Journal of Mines, Metals and Fuels, *71(10): 1809-1816; 2023. DOI: 10.18311/jmmf/2023/35878*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Suitability Study on Strength Properties of Crumb Rubber in Geopolymer Concrete

Divya Nair[1] and Dr. Madhavi Gopal Rao Kulkarni[2]

[1]Assistant Professor, Presidency University, Bangalore – 560064, Karnataka, India; divya.nair@presidencyuniversity.in
[2]Associate Professor, Department of Civil Engineering, Presidency University, Bangalore – 560064, Karnataka, India; madhavit@presidencyuniversity.in

Abstract

Due to an incessant upsurge in the construction industry and the steep increase in the cost of raw materials, researchers are focusing on various resources that can be replaced with cement as a construction material. One such material that is rich in Silicon and Aluminium is Flyash. Flyash as an additive to concrete made a way for a contemporary material that was coined as Geopolymer Concrete (GPC). In Geopolymer, alkaline activators such as sodium hydroxide or potassium hydroxide are mixed with sodium silicate so as to form geo-polymerization with products like GGBS, flyash etc. and which as a result binds the aggregate. This paper mainly emphasizes on role of Crumb Rubber (CR) in the formation of GPC replacing the fine aggregates by various percentages (5% - 15%) of CR. The Geopolymer mix design is proposed for M40 grade. Compressive and tensile strength tests were carried out on concrete modified with Flyash and GGBS (Ground Granulated Blast Furnace Slag) in 60:40 ratios. At a molarity of 14M, ratio of sodium silicate to sodium hydroxide is maintained as 2.5. The samples were placed in an ambient condition and were tested for strength on 7, 14 and 28 days. Based on the experimental results, it was observed that use of CR in GPC does not enhance the strength properties and cannot be used in high-end structural applications only.

Keywords: *Alkaline Activator, Flyash, Geopolymer, GGBS, Nanofibres*

1.0 Introduction

Concrete is one of the most versatile construction materials used worldwide. The Ordinary Portland Cement (OPC) is an indispensable element of concrete. But OPC is not considered to be environment-friendly. The main reason is emission of Carbon Dioxide (CO_2) and other gases during the manufacturing of cement. Hence, researches are being conducted to unearth suitable replacements that can help to reduce the global warming issues. Some of the supplements are Flyash, Ground Granulated Blast Furnace Slag (GGBS), Rice husk ash, Metakaolin etc that can be used as a binding material with cement to give better results. GPC is known for its durability and environment friendly nature. The term "Geopolymer" was pioneered by Davidovits in 1978 which was introduced as a substitute for cement. Geopolymers are prepared by combining an alkaline solution (e.g. sodium hydroxide and sodium silicate) with industrial by-products rich in Silicon and aluminium (Flyash, Slag, Metakaolin etc). Since cement is not used in the production of GPC, Flyash and GGBS can be taken as source materials in case of GPC. Similarly, the use of rubber products are escalating year by year. Apart from other products, rubber is majorly used in manufacturing of tyres for the vehicles. After the use, the waste tyres are either decomposed by burning or are buried. Since the burning of tyre cause emission of many toxic gases,

**Author for correspondence*

the disposal of tyre has been banned in many places. Thus many industries have come up with recycling of tyres by shredding it into small granules. The irregular granules called Crumb Rubber (CR) is used in many structural applications, like flexible pavements. CR was used in GPC as a partial replacement of fine aggregate to analyze the performance and strength characteristics. CR is irregularly shaped recycled rubber particles from scrap tyres. The steel and tyre cords are removed during recycling and which helps in the reduction of wastes thereby providing a better environment.

The size of the CR ranges from 4.75 mm to 0.075 mm. Some times the size can be less than 0.075 mm. CR reduces reflective cracking because stress absorbing membranes present in it has elastic properties. Sand percentage present in GPC is partially substituted with sand by 5%, 10%, 15% and so on. CR is used in this experiment to study the strength characteristics of geopolymer. The size of CR is taken as 4.75 mm. Flyash is replaced with 40% of GGBS by weight. Much research has been done using CR as a partial supplement of fine aggregate in cement concrete. However, experiments related to the addition of CR with geopolymer have not been done to the desired levels.

2.0 Literature Review

Several researchers have investigated the incorporation of CR, derived from recycled tyres, in GPC to explore its effects on various properties. The addition of CR in GPC offers several potential benefits, including improved sustainability, enhanced mechanical properties, and increased resistance to certain environmental conditions.

2.1 Siddique *et al* (2021)

Evaluation of durability and mechanical properties of GPC with CR aggregates has been carried out by researchers. The researchers found that the addition of CR aggregates influenced the concrete's mechanical properties, such as Compressive Strength (CS), split tensile strength, and flexural strength. CS decreased with increasing rubber content, but an improvement in Flexural Strength (FS) is observed. The concrete also exhibited reduced water absorption, improved abrasion resistance, and enhanced chloride ion penetration resistance[1].

2.2 Zhang *et al* (2022)

The study focused on CR-sand-geopolymer composites. The researchers investigated the mechanical and thermal properties of these composites and found that the incorporation of CR and sand resulted in a reduction in CS, FS, and tensile strength compared to pure geopolymer composites. However, the composites exhibited improved thermal insulation properties and reduced thermal conductivity and coefficient of thermal expansion[2].

2.3 Abdelhameed *et al* (2021)

He explored the performance of CR in GPC under severe environmental conditions. They subjected the concrete to high temperatures, freeze-thaw cycles, and sulfate attack, and found that the inclusion of CR improved its resistance to these conditions. The concrete exhibited good mechanical properties and enhanced resistance to moisture ingress[3].

2.4 Parmender Gill *et al* (2023)

This study aims to mitigate the potential decrease in strength and durability by incorporating additives such as cement and fibers into the geopolymer mixture. Geopolymer specimens were prepared with varying replacement levels of CR for fine aggregates by volume, including 0%, 5%, 10%, and 15%. It showed a reduction in CS till 17% when tested according to ASTM standards. The inclusion of Steel Fibers (SF) further improved the CS and FS of the GPC specimens. Validation of above results were carried out using Micro-structural analysis to know the combined effect of these additives on GPC. Various tests such as Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and Fourier Transform Infrared (FTIR) spectroscopy were conducted. It was concluded that with these additives incorporation, the properties of GPC were enhanced[4].

2.5 Liu *et al* (2020)

Researchers explored the influence of different sizes of CR on the mechanical and thermal properties of GPC. They investigated three size ranges: fine rubber powder, small-sized rubber particles, and large-sized rubber particles. The study revealed that the addition of fine rubber powder improved the deformability and ductility of the concrete, while small-sized rubber

particles enhanced the impact resistance and crack resistance. Large-sized rubber particles contributed to the concrete's vibration damping and sound absorption properties[5].

2.6 Suresh Patil G. *et al* (2017)

Investigations were done for GPC to determine the CS for ambient cured samples. Different proportions of flyash to GGBS were considered. 20:80, 40:60, 50:50, 60:40 and 80:20 were the batches taken. Different molarities of 8M, 10M and 12M were also used. The sodium silicate to sodium hydroxide ratio of 1.5, 2 and 2.5 were also tested for maximum strength. These batches were tested for CS on 1st, 3rd and 7th day. The results showed an increase in CS for 40:60 mix. The sodium silicate to sodium hydroxide ratio of 1.5 gave the best results. Whereas the liquid - binder ratio was taken as 0.5. The final batch obtained consisted of 40:60 (flyash to GGBS), (Na_2SiO_3/NaOH) as 1.5. They found that the addition of GGBS in high quantity results in higher strength. They also came to the conclusion that it is not necessary to have a higher molarity to get the maximum strength[6].

2.7 Vijaya Rangan B. (2008)

The studies conducted by researcher lead to the breakthrough in the research of Geopolymers. Since there was no mix design available for Geopolymer, the studies were done truly on the basis of trial and error. He found out that a source material and alkaline solution is required for conducting the experiment. Flyash was one of the source materials that was zeroed on. The Cost effectiveness, availability and its applications were the main reason for choosing the material for the investigation. The Flyash with low calcium content was selected for the design as it increases the fineness, binding property and indicates the behavior of the material. Molarity of the solution is an important factor in the design and unlike others, the geopolymer was found to attain maximum strength by placing the specimen in Hot Air Oven. They also conducted experiments on the curing methodology. The specimens were placed exposed to sunlight and also in sunshade. The specimen was found to reach maximum strength when kept in ambient temperature[7].

2.8 Singh *et al* (2020)

The concrete mixtures were prepared by replacing a portion of the conventional aggregates with crumb rubber in different proportions. The study found that CR+Flyash mix in GPC had a significant impact on its mechanical and durability properties. The incorporation of CR resulted in the reduction in CS, split tensile strength, and FS compared to conventional GPC. However, the decrease in strength was within acceptable limits for certain applications. The concrete samples with CR exhibited reduced water absorption, enhanced acid resistance and also was observed that resistance offered against chloride ion penetration is more pronounced as compared to the conventional concrete. Unique properties of rubber which can absorb energy and resistance to chemical attacks are the contributing factors for strength gain[8].

3.0 Methodology

GPC is a combination of Flyash and GGBS as the source material. A highly viscous alkaline solution is added to a mixture of source material, aggregates and CR. Since water used is only 5% of the total weight of GPC mix, hence superplasticizers are used to increase the workability of the mix. However, the use of the viscous alkaline solution makes the mixing process quite tedious.

The mix design was prepared for M40 grade with reference to "Concrete Construction Engineering Handbook" by B. Vijaya Rangan[9]. The Molarity of NaOH was taken into account for the preparation of the concentrated solution. The quantities of materials required are calculated using the design mix. Since, the specimen once demoulded, has to be kept for drying in Hot Air Oven, the same has to be arranged. Oven of size

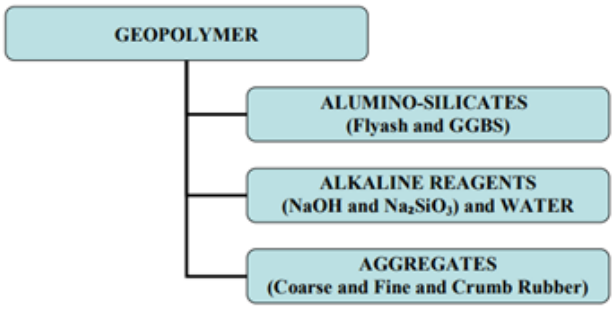


Figure 1. Components of GPC.

7 x 4 x 4 ft was used. After demoulding the specimen, the Hot Air Oven is set at 60˚C in which the specimen should be kept in it for 24 hrs. Followed by the exposure to temperature, the specimen should be kept for ambient curing for periods of 7, 14 and 28 days. The specimens were tested for flexure, compression and tensile strength and the results obtained are compared by means of graphs.

3.1 Components GPC

The following are the constituents used in GPC for conducting the investigation shown in Figure 1

- Class F (Low- calcium) dry Fly ash
- Ground Granulated Blast furnace Slag (GGBS)
- Alkaline solution - Sodium Hydroxide pellets and Sodium Silicate solution
- Coarse Aggregates
- 20 mm size aggregates
- 12 mm size aggregates
- 6 mm size aggregates and
- Fine aggregates (river sand)
- Crumb rubber of 4.75 mm size
- Super plasticizer (Conplast SP-430)
- Electric Hot Air Oven
- Water (5% of the weight of the mix)

3.1.1 Alkaline Solution

The alkaline solution is prepared 24 hrs prior to the mixing shown in Figure 2. When NaOH is mixed with Na_2SiO_3, it takes at least 24 hours for polymerization of chemicals. As a result, the alkaline solution acts as a binder in geopolymer. The solution should be prepared based on the Molarity of NaOH to be used.



Figure 2. Alkaline solution.

3.1.2 Hot Air Oven

After casting, the specimens should be succumbed to a temperature of 60˚C for 24 hrs. In order to expose the specimen to this temperature, a Hot Air Oven is used shown in Figure 3. The electric oven present in the laboratory was used for the purpose of curing. Before keeping the specimens inside the Hot Air Oven, the temperature should be set appropriately. For setting the temperature to desired levels, a thermostat is used. The thermostat always shows the Set Value (SV) and Present Value (PV). To increase the temperature, the upward arrow is pressed and is set to 60˚C. The temperature



Figure 3. Heater, thermocouple and fan set up in hot air oven.

inside the oven has to rise from room temperature to the set value. The thermocouple senses the temperature and the same is displayed in the thermostat as present value.

As a result, the thermostat gives power supply to the contactor which in turn gives power to the room heaters. The heater increases the temperature to the set value. If the present value becomes more than the set value, the relay cuts off. The contactor stops getting power supply and the heaters gets turned off. Automatically, the temperature decreases to 59˚C and the procedure is continued.

3.2 Mix Design Assumptions

- Low- calcium Flyash (Class F) - 60% of weight

- GGBS - 40% weight
- Ratio of Na_2SiO_3 to NaOH solution - 2.5
- Alkaline liquid to Flyash ratio - 0.4
- Concentration of NaOH solution - 14M
- Aggregates used - 78% of mass of concrete
- CR- 4.75mm size
- Conplast SP 430 (superplasticizer) - 2% of (Flyash + GGBS)

The usage of CR in various sizes in geopolymer concrete has gained attention as a sustainable approach for waste rubber disposal and enhancing the properties of GPC. Mechanical, thermal, and durability properties of GPC enhanced with incorporation of CR particles of different sizes. Here is an overview of the usage of CR of various sizes in GPC:

3.2.1 Fine Crumb Rubber

Fine crumb rubber particles, typically ranging from a few micrometers to a few millimeters in size, can be used in GPC. These fine particles provide better dispersion within the geopolymer matrix and contribute to improved workability and packing density. They also enhance the flexural strength, impact resistance, and energy absorption capacity of GPC.

3.2.2 Coarse Crumb Rubber

Coarse crumb rubber particles, ranging from a few millimeters to several centimeters in size, can also be incorporated into GPC. These larger rubber particles act as fillers and reinforcements, contributing to increased toughness and crack resistance. Coarse crumb rubber can also help in mitigating shrinkage and improving the ductility of GPC.

3.2.3 Combination of Different Sizes

Some studies have explored the use of a combination of fine and coarse crumb rubber particles to achieve a balance between workability, mechanical properties, and durability. The synergistic effects of different-sized CR particles can lead to optimized performance with respect to strength, toughness, and resistance to environmental conditions. The experiments were performed using CR.

4.0 Test Results and Comparative Studies

GPC has been found to exhibit comparable or even superior strength parameters when compared to conventional concrete. Some of the strength parameters that are commonly evaluated include CS, TS, flexural strength, and split tensile strength. A general overview of how GPC can be compared to conventional concrete in with respect to strength.[10]

4.1 Compressive Strength as per Literature

GPC has shown excellent CS performance. It has been reported that similar or higher CS as compared to conventional concrete and its comparative data is seen in Figure 4. The early-age strength gain of GPC is often faster, allowing for early formwork removal and faster construction progress.

4.2 Tensile Strength (TS) as per Literature

GPC generally exhibits good TS properties shown in Figure 5. While conventional concrete is known to have low TS, and this is mainly because of the presence of reinforcing fibers or the use of special mix designs.

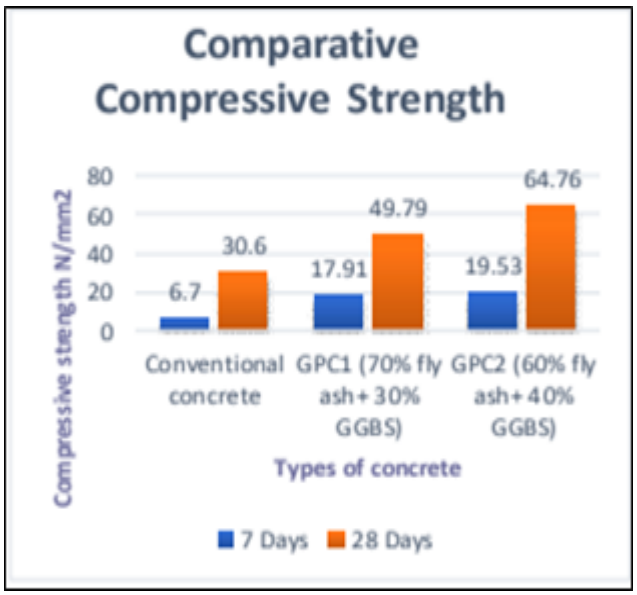


Figure 4. Comparative compressive strength[10].

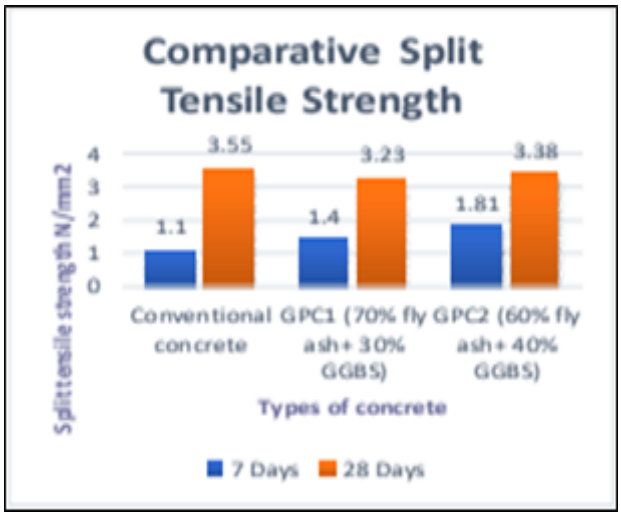


Figure 5. Comparative split tensile strength[10].

4.3 Flexural Strength

GPC has demonstrated comparable or higher flexural strength compared to conventional concrete as seen in Figure 6. This is particularly important for structural applications where the ability to withstand bending loads is crucial.

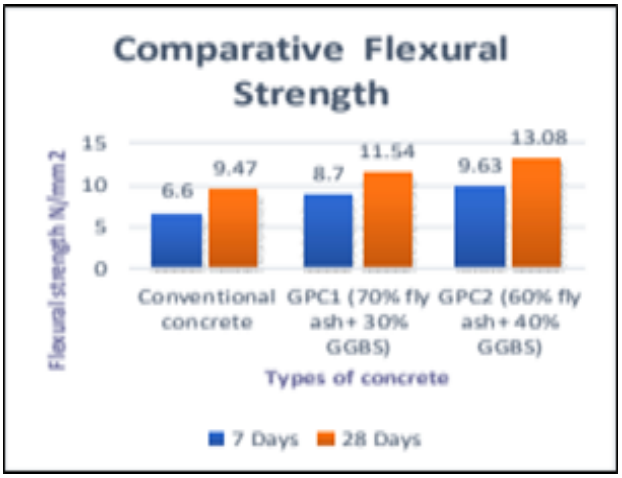


Figure 6. Comparative flexural strength[10].

4.4 Split Tensile Strength

GPC has shown promising split tensile strength, which is the resistance to cracking under tensile stresses. The presence of geopolymers in the concrete matrix enhances the cohesion and resistance to cracking, resulting in improved split tensile strength. The above observations were made from Vrushabh V. Patil and S.P. Deshamukh. (2022)[10]. Further experiments were done by altering the percentages of crumb rubber in fine aggregate; the comparison of results shows its effect on the strength of GPC. The results obtained by conducting compressive strength test, split tensile strength test and flexural strength test for geopolymer cubes, cylinders and prisms respectively are compared by means of tables and charts. We have to review whether the presence of crumb rubber increases the strength or decreases it. The Flyash to GGBS ratio is kept constant at 60:40 and the crumb rubber is added at 5%, 10% and 15%.

4.5 Compressive Strength Test Results

Table 1 show that in all the cases, the CS of geopolymer with or without CR increases from 7 to 28 days. It is also has been seen that as the percentage of CR in the mix

Table 1. Compression test results in MPa for 14 Molar

GEOPOLYMER(GPC)	7 DAYS	14 DAYS	28 DAYS
Without crumb rubber	32.49	38.43	46.91
5% crumb rubber	27.80	31.63	40.83
10% crumb rubber	19.77	24.78	33.40
15% crumb rubber	12.6	20.43	23.23

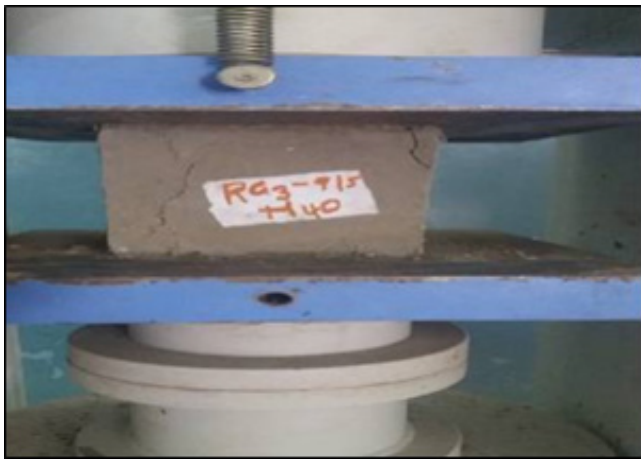


Figure 7. Cube failure.

increased, then CS of GPC decreased on the same day. The failure of the sample can be observed from Figure 7 with increase in percentage of CR.

That is, the CS for geopolymer with 5% CR on the 7th day is more than that with 15% Cr on 7th day. Hence, the CS of geopolymer without addition of CR gives more strength than the geopolymer with CR.

The maximum strength of geopolymer with CR is obtained for 5% crumb addition for 28 days. And the minimum value for compressive strength is obtained on 7th day for 15% crumb addition.

4.6 Split Tensile Strength Test Results

From Table 2 below, the split tensile strength of geopolymer with or without CR also increased from 7 to 28 days. In the case of compression test, it is observed that as the percentage of CR in the mix increases, the CS of GPC decreases at the same period.

Similarly, for geopolymer with 5% CR on 7th day is more than that with 15% CR on 7th day. Hence, the split tensile strength of geopolymer without addition of CR gives more strength than the geopolymer with CR. Failure of the sample is shown in Figure 8 with CR addition.

The maximum strength of geopolymer with CR is obtained for 5% crumb addition for 28 days.

Table 2. Tensile test results in MPa for 14 Molar

GEOPOLYMER(GPC)	7 DAYS	14 DAYS	28 DAYS
Without crumb rubber	3.74	4.14	5.95
5% crumb rubber	3.20	3.53	3.91
10% crumb rubber	2.18	2.88	2.61
15% crumb rubber	1.64	2.04	2.05



Figure 8. Cylinder split showing central crack.

4.7 Flexural Strength Test Results

In flexural strength test too, it is confirmed that the maximum strength is obtained for geopolymer without addition of CR. And the geopolymer with 15% CR on 7th day gives the minimum value and 5% CR on 28 days gives maximum value is shown in Table 3. Failure of the specimen due to flexure is seen in Figure 9.

Table 3. Flexural strength test results in MPa for 14 Molar

GEOPOLYMER(GPC)	7 DAYS	14 DAYS	28 DAYS
Without crumb rubber	2.82	4.22	4.31
5% crumb rubber	2.08	3.33	4.00
10% crumb rubber	1.75	2.17	2.25
15% crumb rubber	0.625	1.08	1.17



Figure 9. Beam showing failure.

5.0 Conclusion

The following are the conclusions drawn from the experiments performed:

With an increase in percentage of CR, it was found that the CS, Split tensile strength and FS of GPC decreased

from 7 days to 28 days of curing which indicates that CR replacement for sand is not recommended in GPC. The use of crumb rubber in the GPC does not increase the strength. Hence this concrete cannot be used in high-end structural applications. The specific proportions of crumb rubber and the optimum particle size distribution may vary depending on the desired properties and application of geopolymer concrete. It is crucial to conduct comprehensive experimental investigations to assess the mechanical and durability properties of geopolymer concrete with different sizes of crumb rubber. To gain more detailed insights into the usage of CR of various sizes in geopolymer concrete, it can be recommend referring to research papers and scientific publications that specifically focus on this topic. These studies provide experimental data, analysis, and insights into the effects of different-sized CR particles on the performance of GPC.

6.0 References

1. Siddique R, Rajor A and Jain A. Mechanical and durability properties of geopolymer concrete incorporating crumb rubber aggregates. Journal of Cleaner Production. 2021; 280:124443
2. Zhang Z, Zhang Y and Chen X. Mechanical and thermal properties of crumb rubber–sand–geopolymer composites. Journal of Cleaner Production. 2022; 330:129137.
3. Abdelhameed M and Ibrahim O. Performance of crumb rubber geopolymer concrete under severe environmental conditions. Construction and Building Materials. 2021; 297:123777.
4. Gill P, Jangra P, Roychand R, Saberian M, and Li J. Effects of various additives on the crumb rubber integrated geopolymer concrete. Journal of Cleaner Materials. 2023; 8:100181.
5. Liu Z, Zhang Z and Deng X. Experimental investigation on the effects of crumb rubber on the mechanical properties of geopolymer concrete. Construction and Building Materials. 2020; 241:118034.
6. Patil SG, Rampanth. Experimental studies of Ambient Cured Geopolymer Concrete. Journal of Mechanical and Civil Engineering. 2017; 14(3):44-9.
7. Rangan VB. Mix design and production of flyash based geopolymer concrete. Indian Concrete Journal, 2008; 82(5):7-15.
8. Singh RP, Goyal S and Goyal A. Influence of crumb rubber on mechanical and durability properties of fly ash-based geopolymer concrete. Journal of Materials in Civil Engineering, 2020; 32(11):04020342.
9. Rangan VB. Concrete Construction Engineering Handbook; Taylor and Francis group, CRC presss: New Jersey.
10. Patil VV and Deshamukh SP. Comparative Analysis of Geopolymer Concretewith Different Proportions of Fly ash and GGBS with Conventional Concrete Considering the Strength and Durability Parameters. IJRASET. 2022; 10(11):73-82.