Investigation of Elevated Temperature on Concrete with GGBFS

Akshay Jaikumar Pawar[1] Dr. Valsson Varghese[2] Prof. Vinayak D. Vaidya[3]
[1]P.G. Student [2,3]Professor
[1,2,3]Department of Structural Engineering
[1,2,3]KDK College of Engineering, Nagpur, Maharashtra, India

Abstract— Ground granulated blast furnace slag (GGBFS) has been widely utilized as ingredients in concrete due to the advantages of economic, technical and environmental benefits of this material. This paper deals with the effects of elevated temperatures on properties of concrete made with ground granulated blast furnace slag (GGBFS) with replacement ratios of 20%, 40% and 60% by weight of cement. The concrete specimens were subjected to different elevated temperatures from 200^0C to 1200^0C. Afterward, the residual compressive strength, split tensile strength and the flexural strength of concrete were determined. For this purpose cube, cylindrical and beam Specimens of size (150 x 150 x 150 mm), (150 x 300 mm) and (100 x100 x500 mm) were made. This investigation developed some important data on the properties of concrete exposed to elevated temperatures. Test results shows that at elevated temperature 20% Ground granulated blast furnace slag +1% steel fibre found suitable combination as compared with the other combinations.

Key words: Ground-Granulated Blast-Furnace Slag (GGBS or GGBFS), Steel fibre, Compressive strength, Split tensile strength, Flexural strength

I. INTRODUCTION

Fire is one of the natural hazards that attack the building constructions. Subjecting concrete to a higher temperature (due to accidental fire etc.) leads to severe deterioration and it destroy the building structures, The stability of the building components are greatly weakened under high temperature, including compressive strength, split tensile strength, flexural strength and so on ,it also reduced durability, structural cracking and associated aggregate colour changes. During design, in several cases the fact is ignored that a building may also be exposed, to the effect of high temperature, when the properties and the bearing capacity of materials also change. Therefore it is very important to get acquainted with the behaviour of the different materials under high temperature, as a consequence of which a building may also collapse.

Concrete has excellent properties in regards of fire resistance compared with other materials because of its low thermal conductivity and high specific gravity and can be used to shield other structural materials such as steel. Concrete must at times resist the effects of artificially induced high temperatures such as might be encountered near furnaces or in atomic reactors, in pavements subjected to jet engine blast, and in areas exposed to fire. Applications of concrete involving extremely high temperatures, such as landing pads for missiles, are considered expendable, but in most instances it is desired to avoid deterioration of the concrete's physical properties as much as possible.

It has become imperative for engineers to be interested in the residual design strength of concrete subjected to high temperatures in order to form data base for performance at these elevated temperatures for practical research applications. One of the advantages of concrete over other building materials is its inherent fire-resistive properties. However, concrete structures must still be designed for fire effects. Structural components must still be able to withstand dead & imposed loads without collapse even though the rise in temperature causes a decrease in strength & modulus of elasticity for concrete & steel reinforcement. To be able to predict the response of structure after exposure to high temperature, it is essential that the strength properties of concrete subjected to high temperatures be clearly understood.

A. Ground Granulated Blast Furnace Slag (GGBS or GGBFS)

Blast furnace slag is a by-product of iron manufacturing industry. Iron ore, coke and limestone are fed into the furnace, and the resulting molten slag floats above the molten iron at a temperature of about 1500°C to 1600°C. The molten slag has a composition of 30% to 40% silicon dioxide (SiO_2) and approximately 40% CaO, which is close to the chemical composition of Portland cement. After the molten iron is tapped off, the remaining molten slag, which mainly consists of siliceous and aluminous residues is then rapidly water quenched, resulting in the formation of a glassy granulate. This glassy granulate is dried and ground to the required size which is known as ground granulated blast furnace slag (GGBS). The production of GGBS requires little additional energy compared with the energy required for the production of Portland cement. The replacement of Portland cement with GGBS will lead to a significant reduction of carbon dioxide gas emission. GGBS is therefore an environmentally friendly construction material.

B. Effect of elevated temperature on concrete

The rise in temperature causes the free water in concrete to change from a liquid state to a gaseous state. This change in state causes changes in the rate with which heat is transmitted from the surface into the interior of the concrete component. Above this threshold cement paste undergoes shrinkage (contraction) due to temperature rise which result in overall expansion of concrete and decrease in the strength and modulus of elasticity for both concrete and steel reinforcement. However, the rate at which the strength and modulus decrease depends on the rate of increase in the temperature of the fire and the insulating properties of concrete.

C. Benefits of GGBS Concrete

GGBS concrete has better water impermeability characteristics as well as improved resistance to corrosion and sulphate attack. As a result, the service life of a structure is enhanced and the maintenance cost reduced. It also reduces heat in concrete. High volume eco-friendly replacement slag leads to the development of concrete which not only utilizes the industrial wastes but also saves significant natural resources and energy. This in turn reduces the consumption of cement. The use of GGBFS as cementing components needs only grinding, it will save substantial amounts of energy compared with the productions of OPC. GGBFS is receiving more and more attention now since it generally improves the properties of the blended cement concrete, the cost and the reduction of negative environmental effects. Concrete containing GGBFS should have either equal or slightly worse properties than OPC concrete.

II. OBJECTIVES

To investigate the effect of elevated temperature on conventional concrete and concrete with GGBFS as a Mineral admixtures with 1% steel fibre.

1) To investigate the effect of elevated temperature on compressive strength, flexural strength and tensile strength of conventional and concrete with GGBFS as Mineral admixture.
2) To investigate most suitable combination.

III. EXPERIMENTAL INVESTIGATION

A. *Material*

Ordinary Portland (53 grade) cement was used and its properties are given in Table 1. It met the requirements of Indian Standard Specifications as per IS 269-1976. Natural sand with a 4.75-mm maximum size was used as a fine aggregate. Its properties are given in Table 2. Coarse aggregate was crushed stone with a maximum size of 20 mm was used. They were tested as per Indian Standard Specifications IS: 383-1970 and their physical properties are given in Table 3. The water used in this investigation was potable water which is free from injurious amount of deleterious materials. Ground granulated blast furnace slag (GGBFS) was obtained from JSW Cement Limited and its properties are given in Table 4 and 5.

1) *Cement*

The physical properties of the cement tested according to Indian standards procedure are given in table –

Sr. No.	Properties	Result Obtained	Standard Values
1	Standard Consistency	29%	-
2	Initial Setting Time (minutes)	34	Not be less than 30 minutes
3	Final Setting Time(minutes)	340	Not be greater than 600 minutes
4	Soundness(mm)	5	<10
5	fineness	8.0%	<10%
6	Specific gravity	3.15	-

Table 1: Physical properties of cement

2) *Fine Aggregates*

The sand confirming to zone II as per IS 383:1970 was used for making concrete. Properties used in the experimental work are given in table-

Sr. No.	Properties	Result Obtained
1	Type	Natural
2	Specific Gravity	2.62
3	Bulkage of sand	7.14%
4	Fineness Modulus	2.47
5	Surface Texture	Smooth
6	Particle Shape	Rounded

Table 2: Physical properties of fine aggregates

3) *Coarse Aggregate*

Coarse aggregate confirming to IS 383:1970 was used for making concrete. Properties used in the experimental work are given in table-

Sr. No.	Properties	Result Obtained
1	Type	Natural
2	Specific Gravity	2.75
3	Fineness Modulus	7.2
4	Surface Texture	Rough
5	Particle Shape	Angular

Table 3: Physical Properties of Course Aggregates (20 mm)

4) *GGBS (Ground Granulated Blast Furnace Slag)*

a) Physical properties of GGBS are

Properties	Results Obtained
Colour	Off White
Specific gravity	2.87
Fineness (retained on 90 micron sieve)	0
Fineness (retained on 45 micron sieve)	0.8%
Initial time (min)	180
Soundness (mm)	1

Table 4: Physical properties of GGBS

b) Chemical compositions of GGBS are

Parameter	JSW GGBS	As per IS 12089-1987 (Reaffirmed 2008)	
CaO	37.34%	-	
Al_2O_3	14.42%	-	
Fe_2O_3	1.11%	-	
SiO_2	37.73%	-	
Magnesium Oxide (MgO)	8.71%	Max. 17%	
Manganese Oxide (MnO)	0.02%	Max. 5.5%	
Sulphide Sulphur	0.39%	Max 2%	
Loss on Ignition	1.41%	-	
Insoluble Residue	1.59%	Max. 5%	
Glass content in %	92%	Min 85%	
Chemical Moduli: 1. $\frac{CaO+MgO+1/3Al2O3}{SiO2+2/3Al2O3}$	1.07	≥1.0	The presence of major oxides with granulated slag shall satisfy at least one of the equation
2. $\frac{CaO+MgO+Al2O3}{SiO2}$	1.60	≥1.0	

Table 5: Chemical composition of GGBS

B. *Mix Proportion and Mix Details*

In this investigation, M25 mix concrete is considered to perform the test by-weight basis by replacing 20%, 40% and 60% of cement by GGBS + 1% steel fibre was added. Adopted Mix Proportion is: (1: 1.6: 2.86).

Four concrete mixtures were used to explore the influence of elevated temperature on the properties of concrete containing GGFBS. Details of the concrete mixtures are presented in Table 6.

One control mixture of conventional concrete was designed per Indian Standard Specifications IS: 10262-2009 to have 28-day compressive strength. The other concrete mixtures, viz. GB1, GB2 and GB3, were made with replacement levels of 20%, 40%, and 60% of GGBFS by weight of cement. In doing so, the water-to-cementitious materials ratio was kept the same in order to investigate the effects of replacing cement with GGBFS when other parameters were unchanged.

Sr. No	Combination	Specimen	Temperature °C
1	Conventional Concrete	Cube	200°C, 400°C, 600°C, 800°C, 1000°C,1200°C Exposure time 1 hour
		Cylinder	
		Beam	
2	20%GGBFS+1%Steel fibre (GB1)	Cube	
		Cylinder	
		Beam	
3	40%GGBFS+1%Steel fibre (GB2)	Cube	
		Cylinder	
		Beam	
4	60%GGBFS+1%Steel fibre (GB3)	Cube	
		Cylinder	
		Beam	

Table 6: Mixture proportions used in the study.

C. Heating and cooling regimes

After curing for 28 days, the specimens were taken out of the tank and air-dried. Then the specimens were heated in an electric oven up to 200^{0}C, 400^{0}C, 600^{0}C, 800^{0}C, 1000^{0}C and 1200^{0}C. The temperature was maintained at the respective temperature for 1 hour to achieve a thermally steady state. Then the furnace door was opened and the specimens were allowed to cool naturally to room temperature.

D. Test Specimens and Test Procedure

After the concrete specimens were cooled down to room temperature, compressive strength, split tensile strength and flexural strength were tested. The tests were performed according to the relevant Indian standards 150 mm concrete cubes and cylinders of (150 x 300 mm) were used as test specimens to determine the compressive strength of concrete and split tensile strength of concrete for both cases (i.e., conventional concrete and GGBS concrete). The ingredients of concrete were thoroughly mixed till uniform consistency was achieved. The cubes and cylinders were properly compacted by machine mixing. All the concrete cubes and cylinders were de-moulded within 24 hours after casting. The de-moulded test specimens were properly cured in water available in the laboratory at an age of 28 days. Compression test was conducted on a compression testing machine available in the laboratory as per IS 516-1959. The load was applied uniformly until the failure of the specimen. The split tensile strength was conducted as per IS 5816-1976. The specimen was placed horizontally between the loading surfaces of the compression testing machine and the load was applied without shock until the failure of the specimen. The concrete beams of size (100mm x 100mm x 500mm) were tested as per IS 516-1959 for flexural strength. The load was applied through two similar rollers mounted at one third points of the supporting span. The load was applied without shock until the failure occurs.

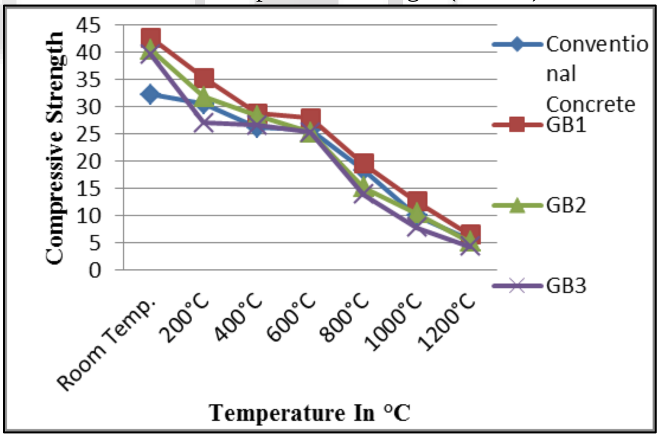
E. Results and Discussion

1) Compressive Strength

Compressive strength test results are shown in Graph 1.
From the test results it is shown that the compressive strength of concrete is decreases with increase in temperature for both conventional and GGBS concrete. Compressive strength is also decreases with increase in GGBS content. Concrete with 20% GGBS+1% steel fibre gives higher compressive strength as compared to other combinations. % Reduction in compressive strength is more for concrete with 60% GGBS+1% steel fibre as compared with other combinations.

Temperature in °C	Conventional Concrete	GB1	GB2	GB3
Room temp.	32.25	42.71	40.53	39.66
200°C	30.51	35.30	31.82	27.02
400°C	26.15	28.77	28.33	26.59
600°C	25.72	27.89	25.28	25.28
800°C	18.31	19.61	15.25	13.95
1000°C	10.02	12.64	10.46	7.85
1200°C	5.67	6.54	5.23	4.36

Table 7: Compressive Strength (N/mm²)



Graph 1: Compressive strength

2) Split Tensile Strength

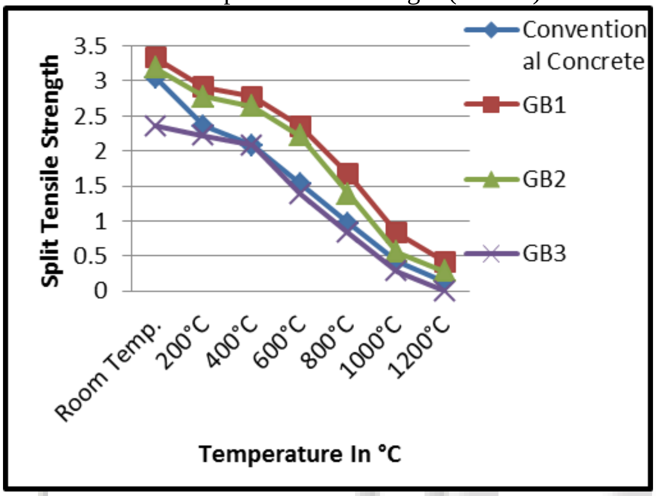
Split tensile strength test results are shown in Graph 2.

From the test results it is shown that the Split tensile strength of concrete is decreases with increase in temperature for both conventional and GGBS concrete. Split tensile strength is also decreases with increase in GGBS content. Concrete with 20% GGBS+1% steel fibre gives higher Split tensile strength as compared to other combinations. % Reduction in Split tensile strength is more for concrete with 60% GGBS+1% steel fibre as compared with other combinations at 1000^{0}C to 1200^{0}C.

Temperature in °C	Conventional Concrete	GB 1	GB 2	GB 3
Room temp.	3.05	3.3	3.1	2.3

		3	9	6
200°C	2.36	2.91	2.78	2.22
400°C	2.08	2.78	2.64	2.08
600°C	1.53	2.36	2.22	1.39
800°C	0.97	1.67	1.39	0.83
1000°C	0.42	0.83	0.56	0.28
1200°C	0.14	0.42	0.28	0

Table 8: Split Tensile Strength (N/mm²)



Graph 2: Split tensile strength

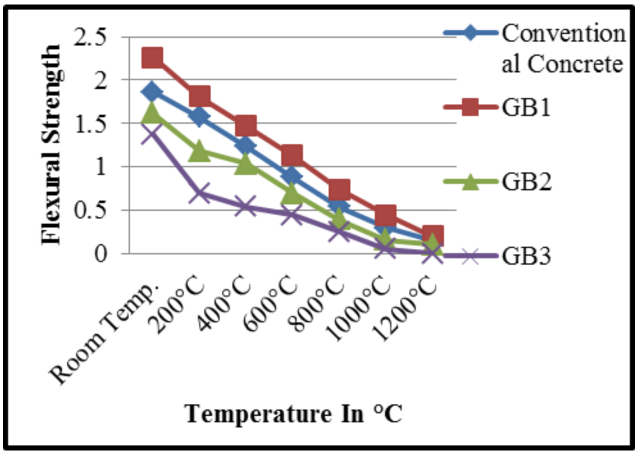
3) Flexural Strength

Flexural Strength test results are shown in Graph 3.

From the test results it is shown that the Flexural strength of concrete is decreases with increase in temperature for both conventional and GGBS concrete. Flexural strength is also decreases with increase in GGBS content. Concrete with 20% GGBS+1% steel fibre gives higher Flexural strength as compared to other combinations. % Reduction in Flexural strength is more for concrete with 60% GGBS+1% steel fibre as compared with other combinations.

Temperature in ℃	Conventional Concrete	GB 1	GB 2	GB 3
Room temp.	1.86	2.26	1.62	1.37
200°C	1.57	1.81	1.18	0.69
400°C	1.23	1.47	1.03	0.54
600°C	0.88	1.13	0.69	0.44
800°C	0.54	0.74	0.39	0.25
1000°C	0.29	0.44	0.15	0.05
1200°C	0.15	0.2	0.1	0

Table 9: Flexural Strength (N/mm²)



Graph 3: Flexural strength

4) Visual Observations

Change in colour after heating of concrete

During an initial inspection, spalling, the flaking of the concrete, the formation of major cracks and the distortion of the construction are relatively easy to detect. This can be seen just by looking at it. Concrete is made from limestone or siliceous aggregate its colour changes when subjected to heat. The change of colour is due to the presence of certain ferri-ferrous components. Subsequently, it varies according to the type of concrete. When the sample is heated between 300^{0}C to 600^{0}C the colour of concrete changes to red due to siliceous aggregate in concrete as shown in fig.1, between 600^{0}C to 900^{0}C the colour of concrete changes to whitish grey due to the aggregate containing calcium carbonate do the calcinations process $CaCO_3$ turns to lime and give pale shades of white and grey colour as shown in fig 2.when the temperature is in between 900^{0}C to 1200^{0}C concrete shows light yellow colour as shown in fig. 3. The colour change of heated concrete results principally from the gradual water removal and dehydration of the cement paste, but also transformations occurring within the aggregate.

Fig. 1: Red patches on sample after heating.

Fig. 2: White patches on sample after heating

Fig. 3: Yellow patches on sample after heating.

Fig. 4: Cracks on sample after heating

IV. CONCLUDING REMARKS

Effects of elevated temperature on the properties of concrete containing GGBFS as cementitious material were studied. Compressive strength, split tensile strength and flexural strength of concrete were investigated. Given the results presented in this study, the following conclusions can be drawn.

1) With the increasing temperature upto 1200^0C, the compressive strength, Split tensile strength and flexural strength of concrete gets reduced, due to the hardening of cement paste caused by drying, due to which the bond of cementations materials was got loss.
2) It is observed that GGBS based concretes have achieved an increase in strength for 20% replacement of cement by GGBS+1% steel fibre. The Increase in strength, which is due to high reactivity of GGBS with cement and the filler effect of GGBS.
3) % Reduction in strength is more for 60% replacement of cement by GGBS+1% steel fibre as compared with other combinations, which is due to the slower reaction of GGBS at early ages.
4) As temperature and exposure time increases the effect of elevated temperature on concrete increases.
5) Effect of elevated temperature can be observed on the surface of concrete in the form of deep cracks as shown in fig 4, which is due to the expansion of the concrete matrix.
6) When the sample is heated between 300^0C to 600^0C the colour of concrete changes to red, due to siliceous aggregate present in concrete.
7) When the sample is heated between 600^0C to 900^0C the colour of concrete changes to whitish grey, due to the reaction of calcium carbonate in the calcinations process $CaCO_3$ which turns to lime and give pale shades of white and grey colour.
8) When the temperature range in between 900^0C to 1200^0C concrete shows light yellow colour.
9) At elevated temperature the concrete becomes more & more brittle and the loss of strength is more.
10) The use of GGBS as a replacement of cement helps to reduce the Energy consumption in the manufacturing of cement.
11) Reuse of the slag helps to protect the environment from pollution (reduced CO_2 emission) and conserves natural resources.

REFERENCES

[1] S. O. Osujiand U. Ukeme, "EFFECTS OF ELEVATED TEMPERATURE ON COMPRESSIVE STRENGTH OF CONCRETE" Nigerian Journal of Technology (NIJOTECH) Vol. 34 No. 3, July 2015, pp. 472 – 477
[2] Xianjun Tan, Weizhong Chen, Jiuhong Wang, Diansen Yang, Xianyin Qi, Yongshang Ma,Xu Wang, Shaosen Ma, Changjun Li "Influence of high temperature on the residual physical and mechanical properties of foamed concrete" Construction and Building Materials 135 (2017) 203–211
[3] Persson. B., "Fire resistance of self-compacting concrete SCC",Materials and Structures, 37, November 2004, pp 575-584
[4] Chi-Sun Poon, Salman Azhar, Mike Anson and Yuk-Lung Wong., "Performance of metakaolin concrete at elevated temperatures"Cement and Concrete Composites, pp 83-89, 2003.
[5] Yue Li, Xiongfei Liu and Miaoke Wu "Mechanical properties of FRP-strengthened concrete at elevated temperature" Construction and Building Materials 134 (2017) 424–432
[6] Long T. Phan and Nicholas Carino J., "Effects of test Conditions and Mixture proportions on Behavior of High Strength concrete Exposed to High Temperatures" ACI Materials Journal, January-February 2002 PP 54-62
[7] Q. Sobia, A. Shyzleen, M. S. Hamidah, I. Azmi, S. F. A. Rafeeqi, and S. Ahmad "Post Elevated Temperature Effect on the Strength and Microstructure of Thin High Performance Cementitious Composites (THPCC)"World Academy of Science, Engineering and Technology International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol:7, No:2, 2013
[8] Chan Y. N., Peng, G. F and Anson M., "Residual strength and pore structure of high-strength concrete and normal strength concrete after exposure to high temperatures" Cement and Concrete Composites, pp 23-27, 1999.
[9] Latha K.S, Rao M.V.S, and Reddy V. S. "Estimation of GGBS and High Volume Fly Ash (HVFA) strength efficiencies in concrete with age"International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Vol. 2, Issue 2, December (2012)
[10] Santosh Kumar Karriet, G.V. Rama Rao and P. Markandeya Raju, "Strength and Duribility Studies on GGBS Concrete"International Journal of Civil Engineering(SSRG-IJCE), Vol. 2, Issue 10, October 2015, pp. 34-41, ISSN: 2348-8352
[11] Reshma Rughooputh and Jaylina Rana, "Partial Replacement of Cement by Ground Granulated Blast Furnace Slag in Concrete" Journal of Emerging Trends in Engineering and Applied Sciences(JETEAS), Vol. 5, Issue 5, 2014, pp. 340-343, ISSN: 2141-7016