Influence of High Temperature on Non-Silicate Based Activated Blast Furnace Slag

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Abstract. The energy consumption and the greenhouse gases emission in order to manufacture Portland cement (PC) is very high. To find an alternative, the researchers initially replace the PC partially by Fly Ash. Later on, the researchers introduce a new binder which is being manufactured by the activation of ground granulated blast furnace slag (GGBFS). The paper presents the detail of the binder, manufactured by GGBFS and mild alkali as activator having the pH value of 10. The binder is manufactured by simple blending in which 85% is GGBFS, and 15% is the chemical activator. The test results of the alkali activated binder concrete (AABC) for compressive strength, splitting-tensile strength and flexural strength were found after exposure to elevated temperature 100 ℃, 200 ℃, 300 ℃, 400 ℃, 500 ℃, 600 ℃, 700 ℃ and 800 ℃. It has been observed that these results of the AABC at elevated temperature were very much comparable with that of the ordinary Portland cement concrete (OPCC). The deterioration in strength starts from 200 ℃ onwards. No spalling of the alkali activated binder concrete (AABC) has been observed at elevated temperature even at 800 ℃.

Keywords: Ground granulated blast furnace slag, alkali, chemical, activator, elevated temperature.

1 Introduction

Since Portland cement is an ancient commodity, hence it has become the governing binder in concrete for construction. Industrial production and supply of the cement had begun in the 19th century. The per year production of cement is 3 billion tonne and expected to increase up to 4 billion tonne. This growth is majorly due to meet the demand and the major part played by Republic of China, India, Middle East and Northern Africa. In 19th century, the cement production was begun with shaft kilns which was later transform into rotary kiln as a standard equipment worldwide [1]. The cement production as well as the demand is rising every day, the cement industries facing several issues such as energy supply, carbon dioxide emission, raw materials etc. Cement production makes the cement manufacturing third largest man-made carbon dioxide (CO_2). The CO_2 is the resultant of lime heating which is prominently used in the cement manufacturing process. This required change accomplished by means of two methods i) by bringing the change in manufacturing and production

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process, ii) by bringing the change in the chemical composition of cement [2]. In order to reduce the energy consumption, the conventional fuel is being substituted by waste and biomass. In some of the European countries, the cement manufacturing plant has substituted the conventional fuel by the high calorific waste material. Some of the cement manufacturer achieved 100% replacement level of conventional fuel by using suitable waste materials [2]. In the year 1996, the carbon dioxide emission is around 1.12 tonne CO_2/tonne of cement production, which reduces to the average of 0.719 tonne CO_2/tonne cement in the year 2010 [3]. Another way to reduce the emission of CO_2 is the incorporation of supplementary cementitious material (SCM) like volcanic ash, Ground Granulated Blast Furnace Slag (GGBFS), Fly Ash. Volcanic ash, GGBFS and Fly Ash are also considered as non-hazard pollutant when dumped directly in nature. These SCMs exabit similar property when mixed with cement and also help to bring down the overall clinker consumption for manufacturing cement.

Hence it is required to develop a binder or to develop an alternative system in which the energy consumption and CO_2 emission is very minimal. In the search of alternative, one binder has been developed namely, alkali activated binder. This alkali activated binder is first developed in 1908 by and later pioneering work has been done by Glukhovsky, Krivenko, Davidovits, and Palomo et al [4]. Alkali activated binder (AAB) are formed by chemical reactions between the combinations of concentrated aqueous solutions of alkali hydroxide, silicate or carbonate and solid aluminosilicate powders. In the present study the alkali activated binder is prepared by using 85% of GGBFS and 15% of powder blend activator.

2 Materials

GGBFS used in the study for manufacturing the binder is collected from Jindal Pvt. Ltd. Conforming Indian Standard code IS: 12089:1987 [5]. The chemical constituent of GGBFS used in the study is provided in table 1. The locally available fine and coarse aggregates have been used in the study which meet all the requirements of Indian standard IS 383:2016[6].

Table 1 Chemical constituent of GGBFS

Chemical Constituent	%
SiO_2	37.7
Al_2O_3	14.4
Fe_2O_3	1.1
CaO	37.3
MgO	8.7
MnO	0.02
SO_3	0.4
LOI	1.4
Glass Content	92

3 Methodology

3.1 Mixing, Casting and Curing

The mix of concrete is prepared by using alkali activated binder, coarse aggregate fine aggregate, and water. The binder is blend with activator in such a way that it acts as a single part system just like convention cement. The properties of AAB and conventional OPC have been given in table 2. In the present study, the used AAB is having edge over other AAB, where while preparing other AABC, there is a need to prepare a solution prior for mixing. The process of preparation of concrete manufactured from OPC and AAB are similar and the design mix has been done for medium workability as given in table 3. The standard specimens of cube, cylinder, and prism have been cast and keep for water and ambient air curing after demolding. A reference mix has also been prepared by using Ordinary Portland cement (OPC) for comparative study.

Table 2 Physical property of AAB and OPC

Physical Property	AAB	OPC
Fineness (m^2/kg)	340	225
Specific gravity	2.81	3.14
Soundness Le-chatelier (mm)	1.00	2.00
Standard Consistency	35%	33%
Initial Setting time (minutes)	50	65
Final Setting Time (minutes)	95	320

Table 3 Detail of concrete mix proportion per meter cube

Concrete ingredients	Type of cementitiuos materials	
	AAB	OPC
Type of Binder (kg/m^3)	350.94	350.94
Fine Aggregate (kg/m^3)	667.07	680.47
Coarse Aggregate (kg/m^3)	1187.75	1210.37
Water (kg)	186	186

4 Analysis of Test Result

4.1 Result of Compressive strength, Flexural Strength and Split Tensile Strength

Evaluation of compressive strength, the standard cube of size 150 mm have been cast and cured in air and in water for 1, 3, 7, 14, 28 days of maturity. The specimens prepared with OPC have been cured in water only as reference concrete mix. The test results of compressive strength have been depicted in fig. 1. The trends of the compressive strength development of the alkali activated binder concrete (AABC) at different maturity days viz. 1, 3, 7, 14 and 28 days are being always higher than that of the ordinary Portland cement concrete (OPCC). In similar process, the standard cylindrical concrete specimens (height/length = 300 mm, diameter = 150 mm) were cast for split tensile strength with AAB and OPC binder by using same mix proportion of the ingredients. The test results of split tensile strength after 1, 3, 7, 14 and 28 days maturity have been shown in fig. 2. The prism specimen of cross section (width & depth) 100 mm and length 500 mm have been cast for flexural strength test. After 1, 3, 7, 14 and 28 days of maturity of the concrete specimens the flexural strength test have been conducted and the test results are being shown in fig. 3. Similar to the compressive strength development, it can be seen from fig. 2 and fig. 3 that the split tensile strength and flexural strength of the alkali activated binder concrete (AABC) are always higher than that of the ordinary Portland cement concrete (OPCC), respectively.

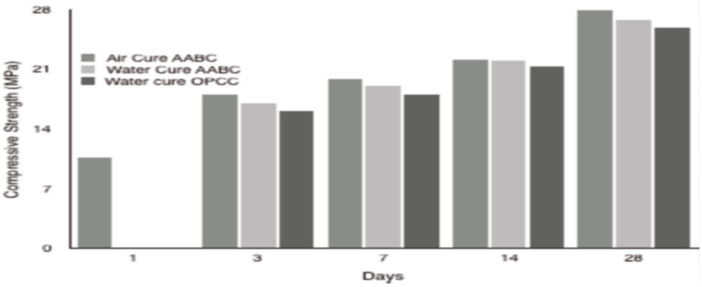

Fig. 1 Compressive strength vs age of air & water cure AAB and OPC concrete

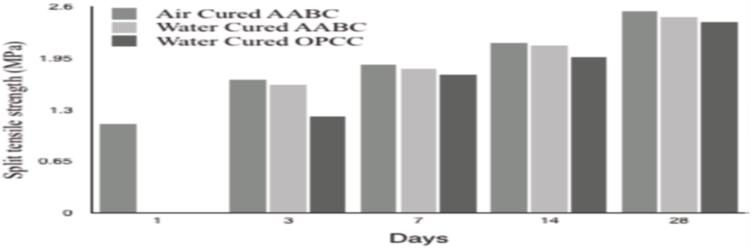

Fig. 2 Split tensile strength vs age of air & water cure AAB and OPC concrete

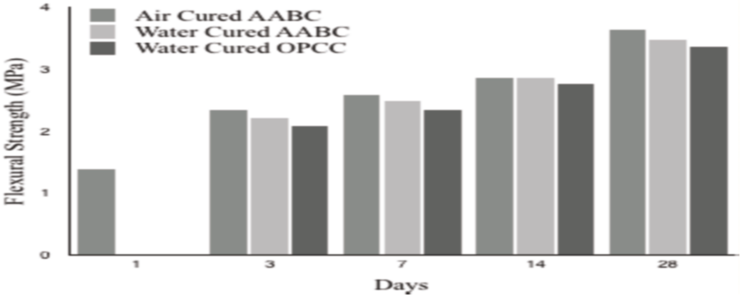

Fig. 3 Flexural strength vs age of air & water cure AAB and OPC concrete

4.2 Result of Compressive strength, Flexural Strength and Split Tensile Strength at elevated Temperature

After proper curing and maturity for the desired days, the standards specimens have been exposed to 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C and 800 °C temperature. The rate of heating on the concrete specimens inside the muffle furnace has been taken 10°C/minute and keeps the desired exposure temperature for 4 hours and then finally allowed to cool naturally in the furnace only. After natural cooling to the room temperature, these specimens have been tested for compressive strength, split tensile strength and flexural strength to evaluate the residual strengths. Additionally, the change is weight has also been recorded before and after heating.

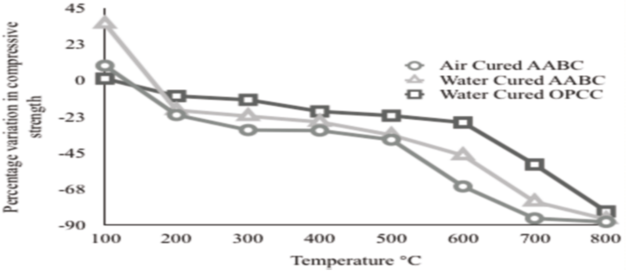

Fig. 4 Percentage variation in compressive strength vs temperature.

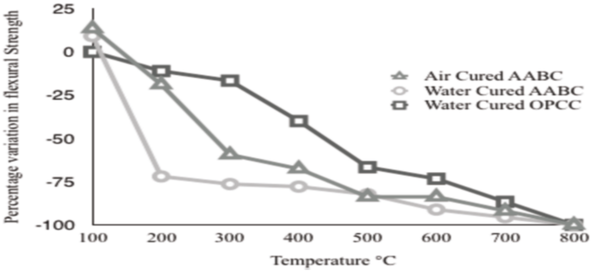

Fig. 5 Percentage variation in split tensile strength vs temperature

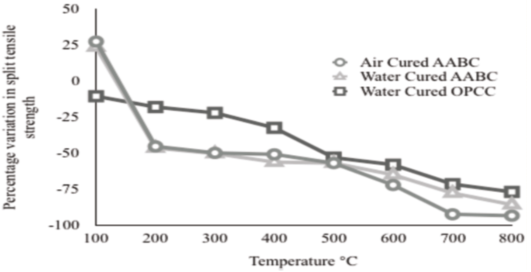

Fig. 6 Percentage variation in flexural strength vs temperature

The percentage variations in compressive strength, split-tensile strength and flexural strength vs temperature have been depicted in fig. 4, 5 and 6, respectively. From the figure, it is clear that that there is a rise in strengths at 100°C for AABC which are being higher than that of the OPCC. This rise in strengths for AABC may be due to participation of the unreacted binder particle at 100°C. Considerable percentage losses in residual strength have been observed above 100°C. The downfalls in strengths get very severe beyond 400°C because of loss of the free water and bounded water escape from the specimens. Overall, it has been observed that the residual strengths of the AABC are lower than that of the OPCC. The appearances of the micro-cracks have also been observed on the surface of specimen after exposure to temperature above 400 °C. This may be attributed to the increase in volume of aggregate at desired elevated temperature which leads to ultimately cracks and downfall in residual strengths. It can be seen that the general trends of deterioration in residual strengths are similar for both AABC and OPCC. Hence, it gives a clear indication that the AAB may be used in place of OPC, even exposure at elevated temperature.

5 Conclusion

The present binder, namely alkali activated binder (AAB) is being manufactured by simple blending in which 85% is GGBFS, and 15% chemical activator. It is clear that the AAB is having potential to replace OPC. The used CAB doesn't contain neither clinker nor chemicals that are highly corrosive in nature. From the study, it is observed that the AAB could also be manufacture by using weak alkali chemicals. It has been found that the hardened strengths viz. compressive strength, split tensile strength and flexural strength of the alkali activated binder concrete (AABC) are always higher than that of the ordinary Portland cement concrete (OPCC). Even, the trends of reduction in strengths of AAB concrete at different elevated temperature are found to be similar to that of the OPC concrete. No spalling of the concrete has been observed at different elevated temperature. Additionally, the air cured concrete with alkali activated binder (AAB) exhibits comparable strengths as compared to OPC concrete, resulting in the additional benefit of the reduction in construction cost.

References

1. Schneider, M., Romer, M., Tschudin, M., Bolio. H.: Sustainable Cement Production – Present and Future. Cement and Concrete Research 41 (2011) 642-650.
2. https://www.climatetechwiki.org/technology/energy-saving-cement.
3. Kumar, V., Kumar. A., Prasad, B.: Mechanical Behaviour of Non Silicate based alkali activated ground granulated blast furnace slag, Construction and building Material 198(2019) 494-500.
4. Glukovsky V.D. Soil silicates. Gosstroiizdat, Kevin, 1959.
5. IS:12089-1987, Specification of granulated slag for the manufacture of Portland slag cement.
6. IS: 383-2016, Coarse and fine aggregate for concrete – specification.