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Testing of Mechanical Properties of Air Cooled Blast Furnace Slag

Deepti Shri Soumitra[1], Ajay Kumar Singh[2]
[1]Mtech scholor, Shri Shankaracharya Technical Campus Junwani Bhilai C.G.
[2]Assistant Porofessor, Shri Shankaracharya Technical Campus Junwani Bhilai C.G.
Corresponding Author: Deepti Shri Soumitra

ABSTRACT: *The cement industry is one of the part producers of carbon dioxide, protect green house gas, which causes damage to most fertile layer of the earth, the top soil. Concrete is used to create hard surface which contribute to surface runoff that may cause soil erosion, water pollution and flooding.*
From structural point of view, GGBS replacement enhances lower heat of hydration, higher durability and higher resistance to sulfate and chloride attack when compared with normal ordinary concrete. On the other hand, it also contributes to environmental protection because it minimizes the use of cement during the production of concrete.
The quantitatively evaluate the influence of ground granulated blast-furnace slag (GGBS) as a supplementary cementitious material on the industries environmental impact of concrete. The life-cycle environmental impacts of concrete could be classified into three categories including global warming, photochemical oxidant creation and a biotic resource depletion.
GGBS concrete suffers from lower rate of strength development which is highly sensitive to curing conditions. In this connection, certain site measures have to be introduced to the constructions industry to ensure better quality of curing process in order to secure high quality of GGBS concrete.
Ground granulated blast furnace slag (GGBS) hardens very slowly and, for use in concrete, it needs to be activated by combining it with Portland cement. The greater the percentage of GGBS, the greater will be the effect on concrete properties. The compressive strength of air-cooled blast furnace slag concrete increases with the replacement of fine aggregates by blast furnace slag till 25% replacement after that it gradually decreases. Air cooled blast was used for the replacement of fine aggregate in the percentages 12.5%, 25%, 37.5% and 50%. The compressive strength and flexural strength of air-cooled blast furnace slag concrete increases with the replacement of fine aggregates by blast furnace slag till 25% replacement after that it gradually decreases. The Split tensile strength of the cubes 7days, 56days and 90 days has highest value for 25% replacement and of 28 days has highest value for 12.5% replacement.

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I. INTRODUCTION

Cement is the fine powder that, which mixed with water, sand and gravel or crushed stone (fine aggregate and coarse aggregate) forms the rock, known as concrete, which are economically available. Concrete is the second most highly used item in the world after water. Production of cement used in concrete involves emission of large amount of CO_2. For green house effect and global warming, major contributor is CO_2. Ground granulated blast furnace slag, limestone powder and fly ash is successfully used in concrete as a cement replacement which are cement saving, energy saving and cost saving and moreover cause environmental and socio-economic benefits.

Concrete made with blast furnace slag cement or with GGBS as an addition has a high durability as a result of the low capillary porosity. It is resistant to chloride penetration, sulfate and Thaumasite sulfate attack.

Blast furnace slag is a nonmetallic by-product produced in the process of iron making (pig iron) in a blast furnace and 300kg of Blast furnace slag is generated when 1 ton of pig iron produced. In India, annual productions of pig iron is 70-80 million tons and corresponding blast furnace slag are about 21-24 million tons. Blast furnace slag is mildly alkaline and exhibits a pH in solution in the range of 8 to 10 and does not present a corrosion risk to steel in pilings or to steel embedded in concrete made with blast furnace slag cement or aggregates. The blast furnace slag could be used for the cement raw material, the roadbed material, the mineral admixture for concrete and aggregate for concrete, etc.

In short, blast furnace slag is formed when iron ore or iron pellets, coke (fuel) and flux (lime stone and dolomite) are melted together. When the melting process is complete lime is chemically combine with alluminate and silicate and also with coke ash. The property of blast furnace slag is similar to natural sand, but the price is cheap and the output is large too, could be regarded as the substitute of the natural sand.

II. MATERIAL AND METHODS

PRODUCTION OF GGBS

Two major uses of GGBS are in the production of quality-improved slag cement, namely Portland Blast furnace cement (PBFC) and high-slag blast-furnace cement (HSBFC), with GGBS content ranging typically from 30 to 70% and in the production of ready-mixed or site-batched durable concrete. Concrete made with GGBS cement sets more slowly than concrete made with ordinary Portland cement, depending on the amount of GGBS in the cementitious material, but also continues to gain strength over a longer period in production conditions. This results in lower heat of hydration and lower temperature rises, and makes avoiding cold joints easier, but may also affect construction schedules where quick setting is required.

PROPRTION OF GGBS

Water Demand

GGBS allows for water reduction of 3 to 5% in concrete without any loss in workability. Water should not be added to GGBS concrete after dispatch from the concrete plant as it reduces strength and durability of the concrete. (Reference: -The Green Cement).

Placing, Compacting and Pumping

GGBS makes concrete more fluid, making it easier to place into formwork and easier to compact by vibration. GGBS concrete remains workable for larger periods allowing more time for placing and vibrating. Pumping is also easier due to the better flow characteristics. (References:- The Green Cement).

Strength Development

GGBS concrete has slightly slower strength development at early ages, but will have equal if not greater strength at 28 days compared to non GGBS concrete. At 7days GGBS concretes will have 50 to 60% of its characteristic strength compared to 70 to 80% for Portland cement only concrete at the same time. At 28 days GGBS concrete will have fully developed its characteristic strength and will continue to develop strength past 90 days. It is good practice to make 56 day cubes when using GGBS concrete at 50% and above should there be any concern over later strength development. (References:-The Green Cement).

Setting Times

The initial setting time of concrete is dependent on the concrete's constituents, curing conditions and its application use. Concrete with up to 30% GGBS will exhibit similar initial setting as concrete with Portland cement only. At replacement levels of 40 to 50% the initial set is likely to be extended by one to two hours and for concrete containing more than 50% GGBS setting time maybe extended past three hours. (Reference :- The Green Cement).

Bleeding

Concrete with up to 40% GGBS replacement does not exhibit different bleeding characteristics from that of concrete made with Portland cement. For higher percentages of GGBS there is a period of bleeding due to the increase in setting times of these mixes. Concrete should be allowed to bleed fully before finishing. Early finishing can lead to the remixing of the surface layer of the concrete which can reduce the surface integrity and lead to dusting and delamination. (References :-The Green Cement).

Color

GGBS is white in color and it will noticeably lighten the color of concrete at replacement levels of 50% plus. (Reference:- Ecocem.ie -The Green Cement). Ground granulated blast furnace slag is off-white in color. If the replacement is greater than 50% this whiter color is also seen in concrete made with GGBS, The more aesthetically pleasing appearance of GGBS concrete can help soften the visual impact of large structures such as bridges and retaining walls. For colored concrete, the pigment requirements are often reduced with GGBS and the colors are brighter.

Sustainability

As GGBS is a by-product of iron manufacturing industry, it is reported that the production of one ton of GGBS would consume only about 1300 MJ of energy which is lesser than the 5000MJ of energy which is required for the manufacture of one ton of Portland cement.

Manufacturing of Portland cement would require approximately1.5 tons of mineral extractions and would generate 0.95 ton of CO^2 equivalent. GGBS would generate only about 0.07 ton of CO^2 equivalent.

Chemical Composition

The chemical composition of a slag varies considerably depending on the composition of the raw materials in the iron production process. Silicate and alluminate impurities from the ore and coke are combined in the blast furnace with a flux which lowers the viscosity of the slag. In the case of pig iron production the flux consists mostly of a mixture of limestone and forsterite or in some cases dolomite. In the blast furnace the slag floats on top of the iron and is decanted for separation.

Typical chemical composition:

Calcium oxide = 40%
Silica = 35%
Alumina = 13%
Magnesia = 8%

The glass content of slag suitable for blending with Portland cement typically varies between 90- 100% and depends on the cooling method and the temperature at which cooling is initiated. The glass structure of the quenched glass largely depends on the proportions of network-forming elements such as Si and Al over network-modifiers such as Ca, Mg and to a lesser extent Al. Increased amounts of network-modifiers lead to higher degrees of network DE polymerization and reactivity. It is a granular product with very limited crystal formation, is highly cementitious in nature and, ground to cement fineness, and hydrates like Portland cement.

Typical physical properties:-

Color : off white
Specific gravity : 2.9
Bulk density : 1200 Kg/m^3
Fineness: 350 m^2/kg

III. EXPERIMENTAL PROGRAM AND METHODOLOGY

Table 1. Showing Mix Proportions and quantity of materials used for M25 Mix ‘A’

S.No.	Material	Quantity kg/m^3	Quantity for
			6 cubes in kg
1	Cement	405.17	8.20
2	Fine aggregate	537.39	10.90
3	Corse aggregate	1194.20	24.20
4	Waste paper pulp	21.33	0.431
5	Water	191.92	3.89
	Density	2372	

Table 2. Showing Mix Proportions and quantity of materials used for M25 Mix ‘B’

S.No.	Material	Quantity kg/m^3	Quantity for
			6 cubes in kg
1	Cement	383.85	7.77
2	Fine aggregate	537.39	10.90
3	Corse aggregate	1232.64	24.96
4	Waste paper pulp	57.78	1.17
5	Water	173.34	3.51
	Density	2332	

Table 3. Showing Mix Proportions and quantity of materials used for M25 Mix ‘C’

S.No.	Material	Quantity kg/m^3	Quantity for
			6 cubes in kg
1	Cement	362.52	7.34
2	Fine aggregate	537.39	10.90
3	Corse aggregate	1194.20	24.20
4	Waste paper pulp	63.98	1.30
5	Water	191.92	3.89
	Density	2372	

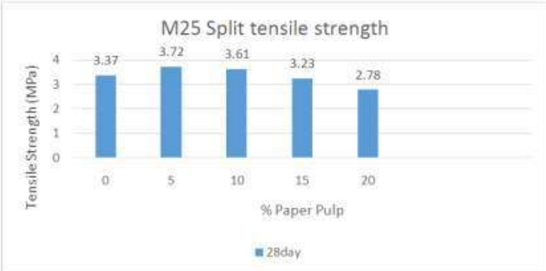
Table 4. Showing Mix Proportions and quantity of materials used for M25 Mix 'D'

S.No.	Material	Quantity kg/m^3	Quantity for 6 cubes in kg
1	Cement	341.20	6.91
2	Fine aggregate	537.39	10.90
3	Corse aggregate	1194.20	24.20
4	Waste paper pulp	85.30	1.72
5	Water	191.92	3.89
	Density	2372	

IV. RESULTS

Compressive strength of cubes

Split tensile strength of specimen



Flexural strength of cubes

V. DISCUSSION AND CONCLUSION

The effects of various important parameters on compressive strength, split tensile strength and flexural strength of air-cooled blast furnace slag concrete and Ordinary Portland cement concrete. The parameters considered are as follows:

1. Ratio of blast furnace slag, by weight of fine aggregates,
2. Curing Temperature and Time,
3. Water/cement ratio by mass,

5.1 COMPRESSIVE STRENGTH OF CUBES

5.1.1 Effect of Air-Cooled Blast Furnace Slag on Compressive Strength of Cubes

Table 5.1 Strengths of air cooled blast furnace slag concrete M25 of different mixes.

S.No.	Air Cooled Blast Furnace Slag %	7 Days Compressive Strength (MPa)
Mix 1	0	27.24
Mix 2	12.5	28.58
Mix 3	25	29.49
Mix 4	37.5	27.70
Mix 5	50	26.37

Figure 5.1 Variation of M25 Compressive Strength with variation of ACBFS

Table 5.2 Strengths of air cooled blast furnace slag concrete M25 of different mixes.

S.No.	Air Cooled Blast Furnace Slag %	28 Days Compressive Strength (MPa)
Mix 1	0	38.80
Mix 2	12.5	39.23
Mix 3	25	39.70
Mix 4	37.5	38.37
Mix 5	50	37.88

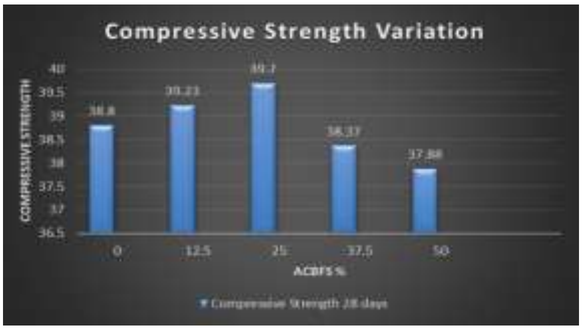


Figure 5.2 Variation of M25 Compressive Strength with variation of ACBFS

Table 5.3 Strengths of air cooled blast furnace slag concrete M25 of different mixes.

S.No.	Air Cooled Blast Furnace Slag %	56 Days Compressive Strength (MPa)
Mix 1	0	41.46
Mix 2	12.5	42.79
Mix 3	25	44.15
Mix 4	37.5	41.05
Mix 5	50	40.37

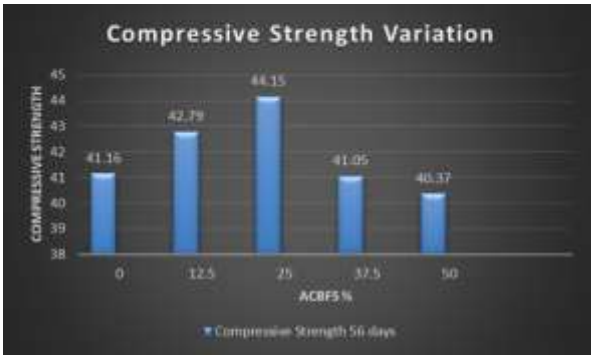


Figure 5.3 Variation of M25 Compressive Strength with variation of ACBFS

Table 5.4 Strengths of air cooled blast furnace slag concrete M25 of different mixes.

S.No.	Air Cooled Blast Furnace Slag %	90 Days Compressive Strength (MPa)
Mix 1	0	43.70
Mix 2	12.5	45.05
Mix 3	25	45.94
Mix 4	37.5	44.63
Mix 5	50	42.45

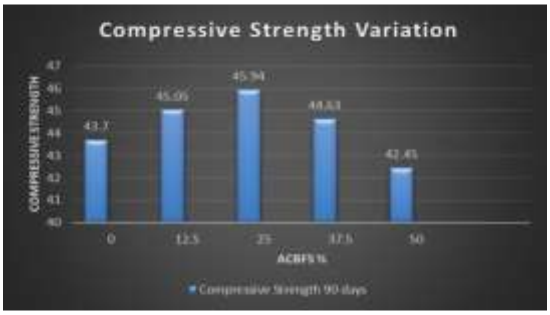


Figure 5.4 Variation of M25 Compressive Strength with variation of ACBFS

From Table 5.1, 5.2 and 5.3, it can be seen that the compressive strength of air-cooled blast furnace slag concrete increases with the replacement of fine aggregates by blast furnace slag till 25% replacement after that it gradually decreases.

5.2 SPLIT TENSILE STRENGTH OF CYLINDERS

5.2.1 Effect of Glass Fiber on Tensile Strength of Cylinders

Table 5.5 Tensile strength of air-cooled blast furnace slag concrete M25 of different mixes.

S.No.	Air Cooled Blast Furnace Slag %	7 Days Split Tensile Strength (MPa)
Mix 1	0	1.76
Mix 2	12.5	1.90
Mix 3	25	2.05
Mix 4	37.5	1.84
Mix 5	50	1.74

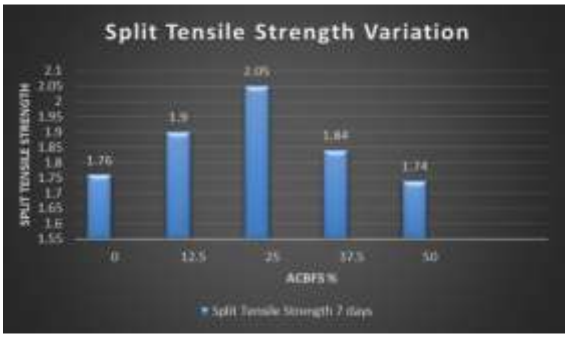


Figure 5.5 Variation of M25 Split Tensile Strength with variation of ACBF

Table Error! No text of specified style in document.**.6 Tensile strength of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	28 Days Split Tensile Strength (MPa)
Mix 1	0	2.18
Mix 2	12.5	2.48
Mix 3	25	2.33
Mix 4	37.5	2.19
Mix 5	50	2.05

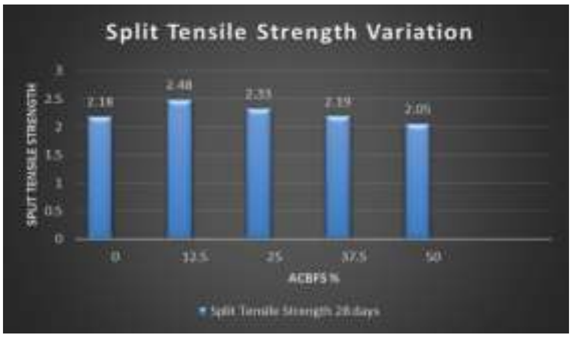


Figure Error! No text of specified style in document.**.6 Variation of M25 Split Tensile Strength with variation of ACBFS**

Table Error! No text of specified style in document.**.7 Tensile strength of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	56 Days Split Tensile Strength (MPa)
Mix 1	0	2.49
Mix 2	12.5	2.75
Mix 3	25	2.91
Mix 4	37.5	2.64
Mix 5	50	2.35

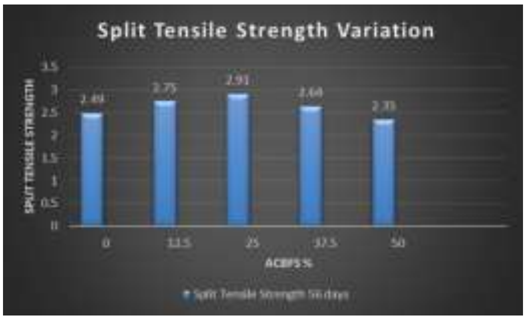


Figure Error! No text of specified style in document.**.7 Variation of M25 Split Tensile Strength with variation of ACBFS**

Table Error! No text of specified style in document.**.8 Tensile strength of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	90 Days Split Tensile Strength (MPa)
Mix 1	0	2.64
Mix 2	12.5	2.91
Mix 3	25	3.05
Mix 4	37.5	2.78
Mix 5	50	2.50

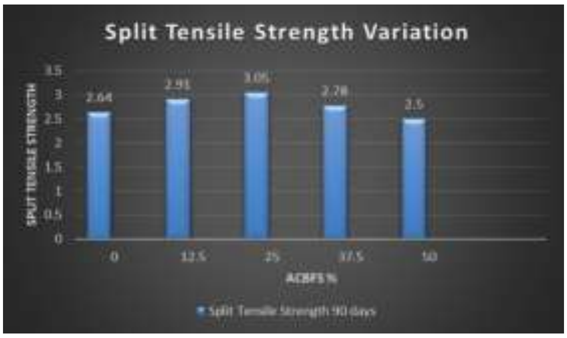


Figure Error! No text of specified style in document.**.8 Variation of M25 Split Tensile Strength with variation of ACBFS**

The split tensile strength was conducted as per IS 5816:1999. The test was conducted on the compression testing machine on cylinders. From the tables, it can be noted that the split tensile strength increased till 25% and after that it gradually decreased.

5.3 FLEXURAL STRENGTH OF PRISMS

5.3.1 Effect of Glass Fibre on Flexural Strength of Prisms

Table Error! No text of specified style in document.**.9 Strengths of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	7 Days Split Tensile Strength (MPa)
Mix 1	0	5.60
Mix 2	12.5	6.59
Mix 3	25	7.11
Mix 4	37.5	6.10
Mix 5	50	5.58

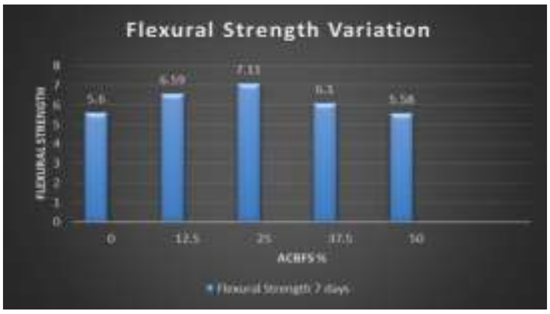


Figure Error! No text of specified style in document.**.9 Variation of M25 Split Tensile Strength with variation of ACBFS**

Table Error! No text of specified style in document.**.10 Strengths of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	28 Days Split Tensile Strength (MPa)
Mix 1	0	7.08
Mix 2	12.5	7.59
Mix 3	25	7.97
Mix 4	37.5	6.94
Mix 5	50	6.58

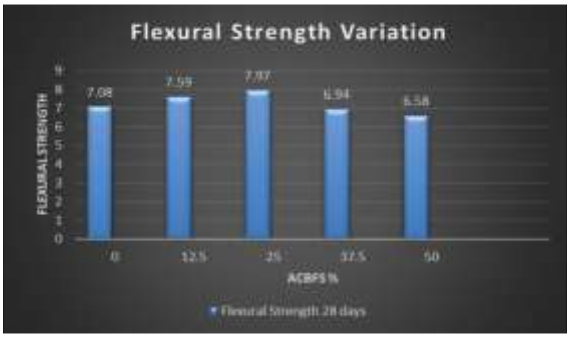


Figure Error! No text of specified style in document.**.10 Variation of M25 Flexural Strength with variation of ACBFS**

Table Error! No text of specified style in document.**.11 Strengths of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	56 Days Split Tensile Strength (MPa)
0Mix 1	0	7.58
Mix 2	12.5	8.10
Mix 3	25	8.59
Mix 4	37.5	7.58
Mix 5	50	7.07

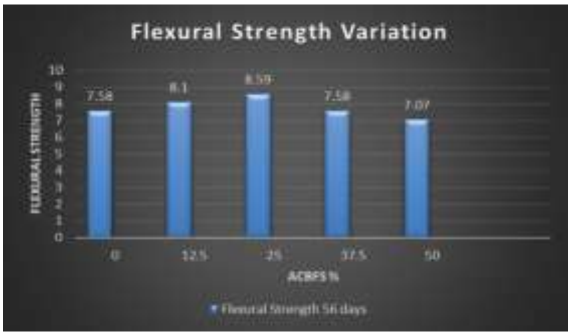


Figure Error! No text of specified style in document.**.11 Variation of M25 Flexural Strength with variation of ACBFS**

Table Error! No text of specified style in document.**.12 Strengths of air-cooled blast furnace slag concrete M25 of different mixes.**

S.No.	Air Cooled Blast Furnace Slag %	90 Days Split Tensile Strength (MPa)
Mix 1	**0**	**8.55**
Mix 2	**12.5**	**8.97**
Mix 3	**25**	**9.57**
Mix 4	**37.5**	**8.06**
Mix 5	**50**	**7.57**

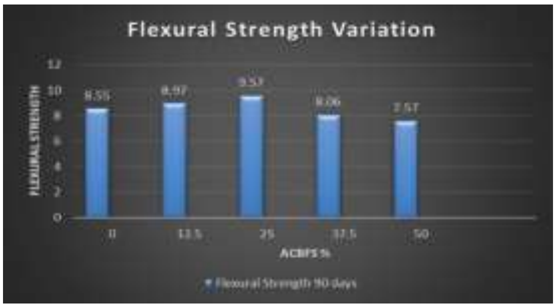


Figure Error! No text of specified style in document.**.12 Variation of M25 Flexural Strength with variation of ACBFS**

The flexural strength of concrete is carried out as per IS: 516: 1959. The test was carried out on a universal testing machine. ACBFS concrete showed improved flexural strength than ordinary Portland cement. The following conclusions have been made :-

1. The Compressive strength of the cubes of 7days, 28days, 56 days and 90 days has highest value for 25% replacement.
2. The Split tensile strength of the cubes 7days, 56days and 90 days has highest value for 25% replacement.
3. The Split tensile strength of the cubes 28 days has highest value for 12.5% replacement
4. The flexural strength of the cubes 7days, 28days, 56days and 90 days has highest value for 25% replacement.
5. Reprocess of the slag as a by-product helps to reduce the pollution from environment as it reduced CO_2 emission and conserves natural resources for future generation.
6. The risk of thermal cracking is reduced as heat of hydration is slower in case of blast furnace slag cement.

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