	0.40	7.37	13.00	17.42
5	0.36	6.03	12.40	15.15
6	0.32	5.83	11.68	13.26
7	0.30	5.34	10.19	11.84
8	0.27	4.53	8.02	11.28

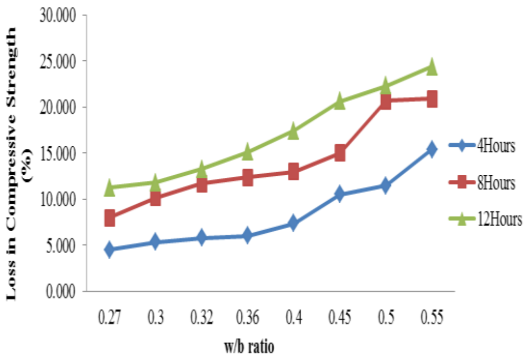

Fig. 3 Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 200 °C at 4, 8, 12 Hours Duration

Table 5 : Percentage Loss in Weight of High Volumes of Slag Concrete at 400 °C at 4, 8, 12 Hours Duration with reference to 28 Days weight

S. No.	w/b ratio	Loss in Weight (%)		
		Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	6.67	7.11	7.52
2	0.50	6.42	6.65	6.97
3	0.45	6.32	6.48	6.52
4	0.40	5.90	6.14	6.17
5	0.36	5.76	5.91	5.99
6	0.32	5.47	5.79	5.98
7	0.30	4.96	5.63	5.76
8	0.27	4.86	5.46	5.72

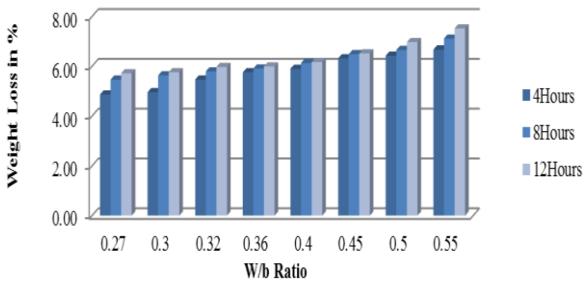

Fig. 4 Percentage Loss in Weight of High Volumes of Slag Concrete at 400 °C at 4, 8, 12 Hours Duration

Table 6 : Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 400 °C for 4 hours, 8 hours and 12 Hours Duration

S.No.	w/b ratio	Compressive Strength (MPa)			
		Duration			
		At Room Temperature	4 Hours	8 Hours	12 Hours
1	0.55	29.09	22.76	21.97	20.4
2	0.50	30.60	24.2	23.51	22.12
3	0.45	33.93	27.06	26.69	25.99
4	0.40	37.31	31.05	30.91	29.26
5	0.36	42.08	35.76	34.99	33.25
6	0.32	45.39	39.65	38.78	35.94
7	0.30	45.47	40.89	39.51	37.3
8	0.27	54.00	49.64	47.38	45.71

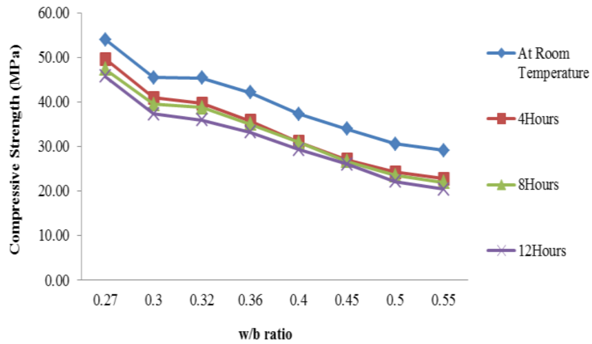

Fig. 5 Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 400 °C for 4 hours, 8 hours and 12 Hours Duration

Table 7 : Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 400 °C at 4, 8 and12 Hours Duration with reference to 28 Day Strength

S. No.	w/b ratio	Loss in Compressive Strength (%)		
		Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	21.76	24.5	29.88
2	0.50	20.92	23.18	27.72
3	0.45	20.26	21.35	23.42
4	0.40	16.78	17.16	21.59
5	0.36	15.01	16.84	20.99
6	0.32	12.65	14.56	20.82
7	0.30	10.08	13.12	17.98
8	0.27	8.07	12.26	15.35

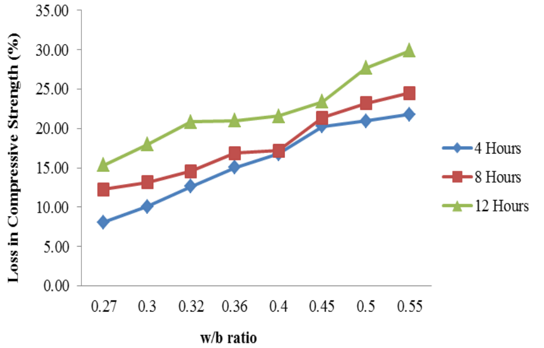

Fig. 6 Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 400 °C at 4, 8 and12 Hours Duration

Table 8 : Percentage Loss in Weight of High Volumes of Slag Concrete at 600 °C at 4, 8, 12 Hours Duration with reference to 28 Days weight

S. No.	w/b ratio	Loss in Weight (%)		
		Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	6.78	7.36	7.74
2	0.50	6.58	7.29	7.52
3	0.45	6.34	7.09	7.23
4	0.40	6.01	6.99	7.02
5	0.36	5.85	6.8	6.95
6	0.32	5.66	6.27	6.67
7	0.30	5.75	5.75	6.34
8	0.27	5.62	5.64	5.88

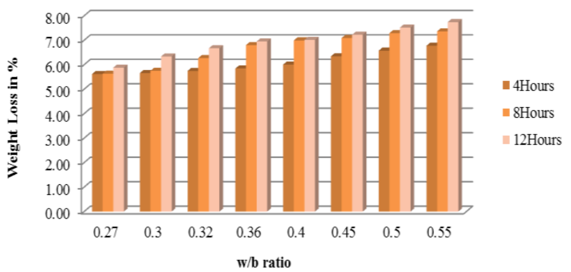

Fig 7 Percentage Loss in Weight of High Volumes of Slag Concrete at 600 °C at 4, 8, 12 Hours Duration

Table 9 : Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 600 °C at 4, 8 and 12 Hours Duration

S.No.	w/b ratio	Compressive Strength (MPa)			
		Duration			
		At Room Temperature	4 Hours	8 Hours	12 Hours
1	0.55	29.09	21.5	20.52	18.37
2	0.50	30.60	23.07	22.41	19.85
3	0.45	33.93	26.39	25.32	23.72
4	0.40	37.31	29.96	28.6	26.82
5	0.36	42.08	34.21	32.54	30.72
6	0.32	45.39	37.54	36.44	34.52
7	0.30	45.47	39.33	38.65	36.16
8	0.27	54.00	47.88	46.58	44.78

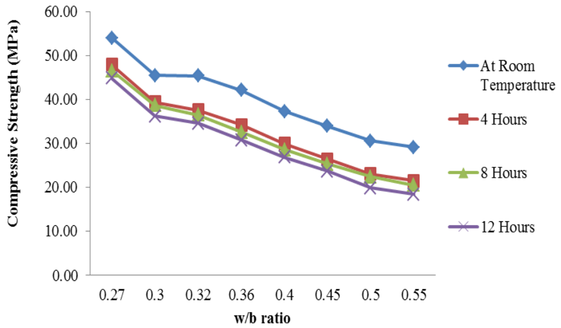

Fig. 8 Compressive Strength of High Volumes of Slag Concrete for 28 Days at Room Temperature, 600 °C at 4, 8 and 12 Hours Duration

Table 10 : Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 600 °C for 4, 8 and 12 Hours Duration with reference to 28 Days Strength

S. No.	w/b ratio	Loss in Compressive Strength (%)		
		Duration		
		4 Hours	8 Hours	12 Hours
1	0.55	26.09	29.48	36.85
2	0.50	24.61	26.77	35.14
3	0.45	22.23	25.40	30.11
4	0.40	19.70	23.34	28.13
5	0.36	18.70	22.68	27.00
6	0.32	17.30	19.72	23.95
7	0.30	13.51	15.02	20.49
8	0.27	11.33	13.74	17.07

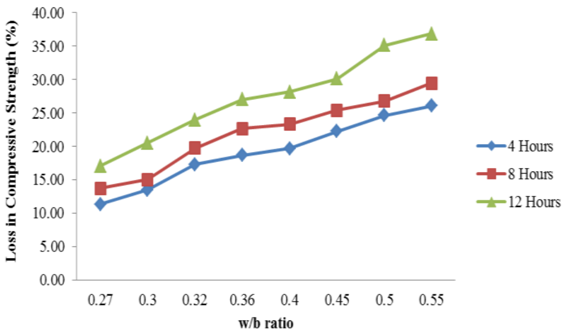

Fig. 9 Percentage Loss in Compressive Strength of High Volumes of Slag Concrete at 600 °C for 4, 8 and 12 Hours Duration with reference to 28 Days Strength

VII.DISCUSSIONS

Concrete structures can be exposed to high temperatures during fire accidents. High temperatures cause the deterioration of physical properties of concrete. Special applications such as missile launching pads, nuclear reactor vessels, aircraft engine test cells and turbo jet runways require enduring higher temperatures.

At elevated temperatures, thermal incompatibility between two gradients causes loss in strength of High Volumes of Slag Concrete and subjected to formation of cracks between binder paste and aggregate.

The percentage decreases in compressive strengths is less for lower water/binder ratios are because of nucleation as well as pozolanic action of GGBS particles. This reaction causes the formation of additional C-S-H gel is called pozzlancity. Further, the GGBS particles which are inert are filling the pores by nucleation effect. In this way percentage decrease of compressive strength is less for lower w/b ratios.

The quantities of materials for one cubic meter of High Volumes of Slag Concrete are shown in **Table.1**. A medium workability was maintained for almost all the mixes by addition of suitable quantities of super plasticizer. In this investigation, the specimens of High Volumes of Slag Concrete of different w/b ratios ranging from 0.55 to 0.27 exposed to temperatures of 200 °C, 400 °C and 600 °C. The duration of exposure of every temperature is 4 hours, 8 hours and 12 hours. The weights and Compressive strengths of specimens are to be taken before and after exposure of temperature. Then loss in weight and loss in compressive strengths are estimated.

1) Loss in weight of High Volumes of Slag Concrete exposure to 200 °C

The percentage weight loss of High Volumes of Slag Concrete after exposing to 200 °C for 4, 8, 12 hours at 200 °C are shown in Table 2. After exposed to 200 °C, the percentages weight losses are 4.23% to 2.00% at 4 hours, 6.23% to 3.15% at 8 hours and 7.34% to 5.04% at 12 hours respectively for w/b ratios varying from 0.55 to 0.27 respectively. These variations are shown in Fig. 1.

2) Loss in Compressive Strength of High Volumes of Slag Concrete exposure to 200 °C

The compressive strengths and percentage decrease in compressive strength of High Volumes of Slag Concrete for various w/b ratios after exposure to 200 °C for 4, 8 and 12 hours duration respectively and values are shown in Table 3 and Table 4.

The percentage decrease in compressive strength of High Volumes of Slag Concrete are 15.42% to 4.53% after exposing to 4 hours, 20.92% to 8.02% after exposing to 8 hours and 24.41% to 11.28% after exposing to 12 hours for w/b ratios varying from 0.55 to 0.27 at 200 °C respectively. These variations are shown in Fig. 2 and Fig. 3.

3) Loss in weight of High Volumes of Slag Concrete exposure to 400 °C

The percentage weight loss High Volumes of Slag Concrete after exposing to 4, 8 and 12 hours at 400 °C are shown in Table 5. After exposed to 400 °C, the percentages weight losses are 6.67% to 4.86% at 4 hours, 7.11% to 5.46% at 8 hours and 7.52% to 5.72% at 12 hours for w/b ratios varying from 0.55 to 0.27 respectively. These variations are shown in Fig. 4.

4) Loss in Compressive Strength of High Volumes of Slag Concrete exposure to 400 °C

The compressive strengths and percentage decrease in compressive strength of High Volumes of Slag Concrete for various w/b ratios after exposure to 400 °C for 4, 8 and 12 hours duration respectively and the values are given in Table 6 and Table 7.

The percentage decrease in compressive strength of High Volumes of Slag Concrete are 21.76% to 8.07% after exposing to 4 hours, 24.50% to 12.26% after exposing to 8 hours and 29.88% to 15.35% after exposing to 12 hours for w/b ratios varying from 0.55 to 0.27 at 400 °C respectively. These variations are shown in Fig. 5 and Fig. 6.

5) Loss in weight and Compressive Strength of High Volumes of Slag Concrete exposure to 600 °C

The percentage weight loss High Volumes of Slag Concrete after exposing to 4, 8 and 12 hours at 600 °C are shown in Table 8. After exposed to 600 °C, the percentages weight losses are 6.78% to 5.62% at 4 hours, 7.36% to 5.64% at 8 hours and 7.74% to 5.88% at 12 hours respectively for w/b ratios varying from 0.55 to 0.27 respectively. These variations are shown in Fig. 7.

6) Loss in weight and Compressive Strength of High Volumes of Slag Concrete exposure to 600 °C

The compressive strengths and percentage decrease in compressive strength of High Volumes of Slag Concrete for various w/b ratios after exposure to 600 °C for 4, 8 and 12 hours duration respectively and the values are shown in Table 9 and Table 10.

The percentage decrease in compressive strength of High Volumes of Slag Concrete are 26.09% to 11.33% after exposing to 4 hours, 29.48% to 13.74% after exposing to 8 hours and 36.85% to 17.07% after exposing to 12 hours for w/b ratios varying from 0.55 to 0.27 at 600 ^{o}C respectively. These variations are shown in Fig. 8 and Fig. 9.

From the results, it is observed that the loss in weight and loss in compressive strengths are more in the cases of higher w/b ratios at all exposures. The compressive strength loss and weight loss is insignificant for the exposure of 200 ^{o}C for 4 hours. And highest loss in weight and loss in Compressive Strengths are observed in the case of higher w/b ratios and 600 ^{o}C at 12 hour duration are 7.74% and 36.85 respectively.

The HVSC in which 50% cement is replaced with GGBS exhibited insignificant change in the compressive strength and weight after exposed to higher. This indicates that GGBS may contribute to some extent to the compressive strength of concrete after exposure at higher temperatures. Similar results were stated by Rafat Siddique, Xiao and Falkner.
From the results, it is revealed that High Volumes of Slag Concrete exhibiting durability against higher temperatures upto 200 ^{o}C for lower w/b ratios.

VIII. CONCLUSIONS

- GGBS used in this investigation exhibits good pozzolanic properties and can be used in the production of high strength High Volumes of Slag Concrete. Further addition of slag makes the concrete more impermeable due to micro filler action.
- High Volumes of Slag Concrete achieved good workability for higher w/b ratios without addition of super plasticizer having lower content of cement.
- The compressive strength of High Volumes of Slag Concrete increase with decreasing water/binder ratio for 0.27 exhibiting compressive strength as high as 54.0MPa.
- The percentage weight loss will be higher for higher exposure time for all water-binder ratios.
- High Volumes of Slag Concrete exhibits good temperature resistance against 200 ^{o}C for all water-binder ratios for 4 hour duration
- Appreciable reduction in strength is observed with increase in temperature from 200 ^{o}C to 600 ^{o}C and exposure time from 4 to 12 hours.
- For High Volumes of Slag Concrete, compressive strength is found to be less for high temperatures and for longer duration.
- The loss in weight and compressive strength in High Volumes of Slag Concrete is insignificant for lower water/binder ratios.
- High Volumes of Slag Concrete of higher w/b ratio exhibited maximum decrease of 37% compressive strength at 600 ^{o}C at 12 hours duration. Whereas High Volumes of Slag Concrete (lower w/b ratio) exhibited maximum decrease of 17% in compressive strength.

REFERENCES

[1] Santosh Kumar Karri, G.V.Rama Rao, P.Markandeya Raju, “Strength and Durability Studies on GGBS Concrete”, SSRG International Journal of Civil Engineering (SSRG-IJCE) – volume 2 Issue 10 October 2015, pp-34-41.

[2] R. Sri Ravindrarajah, R. Lopez and H. Reslan, “Effect of Elevated Temperature on the Properties of High-Strength Concrete containing Cement Supplementary Materials”, 9th International Conference on Durability of Building Materials and Components, Brisbane, Australia, 17-20th March, 2002.

[3] Albert Noumowé, Rafat Siddique, Guillaume Ranc, “Thermo-mechanical characteristics of concrete at elevated temperatures up to 310 ◦C”, Nuclear Engineering and Design 239 (2009) 470–476.

[4] P. Sravana, P. Srinivasa Rao and P. Sravana, “Effect Of Thermal Cycles On Compressive Strength Of High Volume Fly Ash Concrete”, 31st Conference On Our World In Concrete & Structures: 16 – 17 August 2006, Singapore.

[5] F. Falade, E. E. Ikponmwosa and N. I. Ojediran, “Behaviour of Lightweight Concrete Containing Periwinkle Shells at Elevated Temperature”, Journal of Engineering Science and Technology Vol. 5, No. 4 (2010) 379 - 390 © School of Engineering, Taylor’s University.

[6] Rafat Siddique, Deepinder Kaur, “Properties of concrete containing ground granulated blast furnace slag (GGBFS) at elevated temperatures”, Journal of Advanced Research (2012), 45-51.

[7] M.A.Pathan and M.A.Jamnu, “Compressive Strength of Conventional Concrete and High Strength Concrete with Temperature Effect”, International Journal of Advanced Engineering Research and Studies, IJAERS/Vol. I/ Issue III/April-June, 2012/101-102.

[8] Srinivasa Reddy V, Seshagiri Rao M V, Sreenivasa Rao D and Rahul K, “Studies on Bacterial Concrete Exposed to Elevated Temperatures and Thermal Cycles”, IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol.3, No.1, February 2013.

[9] H. Shehab El – Din, Heba A. Mohamed, “Effect of Temperature on Strength of Concrete Strengthening With CFRP”, International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 2, Issue 5, September 2013.

[10] Saeed Ahmed Al.Sheikh, “Mechanical Properties for High Performance Concrete Exposed to High Temperature”, International Journal of Civil and Structural Engineering, Volume 2, No 2, 2011, pp-438-444.

[11] A Ferhat Bingol & Rustem gul, “Compressive Strength of Light Weight Aggregate Concrete exposed to high temperatures”, Indian Journal of Engineering & Material Sciences Vol.11, February 2004,pp-68-72.

[12] Stephen S. Szoke, “Resistance to Fire and High Temperatures”, ©Reprinted by permission of ASTM International, West Conshohocken, Pennsylvania 2006.

[13] S.H. Chowdhury, “Effect Of Elevated Temperature On Mechanical Properties Of High Strength Concrete”, 23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23), Byron Bay, Australia, 9-12 December 2014, S.T. Smith (Ed.)