Strength studies on Geopolymer Concrete produced by Recycled Coarse Aggregate and Quarry Stone Dust as Fine Aggregate

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Abstract. Geopolymer concrete is one of the trending techniques adopted to replace the conventional binder by any alumino-silicate material like fly ash or GGBFS. Approximately Geopolymer concrete are as productive as conventional concrete. But the key pro of Geopolymer concrete utility is to recycle concrete waste and demolition waste are transformed into coarse aggregate, which reflects in the environment and economic benefits. The natural fine aggregate (NFA) is replaced by the residue quarry fines obtained from the crushed quarry rock often termed Quarry dust or Quarry stone dust (QSD) by proportions 0%, 20%, 40%, 60%, 80%, and 100%. In this research study, fly ash is utilized as the binding material activated by the di-solution of NaOH and Na\textsubscript{2}SiO\textsubscript{3} collectively to initiate a chemical reaction to attain productive strength. From the overview of previous papers literature, the geopolymer concrete is not having any proper mix design procedures, Therefore the trial and error method adopted. This research is conducted to study over results of the practical approach on geopolymer concrete composed with 40% of recycled coarse aggregate (RCA) in place of Natural coarse aggregate and varying different percentages of QSD in the place of Natural fine aggregate.

Key Words: Geopolymer Concrete, Quarry Stone Dust, Alumino-Silicate, Fly Ash, RCA

1. Introduction
In the production of concrete, binder material, coarse aggregate and fine aggregate are the three key ingredients that play a major role in attain desirable strength. In general, we use cement as the conventional binder material. But, in the present competitive concrete world cement is becoming a major issue in terms of cost and more eminently towards environmental adulteration. Many people carrying out multiple kinds of research in order to reduce the cost and environmental impacts. Many solutions were adopted and investigated like replacing cement with some non-conventional binding materials. On the other hand, Aggregate like Sand is substituted partially with QSD (Quarry Stone Dust) produced in the crushing process. This Stone dust is considered as a Waste by-product produced from crushers. Usage of such by-products reduce the exploitation of Natural resource and provides
effective disposal of wastes. Cost analysis also provides various economic benefits, which thereby reduces natural resources long transportation and hauling charges. By the advancement in constructional technology, many alternative aggregates like fly ash, glass powder, ceramic waste, quarry dust are supporting to fight with the waste management, economical factors, environmental factors and global warming issues. The thought-provoking challenge was answered with geopolymer concrete generated out of the deteriorated waste of infrastructure. This geopolymer concrete is a hybrid concrete composed of deteriorated infrastructural waste as coarse aggregate and fine aggregate based on its size and proportioned to a specified ratio. Upon comparison with the Natural Coarse aggregate, Recycled Aggregates produced from demolished wastes provide enhanced water absorption resistance, Higher Crushing Value, and Abrasive resistance thereby showing promising results. However, there is a decrease in Specific Gravity and the Bulk Density of the material. Before using the recycled aggregate as a building material, it undergoes several refinement processes to bring them into the required potential aggregate. It is thoroughly cleaned from any form of external agents and impurities. The aggregates are washed and dried to remove any other particulates to provide better adhesion with aggregate.

It is quite evidently known that the Superstructure plays a crucial and primary role in construction, which is prominently composed of Concrete and reinforcement. The main constituents of concrete are cement, water and aggregates, which are a part of mobilizing environmental pollution. After the Paris treaty, the main concern of the world is the reduction of carbon emissions. Cement producing industries contribute about 5% of carbon emissions. In order to reduce this effect, the world has adopted a new technique known as Geoconcrete. Professor Joseph Davidovits first introduced the term geocement in 1978 [1]. He explained how the metakolinite material on activating with any alkaline solution forms a Si-O-Al gel which acts as a binding material and attains the strength as conventional concrete within the less span during the polycondensation with alkaline solution an amorphous polymer byproduct is produced which is similar to the zeolite composition. According to Davidovits research geopolymer can attain the 28days strength of conventional concrete just in 2 days. Geopolymer concrete is the best alternative for conventional concrete not only because of its high strength but it also good fire and acid resistant, its low carbon emission level, and due to low permeability it is more durable [2].

Hence these geopolymers are used as adhesives and coating, as a binder for fiber composites and as a replacement for cement. From the previous studies, it is evident that many other alumino-silicate materials like silica fume, rice husk, etc., are also good at producing effective Geopolymer [3]. There are certain parameters which provides significant impact on the strength characters of Geopolymer concrete, especially the ratio of sodium silicate and sodium hydroxide. Generally most of them prefer NaOH as an alkaline activator solution because it results in better compressive strength than KOH. For optimum results, the alkaline activators ration is taken as 2.0 [4]. From some past research, it’s observed that when the Geopolymer concrete is cured at 85ºc we can observe that the mechanical properties of concrete are higher than at 65ºc [5].

Various studies proved that the calcium content present in the Geopolymer concrete had led a considerable effect over both wet and Dry Characteristics of Concrete. Not only providing better workability for wet concrete but also it enhanced the properties of Hardened Geopolymer concrete, where additionally, the Calcium Silicate Hydrate (C-S-H) were formed. C-S-H is such a compound that is primarily responsible to attain and improve later strength in the Hardened Concrete [6], which improves the mechanical strength of the Geopolymer concrete Significantly [7]. As fine aggregate rising environmental impacts researches are carried out in replacing it with multiple options such as fine quarry dust, fly ash, glass powder, ceramic waste dust [8]. In this research, quarry dust is preferred because of the abundant availability of quarry dust nearby locality compared to other options for the replacement of fine aggregate [9]. In Geopolymer, each and every factor play key roles independently but results in productive strength together and many researches prove that it’s safe to use Geopolymer concrete in infrastructure works, bridge works [10]. In the present study, we are
working on strength studies by replacing the coarse aggregate with 40% of the recycled coarse aggregate of 20mm and 10mm dia, and the natural fine aggregate are replaced with quarry dust.

2. Research Methodology

2.1. Materials

The present experiments were carried out on specimens where Class F Fly Ash replaced the cement, which possess low calcium content. This Fly ash fineness was measured through sieving it in 45µ sieve, where not more than 10% was retained. The Coarse Aggregates and Quarry Stone Dust was brought from the Quarry locally available with crushing mills at Ananthasagar, Warangal. For Coarse Aggregate, the aggregates passing and retaining between Sieve Size ranging from 20mm and 10mm were selected. The Recycled coarse aggregate acquired from demolished waste was cleaned from impurities and external agents. They were sieved through 20mm and retaining 10mm were used for exploratory investigational work. The Fine Aggregate used was brought from a natural river basin comprising Zone – II which was sieved and Evaluated as per the Standard Practice. For Experimentation, the Fine Aggregate passing 4.75mm Sieve was used. The Quarry Stone Dust passing through the 4.75mm whose specific gravity was determined to be 2.66 was brought and partially substituted with Fine aggregate.

As Fly ash attains no binding characteristics, being highly plastic in nature certain activators were required to impart binding characteristics. The activator used for aluminosilicate for providing adequate strength was prepared by using a mixture of sodium hydroxide, with a purity of 97.2% Sodium silicate solutions with a proportion of Na2O = 14.7%, SiO2 = 29.4% and water =55.9% by mass. This solution is considered as the alkaline solution. Generally, fluid to binder ratio was adopted between 0.3 to 0.6 and the alkaline solution to fly ash ratio was adopted as 0.349 for trials.

Conventionally, workability increments with an increase in Water cement ratio, whereas, in Geopolymer Concrete the rise in water to binder ratio lowers strength characteristics of the concrete.

2.2. Preparation of sodium hydroxide solution

A suitable concentration of sodium hydroxide was evaluated and considered for the preparation of solution. From the previous research studies, it was preferable to consider the molarity of sodium hydroxide to be in between 9M to 12M to attain the required optimistic strength of above 30MPa. To my research work 8M of concentrated NaOH solution is considered with respect to the trial mix ratios and also from the earlier studies. The molecular weight of NaOH is 40gm. So, to prepare 8M of NaOH solution, sodium hydroxide flakes of 8 X 40 = 320gm are to be diluted per liter H2O. Solid NaOH of mass 248gms per kg for 8M concentrated solution was taken. The ratio of sodium silicate to sodium hydroxide is taken as 2.0 in terms of mass [11]. These mixture consisting of compounds like sodium hydroxide and sodium silicate solution were kept ready a day before in order to stabilize it chemically and allowing the temperature to drop down prior to mix it with the solution. Any Delay in preparation of Solution leads to inefficient reactions, which thereby gives altered results reducing the binding property of the mixture.

2.3. Preparation of Mix

A similar mix as per the conventional concrete for M30 Grade was prepared using Fly ash, Coarse Aggregate, Recycled Coarse Aggregate, Fine Aggregate, Quarry Stone Dust, Alkaline Solution and extra water for 1m3 is as mentioned in Table. 1 and Table. 2. In the Mix Recycled Coarse aggregate was kept at an optimum constant of 40% evaluated in previous studies and only Quarry Stone Dust was varyingly replaced with FA. A slightly modified mix design approach is evaluated for Geopolymer Concrete as the Cement is completely replaced by the Fly ash and the Water is replaced with the alkaline solution. The final mix attained is in the ratio 1:1.2:3.25.
Table 1. Final mix proportion for M30 concrete

| Mix | Fly ash | F.A | C.A | NaOH | Na$_2$SiO$_3$ | Extra water |
|-----|---------|-----|-----|------|-------------|-------------|
| M1  | 310     | 380 | 1010| 62   | 124         | 3.1         |
| M2  | 310     | 304 | 20  | 76   | 60          | 40          |
| M3  | 310     | 228 | 40  | 152  | 60          | 40          |
| M4  | 310     | 152 | 60  | 228  | 60          | 40          |
| M5  | 310     | 76  | 80  | 304  | 60          | 40          |
| M6  | 310     | 0   | 100 | 380  | 60          | 40          |

Table 2. Final mix proportion for M30 concrete

| Mix Type | Fly ash | Fine aggregate | Coarse aggregate |
|----------|---------|----------------|------------------|
|          | NFA     | Wt. of NFA     | % of QSD         | Wt. of NCA | % of NCA | Wt. of RCA | % of RCA | Wt. of RCA |
| M1       | 100     | 380            | 0                | 60         | 606      | 40         | 40       | 40        |
| M2       | 80      | 304            | 20               | 76         | 606      | 40         | 40       | 40        |
| M3       | 60      | 228            | 40               | 152        | 606      | 40         | 40       | 40        |
| M4       | 40      | 152            | 60               | 228        | 606      | 40         | 40       | 40        |
| M5       | 20      | 76             | 80               | 304        | 606      | 40         | 40       | 40        |
| M6       | 0       | 100            | 100              | 380        | 606      | 40         | 40       | 40        |

The mixes were proportioned as per the following notations, which are used in this study. 40% Recycled Coarse aggregate was set as optimum replacement [12] constant and varying QSD with Fine Aggregate was used for investigation.

- Mix-1 (M 1) - 40% RCA, 100% FA, QSD 0%
- Mix-2 (M 2) - 40% RCA, 80% FA, QSD 20%
- Mix-3 (M 3) - 40% RCA, 60% FA, QSD 40%
- Mix-4 (M 4) - 40% RCA, 40% FA, QSD 60%
- Mix-5 (M 5) - 40% RCA, 20% FA, QSD 80%
- Mix-6 (M 6) - 40% RCA, 0% FA, QSD 100%

2.4. Manufacture of Fresh Concrete and Casting
Portland cement concrete manufacturing techniques are used in Geopolymer concrete manufacturing also i.e. aggregates are mixed with fly-ash for about 3 minutes using a laboratory pan mixer. Gradually to the dry mix alkaline solution is added by continuously stirring for about 3 minutes and later the superplasticizer is added similar to that of the alkaline solution by stirring it about 4 minutes. Immediately after the preparation of mixes, they are transferred to respective moulds [13]. The casting size of the cube is 150x150x150mm, the prism of size 150mm×150mm×700mm, and cylindrical molds of size diameter 150mm and height 300mm.

2.5. Curing of test specimen
Curing of concrete is done in various methods. Many adopt for Self curing reagents to be used for better curing. Even membrane curing techniques and other advanced methods are being adopted. For Geopolymer concrete a slightly modified method of curing is adopted from traditional curing methods. Many researches state that the Geopolymer made up of fly ash gives the best result when its cured at a temperature of 30°C to 90°C. After casting the next stage of production is curing. For the Geopolymer concrete made up of fly ash, the better results can be attained when it is cured at a certain temperature.
There are two techniques usually in practice they are the specimens are either oven-dried or the curing is done by steam. Here we adopted oven curing. At this stage, the cubes are cured with a temperature of water ranging between 75 - 80°C with a minimum duration of 24 hrs [15]. After that, the specimens are allowed to air dry for the whole day before testing.

3. Results and Discussion

3.1. Workability

Workability tests were carried over fresh concrete by using the Compaction factor test and Vee-Bee Consistometer test. The workability for concrete is considered to be of greater importance rather than it seems. It affects the placement of concrete which in turn results in the Strength and Durability of concrete, as lower workability results in Voids and Higher workability results in Bleeding [16]. Hence to get an Optimum workability with suitable binder – alkaline solution ratio is considered. The workability of test results is represented graphically. The result of the compaction factor test is presented in the graphical form in Figure 1.

![Figure 1. The variation of compaction factor values](image)

From the above experimental observation was plotted into graphical informative data. The data expresses the most magnificent result as the compaction factor tends to follow a definite limit that affects compression factors. Compaction factors are all after quarry dust and recycled aggregate proportion. It is observed that the compaction factor proportion intensifies at 60% and 40% of quarry dust and recycled aggregate respectively further abates. The result of the Vee-Bee Consistometer test is presented the graphically in Figure 2.

![Figure 2. The variation of Vee - Bee Consistometer values](image)
It can be noticed that the Vee-Bee Test results confirm the same trend as the compaction factor test results showcased. An increase in Workability was gradually observed till M4 Mix and decreased thereafter.

3.2. Compressive Strength
Compressive Strength plays the dominant role in the concrete, which is considered to be one of the key and primary purpose for its usage. So, Far Concrete is the most economical material, which shows promising Compressive strength and structural benefits when compared to other materials in Industry. The results obtained after testing the specimens under CTM for the compressive strength test for 7, 14 and 28 days are represented [17] graphically in the Figure 3, 4 & 5.

Figure 3. Compressive strength Value for Various proportions at 7-days

Figure 4. Compressive strength Value for Various proportions at 14-days
Figure 5. Compressive strength Value for Various proportions at 28 – days

A comparative representation of Compressive Strength values for various mixes for 7, 14, and 28 days is shown in Figure. 6

Figure 6. The variation of 7, 14 and 28 days compressive strength

The optimum compressive strength values are attained through the graph at a M3 Mix whose aggregate ratio is 40% QSD and 40% of RCA. We can observe a certain increase of strength up to M3 later the strength started decreasing.

3.3. Split Tensile Strength
The results obtained after testing the specimens under UTM for the Tensile strength test for 7, 14 and 28 days are represented as shown in Figure.7, 8 & 9 respectively.
A comparative representation of Tensile Strength values for various mixes for 7, 14 and 28 days is shown in Figure. 10
We can observe the same pattern of increase in tensile strength of our specimens the same as compressive strength that is the strength starts increasing with the replacement of aggregate only up to 40% replacement of fine aggregate with Quarry stone Dust, beyond that limit the strength started declining.

3.4. Flexural Strength
The results obtained after testing the specimens under UTM for the Flexural strength test for 7 and 28 days are represented as shown in the graphical form in Figure. 11&12.
Figure 12. Flexural strength Value for Various proportions at 28 days

A comparative representation of Flexural Strength values for various mixes for 7 and 28 days as shown in the graphical in Figure 13. For all mixes, the flexural strength increases in age.

Figure 13. The variations for 7 and 28 days Flexural strength

4. Conclusion

Upon investigation the following highlights from the above experiments,

- The Compaction factor value increased significantly up to 0.91 for M4 Mix (RCA 40%, FA 40%, and QSD 60%) and decreased further.
- The Vee-Bee time gradually decreases from Mix M1 to mix M4 and later increases with an increase in the percentage of QSD and RCA.
- The Optimum results for Compressive Strength, Tensile Strength, and Flexure Strength was observed for M3 Mix (RCA 40%, FA 60%, and QSD 40%) at 7, 14 and 28 days of curing period for Geopolymer Concrete.
Analyzing the above Highlights it is quite evident that the M3 Mix is the optimum of all the mix performing better in both Fresh and hard Concrete. There was a significant increase for M3 Mix in the compressive strength (38.296 MPa), Split Tensile Strength (3.05 MPa), and Flexural Strength (5.94 MPa). Upon further replacement of Quarry Stone Dust beyond 60% there was a gradual decrement in the strength results. Using Waste materials and a sustainable approach, the next-gen construction materials like Fly Ash and Quarry Stone Dust provides a solution for waste disposal and also Sustainable, Effective, and efficient Construction providing better Strength and durability.

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