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A STUDY ON MECHANICAL PROPERTIES OF INDUSTRIAL BY PRODUCTS AS FINE AGGREGATE IN METAKAOLIN CEMENT CONCRETE

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ABSTRACT

From the study, it is understood that many research works have been done by using copper slag as individual replacement for sand. And also the researches have been done by replacing cement by individual GGBS and metakaolin or the blends of these two materials. There are no studies available by combining these three materials together to improve the mechanical performance of concrete. Hence in this paper, the above three materials copper slag, GGBS and metakaolin are simultaneously replaced in concrete mixture for sand and cement respectively. And also this paper presents, ternary replacement of industrial wastes for binder and fine aggregate was simultaneously replaced in each concrete mix to determine the strength of concrete. The merger effect of these ternary materials is investigated and the characteristics of concrete are upgraded more than individual or binary materials replacement.

***KEYWORD:-** Cement, industrial waste, environmental impact, benefits, properties*

INTRODUCTION

Cement, sand, coarse aggregate, and water are the most common ingredients in conventional concrete. A large amount of heat is produced during hydration and manufacturing of cement, and greenhouse gas CO_2 is emitted, causing global warming and climate change. Furthermore, natural sand is consumed for the production of concrete, resulting in the depletion of natural resources. To address this issue, traditional concrete-making materials are being replaced with industrial waste.

Various actions have harmed our natural environment in general. Natural resources are mostly reduced as a result of human activities such as industrialisation and technological advancement. However, industrialisation is a critical aspect in our country's development. There are several industries all over the world that contribute to the prosperity of the country. Meanwhile, the industries are growing, as are the wastes created by the industry. To reduce pollution in our environment, industrial wastes are reduced by substituting cement and sand in the making of concrete.

Concrete is most often utilised building material because to its low cost, availability, and durability. Cement, sand, coarse aggregate, and water are the most common elements of concrete. Mineral admixtures and chemical admixtures are sometimes added to concrete to improve its mechanical, durability, & microstructure qualities. Fine aggregate and cement are partially substituted in this study by certain industrial materials that are dangerous to our environment. Our ecosystem has been contaminated as a result of the disposal of these wastes to land, water, and air bodies. Furthermore, by partially substituting industrial wastes in concrete, the properties of the material are enhanced. By utilising industrial wastes in concrete, the environment is preserved as well as the qualities of concrete are improved.

The wastes include solid, liquid, and gas, and each requires a separate disposal method. The wastes might be industrial, biological, domestic, or special wastes that are hazardous to human health and the environment. Industrial wastes are wastes generated by industries during the manufacturing process. Metals, industrial byproducts, sludge, radioactive wastes, chemical solvents, paints, ash, paper products, sludge, pigments, and sand paper are some types of industrial waste. The effective utilisation of industrial by-products is investigated here. To avoid environmental contamination, industrial wastes containing harmful pollutants should be handled effectively. Otherwise, the wastes pollute the land, water, and air, posing a hazard to human health and the environment. Some wastes are recycled, while others are changed from poisonous to non-toxic and disposed of in landfills. Some are burnt at high temperatures in order to be destroyed. And the impacts of these wastes have grown less hazardous than previously. Hazardous industrial wastes exhibit a variety of hazardous properties, including corrosivity, reactivity, ignitability, and toxicity. Our natural resources are harmed as a result of the disposal and dumping of these harmful industrial wastes.

ENVIRONMENTAL IMPACT OF DISPOSING INDUSTRIAL WASTES

In general, dumping industrial waste into bodies of water, land, and air pollutes the environment. The wastes emitted by industry are used in this task. Copper slag from the copper industry, GGBS (Ground Granulated Blast Furnace Slag) from the steel industry, & metakaolin from the kaolin sector are all utilised efficiently. While producing one tonne of copper, around 2 to 3 tonnes of copper slag are discharged. Every yr, about 24.6 million tonnes of slag from all around the world are disposed of. This vast amount of copper slag is disposed of and poured onto the soil, causing environmental and space problems. Copper, cadmium, arsenic, barium, zinc, and lead are all hazardous metals found in copper slag. Copper slag contains harmful substances that damage the soil and pollute the plants. GGBS is released in quantities ranging from 150 to 230 million tonnes per year. Metakaolin is created by activating ordinary clay with kaolinitic clay at temperatures ranging from 500°C to 800°C. Kaolin, often known as china clay, is a clay composed primarily of the hydrated alumino silicate clay mineral kaolinite. Each tonne of Kaolin produced creates 9 tonnes of garbage, with a total of 22 million tonnes of waste created for all industries each year. The disposal of GGBS and kaolin complicates environmental safety. The majority of solid industrial waste is disposed of in landfills. The dumping and disposal of these pollutants infect the soil and harm ground water. Rather than discarding the trash, it may be used to make concrete.

BENEFITS OF CONCRETE WITH INDUSTRIAL WASTES

Despite the fact that industrial waste disposal is hazardous to the environment, it has certain relevant physicomechanical qualities that can be used to substitute concrete forming ingredients. The use of industrial waste in concrete creates a more sustainable environment while also improving the qualities of the concrete. Industrial waste is employed not only in concrete but also in ballast, roofing granules, fill, abrasive aggregate, tiles, glass, and other products.

The copper slag has adequate mechanical qualities, including the highest stability, abrasion resistance, and soundness. Copper slag has a black glassy surface & a high friction angle due to its sharp angular form. It has a larger unit weight and a lesser absorption capacity than standard aggregate. Copper slag has a higher density than natural sand. Furthermore, certain of the qualities of copper slag are comparable to or superior than those of ordinary aggregates. According to microscopic examination, the well-crystallined structure of copper slag contains iron oxides, silica oxides, alumina oxides, lime oxides, and magnesia oxide, which provides the lowest potential of corrosive activity. Copper slag concrete has lesser bleeding and shrinkage qualities than river sand concrete. Similarly, copper slag has a stronger freezing-thawing resistance than river sand. Furthermore, the strength parameters of copper slag concrete are noticeably higher than those of normal concrete.

GGBS is a non-metallic substance that comprises silicates & alumino silicates of calcium & other bases. It has a crystalline and glassy surface, a lower specific gravity, and a finer grain size than cement. When added to concrete, GGBS has beneficial features such as improved workability and pumpability, lower heat of hydration, strength enhancement, permeability, strong resistance to sulphate attack, chloride penetration sulphate attack, and Alkali Silica Reaction. GGBS is finer than cement and has a lower specific gravity. Because GGBS concrete has a more refined pore structure than normal concrete, it is less permeable and more durable. Another factor for GGBS concrete's superior durability is the pozzolanic reaction of GGBS, which reduces gel pores.

Metakaolin has a higher surface area than cement and an uneven or plate-like form, which increases the water requirement in concrete. Super plasticizers are added to overcome this problem, and the merging activity of MK and SP generates more workable concrete than normal concrete. Because of its filling and pozzolanic activity, metakaolin adds to the durability and strength of the concrete. Furthermore, as a result of its pozzolanic activity, a more densified microstructure is formed. When added to concrete, metakaolin has the following benefits: increased strength, reduced permeability, resistance to chemical assault, alkali silica reactivity, increased durability, lesser shrinkage, enhanced workability, and superior finish ability.

EXPLOITATION OF INDUSTRIAL WASTES IN CONCRETE

The most significant criteria for a country's progress are industrialization and technological advancement. However, as companies expand, so do the trash created by those sectors. To address this issue, industrial wastes are recycled into other usable goods. One solution is to use industrial wastes in concrete production materials since they have a lower cast and are more readily available than traditional resources. The cement and sand are mostly replaced by industrial wastes. By replacing the cement and sand with industrial wastes provides both sustainable environment and concrete and protects natural resource and provides resource conservation. Even though having disadvantages while discharging into environment, they both have more benefits when replacing with cement and sand. The utilization of industrial wastes in concrete gives economic and environmental advantages. The environment is protected as well as the cost of concrete is minimized by utilizing the industrial wastes.

LITERATURE REVIEW

Poon et al. (2001) noticed that the highest compressive strength is obtained for 10% metakaolin replacement. The porosity and pore diameter is lessened by the addition of metakaolin as a result of its filling action and pozzolanic action.

Jin & Li (2003) reported that the mechanical strength and modulus of elasticity of concrete is improved by the inclusion of metakaolin. The mechanical properties of young concrete are enhanced due to the addition of metakaolin.

Zain et al. (2004) leant that the requirement of water content with 10% copper slag replacement is lower than control mix due to its low moisture absorption property. The initial and final setting time of concrete is greatly increased by the addition of copper slag. The reason is that the compounds of Cu, Pb, Zn in the copper slag are set inhibiting.

Caijun Shi et al. (2008) reported that the mortar containing 10% copper slag replacement, gives the maximum and flexural strength which improves abrasion resistance. 40% copper slag replacement is best for controlling bleeding due to heavy specific weight and glass like smooth surface properties of irregular grain shape of copper slag.

Rafat Siddique & Juvas Klaus (2009) examined that the CH content is lowered up to 15% metakaolin replacement by the pozzolanic action. Beyond 15% metakaolin replacement, $Ca(OH)_2$ content is increased owing to the hydration of OPC. The metakaolin insertion reduces slump values and increases setting time. For 10% metakaolin replacement, the setting time is same as OPC concrete. For 20% metakaolin replacement, the setting time is diminished.

Wei Wu et al. (2010) revealed that the workability of control concrete is 60 mm and the workability of 100% copper slag concrete is 245 mm. from the results, the slump value is increased while raising copper slag content. The first reason is low moisture absorption property of copper slag which enhances the workability of concrete. Another reason is shear resistance is lowered by copper slag due to its smooth glass surface texture which improves workability of concrete.

Dinakar et al. (2013) examined that the replacement of metakaolin increase when increasing superplasticizer. For example the replacement of metakaolin 5%, 10% and 15% needs 37.5%, 62.5% and 100% dosage of super plasticizer. The high specific area of metakaolin makes the concrete more agglomerate increases the electrostatic force between the cement and particles. The addition of superplasticizer disperses the agglomerated particles and improves the workability of concrete.

San Nicolas et al. (2014) examined that the metakaolin concrete gives lower permeability, high strength concrete. Metakaolin decreases the chloride ion penetration. The overall water demand is reduced and workability is improved by metakaolin concrete.

Narasimhan (2015) reported that the higher density concrete is produced by the higher content of copper slag than control concrete. The low water absorption property of copper slag increases the water demand in concrete which enhances the workable property of concrete.

Erdogan Ozbay et al. (2016) investigated that the workability of GGBS concrete is improved owing to its smoothness, cementitious property, dense, and low water absorption. Up to 30% replacement of GGBS, the better flow ability is improved due to its high specific surface area, roughly spherical particles. The better workable property of concrete is achieved by the addition of GGBS because of its dense and smooth surface characteristics. The highest level heat of hydration is attained for 60% GGBS replacement due to the acceleration of GGBS. The initial and final setting time is increased up to 60% GGBS replacement.

Nikhil Saboo et al. (2019) studied widely considering its environmental benefits. Owing to its porous nature, it reduces the runoff quantity recharging the groundwater and as well reduces the effect of urban heat island. In this study, fly ash and metakaolin were used as partial replacement for OPC with curing condition as another variable. Basic tests such as porosity, density, compressive strength, and permeability were conducted to determine the effect of test variables. Statistical tests indicated that fly ash content dominated the effect on influencing permeability and compressive strength.

Larissa Mello et al. (2020) evaluate the behaviour of SCC at high temperatures replacing cement by sugarcane bagasse ash and metakaolin at contents of 30% to 50%. For this purpose, five SCC compositions were assessed for self-compactness by slump-flow, J-ring, L-box and V-funnel tests, as well as visual stability index. Results showed that SCC with up to 40% of sugarcane bagasse ash and metakaolin is less sensitive to high temperatures presenting less cracking and lower strength losses compared to room temperature.

Ujjwal Sharma et al. (2020) conducted to know the mechanical properties of this concrete having MDP (marble dust powder), BDP (brick dust powder) and CDP (ceramic dust powder as replacement to cement. Additionally, slump test was done to predict the workability of concrete. In relation to MDP and BDP values of slump for CDP were found to be in decreasing order with increase in the replacement percentage. 10%, 12.5% and 7.5% were the best replacement percentages for MDP, BDP and CDP respectively in case of compressive strength test as well as split-tensile-strength for all days of curing. But CDP could not show the long term effect in strength increment in comparison with the conventional concrete.

Gaurav Chand et al. (2021) proposes a sustainable solution to the non-eco-friendly technique of cement production, without compromising the quality of produced concrete. In the primary stages of the investigation undertaken, cement is replaced with different cementitious materials like glass powder, metakaolin and silica fume at different percentages by weight. After conducting mechanical properties tests, optimum replacement percentages are obtained and consequently a quaternary blend of hybrid concrete is prepared containing cement + glass powder + metakaolin + silica fume, in the ratio 60:20:05:15thier. The final test results show an increase in compressive strength of hybrid concrete by 13.42% compared to control mix after 28 days of curing. Additionally, a mild reduction of 11.44% strength at 28 days in acidic environment is noticed as opposed to the 17.92% reduction in control mix in the same environment. The micro-structural investigation conducted under scattered electron microscope (SEM) validates the development of strength imparting compounds like calcium silicate hydrate (C–S–H) and calcium alumino-silicate hydrate (C-A-S-H), leading to the dense formation of microstructure.

MECHANICAL PROPERTIES

COMPRESSIVE STRENGTH TEST

The compressive strength test is used to determine behaviour of concrete when a compressive load is applied. The compressive strength was determined in accordance with IS: 516-1959. Figures 1 and 2 depict the specimens under testing and the specimens following testing, respectively. 150 mm cube specimens were cast and evaluated after 14, 28, 56, 90, & 180 days. The specimens collected during curing were dried and evaluated. The specimen was placed in the machine, & load was applied without shock & steadily increased at a rate of roughly 140 kg/sq.cm/min until specimen failed. The load at the first fracture and the failure load were recorded. Finally, the compressive strength was computed using formula below.

Compressive strength = Ultimate Load /Area of the specimen

FIGURE 1 CUBES UNDER TESTING

FIGURE 2 CUBES AFTER TESTING

SPLIT TENSILE STRENGTH TEST

The split tensile strength was determined in accordance with IS: 5816-1999. Cylindrical specimens with diameters of 150 mm & heights of 300 mm were cast and tested after 28, 56, 90, & 180 days. The specimens collected during curing were dried and evaluated. Figures 2 and 3 depict the specimens under testing and the specimens after testing, respectively. The specimen was placed in the machine, and the load was applied without shock & gradually raised at a notional rate ranging from 1.2 N/(mm^2/min) to 2.4 N/(mm^2/min) until the specimen broke. The load at the first fracture and the failure load were recorded. Finally, split tensile strength was computed using formula below.

Split Tensile strength = $\frac{2p}{\pi ld}$

where,

p = maximum load applied to specimen
d = length and diameter of specimen respectively.

FIGURE 3 CYLINDERS UNDER TESTING

FIGURE 4 CYLINDERS AFTER TESTING

FLEXURAL STRENGTH TEST

The flexural strength was measured in accordance with IS: 516-1959. Beam specimens of 100 x 100 x 500 mm were cast & evaluated after 28, 56, 90, and 180 days. Figures 5 and 6 depict the specimens under testing and the specimens following testing, respectively. The specimens collected during curing were dried and evaluated. The specimen was placed in the machine, & load was applied without shock and steadily increased at a rate of roughly 7 kg/sq cm/min, or 180 kg/min for 10.0 cm specimens. The load is raised until specimen fails. The maximum load was determined. Finally, flexural strength was calculated using the following formula for the case ;a,' which is less than 13.3cm and larger than 11cm for a 100 mm specimen. an is the distance b/w fracture line & nearest support.

Flexural Strength = $\frac{pxl}{bxdz}$

where,

p = ultimate failure load

l, b, d =length, breadth & depth of specimen respectively.

FIGURE 5 BEAMS UNDER TESTING

FIGURE 6 BEAMS AFTER TESTING

IMPACT STRENGTH TEST

The impact test was carried out in accordance with ACI 544.2R-89-2006 on a specimen with a diameter of 150 mm & a height of 63.5 mm. After 28 days of curing, the specimens were placed in an impact testing machine with a steel ball with a diameter of 63.5 mm. The load was then imparted by lowering the hammer from a height of 457 mm. The weight of the hammer is 4.54 kg. The number of blows was applied till the specimen failed. Figure 7 depicts the specimens after failure. The number of strikes at the initial fracture and the ultimate failure were recorded. The following equation was used to compute the impact strength: The impact strength is calculated as M x g x H x N, where,

M – Dropped mass = w/ g
H – Height of dropped mass
N – Number of blows at ultimate failure.

FIGURE 7 IMPACT SPECIMENS AFTER FAILURE

PULL-OUT TEST

The pull out test was performed in accordance with IS: 2770-Part1- 1967 to determine the bond strength of concrete. 150mm cubes are casted as examples. A 500mm long 16mm diameter rod is inserted in the centre of the specimen. The specimens are cured for 28 days with insulated tapes wrapped around the rods. The specimen is positioned such that the rod is well away of UTM's jaws. The load is applied to the reinforcing bar at no more than 2 250 kg/min. P denotes the maximum load of failure. Figures 8 and 9 show the specimens while they are being tested and the specimens after they have been tested. The bond strength or pull out strength is computed as follows:

Bond Strength = P / (□DLe)

where,
P – Load (N)
Le – Length of rod embedded (mm)
D – Diameter of bar (mm)

FIGURE 8 PULL OUT SPECIMENS

FIGURE 9 SPECIMENS AFTER TESTING

FLEXURAL BEHAVIOUR OF RCC BEAM

Figures 10 and 11 depict the reinforcement details of the RCC beam and the experimental setup for the Flexural Behavior of the RCC Beam, respectively. The beams were tested under a 500 Kn capacity loading frame after 28 days of curing. The flexural toughness test was carried out under four-point loading on a beam with a 900 mm span that was simply supported at one end and roller supported at the other. Dial gauges were used to evaluate deflections at mid-span and loading locations. The weight was applied using a hydraulic jack, which was raised until the beams failed. The failure load and the first fracture load were measured.

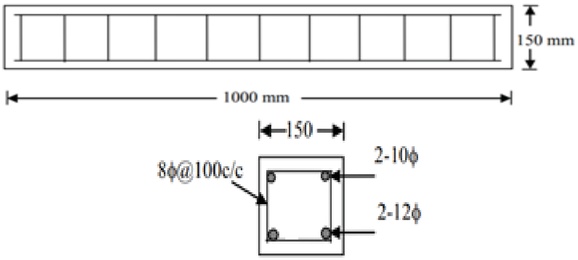

FIGURE 10 REINFORCEMENT DETAILING OF RCC BEAM

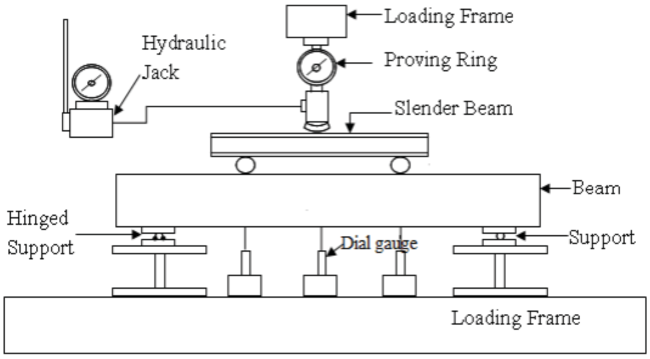

FIGURE 11 EXPERIMENTAL SETUP FOR FLEXURAL BEHAVIOR OF RCC BEAM

DISCUSSION

COMPRESSIVE STRENGTH

Figure 12 depicts compressive strength findings of concrete mixes made by substituting fine aggregate with copper slag & cement with metakaolin and GGBS at various percentage levels. According to the Figure, the concrete specimen with copper slag as fine aggregate enhanced compressive strength of the concrete at all ages. At 14 days, mix MC5 had a compressive strength that was approximately 32 percent higher than standard concrete MC1. After 28 days of curing, compressive strength of MC5 mix was approximately 29% higher than that of concrete without copper slag replacement (MC1). The addition of 10% metakaolin, 10% GGBS, and 40% copper slag replacement may have contributed to the enhanced compressive strength of the MC5 mix. This demonstrates that replacing copper slag with up to 40% copper slag increases compressive strength of concrete. The compressive strength gradually declines beyond 40 percent content.

(Wei Wu et al. (2010) discovered that increased compressive strength of mixes with copper slag replacement was mostly attributable to the copper slag's higher compressibility than normal sand. At 28 days, the strength increase in the MC3 mix, which comprised 10% metakaolin, 10% GGBS, and 20% copper slag, was around 22% when compared to the standard concrete mix MC1. This demonstrates that the amount of copper slag has a greater impact on concrete compressive strength than metakaolin and GGBS. The compressive strength of concrete MC2, which contained 20% copper slag replacement for fine aggregate and 5% GGBS and 5% metakaolin as replacement for cement, was small when compared to compressive strength of mix MC1, whereas strength improvement of concrete mix MC4, which contained the same percentage replacement of copper slag as MC2 mix, showed a 16 percent compressive strength improvement over the normal concrete mix MC1. This demonstrates that copper slag is efficient in raising the compressive strength of concrete, and that inclusion of metakaolin & GGBS raises strength of the concrete to a higher level.

Figure 13 depicts relative compressive strength of concrete using GGBS and metakaolin as percentage replacements for cement and copper slag as fine aggregate replacement. When compared to control mix, range of improvement in strength for 28 days ranges from 4 to 29 percent due to the GGBS cement ratio and copper slag sand ratio with metakaolin. It is obvious that the MC5 mix achieves about 92 percent of the 28-day strength during earlier curing periods of 14 days. The 180-day compressive strength of concrete was raised by approximately 16% above 28-day compressive strength of concrete for the MC5 mix. This demonstrates the joint influence of copper slag replacement, metakaolin, and GGBS on early strength development in concrete as well as enhancing the compressive strength of concrete at later stages of curing. The efficiency of GGBS and metakaolin admixtures, as well as copper slag substitution, may explain the improvement in compressive strength development during early stages of concrete curing.

The MC5 mix exhibited a 31 percent increase in compressive strength at 14 days, a 28 percent increase in compressive strength at 28 days, a 26 percent increase in compressive strength at 56 and 90 days, & a 27 percent increase in compressive strength at 180 days at various percentage replacements of copper slag for fine aggregate & GGBS and metakaolin for cement. The percentage gain in 180-day concrete strength is greater for the MC5 mix, which is consistent at all ages. Because of the agglomeration created by metakaolin, increasing metakaolin has a negative influence on compressive strength of concrete in all of concrete mixes investigated here. However, detrimental impact of metakaolin on compressive strength was offset by the inclusion of GGBS, which increased compressive strength across all curing agents. However, it is obvious that increasing the amount of fine aggregate replacement by copper slag to around 40% has a negative effect on concrete compressive strength. As a result, it can be inferred that maintaining an optimal percentage replacement of copper slag at 40% is useful in boosting the compressive strength of concrete at all ages when compared to concrete with no replacement.

Because of the filler effect, pozzolanic reaction of metakaolin, the presence of 10% metakaolin resulted in greater compressive strength. The compounding effect of metakaolin is also significant in concrete mixes containing copper slag as fine aggregate replacement due to the copper slag's nonwater absorbing capacity, which increases the amount of free water available, causing bleeding and lowering the compressive strength of concrete. In compared to regular sand, metakaolin's compounding action neutralises the influence of copper slag, which promotes workability while affecting concrete's compressive strength. As a result, the combined impact of metakaolin and copper slag is counter-balancing and results in favourable strength outcomes. The increase in compressive strength of the concrete containing 40% substitution of fine aggregate by copper slag might be attributed to physical features of copper slag, such as increased compressibility, which aids in the partial release of stress concentrations.

Furthermore, the angular form of the copper slag enhances cohesiveness between the copper slag & cement matrix, increasing strength of concrete. The rough surface and strong abrasion properties of copper slag can also promote cohesiveness between cement pastes and aggregate, which is an essential element in strength development. The improvement in compressive strength of concrete at later ages of the mix containing the copper slag replacement over normal concrete is due to the negative property of the sand, which weakens with time, as well as the weathering property of the sand, which is said to have round edges, whereas the angular property of the copper slag improves the interlocking capacity of the aggregates with the cement matrix. According to the findings, the strength value of concrete mixes MC6 and MC7 is reduced due to a larger replacement percentage (more than 40%) of copper slag, which results in insufficient cement content for binding concrete matrix together as a result of excess water in concrete.

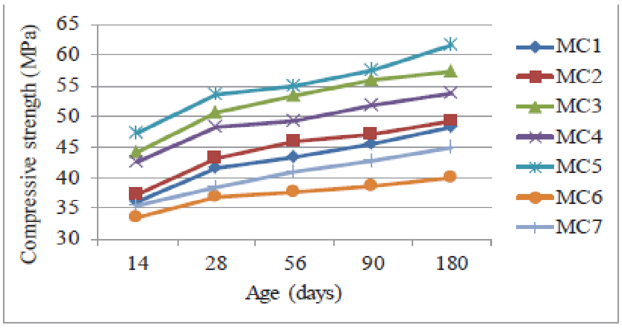

FIGURE 12 COMPRESSIVE STRENGTH OF CONCRETE AT VARIOUS AGES

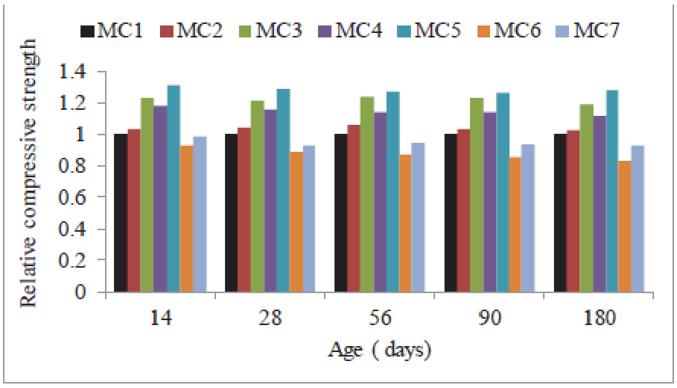

FIGURE 13 RELATIVE COMPRESSIVE STRENGTH OF CONCRETE WITH REFERENCE TO NORMAL CONCRETE (MC1)

TABLE 1 RATE OF COMPRESSIVE STRENGTH DEVELOPMENT OF CONCRETE MIXES AT VARIOUS AGES WITH RESPECTIVE TO 28 DAYS STRENGTH

S.NO.	MIX IDENTIFICATION	COMPRESSIVE STRENGTH DEVELOPMENT COMPARED TO RESPECTIVE 28 DAYS (%)				
		14 DAYS	28 DAYS	56 DAYS	90 DAYS	180 DAYS
1	MC1	86.60	100	104.29	109.64	116.27
2	MC2	85.95	100	106.04	109.10	114.10
3	MC3	87.47	100	105.76	110.55	113.32
4	MC4	88.28	100	102.35	107.63	111.57
5	MC5	88.41	100	102.75	107.63	115.22
6	MC6	90.64	100	101.98	104.86	108.63
7	MC7	92.19	100	106.64	111.22	116.74

FLEXURAL STRENGTH

Figure 14 depicts the flexural strength findings at 28, 56, 90, and 180 days for different mixtures containing copper slag, GGBS, metakaolin, and a control mix. The use of copper slag as a partial replacement for fine aggregate, as well as GGBS and metakaolin as partial replacements for Portland cement, resulted in higher flexural strength than regular concrete. The mix MC3, which exhibited a 45 percent increase in flexural strength at 180 days, demonstrated the greatest gain in flexural strength when compared to conventional concrete. The flexural strength of MC3 mix after 28 days was approximately 23% higher than that of standard concrete mix MC1. The greater flexural strength of MC3 mix was obviously related to the substitution of fine aggregate with 20% copper slag & cement with 10% GGBS and 10% metakaolin. At 28 days, flexural strength of concrete mix MC4 was roughly 12% greater than that of standard concrete mix MC1. At 28 days, MC5 mix had a 19% increase in flexural strength. Thus, the addition of 10% metakaolin and GGBS each improved flexural strength of MC5 by increasing fineness of the matrix due to their larger specific surface area, which actively linked cement matrix & aggregates.

According to findings, a 20% copper slag substitution increased the flexural strength of concrete when combined with 10% metakaolin and 10% GGBS. Figure 15 depicts the relative increase in flexural strength at 28, 56, & 90 days in comparison to standard concrete. It is obvious that MC3 mix had good flexural performance at all ages. These findings reveal that copper slag as a fine aggregate substitute paired with metakaolin and GGBS outperforms standard Portland cement concrete in terms of flexural performance. The enhanced flexural strength of the copper slag replaced concrete blended with metakaolin and GGBS might be attributed to the metakaolin and GGBS filler effect, as well as the greater fineness of copper slag with a wide surface area. When flexural strength is compared to compressive strength findings for the identical MC3 mix, the compressive strength value is not as high as the flexural strength value. The reason for this is that the length of a flexural strength specimen is greater than that of a compression strength specimen, resulting in a major shift in the specimen's stress-strain failure. When stress wave strikes specimen, the longer length specimen takes longer to equilibrate than the shorter length specimen. Table 2 shows the rate of flexural strength development of concrete mixes at various ages with respect to 28 days strength.

It is obvious that the concrete containing 10% metakaolin and GGBS as cement replacements, and 20% copper slag as fine aggregate replacement, shown enhanced strength at all ages of 56, 90, and 180 days. The 180-day flexural strength of the concrete mix MC3 was approximately 40% more than the 28-day strength. This clearly demonstrates GGBS and metakaolin's effective participation in raising the flexural strength of concrete at later phases. In contrast, concrete with 20% copper slag replacement & 5% GGBS & metakaolin replacement in each had a lower strength at later stages than the other mixes. The 180-day flexural strength of MC2 concrete mix was only around 10% higher than the 28-day strength. The flexural strength development with age also revealed that replacing fine aggregate with copper slag results in a gradual rise in flexural strength when paired with 10% GGBS and metakaolin. The flexural strength of concrete mixes MC6 and MC7 was lowered at all ages. The decrease in strength was caused by an increasing proportion of fine aggregate replacement with copper slag. This implies that increasing the percentage replacement of copper slag increases flexural strength of concrete, but only up to an optimal value, beyond which the flexural strength decreases with greater copper slag concentration. This decrease in flexural strength at greater percentages of copper slag replacement is mostly caused by the angular sharp edges of copper slag, which lowers cohesion between matrix and particles, making concrete brittle. Thus, the flexural strength of the concrete may be improved by leveraging beneficial effects of copper slag, however when copper slag is added beyond 20%, the cohesiveness of the concrete decreases, which significantly affects flexural strength of concrete.

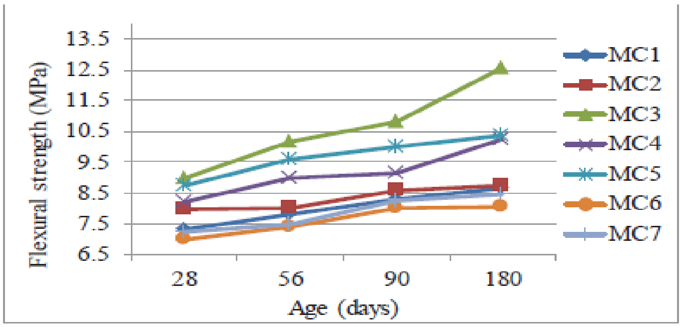

FIGURE 14 FLEXURAL STRENGTH OF CONCRETE AT VARIOUS AGES

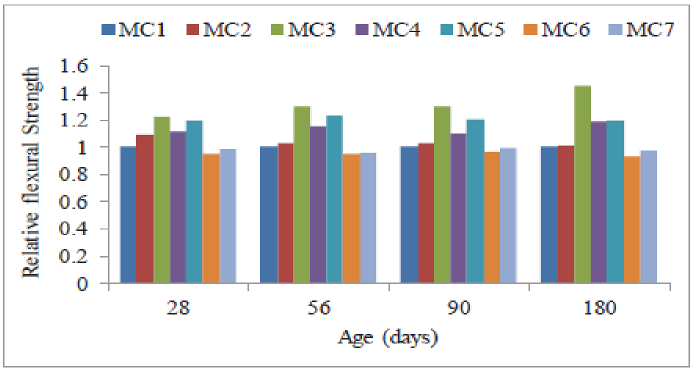

FIGURE 15 RELATIVE FLEXURAL STRENGTH OF CONCRETE MIXES WITH REFERENCE TO NORMAL CONCRETE (MC1)

TABLE 2 RATE OF FLEXURAL STRENGTH DEVELOPMENT OF CONCRETE MIXES AT VARIOUS AGES WITH RESPECTIVE TO 28 DAYS STRENGTH

S.NO.	MIX IDENTIFICATIONS	FLEXURAL STRENGTH DEVELOPMENT D TORESPECTIVE 28 DAYS (%)			
		28 DAYS	56 DAYS	90 DAYS	180 DAYS
1	MC1	100	106.28	113.37	118.14
2	MC2	100	100.50	107.52	109.65
3	MC3	100	112.89	120.33	139.89
4	MC4	100	109.76	111.83	125.12
5	MC5	100	109.49	114.29	118.63
6	MC6	100	105.86	114.71	115.29
7	MC7	100	103.45	113.93	116.55

SPLIT TENSILE STRENGTH

Figure 16 depicts split tensile strength values at 28, 56, 90, & 180 days for different mixtures containing copper slag, GGBS, metakaolin, and a control mix. At all testing ages, split tensile strength of 20 percent copper slag replaced concrete mix MC3 was found to be greater than that of conventional concrete mix MC1 without any replacements. Figure 17 depicts split tensile strength of concrete mixes in relation to reference mix. The Figure clearly demonstrates the enhanced split tensile strength of concrete mix MC3 at all ages. The MC3 mix improved its spit tensile strength by roughly 37% over the standard concrete mix MC1 at 180 days.

The inclusion of metakaolin and GGBS, together with the impact of copper slag replacement, may account for the enhanced split tensile strength of MC3 mix. The angularity of copper slag & the surface roughness of the metakaolin and GGBS both contributed to the concrete's split tensile strength. The split tensile strength of concrete mixes MC6 & MC7 was found to be lower than that of standard concrete mix MC1. This might be attributed to increased replacement levels of copper slag above 40%, which has created the brittleness of the concrete. Table 3 depicts the evolution of the split tensile strength of concrete mixes in relation to 28-day split tensile strength. The improvement in the split tensile strength of MC3 mix after 180 days was determined to be 62 percent greater than the strength at 28 days based on the tabulated data. The data also show that the rate of increase in the split tensile strength of concrete was faster for concrete containing 10% metakaolin and 10% GGBS as cement replacements. This is due to the active interaction of metakaolin with GGBS, which results in the development of reaction products with greater strength than standard concrete.

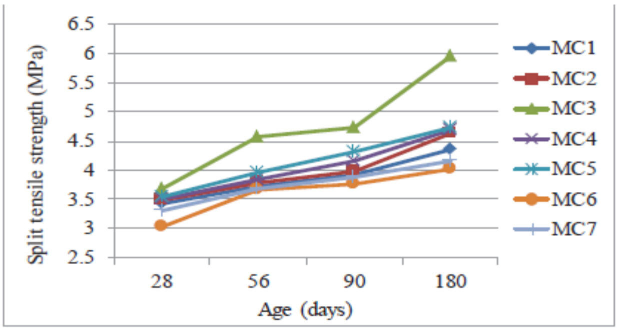

FIGURE 16 SPLIT TENSILE STRENGTH OF CONCRETE AT VARIOUS AGES

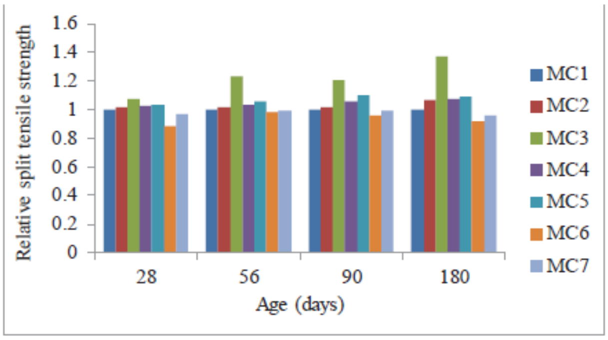

FIGURE 17 RELATIVE SPLIT TENSILE STRENGTH OF CONCRETE MIXES WITH REFERENCE TO NORMAL CONCRETE (MC1)

TABLE 3 RATE OF SPLIT TENSILE STRENGTH DEVELOPMENT OF CONCRETE MIXES AT VARIOUS AGES WITH RESPECTIVE TO 28 DAYS STRENGTH

S. NO.	MIX IDENTIFICATIONS	SPLIT TENSILE STRENGTH DEVELOPMENT COMPARED TO RESPECTIVE 28 DAYS (%)			
		28 DAYS	56 DAYS	90 DAYS	180 DAYS
1	MC1	100	108.77	114.62	127.19
2	MC2	100	108.62	114.37	133.05
3	MC3	100	124.46	128.26	161.96
4	MC4	100	109.12	118.23	133.62
5	MC5	100	111.58	122.03	133.62
6	MC6	100	121.19	124.83	132.78
7	MC7	100	111.18	117.22	125.68

IMPACT STRENGTH

Figure 18 depicts the impact strength values of concrete containing copper slag, GGBS, metakaolin, & control concrete. The impact strength of concrete is primarily determined by its capacity to sustain unexpected loads acting on it. The concrete mix MC5, which contained 10% metakaolin, 10% GGBS for cement, and 40% copper slag replacement for fine aggregate, had highest impact strength. The impact strength of concrete mix MC5 was found to be 39% more than that of standard concrete mix MC1. This demonstrates that the copper slag has a stronger impact on raising the energy required for concrete cracking. It can also be seen that metakaolin and GGBS play an important role in improving concrete's resistance to impact load. The impact strength of the concrete mix MC3 was found to be 31% more than that of standard concrete. These mixtures included the same quantity of GGBS and metakaolin but different % replacements of copper slag.

As a result, the difference in strength between the two mixes was mostly caused by the increased amount of copper slag. The copper slag aids in the development of the impact strength of concrete. Because of their pozzolanic activity, the presence of GGBS & metakaolin has a significant influence on impact strength of concrete. The concrete mix MC6, which comprised 60% copper slag replacement, 5% GGBS, and 5% metakaolin, yielded the lowest impact strength value. The impact strength of concrete mix was reduced by 36% compared to standard concrete mix MC1. This might be related to the copper slag's higher porosity and poorer bonding with the cement matrix.

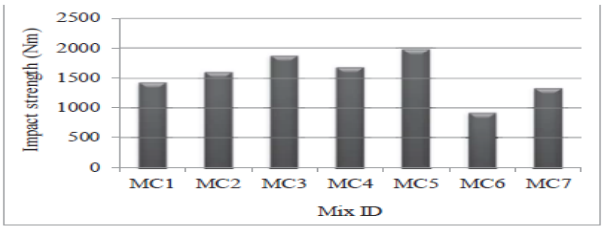

FIGURE 18 IMPACT STRENGTH OF CONCRETE MIXES

BOND STRENGTH

Figure 19 depicts bond strength of different concrete mixes containing copper slag, GGBS, metakaolin, and control concrete. The concrete mix MC3, which comprised 10% metakaolin, 10% GGBS, and 20% copper slag replacement for fine aggregate, had highest bond strength.

However, there was no increase in bond strength for concrete mixtures with a larger % replacement of copper slag. The increase in bond strength followed the same pattern as split tensile strength of concrete. This also guarantees that the increase in split tensile strength enhances the shear resistance of the concrete and strengthens the connection between the concrete and the steel bar. The enhanced bond strength of concrete mixes MC3 and MC5 may be due to 10% replacement of cement by metakaolin and GGBS, which generated superior chemical and physical adhesion b/w concrete & steel bar surface. The increase in concrete bond strength may also be due to an increase in mechanical interlocking behaviour as a result of increasing the fineness of the cement matrix by replacing metakaolin and GGBS, which have a high specific surface area & pozzolanic activity. The production of very dense reaction products resulted in a rise in density & compactness of concrete, as well as an increase in its bond strength.

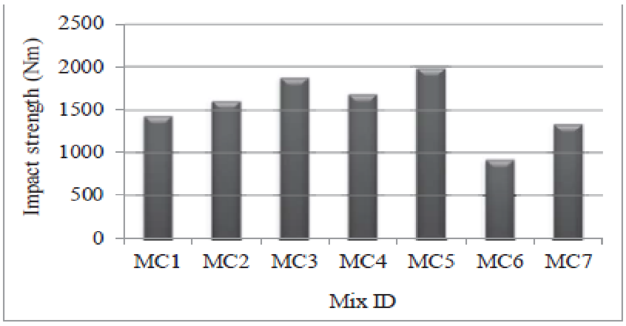

FIGURE 19 BOND STRENGTH OF CONCRETE MIXES

FLEXURAL BEHAVIOUR OF RCC BEAM

The flexural toughness of concrete is used to determine its flexural performance. Flexural toughness in concrete is often determined by measuring the area under load deflection graph up to a particular deflection. Figure 21 depicts the flexural toughness of the concrete as determined by the load deflection graphs generated from the bending tests. The flexural toughness of the concrete was greater in the concrete mix MC4 with 5% metakaolin, 5% GGBS, and 40% copper slag replacement. The explanation for concrete's ductility is due to its increased flexural toughness. The hardness increase in the concrete mix MC2, which comprised 5% metakaolin, 5% GGBS, and 20% copper slag replacement, was approximately 32% more than in regular concrete.

The difference in flexural hardness between the concrete mixes MC2 and MC3 and between MC4 and MC5 was measured to be 15%. This demonstrates that when the copper slag percentage remains constant but the metakaolin and GGBS replacements increase, the hardness of the concrete decreases. Because of their pozzolanic effect, the flexural toughness of concrete containing a minimal amount (5%) of GGBS and MK is increased. Beyond 5% MK (that is, 10%), the flexural hardness decreases due to metakaolin agglomeration, which causes discontinuity in concrete paste. Furthermore, angular surface roughness of GGBS and copper slag enhances the cohesiveness of the concrete only to a point, beyond which it reduces the flexural toughness of the concrete by changing it into a brittle material. The hardness of the concrete mix MC4 increased by approximately 48% when compared to control concrete MC1.

The flexural toughness of concrete mixes increased linearly for all copper slag-containing mixtures up to 40%. Because of the greater percentage substitutions of copper slag as fine aggregate in concrete mixes MC5 and MC6, flexural toughness of the concrete was reduced. Although copper slag is extremely compressible and improves strength performance, adding more than 40% copper slag reduces the hardness of the concrete. The inadequate bonding b/w copper slag particles & cement matrix may be responsible for the lower toughness of the concrete mixes MC6 and MC7. Figure 20 depicts the load deflection graph of the concrete beams when subjected to bending tests.

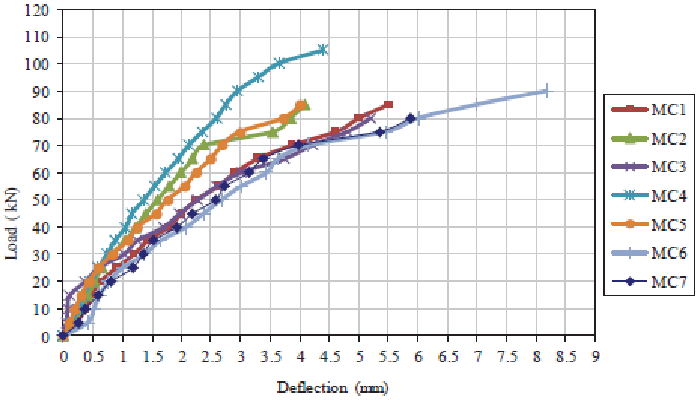

FIGURE 20 LOAD DEFLECTION GRAPH OF CONCRETE MIXES

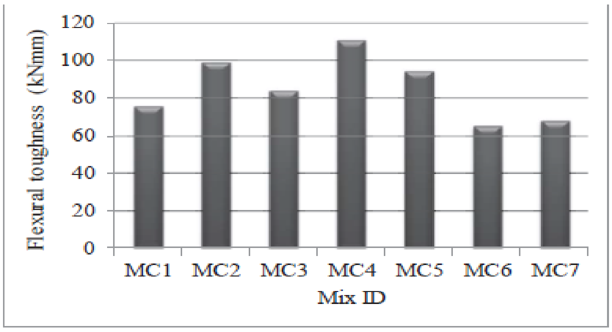

FIGURE 21 FLEXURAL TOUGHNESS OF CONCRETE MIXES

CONCLUSIONS

The following are the findings from the experimental investigation on concrete that replaced sand with copper slag & cement with metakaolin & GGBS at varied percentages.

1. In contrast to regular concrete, compressive strength was nearly doubled due to the copper slag replacement. However, adding more than 40% copper slag reduced the compressive strength of the concrete at all ages. To fulfil the compressive strength requirement of concrete, the ideal proportion of replacement of fine aggregate by copper slag is 40% and 10% by GGBS and MK, respectively. As a result, it is possible to conclude that the merging action with optimal replacement of copper slag, GGBS, and MK considerably increases the compressive strength of concrete.
2. The flexural strength of the concrete containing copper slag, metakaolin, and GGBS was likewise higher than that of the standard concrete. For maximal flexural strength, the optimum proportion of replacement of fine aggregate by copper slag was found to be 20%. The inclusion of 10% metakaolin and 10% GGBS also proved effective in increasing the flexural strength of the concrete.
3. The split tensile strength was also increased by replacing fine aggregate with 20% copper slag and cement with 10% metakaolin and 10% GGBS. The existence of an excessive amount of free water, as well as the glassy structure of the copper slag, can be attributed to the strength decline beyond the addition of 20%.
4. The impact strength of concrete with a 10% separate replacement of metakaolin and GGBS and a 40% replacement of copper slag is increased. The high compressibility of the copper slag, which consumes the impact energy acting on the concrete, was responsible for the increased impact strength. Furthermore, the pozzolanic action of the pozzolanic materials increases impact strength (GGBS and metakaolin).
5. The bond strength of concrete was also increased when 10% metakaolin and GGBS were used as cement replacements, and 20% copper slag was utilised as fine aggregate replacement. The addition of metakaolin and GGBS increased the shear strength of the concrete, which in turn increased the bond strength of the concrete due to their filling action.
6. The flexural toughness of concrete was increased by up to 40 percent when copper slag was added, and the cement was substituted with 5% metakaolin and GGBS. The increased amount of metakaolin has a compounding impact on the cement matrix, making the concrete brittle. Flexural toughness was increased by GGBS and MK, both of which have pozzolanic action.

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