# EXPERIMENTAL INVESTIGATION ON LOW CALCIUM FLY ASH BASED GEOPOLYMER CONCRETE USING STEEL SLAG AS COARSE AGGREGATE

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## ABSTRACT

Geopolymer concrete is produced by replacing cement by alkali activated pozzolanic materials which are rich in silica and alumina. This experimental work involves an attempt to replace the natural coarse aggregate by steel slag. Steel slag obtained from steel rerolling mill is used as coarse aggregate to produce concrete and the performance of the concrete in terms of mechanical strength and durability are studied. This work presents the short – term performance of the geopolymer concrete in various aspects. Standard concrete grade M 40 is taken for the purpose of this study. With increase in demand over decades for a sustainable concrete which would minimize the use of natural sources to a possible limit, this work presents a concrete that would replace both cement and natural gravel in concrete by 100% with fly ash and steel slag, both being the industrial by-products seeking potential way of safe disposal to avoid environmental hazards. Also the availability of this industrial by-product is abundance in India, these can be used to produce eco-friendly concrete. The test results show that geopolymer concrete with scrap steel slag as coarse aggregate excels in performance in terms of mechanical and durability studies. Thus this can be suggested for structural applications widely.

*Key Words* - Low calcium Fly ash, Geopolymer, Coarse aggregate, Steel slag

## INTRODUCTION

Concrete is the indispensible constituent to a nation's development. Being the fastest developing country, India will become the world's third largest construction market by 2025 and thereby the infrastructure sector is a key drive for the Indian economy. Making this development sustainable, it involves the significant reduction of raw materials in the production of concrete, as the topic of global climate change is frequently discussed now-a-days. The international panel on climatic change (IPCC) reports that the increase in concentration of many compounds in the atmosphere will impact global climate. Use of concrete contributes to the emission of greenhouse gases, especially carbon dioxide. All construction processes are energy dependent.

With this basic knowledge, this study involved the selection of geopolymer concrete – the cement free concrete and further adding to its greener value, replacement of its natural gravel coarse aggregate by steel slag is proposed and evaluated experimentally. Though any official data is not available regarding the amount of steel slag produced, it is learnt that India is the third largest importer of the scrap steel and hence large amount of steel slag can be obtained during the process of these imported steel. With abundance availability of the these material, this experimental work presents a report on value added geopolymer concrete in terms of both structural and environmental applications.

**OBJECTIVE**

- Check feasibility of scrap steel slag as coarse aggregate.
- Make a Low calcium fly ash geopolymer mix proportion for M 40 grade concrete based on trials.
- Replace the gravel aggregate by steel slag – 100% and study of its performance.
- Make the geopolymer concrete more sustainable.

**LITERATURE STUDY**

**B. Vijaya Rangan** [(1)] reports about the materials, mix proportion and manufacturing process of low calcium fly ash geopolymer concrete and its fresh and hardened state properties with the parameters influencing the strength. It reports that low calcium fly ash geopolymer undergoes low creep and low shrinkage.

**N A Lloyd and B V Rangan** [(2)] reports various short – term and long – term properties of fly ash based geopolymer concrete and its engineering applications. States that geopolymer is well suitable for precast applications with sustainability and economic benefits.

**Pradip Nath et al,** [(3)] studied geopolymer for ambient curing and reports that fly ash geopolymers blended with small percentages of Ground Granulated Blast furnace Slag (GGBS), Ordinary Portland Cement can be a suitable binder for low to moderate strength concrete production at ambient curing condition.

**Vinothini et al** [(4)], reports that GGBS in binder accelerates the setting time of geopolymer concrete at ambient conditions. Microscopic images show amorphous calcium containing hydrated product with the addition of GGBS.

**Chinnaraju1, Ramkumar** [(5)] reports 60% as optimum replacement level of coarse aggregate by steel slag for strong and durable concrete, however suggests that the replacement level may vary with the source of steel slag.

**Mohammed Nadeem1, Arun D. Pofale** [(6)] - Concrete of M20, M30 and M40 grades were considered respectively for the replacements of 0, 30, 50, 70 and 100% of aggregates (Coarse and Fine) by slag. 100 % slag aggregate (coarse) increased concrete density by about 5 to 7 % and the compressive strength of concrete improved by 4 to7 % at all the % replacements of gravel coarse aggregate with crystallized slag.

**Maslehuddin, et al** [7] compared steel slag and crushed limestone aggregate. Compressive strength of steel slag aggregates increased with 65% coarse aggregates. The flexural strength and split tensile strength also increased. Water absorption was reduced. Shrinkage of steel slag exposed to dry environment is similar to limestone aggregate.

## EXPERIMENTAL WORK

### (I) MATERIALS

*Fly Ash* – Low Calcium (Class F) Fly ash obtained from Mettur Thermal Power Station was used. Fly ash was obtained in dry state. Specific gravity of Fly ash was found as 2.3.

*Alkaline activator solution* – Combination of Sodium silicate and Sodium hydroxide was used. Sodium silicate was obtained in liquid form and sodium hydroxide solution was prepared by mixing its pellets in distilled water at required concentration. 8 Molarity concentration of sodium hydroxide solution was used for this study. Hydroxide solution was prepared, a day before use and it was mixed with sodium silicate solution together just before mixing of concrete.

*Coarse aggregate* – Locally sourced natural gravel with specific gravity 2.66 was used.

*Sand* – Local river sand with specific gravity 2.60 was used.

*Steel slag* – Collected from a local steel re-rolling mill. Irregular shaped slag balls were crushed down using mechanical jaw type crusher. Specific gravity was found as 2.18.

*Superplasticizer* – Conplast SP 430 with specific gravity 1.22 was used.

### (2) MIX PROPORTION

Mix proportion for geopolymer concrete was based on laboratory trial and error method with reference to the conventional concrete mix design. The mix proportion of M 40 grade geopolymer concrete is made and it is given in Table.1. Mix I and Mix II are based on conventional coarse aggregate and steel slag coarse aggregate respectively.

**Table 1 – Mix Proportion**

| Sl. No | INGREDIENTS | Mix I | MIX II |
|---|---|---|---|
| | | kg/m$^3$ | kg/m$^3$ |
| 1 | Fly Ash | 311 | 311 |
| 2 | GGBS | 133 | 133 |
| 3 | Sodium Hydroxide solution (8M) | 57 | 57 |
| 4 | Sodium silicate solution | 143 | 143 |
| 5 | Fine Aggregate | 815 | 815 |
| 6 | Coarse Aggregate (12.5 mm) | 1061 (Gravel) | 870 (Steel Slag) |
| 7 | Super Plasticizer | 7.4 | 7.4 |

## (3) CASTING AND TESTING OF SPECIMENS

First, all the dry ingredients were mixed and then the activator solution was added to obtain a cohesive mix. Super Plasticizer was also used to improve the workability to get the slump value of 50mm. Standard test specimens of 150 x 150 x 150mm cubes, cylinders of 300mm length x 150 mm dia. and prism of size 100 x 100 x 500mm were used to cast the geopolymer concrete specimens (Figure 1). After 24 hours of casting, the specimens were released from moulds and were exposed to sunlight – ambient temperature. ($32^0$C ± $2^0$C). After three days of ambient curing (Figure 2), the specimens were put to laboratory strength testing. Mechanical (Compressive, Tensile and Flexural strength) and durability (Acid resistance, Sulphate resistance) performance of the concrete were conducted. Standard conventional procedure was followed while testing the concrete specimens (Figures 3 to 7).

The mechanical strength report (Table 2) shows that the steel slag aggregate Geopolymer concrete behaves similar to that of conventional aggregate Geopolymer. The Compressive and tensile strength values are relatively higher for steel slag Geopolymer. But a slight decrease in flexural strength was observed which was understood to happen because of a coarse finishing of the test specimen during casting because of higher angular slag aggregates. This shall be adjusted by increasing the mortar mass slightly, when put to larger structural applications.

**Figure 1. Casting of specimens**

**Figure 2. Speciments under ambient curing**

**Figure 3. Specimen in Sulphuric acid**

**Figure 4 Compression test**

**Figure 5 Tensile test**

**Figure 6 Flexural test**

## RESULTS AND DISCUSSION

**Table 2 – MECHANICAL PROPERTIES**

| S. No | Test Conducted | Result at 3 days in MPa | |
|---|---|---|---|
| | | M I | M II |
| 1 | Compressive Strength | 49.92 | 51.11 |
| 2 | Tensile Strength | 4.98 | 5.47 |
| 3 | Flexural Strength | 10.88 | 9.53 |

**Table 3 – DURABILITY REPORT**

| Sl. No. | Parameter | Result after 30 days immersion in 1% Sulphuric acid | | Result after 30 days immersion in 5% Sodium sulphate | |
|---|---|---|---|---|---|
| | | M I | M II | M I | M II |
| 1 | Compressive Strength (MPa) | 49.33 | 50.22 | 49.55 | 50.66 |
| 2 | % reduction in strength | 1.20 | 1.74 | 0.74 | 0.88 |

Durability report (Table 3) shows an excellent resistance to acid and sulphate attack by geopolymer concrete. However, the reduction in strength for slag aggregate Geopolymer is slightly higher as the aggregates were relatively more porous than convention aggregate which led to relatively more active change

## CONCLUSION

From this short-term experimental work, it is clear that scrap steel slag can be potentially used as coarse aggregate in low calcium fly ash based geopolymer concrete as it behaves similar to conventional gravel aggregate. This will add to the sustainability of this cementless concrete. Long term research is recommended for implementing this concrete in wide structural applications.

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