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EXPERIMENTAL INVESTIGATION ON COPPER SLAG AS FINE AGGREGATE REPLACEMENT AND GGBS & RED MUD AS CEMENT REPLACEMENT ALONG WITH HYBRID FIBRES

Chethan C S*[1] & V S Jagadeesh[2]

*[1]Student, M.Tech (Structural Engineering), S.J.M Institute of Technology, Chitradurga-577502, Karnataka, India.
[2]Professor, Dept. of Civil Engineering, S.J.M Institute of Technology, Chitradurga-577502, Karnataka, India.

Abstract - *In this study, the main aim is to define the favorable conditions suitable for geo-polymerization process in the construction materials production. GGBS - Ground Granulated Blast furnace Slag and Red Mud (Calcined Clay) are the two industrial byproducts used in this study to replace OPC. The world's major problem that is facing now a day is environmental pollution. Production of ordinary Portland cement (OPC) is emitting carbon di-oxide (CO_2) to the atmosphere which causes pollution of environment. Since OPC can be partially replaced by GPC, it reduces the global warming. And the test results show that variation in compressive strength of 7 days and 28 days, flexural strength of 28 days and Split-Tensile strength of 28 days incorporating with hybrid fibers. Six different mixes are prepared to investigate the properties of materials comparatively.*

Key Words: GGBS, Red Mud, Compressive strength, Copper slag, Flexural strength, Split-Tensile strength.

1. INTRODUCTION

Due to concrete's versatility and cost effectiveness, it has become one of the most widely used construction material now a day according to recent investigation in concrete technology. The primary binder used in concrete production is ordinary Portland cement (OPC). Production of Portland cement exceeds the emission of carbon di-oxide to the atmosphere. The major problem that world facing now a day is pollution of environment which is majorly caused by the production of Portland cement. According to investigation in 2010, in India about 2.6 billion tons of Portland cement is manufacturing per year. And it is increasing by 5% every year. Mining of these raw materials also causes pollution of environment. Around 1.6 tons of raw materials are required to produce 1 ton of cement and time taken to form the lime stone is longer.

As the concrete is easy to prepare and fabricate in all the required shapes, demand of concrete is increasing every day. So the concrete used should be eco-friendly to reduce the pollution. To reduce the emission of CO_2, we have to use the environmental friendly i.e. industrial by-products such as GGBS, Red Mud, fly ash, silica fume and rice husk ash etc. to replace OPC. Hence it forms the new technique in concrete industry which is known as Geo-polymer concrete in which OPC is partially replaced by GPC up to 50%. GPC shows considerable promise as an alternative binder to Portland cement.

Manufacturing of Ground Granulated Blast furnace Slag (GGBS) is done at JSW CEMENTS LIMITED and it is a part of O.P. JINDAL GROUP. GGBS is available in JSW CEMENT LIMITED, Vidyanagar, Bellary, Karnataka.

2. LITERATURE REVIEW

[1] This experiment is done by using Ground Granulated Blast furnace Slag and Red Mud in the geo-polymerization process. A trial mix design was prepared varying the percentage of mass of combined aggregates and also alkaline liquid to binder ratio. Four different mixes are prepared along with the normal concrete. Hybrid fibers are introduced for all the mixes except normal one in different proportions. And durability aspects were also determined. It is observe that Mix-D (mass of combined aggregates = 77%) shows the good mechanical properties.

[2] The Red Mud (obtained as a byproduct of Bayer process as alumina) and the Metakaolin are used in the geo-polymerization process. A trail mix was done by keeping alkaline liquid to binder ratio constant. And the prism specimens were casted. The samples were kept in room temperature for 48 hours and then kept at a temperature of 100^0C for 72 hours. It is then immersed in water for 14 days and tested. The chemical properties were determined for different materials.

[3] GGBS was fully replaced to ordinary Portland cement in another experimental study. The alkaline liquids such as sodium hydroxide and sodium silicate solutions were used to activate the GPC. Four different mixes are carried out by varying molarities of sodium hydroxide solution along with the conventional concrete. Different mixes are prepared for different alkaline solution's molarity of 3, 5, 7 and 9. Cube specimens were casted and tested for 3 & 7 days. Two types of curing is used here, they are oven curing at 50^0C and sunlight curing. It is observed that the oven cured specimens of age 3 days shows good strength properties and in Geo-polymer concrete, strength improves with the increase in molarity of alkaline solution.

[4] An experimental investigation was carried out on partial replacement of copper slag in fine aggregate to study the

variations in strength. Copper slag is a waste material obtained during matte smelting and refining of copper. Each ton of copper generates approximately 2.5 tons of copper slag. In this study, copper slag from 0% to 100% is replaced to fine aggregate to investigate the properties of strength in copper slag. The obtained results were compared with normal or conventional concrete made of OPC and natural sand.

[5] Experimental investigations are carried out in the laboratory to study the chemical composition of Banana fruit waste and Mango fruit waste. The study shows that Banana fruit waste contains 0.632% starch, 19.75% ash, 1.37% lipid, 5.65% protein and 76.63% moisture. And the mango fruit waste contains 0.507% starch, 13.08% ash, 1.48% lipid, 7.96% protein and 81.26% moisture. In the samples, the total dietary fiber content is in the range of 3.54% to 73.04% and the dietary fiber content is higher in mango fruit waste. The mango fruit waste contains maximum polyphenol content of 54.45% and Banana fruit waste contains minimum of 10.97%.

3. EXPERIMENTAL INVESTIGATION

3.1 MATERIALS USED

3.1.1 Cement

The most commonly used binder in the world is cement. It is a substance that sets and hardens independently, and it can bind other materials together. The word “cement” was introduced by the Romans defined by the term “opuscaementicium”. The most common and important use of cement is it is used in the production of mortar and to bind the concrete with natural aggregates to form strong buildings. The cement used for this experimental investigation is Zuari cement (OPC-43 grade). And it is confirmed to the quality provisions of Indian Standard specification. The specific gravity of cement is 3.15. It is found out by using Le-Chatelier’s flask.

3.1.2 Aggregates

The natural river sand is obtained from T-Narsipura, Mysore for our investigation. The specific gravity of fine aggregate is **2.60**.

The coarse aggregate used in this study is 20mm and 10mm sizes. And it is obtained from a quarry near Chinkurli, Pandavapura taluk, Mandya district. The specific gravity of coarse aggregate is found to be **2.63.**

3.1.3 Copper slag

Copper slag is one of the waste material obtained from the industry which is now behaves as a promising future for the construction industry as a fully or partial replacement of fine aggregate or cement. It is the byproduct obtained from refining of copper and matte smelting. When one ton of copper is produced, about 2.2 to 3 tons of copper slag is generated. It has higher density as the impurities stay in the top layer and copper settles down in the smelter. The impurities are then transported to the basin which contains water for solidification. The product obtained at the end is hard material, solid that is sent to the crushing machine for further process. In this experimental study, the Copper slag used is obtained from **Hatti Gold Mines Ltd.,** Indalgal, Chitradurga. The specific gravity of Copper slag is found to be **2.58.**

Uses of Copper slag:

- It is used as filling material in construction industry.
- Used in concrete constructions.
- As building material and manufacturing of blocks.
- It is used in sand industry and in the manufacture of abrasive tools.
- Used to remove rusts, old coating and dry impurities.

3.1.4 Ground granulated blast furnace slag (GGBS)

GGBS is used in this study for the partial replacement of Portland cement. GGBS is the by-product obtained during the manufacture of pig-iron. When coke, iron ores, and lime stone are sent into the furnace, the molten slag is obtained at the top layer of molten iron at a temperature of 1500^{0}C – 1600^{0}C. The slag obtained has the composition almost similar to the chemical composition of ordinary Portland cement. Molten slag consists of aluminous and siliceous residues and then water is sprayed quickly to get glassy granulate in nature. And then dried, grounded to the required size which is known as Ground granulated Blast furnace Slag.

The Ground Granulated Blast furnace Slag used in this study is obtained from JSW cement limited, Vidyanagar, Bellary. And the specific gravity of GGBS is said to be **2.45.** It is found out by using Le-Chatelier’s flask.

Advantages of GGBS when used with Portland cement:

- ✓ Durability of the structure will be increased.
- ✓ Temperature will be reduced and helps in avoiding early age of thermal cracking.
- ✓ Improves workability of concrete.
- ✓ It is white in colour and lighter than the ordinary Portland cement.
- ✓ GGBS helps in softening the visual impact of large structures such as retaining walls and bridges.

GGBS is used in...

- ✓ High rise buildings.
- ✓ Marine structures such as shore protection constructions and dams.
- ✓ Sewage and effluent treatment plants.
- ✓ Cement products such as pipes, blocks and tiles.

3.1.5 Red mud: (Calcined clay)

The Red Mud used in this investigation is Calcined clay or Clacined Kaolin. It is an anhydrous aluminum silicate produced while heating ultra-fine natural Kaolin at a high temperature in the kiln. The process of calcination increases the hardness and whiteness; electrical properties will be improved and alters the size and shape of kaolin particles.

The Red Mud adopted in this experimental investigation is brought out from a brick manufacturing factory near Mysore. The waste product obtained in the brick kiln is used for this study. And the specific gravity of Calcined clay is **2.55**.

3.1.6 Fibres

The fibres used in this study are classified into metallic, non-metallic and natural fibers.

- **Metallic fibre: (Steel fibre)**

The corrugated steel fibres are used as a metallic fibre in this investigation. The aspect ratio of corrugated steel fibre should be 50. For this experimental investigation, steel fibres are obtained from a fibre manufacturing industry near Mysore.

- **Non-metallic fibre: (Polypropylene fibre)**

The non-metallic fibre used in this study is Polypropylene fibre. The fibre should be of fibrillated type. The size of polypropylene fibre adopted in this study is 12mm. Polypropylene fibre is brought out from Forsroc Enterprises in Mysore for this experiment.

- **Natural fibre: (Banana fibre)**

The natural fibre adopted in this experimental investigation is Banana fibre. The stem of the Banana plant is peeled into small pieces and dried in sunlight. The aspect ratio of Banana fibre should be 50. Before using it in concrete mixes pretreatment of Banana fibre should be done.

3.1.7 Super plasticizer

To improve the workability of concrete, a super plasticizer known as Sulphonated Naphthalene Formaldehyde is used in this investigation. It is also called as Conplast SP-430. The specific gravity of Conplast SP-430 is **1.42**.

3.2 MIX DESIGN

As there is no code provision for Geo-polymer concrete, the trail mix is prepared.

3.3 METHODOLOGY

In this experimental investigation, we have carried out five different mix proportions along with normal mix or conventional concrete so that we can compare it with each other. The normal concrete mix is named as Mix-N where as other mixes are termed as Mix-A, Mix-B, Mix-C, Mix-D and Mix-E. Each mix proportions represent the following.

- Mix-N represents a conventional concrete. It consists of 100% ordinary Portland cement and naturally available aggregates such as fine aggregate and coarse aggregates.
- In Mix-A, fine aggregate is replaced by 25% copper slag whereas coarse aggregate and OPC remains same as Mix-N. The mix proportion is [OPC + (75% fine aggregate + 25% copper slag) + Coarse aggregate].
- By keeping 25% copper slag as constant for all the mixes, Mix-B includes replacement of cement partially by GGBS and Red Mud (Calcined clay). The mix proportion is [(50% OPC + 30% GGBS + 20% RM) + (75% F.A + 25% copper slag) + coarse aggregate].
- The Mix-C is same as mix proportion of Mix-B, but there is an addition of fibre into the concrete mix. Steel fibre of corrugated type is used in this mix and the aspect ratio of steel fibre is 50.
- Repeat the same procedure as Mix-B, but along with the addition of Polypropylene fibre. It should be of fibrillated type and size of the polypropylene fibre is 12mm.
- Once again same as Mix-B, but with the addition of natural fibre, i.e. Banana fibre is used in this mix. Aspect ratio of Banana fibre should be 50.

Totally 36 cubes of size 100X100X100mm are casted, 6 cube specimens for each mix along with normal mix. And 18 cylinders of 150mm diameter and 300mm depth are casted, 3 specimens for each mix. Also 18 prisms or beams of size 100X100X500mm are casted, 3 specimens for each mix along with the conventional concrete. Specimens were de-moulded after 24 hours and immersed in water for curing up to 28 days. The cured test specimens are taken out when it reaches the required age and dried and tested in the laboratory. Compressive strength of cubes was carried out. Split–Tensile strength test is carried out on cylinder specimens and flexural strength test is found out on beam specimen.

3.4 Mix proportions

MIX	N (1)	A (2)	B (3)	C (4)	D (5)	E (6)
Cement (Kg / m^3)	360	360	360	360	360	360
Fine aggregate (Kg / m^3)	731	548.5	548.5	548.5	548.5	548.5
Coarse aggregate (Kg / m^3)	1110	1110	1110	1110	1110	1110
Water / Cement ratio	0.5	0.5	0.5	0.5	0.5	0.5
GGBS (Kg / m^3)	0	0	108	108	108	108
Red Mud (Calcined Clay) (Kg / m^3	0	0	72	72	72	72
Copper Slag (Kg / m^3)	0	182.5	182.5	182.5	182.5	182.5
Super Plasticizer (Kg / m^3)	3.6	3.6	3.6	3.6	3.6	3.6
Steel fibre (Kg / m^3)	0	0	0	3.6	0	0
Polypropylene fibre (Kg / m^3)	0	0	0	0	1.8	0
Banana fibre (Kg / m^3)	0	0	0	0	0	1.8

Table-1 Mix proportions

Fig-1 Mixing process

Fig-2 Fibres added

3.5 DURABILITY TESTS

3.5.1 Acid attack test:

Acid attack test procedure is as follows.

- ✓ Take the cube specimen of initially cured.
- ✓ Immerse the cubes to be tested in a tub containing 5% concentrated sulphuric acid solution (H_2SO_4) of 1N.
- ✓ It is cured in H_2SO_4 solution for 28 days.
- ✓ And note down the weights of specimen before and after attack. Let it be W_b and W_a.
- ✓ The acid attack is evaluated by determining the expansion of concrete cubes, compressive strength and weight losses of the specimens.

Fig-3 Acid attack

3.5.2 Alkalinity measurement test:

The test procedure to measure the alkalinity of specimen is as follows.

- ✓ Take broken pieces of cube specimen after compressive strength test is carried out.
- ✓ It is again broken into small pieces by using hammer or ball mill and powdered.
- ✓ The powdered sample, say about 20gm is taken and put into 100ml distilled water and allowed to stand for 72 hours.
- ✓ The P^H of the aqueous solution is measured using P^H meter after 72 hours.

3.5.3 Sulphate attack test:

The sulphate attack testing procedure is as follows.

- ✓ Take specified initially cured cube specimen of 100mm size.
- ✓ Immerse the specimen in a tub containing 5% sodium sulphate solution for 28 days.
- ✓ Replace the sulphate solution when the P^H of solution exceeds the value of 9.5.
- ✓ Note down the changes as in previous case.

Fig-4 Sulphate attack

4. RESULTS AND DISCUSSION

4.1 COMPARISION OF COMPRESIVE STRENGTH

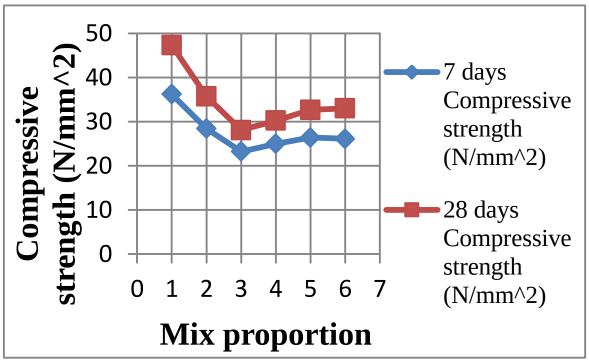

Fig-5 Compressive strength

- ✓ The above figure shows the representation of variations in compressive strength with the different mix proportions at the age of 7 days and 28 days.
- ✓ The variations of compressive strength in both 7 days and 28 days age are almost similar in nature.
- ✓ With respect to the initial compressive strength, the final strength at the age of 28 days gains more strength in the range between 20-30%. This indicates that there is a good hydration of concrete cube specimens between 7 days and 28 days.
- ✓ The variations of compressive strength of Mix-N (conventional concrete) are compared with all other mix proportions. All the mix proportions are 35-40% less than Mix-N and there is slight improvement in Mix-A (25% Copper slag). The fibre added concrete specimen also shows an improvement in compressive strength. i.e Polypropylene fibre and Banana fibre.

4.2 COMPARISON OF SPLIT-TENSILE STRENGTH

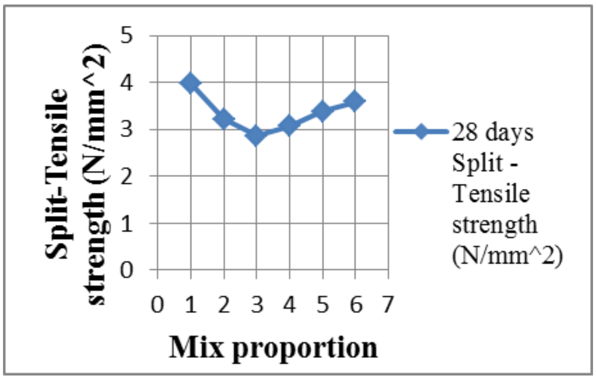

Fig-6 Split-Tensile strength

- ✓ The above figure shows the representation of Split-Tensile strength at the age of 28 days.
- ✓ The Splitting-Tensile strength obtained is in the range of 10-15% of compressive strength of concrete specimens.
- ✓ Mix-B shows that the split-tensile strength decreases when compared all other mixes.
- ✓ In the observation we can say that Mix-A (25% copper slag), Mix-D (Polypropylene fibre) and Mix-E (Banana fibre) shows good mechanical properties. The percentage variation with respect to normal concrete is in between 10-20%.

4.3 COMPARISON OF FLEXURAL STRENGTH:

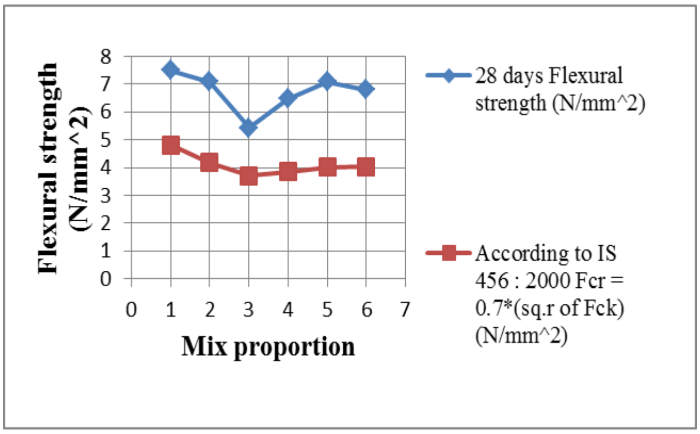

Fig-7 Flexural strength

- ✓ The representation of flexural strength or bending stress to the various mix proportions are shown in figure.
- ✓ Mix-A performs better mechanical properties compared to all other mixes. It gains flexural strength almost equal to 95% of normal concrete (Mix-N).
- ✓ It can be seen that, flexural strength when compared with IS 456: 2000; there is 35-40% increase in flexural strength.
- ✓ When incorporated with hybrid fibres such as Polypropylene fibre and Banana fibre, increases the strength properties compared to steel fibre induced concrete.
- ✓ Flexural strength obtained are almost higher than the flexural strength according to IS 456 : 2000;

4.4 Durability test results

Mix details	Weight loss		Compressive strength before attack (N/mm^2)	Compressive strength after attack (N/mm^2)	% of strength Gain / Loss
	Kg	%			
MIX - N	0	0	47.38	41.82	11.75 (LOSS)
MIX - B	0	0	28.11	30.63	8.9 (GAIN)

Table-2 Acid attack

Mix details	Weight loss		Compressive strength before attack (N/mm^2)	Compressive strength after attack (N/mm^2)	% of strength Gain / Loss
	Kg	%			
MIX - N	0	0	47.38	42.76	9.75 (LOSS)
MIX - B	0	0	28.11	33.06	17.6 (GAIN)

Table-3 Sulphate attack

5. CONCLUSIONS

- Geo-polymer concrete is eco-friendly which reduces the environmental effect by adopting industrial by-products in the construction practices as a replacement of Ordinary Portland cement.
- Among all the mixes, Mix-A performs better strength about 80% of normal concrete (Mix-N) by adopting copper slag as a partial replacement of fine aggregate.
- It is seen that, Mix-A is achieving good mechanical properties than the Mix-B (GGBS & Red Mud). It is due to the use of copper slag which reduces the risk of damages caused by chemical reactions and behaves as a highly resistant to environmental effects.
- The hybrid fibres incorporated such as Banana fibre in Mix-E and Polypropylene fibre in Mix-D gains the strength properties than Steel fibres in Mix-C.
- It is observed that, the Splitting-Tensile strength performs better in Mix-A (25% Copper slag) and when incorporated with hybrid fibres such as Banana fibre (Mix-E) and Polypropylene fibre (Mix-D). The Split-Tensile strength is 80-90% closer to the normal concrete (Mix-N).
- In case of flexural strength, there is improvement of strength in Mix-A (25% copper slag), Mix-D (Polypropylene fibre) and Mix-E (Banana fibre). When compared with normal mix Mix-N, it is observed that Mix-A, Mix-D and Mix-E is 90-95% closer to normal mix.
- Geo-polymer concrete gains 8.9 % strength when immersed in Sulphuric acid and 17.6% strength gain when immersed in Sodium sulphate solutions. And in OPC, the strength reduces due to acid and sulphate attack on concrete specimens in both the cases.

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BIOGRAPHIES:

Chethan C S, Student of M.Tech in Structural Engineering at S.J.M Institute of Technology, Chitradurga, Karnataka. His areas of interest are concrete technology and Structural Engineering.

V S Jagadeesh, M.Tech in Structural Engineering and he is Professor in Department of Civil Engineering at S.J.M Institute of Technology, Chitradurga, Karnataka.