Experimental Study on Geopolymer Rubberized concrete using natural Zeolite

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Abstract: On one hand, the utilization of rubber tires is ever-increasing, expected to further increase at a rapid rate, and with that the waste rubber. When the tires become old, worn out and irreparable, it is often dumped in landfills. For every one billion tires produced, an equal amount of tires being removed from the vehicles. This waste can be utilized in large quantities when employed in the construction industry. On the other hand, cement-based concrete utilization also increasing at a faster rate and with that the CO\textsubscript{2} emissions. These two major issues i.e. waste rubber utilization and curbing of cement consumption can be effectively done by developing geopolymer concrete with the replacement of waste rubber chips and rubber powder in the place of natural aggregates. In the present study, the geopolymer concrete has been developed by using fly ash, GGBS, and zeolite as binder materials, sodium hydroxide, and sodium silicate as alkaline activators, rubber chips as a partial replacement to natural coarse aggregate, rubber powder as a partial replacement to natural fine aggregate. Rubberized geopolymer concretes have been developed by replacing fly ash with 5\% zeolite, natural coarse aggregate with 2.5\% waste rubber chips, and natural fine aggregate with 5\%, 10\%, 15\%, and 20\% by weight of waste rubber powder. The developed concrete is then assessed for its performance through mechanical properties, durability behaviour. The results showed the developed concrete has high impact resistance and good freeze-thaw resistance properties. This concrete is suitable for the members subjected to high-impact loads.

1. Introduction

Human comfort levels are increasing day-by-day and due to that the usage of vehicles. This, in turn, is leading to an increased need for rubber tires usage. With time, these tires going to unusable conditions and are getting thrown away. It is estimated that nearly a billion tires per annum are being thrown out as garbage after they becoming a spent force. It is expected to reach the disposed of tires number above five billion by 2030. Approximately 60\% of end-of-life tires are estimated to be in landfills. The combustion of these tires is dangerous, as they produce a poisonous smell and releases lethal gases, and their combustion is restricted in many countries. The most profitable and efficient way of utilizing these rubber tire waste, without flaming, is by cutting the rubber tires into small pieces and also into powder form to utilize them in the construction industry.
Currently, the construction industry, especially concrete producers, is looking to integrate sustainability into production processes by incorporating many wastes in the place of conventional concrete ingredients. They are doing it mostly in the form of partially or fully replacement of the cement with industrial wastes \[1, 2\]. Some researchers even attempted to replace natural aggregates with inert materials like stone dust, agriculture waste, demolition wastes, ceramic tile powder \[3, 4\]. Further, studies are also available on the development of Portland cement-based concrete with scrap tire chips, crumb rubber, etc. \[5, 6\]. The literature suggests that concrete incorporated with rubber has shown less wear and tear when compared to conventional concrete \[7\]. Studies, further, reported that concrete developed using waste has good ductility and high impact resistance which can be used in structural elements such as bridges, railway lines, airport runways, where the structural elements are subjected to heavy impact and dynamic loads \[8-9\]. Even, some researchers developed geopolymer concrete, a cement-free concrete, by incorporating rubber waste in it \[10\]. They found that the addition of rubber wrecks the strength of the geopolymer concrete. The main reason for the decrease in the strength is found to be the poor bonding between the binder and rubber particles \[11\]. Jokar et al. \[12\] reported that the bond between the rubber particles and cement binder can be improved by treating the rubber particles with 1M NaOH solution. It is also reported that cement replacement with Zeolite in the concrete made with rubber particles has improved the compression and bending characteristics of the cement-based concrete. He et al. \[13\] reported that gradation plays a major role in the bonding between the rubber particles and binder.

Based on the literature study and also by keeping in view the environmental pollution that the unutilized industrial wastes such as fly ash, slag is creating, efforts have been made in this study to develop geopolymer rubberized concrete by employing fly ash, ground granulated blast furnace slag (ggbs), and zeolite powder as binder materials, and replacing coarse and fine aggregates with rubber chips and rubber powder, respectively. In this study, fine aggregate is replaced with both treated and untreated rubber powder with various percentages (5%, 10%, 15%, and 20%). After the formation of rubberized concrete with these percentages, specimens are allowed to ambient curing for gaining sufficient strength. The developed concretes are then assessed for mechanical properties through compressive strength, split tensile strength, impact resistance, and durability through freeze-thaw resistance tests.

### 2. Methods

#### 2.1 Fly ash

Fly ash is a by-product of coal based thermal power plants. Fly ash is classified into two types, Class C and Class F, based on its chemical oxide composition. In this study, class F fly ash is used which is obtained from the Rayalaseema TPP located in Kadapa district of Andhra Pradesh. Table 1 show the physical properties of fly ash and ggbs, and Table 2 shows the chemical composition of all the binder materials used in this study, i.e. fly ash, ggbs and zeolite powder.

| Table 1: Physical properties of fly ash and ggbs |
|-----------------------------------------------|
| Properties | Fly ash | ggbs |
| Colour | Grey | Whitish |
| Specific Gravity | 2.2 | 2.9 |
| Surface Gravity (m$^3$/kg) | 420 | 407 |

#### 2.2 Ground Granulated Blast Furnace Slag

GGBS is a by-product from iron industry. Molten slag and molten iron is formed when blast furnace is fed with proportionate lime, coke and iron-ore operated at the temperature about 1500ºC. This molten slag when water quenched gives a hard clinker type material and which upon fine grinding gives a...
material called ggbs. In this work, ggbs is obtained from JSW steel Ltd, Bellary.

2.3 Zeolite powder
Natural Zeolite is an excellent Supplemental Cementing Material (SCM). Natural zeolite has three-dimensional framework structures and is classified as an alkali and alkaline earth cement hydrated alumino silicate. Zeolite powder used in this study is obtained from Bethamcherla of Kurnool district. Specific gravity of the zeolite used is 2.47. Figure 1 shows the natural zeolite powder.

![Figure 1. Zeolite](image)

**Table 2.** Chemical composition of fly ash, GGBS, and zeolite

| Material  | Percentage of Chemical Oxides |
|-----------|-----------------------------|
|           | SiO₂ | CaO | Al₂O₃ | MgO | Fe₂O₃ | SO₃ | TiO₂ | NaO₃ | K₂O | L.O.I |
| Fly ash   | 62.19| 1.97| 21.15 | 0.40| 3.23  | 0.07| 1.06 | 0.30 | 0.89| 1.75  |
| GGBS      | 37.73| 37.34| 14.42| 8.71| 1.11  | -   | -    | -    | -   | -     |
| Zeolite   | 67.79| 1.68| 13.66| 1.20| 1.44  | -   | -    | 2.04 | -   | 12.23 |

2.4 Coarse aggregate
Coarse aggregate passing through 20 mm and 12.5 mm sieves are used and are taken in equal proportions on weight-basis. The coarse angular crushed granite aggregate was obtained from local crushing plants. The specific gravity of the coarse aggregate used is 2.77.

2.5 Fine aggregate
The fine aggregate used is river sand and is collected from the beds of the Tungabhadra River. From the sieve analysis, it is found that the fine aggregate confirms to zone II, as per IS: 383-1970[14]. The specific gravity of fine aggregate is 2.60.

2.6 Alkaline solutions
Sodium hydroxide (NaOH) and sodium silicate (Na₂SiO₃) are used as alkaline activator solutions in this study. After doing preliminary study and based on the observations from it, Na₂SiO₃ to NaOH ratio of 1.5 and NaOH molarity of 12M has been adopted to develop both conventional geopolymer concrete and geopolymer rubberized concretes. The sodium hydroxide solution is prepared 24 hours prior to adding in the concrete mix.

2.7 Water
Water used in this study is fresh, colourless and clean portable municipal tap water, free of organic matter.
2.8 Super plasticizer
Superplasticizer used is 1B233Glenium made by BASF Chemicals. It is used as high range water reducer. Superplasticizer is added to increase workability and setting times of the fresh concrete mixes. Specific gravity of 1B233 Glenium is 1.06.

2.9 Rubber Powder
The rubber powder is prepared by passing the tyre rubber through rotating corrugated steel drums. Figure 2 shows the rubber powder used in this study. This is replaced in place of the fine aggregate. The specific gravity of the rubber powder is 0.52.

2.10 Chipped Rubber
Chipped rubber piece having size about 20 mm is used. The specific gravity of Chipped Rubber is found to be 1.1. Figure 3 shows the rubber chips used in the geopolymer rubberized concrete.

2.11 Rubber Treatment
The rubber particles are soaked in a 1Molarity of NaOH solution for 24 hours. After 24 hours of treatment with NaOH solution, the rubber particles are thoroughly washed with tap water several times until the pH of the wash water was close to neutral. The treated rubber particles are then air dried by keeping at room temperature.

3. Experimental Study
3.1 Mix Proportioning, Casting and Curing of Geopolymer Rubberized Concrete
In the present study, a total of 9 mixes are synthesized. First, a conventional geopolymer concrete mix is prepared by taking fly ash and ggbs as binder materials in 40% and 60% by weight, respectively, natural crushed stone and river sand as aggregate, and NaOH and Na2SiO3 as alkaline activators. The remaining mixes are synthesized in two batches. The two batches consists of geopolymer concrete mixes developed using 35% fly ash, 5% zeolite powder, 60% ggbs as binders (constant for all the
mixes), replacing coarse aggregate with 2.5% by weight of rubber chips (constant for all the mixes), and replacing river sand with 5%, 10%, 15% and 20% by weight. While, in the first batch, rubber particles are directly induced in mix. In the second batch, the rubber particles are treated with 1M NaOH solution. The properties studied, the age of concrete at the study, the tests conducted and their related codes are depicted in Table 3.

All the concrete mixes are developed by following the mixing sequence shown below.

Dry mixing of binder materials for 3-4 minutes → Addition of coarse and fine aggregates and dry mixing for further 3-4 minutes → Addition of NaOH and Na2SiO3 and then mixing till uniform mix is attained → Addition of SP of required quantity and further mixing for 1-2 minutes.

The fresh concrete mix is then immediately placed in the moulds and given required compaction before keeping them under ambient temperature curing.

**Table 3. Testing Parameters**

| Properties       | Tests                     | Codes                  | Test Ages | Cubes Sizes in mm |
|------------------|---------------------------|------------------------|-----------|-------------------|
| Mechanical       | Compressive Strength      | IS:516-1959            | 28,56     | 100 x 100 x 100   |
|                  | Split Tensile Strength    | IS:5816-1999           | 28        | 100 dia x 200 height |
|                  | Impact Resistance Strength| ACI committee 544.2R-89 | 28        | 100 x 100 x 500   |
| Durability       | Freeze-Thaw               | ASTM C666 2008 C       | 28        | 100 X 100 X 100   |

4. Mix design

Mix design methodology proposed by Pavithra et al. (2016) [15] has been followed and the mix proportioning has been done accordingly. The following are the parameters considered for the mix design:

- AAS content: 200 kg/m³
- Alkaline liquid to binder ratio: 0.40
- Sodium silicate to sodium hydroxide ratio: 2.5
- Molarity of sodium hydroxide solution: 12 M
- Admixture dosage: 1%

The mix designations and mix proportioning of the various mixes developed in this study are shown in Table 4 and Table 5.

**Table 4. Designations**

| G0- Control/conventional geopolymer concrete |
|---------------------------------------------|
| Untreated                                  | Treated                                      |
| G1-5% rubber powder in F.A                 | G5-5% rubber powder in F.A                   |
| G2-10% rubber powder in F.A                | G6-10% rubber powder in F.A                  |
| G3-15% rubber powder in F.A                | G7-15% rubber powder in F.A                  |
| G4-20% rubber powder in F.A                | G8-20% rubber powder in F.A                  |
Table 5. Mix proportions of concrete

| S. No. | Binder Content (kg/m³) | Alkaline solution (kg/m³) | C.A (kg/m³) | F. A (kg/m³) | SP |
|--------|------------------------|---------------------------|-------------|--------------|----|
|        | Fly-Ash | Zeolite | GGBS | NaOH | Na₂SiO₃ | C.A Rubber Chips | F.A Rubber powder |
| G0     | 200     | 0      | 300  | 80   | 120     | 1404 0 | 338 0 | 1% |
| G1     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 321 16.9 | 1% |
| G2     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 304 33.8 | 1% |
| G3     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 287 50.7 | 1% |
| G4     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 270 67.6 | 1% |
| G5     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 321 16.9 | 1% |
| G6     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 304 33.8 | 1% |
| G7     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 287 50.7 | 1% |
| G8     | 190     | 10     | 300  | 80   | 120     | 1368 35.1 | 270 67.6 | 1% |

*C.A indicates coarse aggregate; F.A indicates fine aggregate; SP indicates Super plasticizer;

5. Results and Discussion

5.1 Compressive Strength
The geopolymer concretes developed are kept under ambient temperature curing till the time of testing i.e. 28 and 56 days. The specimens are then tested for compressive strength at 28 and 56 days and the compressive strength test results are shown in the figure 4 and figure 5, respectively. From figure 4 and figure 5, it can be observed that the compressive strength decreases with the increase in the percentage of rubber powder content in the mix. The same trend has been observed at 28 days as well as 56 days. About 10-12% improvement in the compressive strength has been seen in all the mixes from 28 to 56 days. The decrease in the strength, with the addition of rubber powder in the mixes, could be poor bonding between the geopolymer paste and the rubber particles. The hydrophobic nature of rubber is the main reason behind this weak bonding. Surprisingly, the compressive strength, both at 28 and 56 days, increased when the mixes are treated with 1M NaOH solution before adding in the mixes. This could be due to the enhanced hydrophilic nature of the rubber particles, when treated with NaOH solution, causing the improved adhesion between the geopolymer paste and rubber particles [16]. The compressive strength of the geopolymer concrete developed varies from 63 to 80 MPa at 28 days and 65 to 89.7 MPa at 56 days.
Figure 4. Compressive strength at 28 days

Figure 5. Compressive strength at 56 days

5.2 Split Tensile Strength

Figure 6 shows the split tensile strength properties of the developed geopolymer concrete mixes after 28 days. Before modification of rubber particles from G1 to G4 the split tensile strength is depleted, similar to compressive strength. The same parameters that are responsible for the decrease in the compressive strength could be the reason for similar behaviour of geopolymer concrete for tensile strength also. After modified rubber is induced in concrete split tensile strength is increased up to G7 and then it is decreased. Strength varies from 4.0 to 5.57 MPa. The highest and lowest tensile strength is found at G6, G7 with 5.25 MPa and G4 with 4 MPa.

Figure 6. Split tensile strength at 28 days
5.3 Impact resistance test

Impact resistance test is conducted on the beam specimen with size 100 x 100 x 500 mm. Impact resistance test is conducted as per ACI-544.2R-89. The weight of hammer used in this test is 4.45 kg, diameter of ball is 60.2mm, and the hammer is dropped from a height of 457mm repeatedly at the centre of the specimen. In each test “N1“ number of blows at the first crack or initial crack and “N2” number of blows at the failure strength or failure crack of the specimen is recorded. The impact resistance results of all the mixes are depicted in figure 7. From the figure 7, it can be noticed that, the impact resistance of geopolymer concrete increases with the increase in the rubber content in the mix. It can be observed for both the NaOH treated and untreated mixes. Addition of the rubber particles in concrete leads to low stiffness reduced brittleness of concrete, which in turn lead to increased flexibility of rubberized concretes and considerably enhances the energy absorption of the mixture as compared to geopolymer concrete without rubber [17]. The test set-up for conducting the impact resistance test is shown in figure 8 and figure 9. Highest impact resistance is seen at treated rubber concrete with 68 blows and lowest at control mix with 12 blows.

![Figure 7. Impact resistance test](image)

![Figure 8. Impact resistance test equipment](image)

![Figure 9. Testing the specimen](image)
5.4 Freeze-Thaw resistances test
The freeze-thaw resistance test is conducted as per ASTM C666 – 2008 [18] standards. In this test, after 28 days of ambient curing, the specimens are kept in freezer for 24 hours followed by removal and kept in water for another 24 hours. This is considering as 1 cycle, in the same way 3 cycles is conducted. Mass of samples is then measured throughout the freeze–thaw test. After completion of cycles, the weight loss of specimens is measured. Table 5 shows the freeze-thaw test results. From the results, it can be noticed that, treated rubberized concrete shows good freeze-thaw resistances than conventional concrete. The better freeze-thaw resistance of the rubberized concrete could be due to its flexibility to expand and contract. Figure 10 and figure 11 depicts the specimens before testing and after testing, respectively.

Table 6: Freeze-thaw test results

| Designation | % of Weight loss |
|-------------|-----------------|
| G0          | 1.44            |
| G5          | 1.00            |

Figure 10. Before testing specimen

Figure 11. After testing specimen

6. Conclusions
Based on the results obtained from mechanical properties study and freeze-thaw resistance test, the following are the major conclusions drawn. Both the compressive strength and tensile strength decreases with an increase in the rubber content from 5 to 20%. Both the compressive strength and tensile strength decreases for concretes made with treated as well as untreated rubber particles. Maximum compressive strength of 70 MPa for geopolymer rubberized concrete made with untreated rubber particles and 71.5 MPa with treated rubber particles. The highest and lowest tensile strength is found to be 5.25 MPa and 4 MPa, respectively. Highest tensile strength is shown by geopolymer concrete developed with 15% treated rubber particles. By increasing rubber content the impact resistances also increased in both untreated and treated rubber. Among all the mixes, highest resistance shown by the mix with 20% treated rubber particles. This type of concrete can be used where the concrete is subjected to impact loads.

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