Research Article

Journal of Environmental Nanotechnology

Ultrafine GGBS and Fly Ash as Cement Replacement for Sustainable Concrete

Harshit Saxena[1], Vikas Srivastava[1*] Ashish Kumar Yadav[1] and A. K. Tiwari[2]
[1]Department of Civil Engineering, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, UP, India
[2]UltraTech Cement Limited, Lucknow, UP, India
Received: 26.05.2024 Accepted: 21.07.2024 Published: 30.09.2024
*vikas.srivastava@shiats.edu.in

ABSTRACT

The construction industry is one of the major contributors to environmental degradation. Hence, it requires eco-friendly practices to make concrete more sustainable. This can be achieved by addition of mineral admixtures as a cement replacement. This process helps the environment in two ways: by reducing the carbon dioxide emission through cement replacement and by utilizing mineral admixtures such as fly ash, Ground Granulated Blast Furnace Slag (GGBS), metakaolin, rice husk ash and silica fume, which are all industrial wastes or by-products. Hence, this approach lowers the greenhouse effect and global warming by reducing carbon dioxide emissions and prevents environmental contamination by utilizing industrial wastes. This experimental study aims to find the perfect combination of mineral admixtures such as fly ash and ultrafine GGBS to maximize cement replacement in concrete without compromising its mechanical properties and achieving a more sustainable concrete for day-to-day practice. For this study, the fly ash percentage was maintained at 20% for all trials, with the ultrafine GGBS percentage varying from 15% to 30%.

Keywords: Sustainable Concrete; Ultrafine GGBS; Fly ash; Mineral admixture.

1. INTRODUCTION

With the rapidly growing population and developing world, the demand for construction of concrete structures such as high-rise buildings, residential buildings, shopping complexes has also increased. Constructional activities have increased to such an extent that the concrete has become the second most consumed material by humans after water. Hence, it has become an integral part of the modern society's infrastructure. Besides being the most widely used construction material, concrete has a negative impact on the environment. It is associated with high carbon dioxide emissions, resource depletion, concrete dust, and radioactivity. The major component of concrete which is responsible for this negative impacting nature is cement. Cement is widely used for various construction purposes, but during its manufacturing, a lot of dangerous gases, such as carbon monoxide and carbon dioxide as well as hazardous waste like highly alkaline materials and volatile organic compounds are released. This hazardous waste causes different types of diseases and problems in the eco-system leading to environmental imbalance. Thus, using supplementary cementitious material can reduce environmental imbalance and maintain the eco-system in a safe way (Gupta *et al*. 2018). The production of cement generates 0.9 pounds of carbon dioxide for every pound of cement. So, the addition of mineral admixtures such as fly ash, Ground Granulated Blast Furnace Slag (GGBS) as cement replacement helps to make concrete sustainable and more environment friendly by reducing carbon dioxide emission and by utilizing waste material (Desale *et al*. 2018). In response to growing environmental concerns, the concept of sustainable concrete has emerged, aiming to mitigate these adverse effects while maintaining the essential properties and functionality of conventional concrete. Sustainable concrete encompasses a range of strategies, including the use of alternative materials, innovative production techniques, and improved construction practices, all designed to reduce its ecological footprint. This paper deals with the replacement of cement with fly ash and ultrafine ground granulated blast furnace slag, aiming to find the optimal combination of both for maximum cement replacement. The goal is to make concrete more sustainable and eco-friendlier while maintaining its strength and mechanical properties.

1.1 Objective and Scope

The objective of the study is to test the concrete at different levels of ultrafine GGBS while keeping fly ash content at 20 percent for all mixes. The combination must maintain the strength and other mechanical properties of concrete. The scope of the study is to create a much more sustainable concrete by replacing cement as much as possible. This helps to reduce the carbon emissions caused by cement and lower industrial waste accumulation by utilizing them for concrete. If such low cement content concrete is used on a mass scale in different construction activities, then the result will lead to lower greenhouse effect, reduced global warming and less resource depletion.

2. MATERIALS USED

The materials used in this investigation are as follows:

2.1 Cement

In accordance with the Indian standards (IS 1489 (Part 1) - 2015), Portland Pozzolana Cement (PPC) was used as the binder in the preparation of concrete mixtures. Table 1 displays the cement characteristics.

Table 1. Characteristics of cement

S. No.	Characteristic	Value
1	Specific gravity	3.15
2	Normal consistency	29.5%
3	Initial setting time	130 minutes
4	Final setting time	220 minutes

2.2 Fine Aggregate

The natural sand which was locally available was used and examined in accordance with Indian Standards (IS: 383-1970) and (IS: 2386 (Part- I)) for finding the necessary properties of the natural sand. Table 2 represents the characteristics of fine aggregate.

Table 2. Characteristics of fine aggregates

S. No.	Characteristic	Value
1	Specific gravity	2.54
2	Fineness modulus	2.76
3	Grading zone	Zone 3
4	Water absorption	1.6%

Table 3. Characteristics of coarse aggregate

Characteristic	Coarse aggregate	
	20 mm	12.5 mm
Fineness modulus	7	6.61
Specific gravity	2.74	2.74
Water absorption	0.56%	0.40%

2.3 Coarse Aggregate

Locally available coarse aggregate was examined in accordance with Indian Standards (IS: 383-1970) to find its properties. Coarse aggregate of two sizes (one passing through 12.5 mm IS sieve and other through 20 mm IS sieve) were taken for the study. Table 3 represents the characteristics of coarse aggregate used.

2.4 Ultrafine GGBS

Ground granulated blast furnace slag (GGBS) is a waste product from steel and iron making process (Rathod *et al.* 2020). It is obtained from quenching molten iron slag from blast furnace in steam or water. This produces a granular, glassy product that is then dried and ground into a fine powder. The chemical and physical characteristics of GGBS are given in Table 4 and Table 5, respectively.

Table 4. Chemical characteristics of ultrafine GGBS

S. No.	Chemical component	Value (% by mass)
1	Manganese oxide (MnO)	0.45
2	Magnesium oxide (MgO)	8.91
3	Sulphide sulphur (S)	0.63
4	Sulphate (SO_4^{2-})	0.22
5	Chloride content (Cl^-)	0.07
6	CaO	33.03
7	SiO_2	33.80
8	Glass content	93.50

Table 5. Physical characteristics of GGBS

Characteristic	Value
Particle size (μm)	
D50	3.90
D95	14.21
Fineness (m^2/kg)	1822
Slag activity index %	
7 days	94.6
28 days	114
Specific gravity	2.82

Table 6. Chemical characteristics of fly ash

S. No.	Chemical component	Value (% by mass)
1	LOI %	0.56
2	IR %	92.64
3	SiO_2 %	63.44
4	SO_4^{2-} %	0.30
5	Al_2O_3 %	28.26
6	Fe_2O_3 %	0.54
7	CaO %	0.44
8	MgO %	0.48

2.5 Fly Ash

Fly ash is a combustion by-product of coal which is usually collected from coal-fired boilers. The chemical components of fly ash greatly depend on the type of coal being burned. The chemical and physical characteristics of fly ash used are given in Table 6 and Table 7, respectively.

Table 7. Physical Characteristics of fly ash

S. No.	Characteristic	Value
1	Specific surface (m^2/Kg)	372
2	Lime reactivity (Mpa)	5.50
3	Specific gravity	2.30

3. METHODOLOGY

The materials used in this research were all examined first to determine their respective properties. The concrete mix design was done and the proportioning adopted was 1:1.89:3.27 with water-cement ratio of 0.41. The mix was designed according to IS 10262 – 2019 to achieve a concrete grade of M_{60}.The quantity of ingredients of concrete mix is given in Table 8.

Table 8. Concrete mix ingredients

Water	Cement	Fine aggregate	Coarse aggregate
155.8 kg	380 kg	721.06 kg	1243.44 kg

The mixes with different percentages of ultrafine GGBS and fly ash as cement replacement were prepared in laboratory (listed in Table 9) and were tested for workability, density, water absorption, compressive strength, and split tensile strength.

Table 9. Different concrete mixes

S. No.	Mix	Fly ash %	Ultrafine GGBS %
1	A	20	15
2	B	20	20
3	C	20	25
4	D	20	30

4. RESULTS

4.1 Density

The density of fresh concrete was measured by putting the concrete in a container of known volume and then calculating the density from the mass measured. The specimens were tested for density, and it was observed that there is no marginal difference in different mixes of concrete. Fig.1 depicts the test results.

4.2. Workability

The slump cone test was performed on different mixes of concrete to determine their workability. The test was performed as per IS: 1199-1959. The fresh concrete of different mixes was placed into the frustum of a cone shaped mould in three layers with each layer being tamped 25 times with a rod. The mould was then removed and the slump values for each mix was recorded. The results are depicted in Fig. 2.

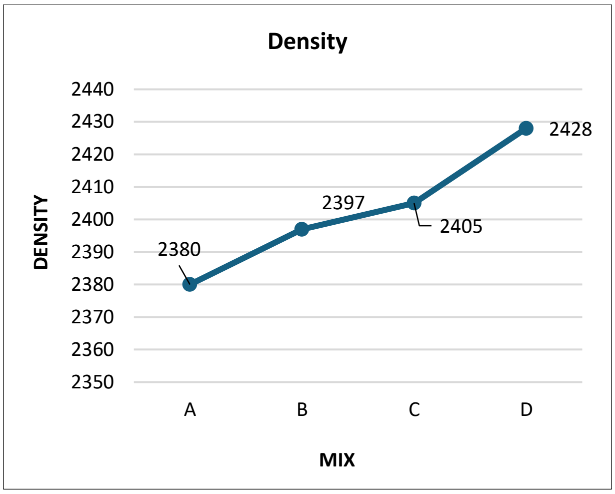

Fig. 1: Density of fresh concrete

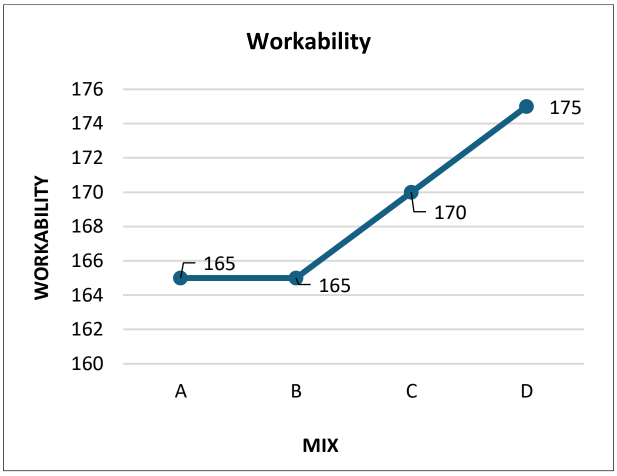

Fig. 2: Workability of different concrete mixes

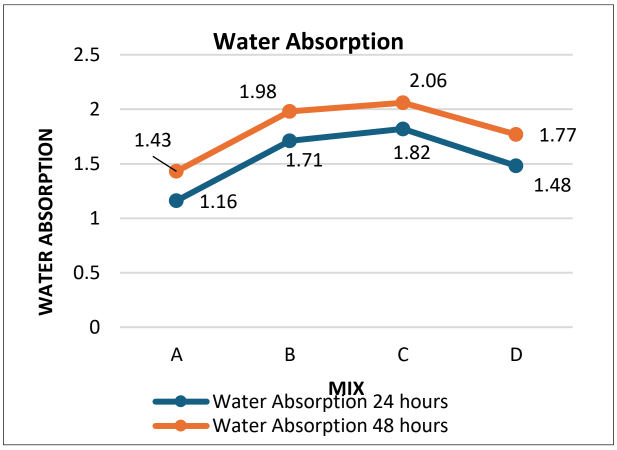

Fig. 3: Water absorption

4.3 Water Absorption

Water absorption was conducted on cube specimens of dimension (150 mm × 150 mm ×150 mm). These specimens were oven dried followed by cooling and were then immersed in water for a period of 48 hours and 24 hours. A graph was plotted to represent water absorption by different mixes after 24 hours and 48 hours of immersion (Fig. 3).

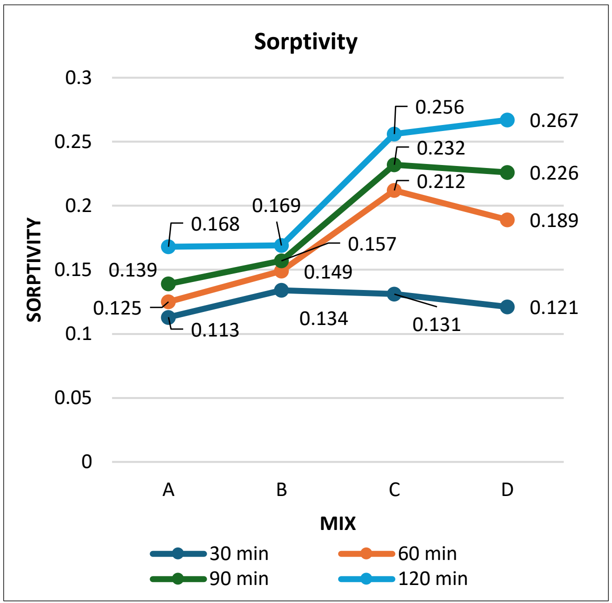

Fig. 4: Sorptivity of water by concrete mixes

4.4 Sorptivity

Sorptivity is a measure of the capacity of a porous material, such as concrete, to absorb and transmit water by capillarity. It is an important property for understanding how concrete interacts with moisture, which affects durability and longevity. It is a critical property for assessing the durability of concrete in moist environments. Sorptivity test indicates the obstruction that occurs in the path of water due to the capillary suction on the surface of concrete specimens. This test was conducted on cube specimens with dimension 150 × 150 × 150 mm. The sorptivity values were recorded for a period of 2 hours at an interval of 30 minutes as shown in Fig.4.

The average sorptivity for the period of 2 hours was also calculated as shown in Fig. 5.

4.4 Compressive Strength

The compressive strength test was performed on cubes (150 mm × 150 mm × 150 mm) of different concrete mixes after 7th day and 28th day of curing to determine their respective compressive strength. The test was performed as per IS 516 (1959) and the specimens were tested using Universal Testing Machine (UTM). The 7 days and 28 days compressive strength result of the specimens is provided in Fig. 6 and Fig. 7, respectively.

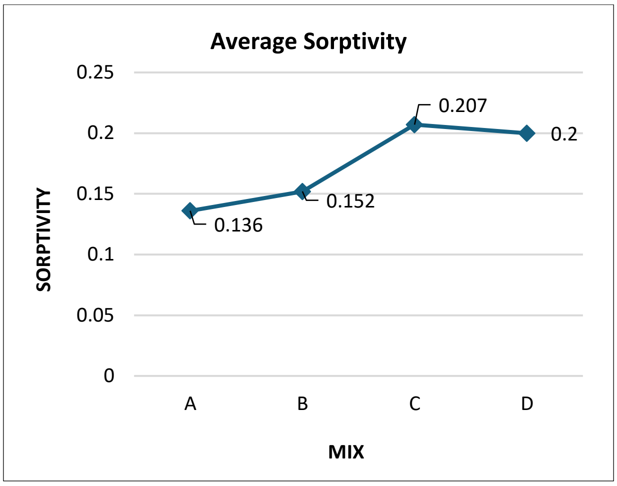

Fig. 5: Average sorptivity

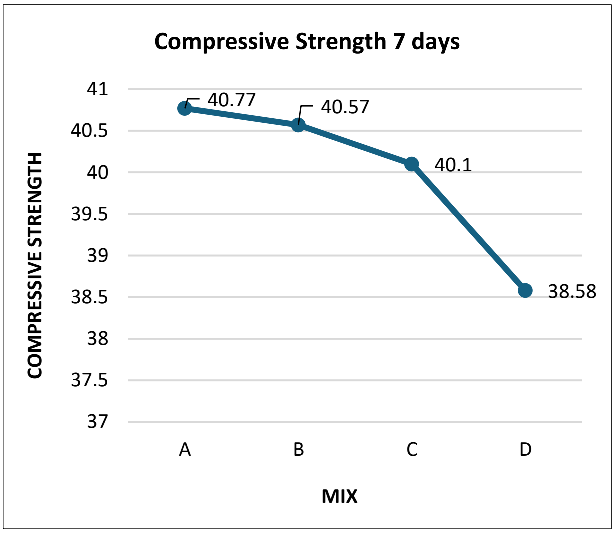

Fig. 6: Compressive strength (7 days)

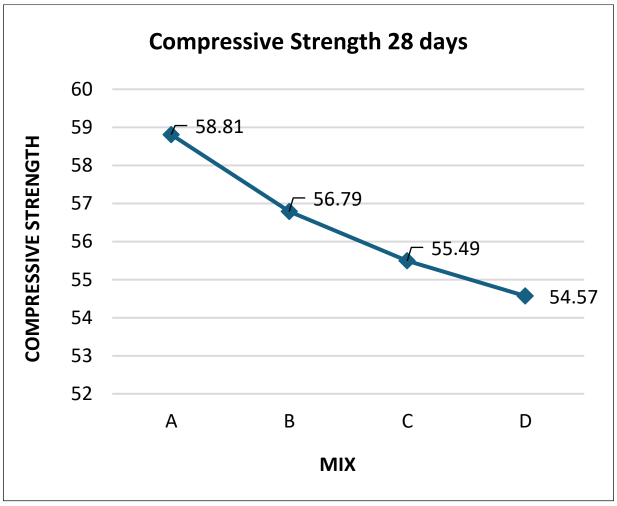

Fig. 7: Compressive strength (28 days)

4.5 Split Tensile Strength

The split tensile strength of concrete is an easy way to assess the tensile strength of concrete. The split tensile test was performed as per IS 516 and IS 5816 on the cube specimens (150 mm × 150 mm × 150 mm) of different concrete mixes to determine their respective split tensile strength. Fig. 8 depicts the 28 days split tensile strength of all concrete mixes.

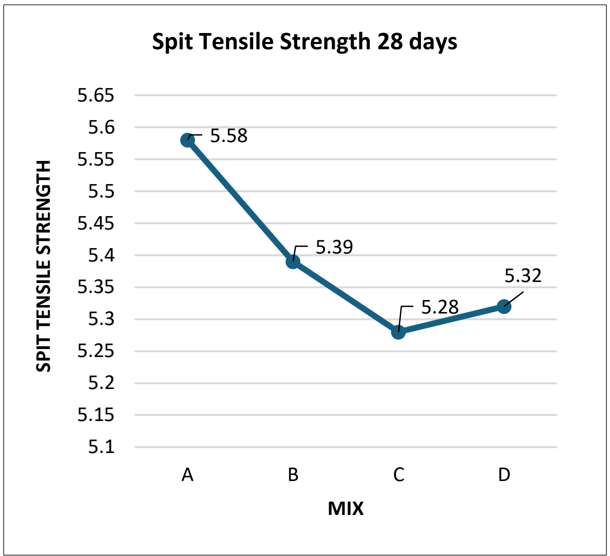

Fig. 8: Split tensile strength (28 days)

4.6 Relationship between Compressive Strength and Split Tensile Strength

The relationship between compressive strength and split tensile strength was derived using MS Excel linear regression computation (Fig. 9). The governing equation is given by:

$$y = 12.925x - 13.278$$
$$R^2 = 0.9352$$

where,

y = Average compressive strength at 28 days
x = Split tensile strength at 28 days
R^2 = Coefficient of determination

The observed and predicted values of compressive strength is shown in Fig. 10.

Table 10. Percentage error for compressive strength values

Compressive strength (N/mm^2) at 28 days		Error (%)
Observed	Predicted	
58.81	58.84	-0.050
56.79	56.38	0.727
55.49	54.96	0.964
54.57	55.48	-1.640

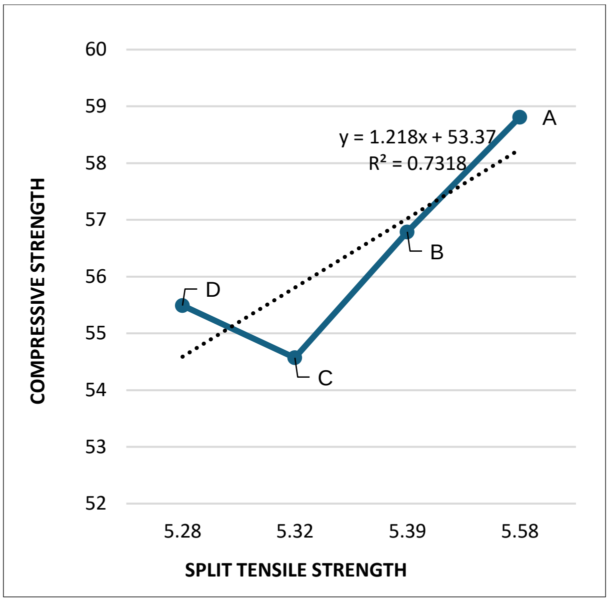

Fig. 9: Relationship between compressive strength and tensile strength

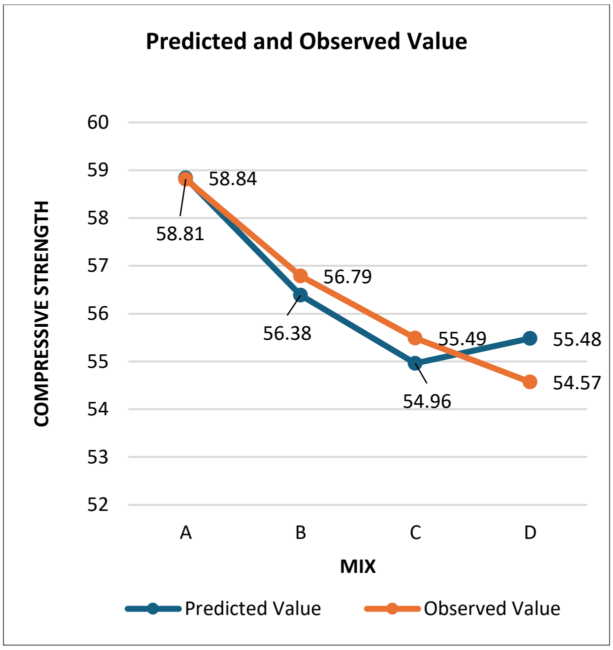

Fig. 10: Predicted and observed values of compressive strength

The percentage error in observed and predicted values was calculated and is given in Table 10.

5. CONCLUSION

The following conclusions were drawn from the research work carried out:

1. With the increasing percentage of mineral admixture (ultrafine GGBS), decreasing trend in compressive strength was observed. However,

this slight decrease in compressive strength can be countered by reducing water cement ratio from 0.41 to around 0.38. Hence, replacing 45-50% cement content without compromising its compressive strength results in more sustainable concrete, reducing carbon dioxide emission and utilizing industrial wastes.

2. The split tensile strength also follows decreasing trend till 25% ultrafine GGBS addition and then shows an increase. But this slight decrease can easily be countered by lowering water cement ratio as in the case of compressive strength.

3. Increase in workability is observed with increase in addition of ultrafine GGBS. The slump value was directly proportional to the percentage addition of mineral admixtures.

4. The density of concrete increased with gradual addition of ultrafine GGBS. This was due to the fine filler effect of the ultrafine GGBS which fills up the interstitial space between cement, fine aggregate, and coarse aggregate.

FUNDING

This research did not receive any specific grant from public, commercial or non- profit funding agencies.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

COPYRIGHT

REFERENCES

Desale, V., Kamble, A., Borwal, P., Ingole, A. and Pathak, S., Experimental Analysis of Partial Replacement of Cement by GGBS and Fly Ash in Concrete, *Int. J. Eng. Res. Technol.*, 7(5), 596-598 (2018). https://doi.org/10.17577/IJERTV7IS050244

Gupta, J., Lata, N. and Mittal, S., Effect of Addition and Replacement of GGBS and Fly ash with Cement in Concrete, *Int. J. Eng. Res. Technol.,* 6(11), 1-7 (2018). https://doi.org/10.17577/IJERTCONV6IS11023

IS 10262 – (2019): Concrete mix proportioning guidelines, Bureau of Indian standards, New Delhi.

IS 1489 (Part 1) – (1991): Specification for Portland Pozzolana cement, Part 1: Fly ash based, Bureau of Indian standards, New Delhi.

IS: 1199 – (1959): Method of sampling and analysis of concrete Bureau of Indian standards, New Delhi.

IS: 2386 (Part- I) - 1963: Indian standards code of practice for methods of test for Aggregate for concrete, Bureau of Indian standard Institution, New Delhi.

IS: 383 – (1970): Specification for Coarse and Fine Aggregates from natural sources for concrete (Second revision), Bureau of Indian standard Institution, New Delhi.

IS: 456 – (2000): Specifications for plain and reinforced concrete, Bureau of Indian standards, New Delhi.

IS: 516 - (1959): Indian Standard Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi.

Rathod, S. M. and Sinha, M., Effect of fly ash and GGBS on strength and durability of concrete up to 90 days, *Int. J. Eng. Dev. and Res.,* 8(1), 71-74 (2020).