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Experimental Investigation on Bond Strength, Impact Resistance and Compressive Strength of Concrete with Industrial By-Products

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Abstract*: The present Experimental investigation is to study the Bond strength of the concrete, Impact Resistance and Compressive strength of concrete with partial replacement of Metakaolin and GGBS(Ground Granulated Blast-furnace Slag) as binder and Copper slag as fine aggregate. Metakaolin and GGBS are varied from 5% and 10% by the weight of cement and copper slag varied from 20%, 40% and 60% by the weight of fine aggregate. Mix design was done for the M30 grade concrete with 0.38 w/c ratio. We have used the water reducing admixture as superplasticizer to maintain the water cement ratio within the minimal range and specimens were test for 28 days. A through literature review was conducted to study and investigate the properties of these materials and testing methods. In this research, the experimental study was done for bond strength by pullout test methods, impact energy and compressive strength of the concrete. The partial replacement of GGBS, MK and copper slag increased the bond strength, impact strength of M30 grade of concrete significantly. The maximum bond stress and impact energy was obtained 9.156MPa and 1974.298Nm respectively in 5% of GGBS, MK and 60% of copper slag replacement combination (MC6) and the maximum compressive strength of concrete was obtained 50.00Mpa in 10% of GGBS, MK and 40% of copper slag replacement combination (MC5) and after that it decreases the strength characteristics. Modified UTM machine can be used for measuring the bond stress and it is easily and economically feasible.
Keywords: High Reactive Metakaolin, GGBS, Copper Slag, Bond Strength, UPV, Impact Strength

I. INTRODUCTION

Concrete is the most widely used man-made construction material in the world. It is obtained by mixing cementitious materials, water, aggregate and sometimes admixtures in required proportions. Fresh concrete or plastic concrete is freshly mixed material which can be moulded into any shape hardens into a rock like mass known as concrete. The hardening is because of chemical reaction between water and cement, which continues for long period leading to stronger with age. The usage, behaviour as well as the durability of concrete structures, built during the last first half of the century with Ordinary Portland Cement (OPC) and plain round bars of mild steel, the ease of procuring the constituent materials (whatever may be their qualities) of concrete and the knowledge that almost any combination of the constituents leads to a mass of concrete have bred contempt.

The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for green house effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. GGBS, High Reactive Metakaolin, are the pozzolanic materials which can be used in concrete as partial replacement of cement and Copper slag as partial replacement of fine aggregate. Metakaolin and GGBS are varied from 5%, 10% by the weight of cement and copper slag varied from 20%, 40% and 60% by the weight of fine aggregate. Mix design is done for the M30 grade concrete with 0.38w/c. The combinations of mix ratio were taken as 5%, 10% for each 20%, 40% and 60% of replacements. Totally 7 number of mix ratios were taken.

II. MATERIALS AND METHODS

A. Materials

1) *Cement:* Cement is a material that has cohesive and adhesive properties in the presence of water. Such cements are called hydraulic cements. These consist primarily of silicates and aluminates of lime obtained from limestone and clay. There are

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different types of cement. In this present work, Locally available Ordinary Portland cement of 53 grade conforming to IS 12269-1987 was used.

Table 1 Test result of cement

Specific gravity	3.15
Consistency	29%
Fineness	2%
Initial setting time	39 min.
Final setting time	220 min.

2) *Aggregate:* Aggregate properties greatly influence the behaviour of concrete, since they occupy about 80% of the total volume of concrete. The aggregate are classified as, fine aggregate and coarse aggregate. Fine aggregate are material passing through an IS sieve that is less than 4.75mm gauge beyond which they are known as coarse aggregate. In this project, Locally available river sand was used as fine aggregate.

Table 2 Test result of aggregate

Tests	Fine aggregate	Coarse aggregate
Fineness	2.86	7.85
Specific gravity	2.58	2.71

3) *Ground Granulated Blast Furnace Slag:* Ground Granulated Blast furnace slag (GGBS) is a by-product for manufacture of pig iron and obtained through rapid cooling by water or quenching molten slag. Here the molten slag is produced which is instantaneously tapped and quenched by water. This rapid quenching of molten slag facilitates formation of "Granulated slag". Ground Granulated Blast furnace Slag (GGBS) is processed from Granulated slag. If slag is properly processed then it develops hydraulic property and it can effectively be used as a pozzolanic material. However, if slag is slowly air cooled then it is hydraulically inert and such crystallized slag cannot be used as pozzolanic material. GGBS essentially consists of silicates and alumino silicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace.

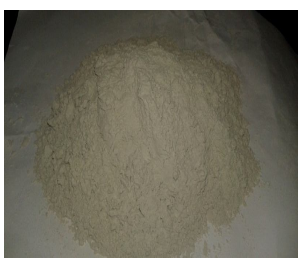

Fig. 1 GGBS

Physical Form	Powder
Color	white

4) *Metakaolin:* Metakaolin differs from other supplementary Cementitious materials like fly ash, slag or silica fume, in that it is not a by-product of an industrial process; it is manufactured for specific purpose under controlled conditions. Metakaolin is produced by heating kaolin, one of the most abundant natural clay minerals, to temperatures of 650-900°C. This heat treatment or calcination, serves to break down the structure of kaolin. Bound hydroxyl ions are removed and resulting disorder among alumina and silica layers yields a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity, suitable for use in cementing applications. When used as a partial replacement for Portland cement, metakaolin may improve both the mechanical properties and the durability of concrete.

Table 3 Physical Properties of Metakaolin

Specific Gravity	2.5
Physical Form	Powder
Color	white
Particle size	4.43

Fig. 2 Metakaolin

5) *Copper Slag:* Copper slag is one of the materials that are considered as a waste material which could have a promising future in construction industry as partial or full substitute of either cement or aggregates. It is a by-product obtained during the matte smelting and refining of copper. Since it has a higher composition of Iron oxide (Fe_2O_3) the density of copper slag is relatively higher when compared to other materials and it is a glassy granular material with high specific gravity. Particle sizes are of the order of sand and have a potential for use as fine aggregate in concrete. In order to reduce the accumulation of CS and also to provide an alternate material for sand, the Sterlite Industries Ltd, proposed to study the potential of CS as replacement material for sand in cement concrete.

Table 4 Physical properties of copper slag

Fig. 3 Copper Slag

Appearance	Black Glassy
Color	Black
Fineness modulus	3.33
Type	Air cooled

B. Methods

1) *Bond Strength:* Bond in reinforced concrete (RC) refers to the resistance of surrounding concrete against pulling out of reinforcing bars. The bond resisting mechanisms in RC members are understood well in normal strength concrete after the numerous studies performed in the last thirty years. If the bond resistance is inadequate, slipping of reinforcing bar occurs destroying composite action. In RC members sudden loss of bond between rebars and concrete in anchorage zones causes brittle failure. The reinforcing bars of 16mm diameter bars are embedded in concrete standard 150mm size cubes. Bond strength can be easily found out by standard pull-out test machine. But in this work, the bond strength was measured using Universal testing machine (UTM) with some modified arrangements. The bond stress τ can be expressed as:

$$\tau = P_{max} / (\pi * L * d)$$

where, Equation gives the flexural bond stress in the tension reinforcement at any section.

2) *Impact Strength:* Many concrete structures are often subjected to short duration dynamic loads. These loads originate from sources such as impact from missiles and projectiles, wind gusts, earthquakes and machine vibrations. The the specimens for impact studies were tested by drop weight method which was recommended by ACI-544 Committee. It recommends a drop weight type test for Impact resistance of Concrete. The drop weight impact test is adopted in this investigation. The size of the specimen recommended by ACI committee is 152 mm diameter and 63.5 mm thickness and the weight of hammer is 4.54 Kg with a drop of 457mm. The results are to be compared to the control specimen that contains without Ground Granulated Blast furnace Slag, High Reactive Metakaolin and copper slag. With the appropriate interpretation of the obtained results, it can be possible to determine the optimum percentage of GGBS, metakaolin, copper slag in concrete. The energy consumption was evaluated from the following equation: Energy = Mass (kg) x Height (m) x g (m/sec2)
3) *Compressive Strength Test:* Compressive test is the most common test conducted on hardened concrete, partly because it is an easy test to perform, the partly because most of the desirable characteristic properties of concrete are qualitatively related to its compressive strength.

The compressive test is carried out on specimens cubical or cylindrical in shape. The cube specimen is of the size 150mm x 150mm x 150mm. The test cube specimens are made as soon as practicable after mixing and such a way as to produce full compaction of the concrete with neither segregation nor excessive laitance. The concrete is filled into mould in layers approximately 50mm deep. The cubes are tested as per IS: 516-1979. The tests are done on an electro-hydraulically operated compression-testing machine and

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compressive load is applied on opposite faces axially, slowly at the rate of 140 MPa/minute. The compressive load is noted for the ultimate failure.

Compressive strength = Load / Area, N/mm^2

III.MIXING AND CASTING DETAILS

Concrete was mixed using a tilting type mixer and specimens were casted using steel moulds, compacted by table vibrator. Specimens were demoulded 24 hours after casting and cured at $27^o + 2^oC$ in water until the testing age of 28days. The specimens were numbered as per the nomenclature using Indian ink before being placed under water for curing say MC1, MC2, MC3, MC4, MC5, MC6 and MC7. The details of the test specimens used for this investigation are shown in the Table No. 3.1.

Fig. 4 Casting of Impact , Pullout and Cube specimen

TABLE 5 SPECIMEN DETAILS

Mix name	Metakaolin	GGBS	Copper slag
MC1	-	-	-
MC2	5%	5%	20%
MC3	10%	10%	20%
MC4	5%	5%	40%
MC5	10%	10%	40%
MC6	5%	5%	60%
MC7	10%	10%	60%

IV. RESULT AND DISCUSSION

A. Out Test

Table 6 Bond Strength of different batches

Mix name	Ultimate load at failure (KN)	Bond strength (N/mm^2)
MC1	59	7.829
MC2	60	7.961
MC3	64	8.493
MC4	64	8.493
MC5	65	8.625
MC6	69	9.156
MC7	63	8.360

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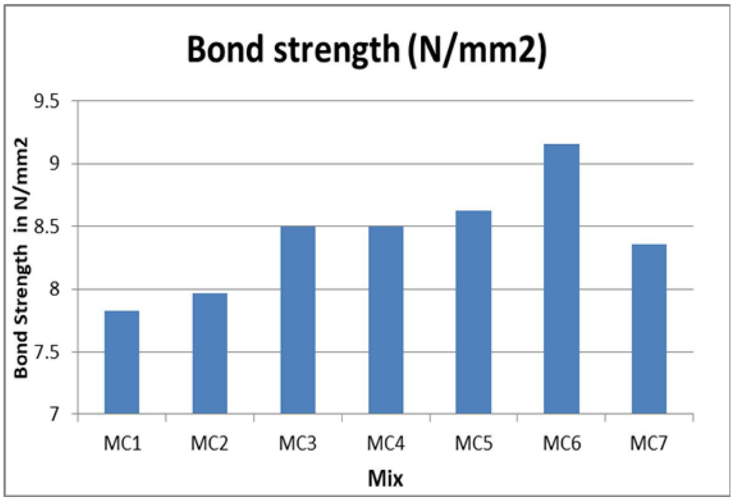
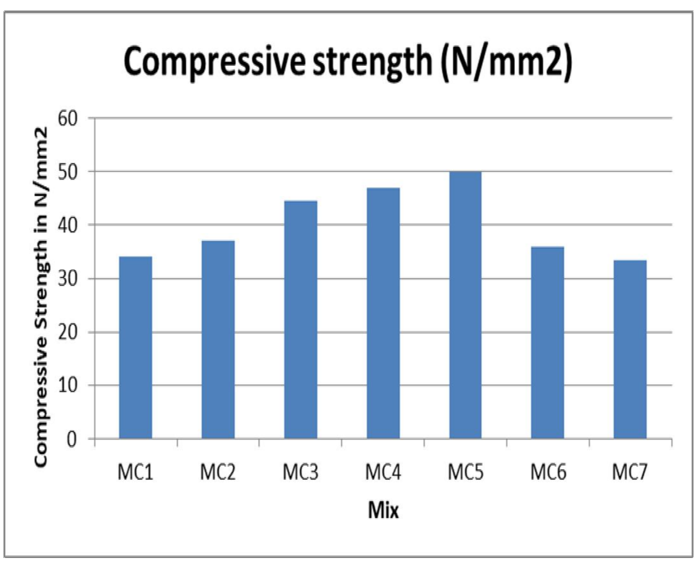


Fig 5 Graph of Bond Strength of different batches

B. Compressive Strength Test

Table 7 Compressive Strength of different batches

Mix name	Ultimate load at failure (KN)	Compressive strength (N/mm^2)
MC1	763.50	34.00
MC2	832.50	37.00
MC3	1008.00	44.50
MC4	1057.50	47.00
MC5	1123.90	50.00
MC6	810.00	36.00
MC7	753.75	33.50



Fig,6 Compressive Strength of different batches

Table 8 Impact Strength of different batches

MMix name	Number Of Blows		Impact Strength (Nm)	
	At First Crack (N1)	At Failure Crack (N2)	At First Crack (N1)	At Failure Crack (N2)
MC1	42	45	854.850	915.912
MC2	60	65	12215	1322.983
MC3	64	70	1302.629	1424.752
MC4	73	79	1485.812	1607.933
MC5	77	83	1567.226	1689.348
MC6	84	97	1709.701	1974.298
MC7	78	92	1587.580	1872.530

Fig.7 Crack Pattern

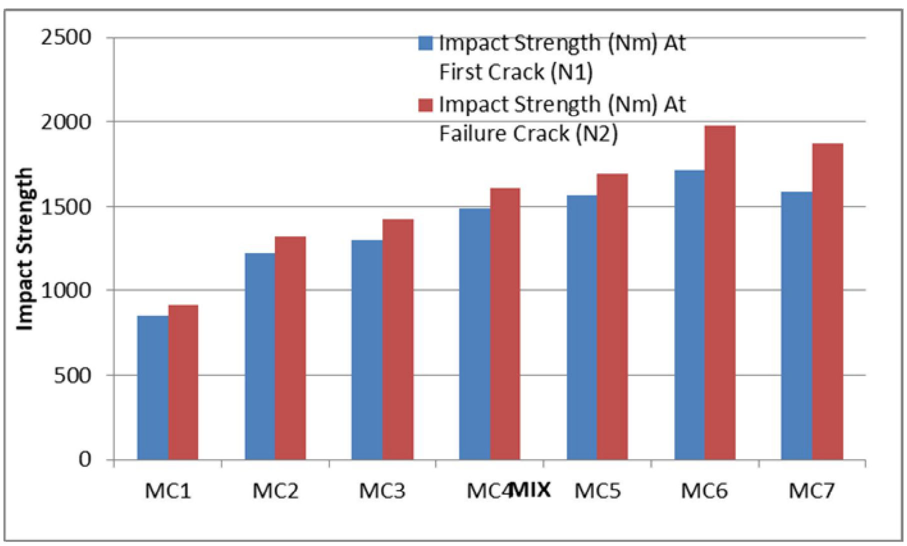


Fig.8 Impact Strength of different batches

V. CONCLUSIONS

Based on experimental results, following conclusion are drawn. It was found that the maximum bond strength achieved is 9.156Mpa at 5% of GGBS, MK replacement and 60% of copper slag replacement combination. So this is 16% of strength greater than the control mix and those achieved for concrete mix name of MC2, MC3, MC4, MC5, MC7 is 7.961Mpa, 8.493Mpa, 8.493Mpa, 8.625Mpa & 8.360Mpa respectively as compare to 7.8291Mpa of strength of plain cement concrete for 28 days .

All the specimens failed with vertical crack along the embedded length of bar with cracking sound and vertical crack width of cracks is found to vary between 1mm and 2.5mm. Modified UTM machine can be used for measuring the bond stress and it is easily and economically feasible.

The maximum compressive strength achieved is 50.00Mpa at 10% of GGBS, MK replacement and 40% of copper slag replacement combination and those achieved for concrete mix name of MC2, MC3, MC4, MC6, MC7 is 37.00Mpa, 44.50Mpa, 47.00Mpa, 36.00Mpa & 33.50Mpa respectively as compare to 34.00Mpa of strength of plain cement concrete for 28 days and it shows the maximum compressive strength of 44% greater than the control mix. The maximum impact strength achieved is 1974.298Nm at 5% of GGBS, MK replacement and 60% of copper slag replacement combination and those achieved for concrete mix name of MC2, MC3, MC4, MC6, MC7 is 1322.983Nm, 1424.752Nm, 1607.933Nm, 1689.348Nm & 1872.530Nm respectively as compare to 915.912Nm of strength of plain cement concrete for 28 days.

The relationship between bond stress, impact energy and compressive strength of concrete at fracture stage has been evaluates, it shows the gradual increment in impact energy, bond strength with compressive strength increased. The partial replacement of GGBS, metakaolin and copper slag increased the bond strength, impact strength of M30 grade of concrete significantly up to 5% and 60% replacement combinations (MC6) and after that it decreases the strength characteristics. Its due to voids in copper slag as fine aggregate and it is also due to low water absorption of copper slag than the fine aggregate. Based on the analysis of test results, it is concluded that cement in concrete can be replaced up to 5% by GGBS, metakaolin with combination of 60% of copper slag replacement to improve its strength characteristics.

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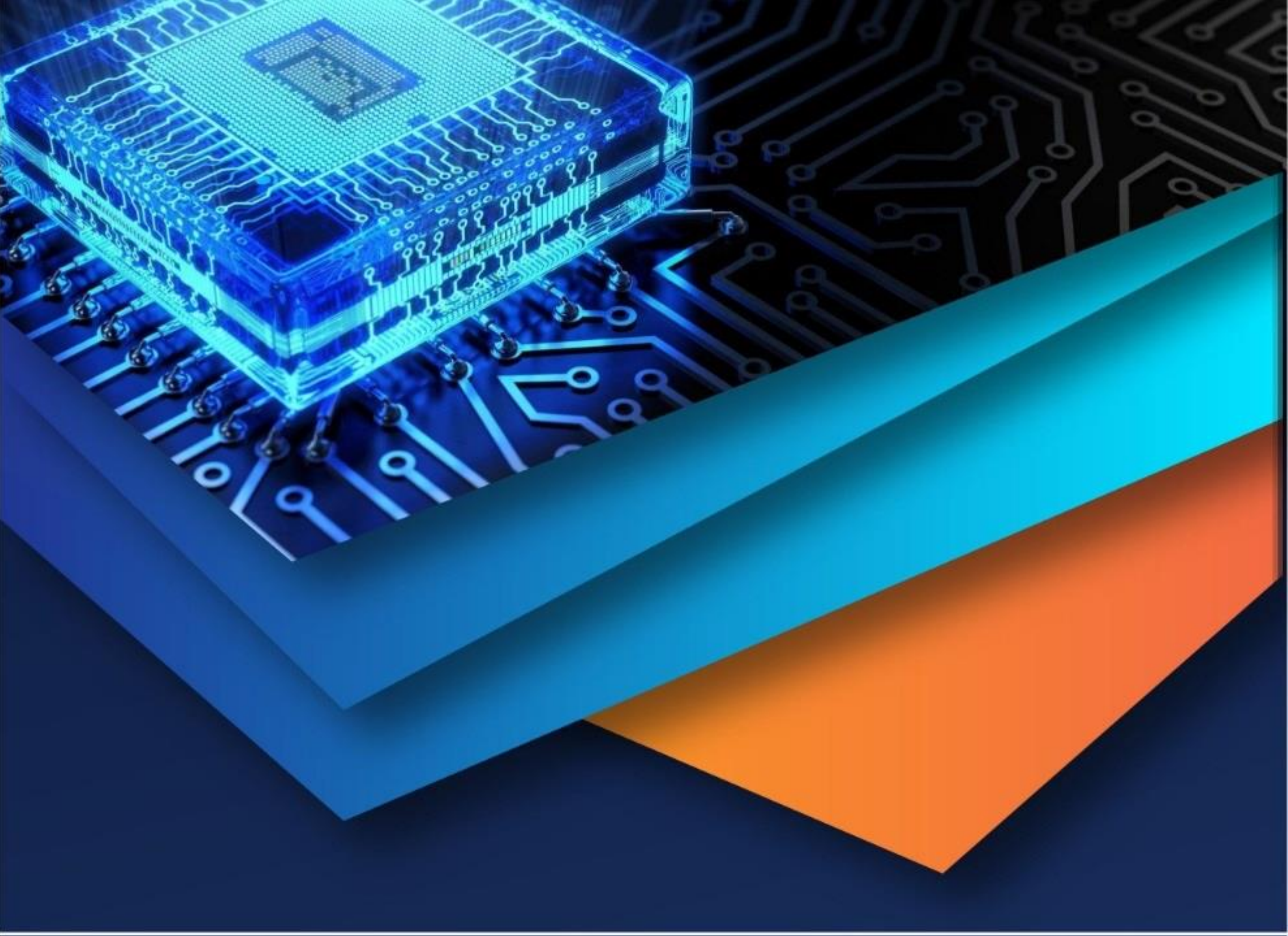

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