International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

PERFORMANCE OF GEOPOLYMER CONCRETE WITH FLYASH AND SILICAFUME AS BINDERS

G. Karthikeyan[*1], ***N. Mathesh***[*2], ***S. A . Akash Vijai***[*3], ***C. S. Dharanish***[*4]

∗ 1 Assistant Professor, Department of Civil Engineering, Kumaraguru College of Technology (An Autonomous Institute), Coimbatore. Tamil Nadu (India).

∗ 2,∗ 3, ∗ 4 B.E Scholars, Department of Civil Engineering, Kumaraguru College of Technology (An Autonomous Institute), Coimbatore, Tamil Nadu (India).

ABSTRACT :

Geopolymer concrete (GPC) is the sustainable material alternative to traditional Portland cement concrete; binding to it using industrial by products such as fly ash and silica fume. This present work characterizes the behavior of GPC with focus on use of fly ash and silica fume as major binding materials and substitute of silica fume with fly ash in 0, 5, 10 and 15 weight percentages. The mechanical characteristics to be looked in this study are compressive strength and split tensile strength at varying times. NaOH and Na_2SiO_3 solution were applied for alkaline activators to improve geo polymerization reaction. Tests results indicate that, change of silica fume substitution makes sense to the GPC strength behavior. The results are important in understanding ideal binder components in geopolymer concrete and to improve high performance and sustainable construction materials.

Keywords: Geopolymer concrete, Silica fume, Fly ash, Sodium Silicate, Sodium Hydroxide, Compressive Strength, Split tensile, Conventional Concrete.

INTRODUCTION :

People use concrete everywhere but its widespread manufacturing accounts for major emissions from cement production. People are starting to use GPC because it offers a sustainable replacement for manufacturing cement with waste materials while protecting the environment and delivering essential mechanical performance.

Fly ash provides the source material for geo polymerization as its chemical composition includes aluminum silicates that react well under alkaline activation. The utilization of silica fume from silicon and ferrosilicon manufacturing increases concrete strength because its tiny particles work as pozzolanic activator. The exact mix ratios of these components must be found to reach maximum performance results.

Our research tests how much silica fume needs to be changed with fly ash in GPC mixtures at 0%, 5%, 10%, and 15% levels to evaluate material performance. Our analysis prioritizes the measurements of concrete strength by evaluating the compressive strength and split tensile test. The research determines how different binder ingredients affect GPC structure which supports our efforts to build better greener concrete products.

1.Industrial By-products in Geopolymer Concrete

The primary ingredient in GPC is industrial waste from various industries like alumina-silicate materials which combine with alkaline activators to produce polymeric connections. Our reaction process replaces regular cement use which reduces both environmental pollution and optimizes our natural resources usage.

- **Fly ash:** A by-product of coal combustion in thermal power plants, fly ash contains a high amount of silica and alumina, making it an ideal precursor for geo polymerization. The usage in concrete not only promotes the sustainability but also reduces the landfill waste.
- **Silica fume:** A by-product of the silicon and ferrosilicon industries, silica fume consists of fine particles with high pozzolanic activity. It generally improves concrete strength, durability and resistance to aggressive environments. The diameter of the silica fume is 100 times smaller than the cement particles.

OBJECTIVE :

This study investigates the effect of replacing silica fume with fly ash at 0%, 5%, 10%, and 15% on the mechanical properties of GPC. The primary focus is to evaluate compressive strength and split tensile strength at different curing periods. The research aims to optimize the binder composition and assess its influence on the structural performance of geopolymer concrete, providing valuable insights into developing durable and sustainable construction materials.

MATERIALS AND MIX PROPORTION :

The manufacturing company in Coimbatore Tamil Nadu produces low calcium Type-F fly ash which meets standards according to IS3812-2013. When we heat quartz we get a by-product SF, which comes as a dry powder product that follows IS 15388:2003 standards. The experiments followed IS 1727:1967 to check fly ash and silica fume specific gravities which came out at 2.4 and 2.2 respectively. The research project uses Zone 2 sand for aggregates along with 20-millimeter coarse aggregate. Use of fine aggregate resulted in Specific gravity measurement of 2.63 at 2.87 for the coarse aggregate. We made the alkaline activator by combining sodium silicate solution and sodium hydroxide solution at a ratio of 2.5 parts to 1 part. The mixture of reactive binders uses a 0.4 ratio of alkaline solution to cement paste. Using this ratio will create basic structural performance results. The pellets mixed with distilled water produced NaOH solution. The solution contains 12 M sodium hydroxide particles alongside 50.32% Sodium silicate powder. Fig 1 and Fig 2 shows the material used in geopolymer concrete.

Fig 1 a. Fly ash

Fig 2 b. Silica fume

MIX PROPORTION

The mix proportion is that concrete mix of M 30 is used. And here various percentages like 0%, 5% 10 % 15 % of silica fume were replaced by the weight of fly ash. The alkaline activators sodium silicate and sodium hydroxide are mixed in the ratio 2.5:1. The Concentration of Sodium Hydroxide in terms of molarity is 12 M. Alkaline to binder ratio is taken as 0.40 for all mixes. Sodium hydroxide is prepared in such a way that 435 g of sodium hydroxide pellets are mixed in 1 liter of distilled water, and it is prepared 24 hrs before the day of casting cubes and it is allowed to settle and there after it is used. Table 1 depicts the mix proportion of geopolymer concrete.

Table 1 - MIX PROPORTION

EXPERIMENTAL NUMBER	SILICAFUME REPLACEMENT	ALKALINE TO BINDER RATIO
1	0%	0.40
2	5%	0.40
3	10%	0.40
4	15%	0.40

EXPERIMENTAL STUDY

The concrete is prepared by mixing the silica fume of 0 to 15% by weight of fly ash with fine and coarse aggregates are mixed uniformly to avoid any lumps i.e.) dry mixing is done for 2 minutes. And the calculated number of alkaline activators are added. For premixing water is added initially in light amount because the alkaline activator contains more water in it. As fly ash is light weight it takes up more water and proper mixing to be done to prevent the concrete from bleeding or segregation. After getting the desired workability, the concrete is then transferred to the cube of size 150mm x 150mm x 150mm and in total of 12 cubes were casted to perform compressive strength test at 7,14 and 28 days respectively and further 4 cylinder of size 150 x 300 mm were casted to perform Split tensile test of the geopolymer concrete. Table 2 shows the quantity of materials required for preparation of geopolymer concrete.

Table 2 - QUANTITY OF MATERIALS

INGREDIENTS OF GPC	FLY ASH	NaOH	Na2SiO3	FINE AGGREGATE	COARSE AGGREGATE	TOTAL WATER
QUANTITY ($kg/m3$)	405	46.29	115.92	679.49	1261.92	108.35
PROPORTION	1	0.40		1.67	3.115	0.211

CASTING OF CUBES AND CYLINDERS

The Cube of size 150mm x 150mm x 150 were used and 12 cubes were cast to perform compressive strength test and further cylinder of size 150 mm x 300 mm were cast to perform Split tensile test of the geopolymer concrete. For curing process, it is first kept in a hot air oven at 70 degrees Celsius and after room temperature curing is done to attain desired strength. Fig 3 and Fig 4 depict the cast images of geopolymer concrete.

Fig 3 a. Casting of cubes

Fig 4 b. Casting of cylinders

RESULT AND DISCUSSION :

COMPRESSIVE STRENGTH

Geopolymer concrete requires a strong mechanical test for us to access its resistance to loads. The GPC material's strength performance relies on binder ingredients choice and activator amount selection plus curing heat and time decisions. The testing machine evaluated compressive strength of the concrete samples at 7, 14, and 28 days. We find from the result that average Compressive strength at 7 days is 24.07 N/mm^2 and average Compressive strength at 14 days is 29.9N / mm^2 and average compressive strength at 28 days is 36N / mm^2.

Geopolymer concrete achieves higher compressive strength when silica fume replaces 5% of the mix due to stronger geo polymerization along with consistent packing density and suitable Si/Al ratio that produces a compact and powerful matrix. Ultrafine silica particles act as void fillers while they combine to decrease material porosity, so the aluminosilicate gel becomes stronger. The proper compaction of geopolymer concrete is achievable because the workability levels remain acceptable while preventing microcracking. The strength suffers from poor bonding and decreased strength because high silica fume content (10%-15%) disrupts Si/Al ratios and deteriorates workability while increasing material porosity. A 5% silica-fume substitution leads to the best combination of reactivity with microstructure and durability which allows maximum compressive strength.

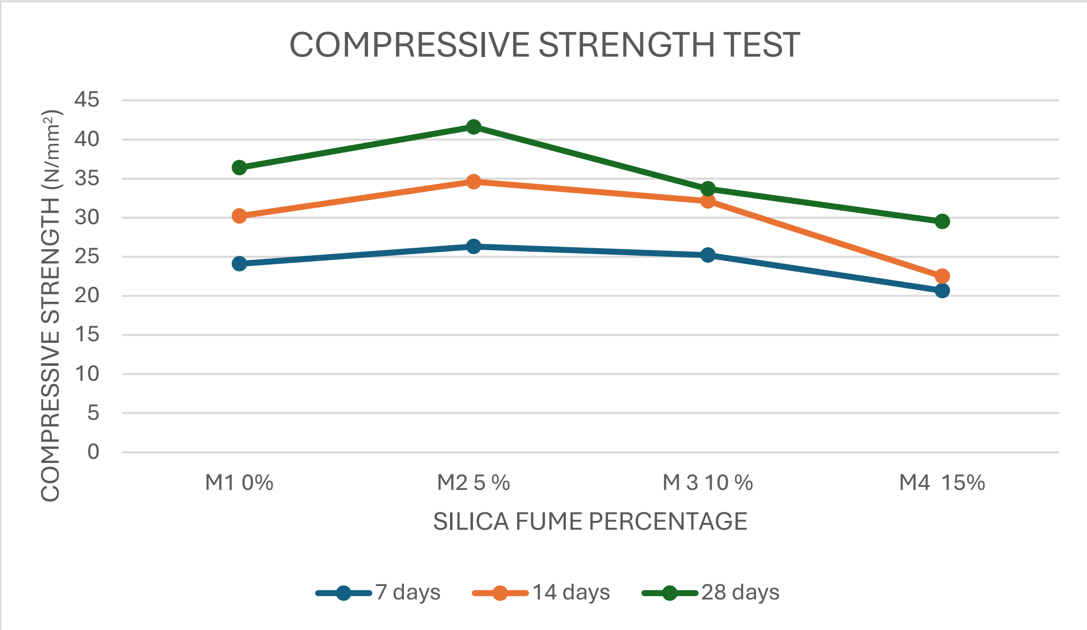
The compressive strength of geopolymer concrete was performed at every 7, 14 and 28 days. And the Table 3 provides the compressive strength values obtained after performing the tests.

Table 3 – TEST RESULT OF COMPRESSION TEST

GRADE OF CONCRETE	% SILICA FUME REPLACED	7 DAYS N / mm^2)	14 DAYS (N / mm^2)	28 DAYS N / mm^2)
M 30	CC	23.5	26.9	30.97
	M1: 0%	24.1	30.2	36.4
	M2: 5%	26.31	34.6	41.6
	M 3: 10%	25.2	32.12	33.7
	M4: 15%	20.67	22.5	29.5

The graph below shows the comparison of compression test values at 7,14 and 28 days with various mix percentages of 0, 5, 10 and15 % of silica fume replacement and conventional concrete.

Fig 5



CONVENTIONAL CONCRETE

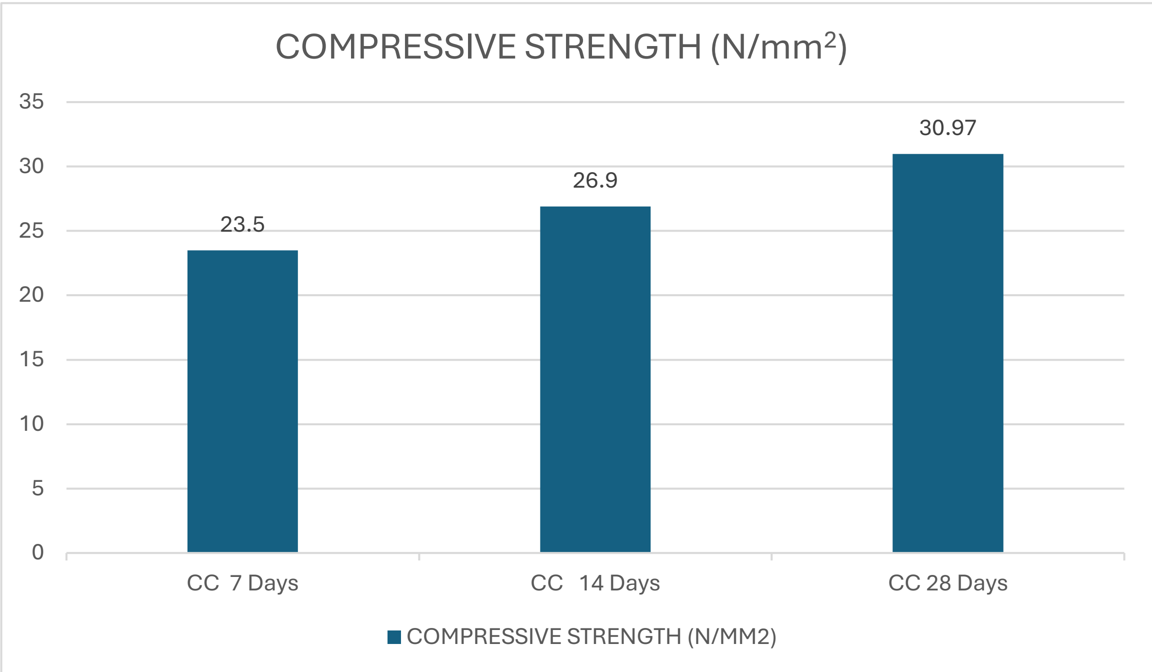


Fig 6

SPLIT TENSILE TEST

The ability of geopolymer concrete (GPC) to withstand breaking forces during tension load tests shows whether this material can resist cracking. Concrete material normally fails under tension, so this test measures its suitability for engineering structures. The GPC tensile strength performance relies on its binder mixture and activator treatment as well as siliceous fume content and curing approach.

A 5% silica fume substitution yields maximum split tensile strength in geopolymer concrete because it leads to improved matrix densification and enhanced bonding while decreasing microcracking. The small size of ultrafine silica particles allows them to improve the pore structure which enhances the tensile binding between geopolymer gel and aggregates to improve load distribution. Among different silica fume levels, the 5% replacement point produces the best Si/Al ratio that allows robust geopolymer gel development with minimal brittleness. The incorporation of excess silica as a replacement at 10%-15% leads to reduced workability and produces inferior compacted material that cultivates more microcracks while showing weakened bond strength until it causes the tensile strength to decline. The optimal strength along with workability and durability exists at 5% silica fume replacement which achieves maximum split tensile outcomes.

The table 4 shows the test results of Split Tensile test performed at 28 days for varying percentages as 0- 15 %.

Table 4- TEST RESULT OF SPLIT TENSILE TEST

GRADE OF CONCRETE USED	%SILICAFUME REPLACEMENT	28 DAYS (N / mm^2)
M 30	CC	2.9
	M1: 0%	2.2
	M2: 5%	3
	M3: 10%	2.5
	M4: 15%	1.9

The graph below shows the comparison of Split tensile test values at 28 days with various mix percentages 0, 5 , 10 and 15 % of silica fume replacement.

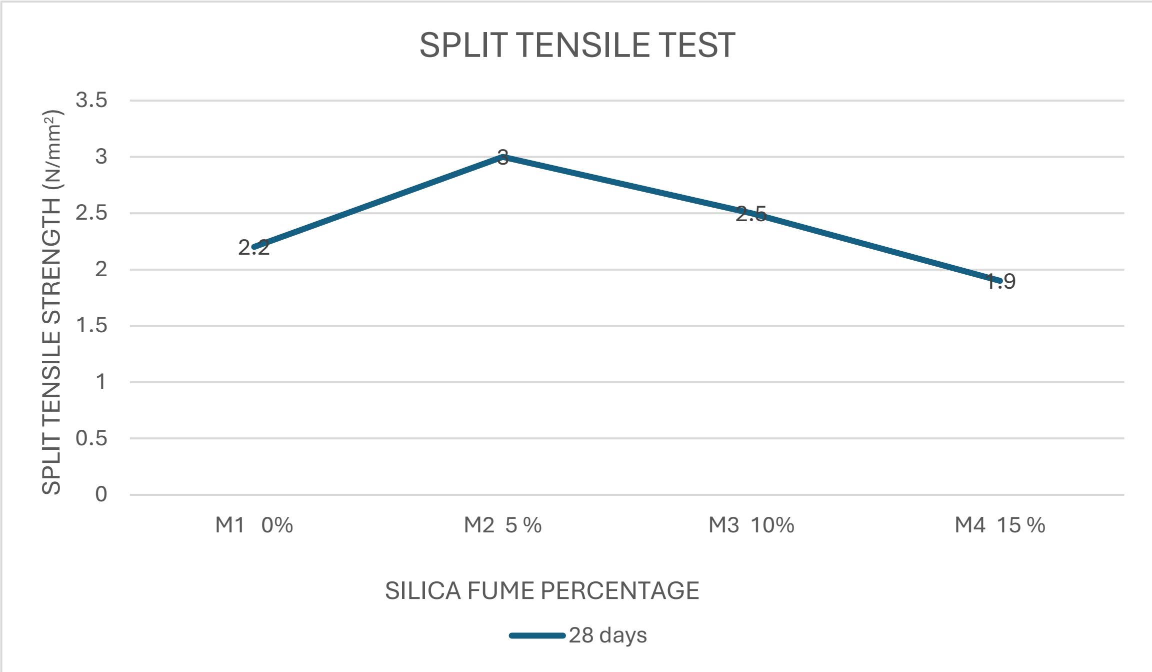


Fig 7

CONCLUSION :

The investigation of geopolymer concrete with fly ash silica fume replacement levels ranging from 0%, 5%,10% and 15% shows 5% replacement delivers peak compressive and split tensile strength because it perfects the geopolymer reaction while improving materials compactness and achieving an ideal Si/Al ratio balance. The strength level remains moderate at 0% but 10% and 15% additions lead to workability problems as well as higher porosity and reduced bond quality. Due to its excellent ability to resist chemical attacks and maintain high strength properties and outstanding durability potential and significant CO_2 reduction, geopolymer concrete presents an environmentally sustainable concrete type of superior to traditional concrete methods. Payments for activators during initial construction might be higher yet the budget becomes favorable because of reduced maintenance costs and improved product longevity. The combination of improved mix optimization methods and large-scale production techniques makes geopolymer concrete better than traditional concrete across performance metrics as well as sustainability indicators and cost-effectiveness perspectives thus creating opportunities for a greener construction sector. The conventional concrete at 28 days Compressive strength shows 30.97 N/mm^2 and for Split tensile Strength shows 2.9 N/mm^2, which when compared with the geopolymer concrete it shows more useability and has unique characteristics of its usage and its strength.

The mix process of conventional concrete remains simple thus enabling more effective transportation and placement for big construction needs. The correct temperature range of 60-80°C for GPC heat-curing requirements presents limitations when on-site construction battles with feasible curing conditions. Standard concrete projects have better adaptability since they need only water-based curing processes compared to GPC requirements.

When properly managed, GPC with 5% silica fume shows better strength and durability properties when compared to conventional concrete methodologies. The basic construction market depends on conventional concrete since it provides better usability compared to GPC. The primary need for GPC should be considered when strength and sustainability alongside durability matter. Large-scale implementation of concrete materials is better served by conventional concrete because of its higher ease of execution and broader usability characteristics.

REFERENES :

1. Naresh, T., Mallik, M., Rao, S. V., Madduru, S. R. C., & Nandipati, S. (2024). *Influence of Activator Solution and Binder Composition on the Characteristics of Self-Compacting Geopolymer Concrete.* Civil Engineering and Architecture, 12(3), 1526-1539.
2. Shilar, F. A., Ganachari, S. V., Patil, V. B., Khan, T. M. Y., Javed, S., & Baig, R. U. (2022). Optimization of Alkaline Activator on the Strength Properties of Geopolymer Concrete.
3. Kanagaraj, B., Anand, N., Alengaram, U. J., Raj, R. S., Praveen, B., & Tattukolla, K. (2022). Performance Evaluation on Engineering Properties and Sustainability Analysis of High-Strength Geopolymer Concrete.
4. Chen, K., Wu, D., Xia, L., Cai, Q., & Zhang, Z. (2021). Geopolymer Concrete Durability Subjected to Aggressive Environments – A Review of Influence Factors and Comparison with Ordinary Portland Cement. Construction and Building Materials.
5. Farooq, F., Xin, J., Javed, M. F., Akbar, A., Shah, M. I., Aslam, F., & Alyousef, R. (2021). Geopolymer Concrete as a Sustainable Material: A State-of-the-Art Review. Construction and Building Materials.
6. Gökçe, H. S., Tuyan, M., & Nehdi, M. L. (2021). Alkali-Activated and Geopolymer Materials Developed Using Innovative Manufacturing Techniques: A Critical Review. Construction and Building Materials.
7. Jena, S., Panigrahi, R., & Sahu, P. (2019). *Mechanical and Durability Properties of Fly Ash Geopolymer Concrete with Silica Fume.* The Institution of Engineers (India), J. Inst. Eng. India Ser. A, 100(4), 697–705.
8. Assi, L. N., Deaver, E., El Batanouny, M. K., & Ziehl, P. (2016). Investigation of Early Compressive Strength of Fly Ash-Based Geopolymer Concrete. Construction and Building Materials.
9. Pavithra, P.; Srinivasula Reddy, M.; Dinakar, P.;Hanumantha Rao, B.;Satpathy,B.K.;Mohanty. A mix design procedure for geopolymer concrete with fly ash J. Clean Prod. 2016,133,117-125.
10. Ryu, G. S., Lee, Y. B., Koh, K. T., & Chung, Y. S. (2013). *The Mechanical Properties of Fly Ash-Based Geopolymer Concrete with Alkaline Activators.* Construction and Building Materials, 47, 409–418.
11. Sanghamitra Jena, Ramakanta Panigrahi, Pooja Sahu, Mechanical and Durability Properties of Fly ash Geopolymer Concrete with Silica fume. The Inst of Eng (India) (2009).
12. Jena, S., Panigrahi, R., & Sahu, P. (2019). Mechanical and Durability Properties of Fly Ash Geopolymer Concrete with Silica Fume. The Institution of Engineers (India), J. Inst. Eng. India Ser.
13. Patankar, S. V., Ghugal, Y. M., & Jamkar, S. S. (2014). Mix Design of Fly Ash-Based Geopolymer Concrete. Springer India.
14. Nguyen, V. C., Trung, B. D., & Tuan, D. V. (2008). Recent Research on Geopolymer Concrete.
15. Okoye, F.N., Prakash, S., & Singh, N.B. (2017). *Durability of Fly Ash-Based Geopolymer Concrete in the Presence of Silica Fume.* Journal of Cleaner Production, 149, 1062–1067.
16. Jena, S., Panigrahi, R., & Sahu, P. (2019). *Effect of Silica Fume on the Properties of Fly Ash Geopolymer Concrete.* Lecture Notes in Civil Engineering, 25, 145–153.
17. Nath, P., & Sarker, P. K. (2017). *Flexural Strength and Elastic Modulus of Ambient-Cured Blended Low-Calcium Fly Ash Geopolymer Concrete.* Construction and Building Materials, 130, 22–31.
18. Mehta, A., & Siddique, R. (2017). *Sulfuric Acid Resistance of Fly Ash-Based Geopolymer Concrete.* Construction and Building Materials, 146, 136–143.
19. Adak, D., Sarkar, M., & Mandal, S. (2017). *Structural Performance of Nano-Silica Modified Fly-Ash-Based Geopolymer Concrete.* Construction and Building Materials, 135, 430–439.
20. Van Chanh, N., Trung, B. D., & Tuan, D. V. (2008). *Recent Research on Geopolymer Concrete.*
21. Mehta, A., & Siddique, R. (2018). *Sustainable Geopolymer Concrete Using Ground Granulated Blast Furnace Slag and Rice Husk Ash: Strength and Permeability Properties.* Journal of Cleaner Production, 205, 49–57.
22. IS 10262-2009. Recommended Guidelines for Concrete Mix Design.
23. IS: 3812 (Part -1), Specifications for pulverized fuel ash (for use as pozzolana in cement, cement mortar, and concrete)(Bureau of Indian standards, New Delhi, India,2003)
24. IS 383:2016, Coarse and Fine aggregate for Concrete- Specification).
25. IS: 15388, Silica fume – Specification (Bureau of Indian Standards, New Delhi, India, 2003).
26. IS :1727, Methods of for pozzolanic materials (Bureau of Indian standards, New Delhi, India ,2003).
27. IS: 516, Methods of test for strength of concrete (Bureau of Indian standards, New Delhi, India ,1959).
28. IS:5816, Splitting tensile strength of concrete- method of test (Bureau of Indian standards, New Delhi, India ,1999).