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Determining the optimum percentages of fly ash, metakaolin and copper slag by replacing cement and fine aggregate in m30 grade concrete.

Determinación de los porcentajes óptimos de cenizas volantes, metacaolín y escoria de cobre mediante la sustitución de cemento y áridos finos en hormigón grado m30.

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ABSTRACT

The overall production of the cement has greatly increased which results lots of problems in environment as it involves the emission of CO_2 gas. Environmental concerns, stemming from the high energy expense and carbon dioxide emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials. Materials such as Metakaolin, fly ash have good pozzolanic activity and are a good material for the production of high strength concrete. Copper slag is a by-product of copper extraction by smelting. Copper slag can be used in concrete production as a partial replacement for sand. However, it is expected that the use of Metakaolin, Fly ash and Copper slag in concrete improves the strength properties of concrete.

Keywords: Supplementary cementitious material, cement, fine aggregate.

RESUMEN

La producción general de cemento ha aumentado considerablemente, lo que genera muchos problemas en el medio ambiente, ya que implica la emisión de gas CO2. Las preocupaciones ambientales, derivadas del alto gasto energético y la emisión de dióxido de carbono asociados con la fabricación de cemento, han generado presiones para reducir el consumo de cemento mediante el uso de materiales complementarios. Materiales como el metacaolín, las cenizas volantes tienen una buena actividad puzolánica y son un buen material para la producción de hormigón de alta resistencia. La escoria de cobre es un subproducto de la extracción de cobre por fundición. La escoria de cobre se puede utilizar en la producción de hormigón como reemplazo parcial de la arena. Sin embargo, se espera que el uso de metacaolín, cenizas volantes y escoria de cobre en el hormigón mejore las propiedades de resistencia del hormigón.

Palabras clave: Material cementante suplementario, cemento, agregado fino.

INTRODUCTION

Concrete means a mixture of a binding material, aggregates as filler materials and water. The cement concrete is a mixture of cement, sand, pebbles or crushed rocks and water. The cement concrete has attained the status of a major building material in the modern construction. Although Portland cement demands are decreasing in industrial nations, it is increasing dramatically in developing countries. Cement demand projections shows that by the year 2050 it will reach 6000 million tons. Portland cement production leads to major CO_2 emissions accounting for almost 0.7 tons of CO_2 per ton of cement, which represents almost 7% of the total CO2 world emissions. Not only CO_2 releases from cement manufacture but also SO3 and NO3 which can cause the greenhouse effect and acid rain. Since Portland cement is used mostly in concrete production, the most important building material on Earth, partial replacement by pozzolanic by-products and mineral additions will allow relevant carbon dioxide emission reductions.

Supplementary cementitious materials (SCM) are finely ground solid materials that are used to replace a portion of the cement in a concrete mixture. The supplementary cementitious materials may be naturally occurring or man-made waste. Various types of pozzolanic materials that improve cement properties have been used in cement industry for a long time such as Metakaolin and fly ash. Metakaolin possesses a high reactivity with calcium hydroxide having the ability to accelerate cement hydration. Since current concrete structures present higher permeability levels that allow aggressive elements to enter, leading corrosion problems, using pozzolanic admixtures not only reduce carbon dioxide emissions but also allow structures with longer service life, thus lowering their environmental impact (Bhaskara Teja Chavali and Perla Karunakar;2016) . Fly Ash is one of the major waste materials available from thermal power plants and its treatment and disposal was a problem in the early stages. When fly ash is replaced with OPC, it reacts with the calcium to form the calcium silicate hydrate (C-S-H) gel (Arka Saha et.al;2014). From previous works it is evident that they are very effective pozzolanic materials and effectively enhances the strength parameters of concrete.

Copper slag is a non ferrous slag obtained as a by-product during the matte (molten copper sulphide) smelting and refining of copper. Major constituents of a smelting charge are sulphides and oxides of iron and copper. As a result, copper-rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The molten slag is discharged from the furnace at 1000–1300 ^{0}C (Ambily P.S et.al;2015). When liquid slag is cooled slowly, it forms a dense, hard crystalline product where a quick solidification by pouring molten slag into water provides amorphous granulated slag. Recycling, recovering of metal, production of value added products and disposal in slag dumps or stockpiles are the options for management of copper slag. It has been widely used for abrasive tools, roofing granules, cutting tools, abrasive, tiles, glass, road-base construction, railroad ballast, asphalt pavements, cement clinker and blended cement production. Fine or coarse aggregate in the preparation of cement mortar Copper slag has been excluded from the listed hazardous waste category of the United States Environmental Protection Agency (USEPA). The United Nations (UN) Basel Convention on the Trans boundary Movement of Hazardous Waste and its Disposal also ruled that copper slag is not a hazardous waste. The slag was made of black glassy particles and granular in nature and has a particle size range similar to sand. At present about 33 million tons of copper slag is generating annually worldwide among that India contributing 6 to 6.5 million tones.

MATERIALS AND METHODS

The materials used in the experimental study are, Cement (OPC53), fly ash and metakaolin as cement replacement material, copper slag as fine aggregate replacement material and Superplasticizer.

A. Cement

In the present experimental work, Ordinary Portland cement of Grade 53 was used grade confirming to IS 12269:1987. Cement is generally used as the main binder material.

B. Fine Aggregate

Fine aggregates usually consist of river sand. Owing to the scarcity of river sand and the environmental impact of river excavations, m-sand was used as the fine aggregate in the present study. M-sand used was confirming to Zone II of IS 383:1970 (Reaffirmed 2016).

C. Coarse Aggregate

The coarse aggregates are generally crushed stones with size ranging from 20 mm to 4.75 mm. They occupy around 35 to 70% of the total volume of concrete. The coarse aggregates used were with a nominal size of 20 mm downgraded crushed granite aggregates. The properties of coarse aggregates were confirming to IS 383:1970 (Reaffirmed 2016).

D. Fly ash

Fly ash is an industrial waste product which is accepted as an environmental pollutant, generated during the combustion of coal for energy production. It can be used as admixtures or as replacement of cement.

E. Metakaolin

Metakaolin is artificially manufactured pozzolanic additive. Chemical formula of metakaolin is $Al_2O_3.2SiO_2$, a dehydroxylated aluminium silicate. It is the dehydroxylated form of the clay mineral kaolinite. Rocks that are rich in kaolinite are known as china clay or kaolin, traditionally used in the manufacture of porcelain.

F. Copper slag

Copper slag is a non ferrous slag obtained as a by-product during the matte (molten copper sulphide) smelting and refining of copper. Major constituents of a smelting charge are sulphides and oxides of iron and copper.

G. Superplasticizer

To improve the workability of concrete Superplasticizer is used. It is an admixture of a new generation based on modified polycarboxylic ether. It is free of chloride and low alkali. It is compatible with all types of cements. The product has been primarily developed for applications in high performance concrete where the highest durability and performance is required. Optimum dosage should be determined with trial mixes, dosage range of 500 ml to 1500ml per 100kg of cementitious material is normally recommended. Because of variations in concrete materials, job site conditions, and/or applications, dosages outside of the recommended range may be required.

EXPERIMENTAL STUDY

The compressive strength test and split tensile strength test were done to determine the optimum values of each material.

A. Compressive Strength Test

The compressive strength of concrete was assessed by crushing to destruction of the test cubes by means of compression testing machine according to IS 516:1959 (Reaffirmed 2013). Cubes of 150 mm size were used for the testing. Load at the failure divided by area of specimen gives the compressive strength of concrete.

$$\text{Compressive strength} = \frac{\text{Load applied}}{\text{Cross sectional area}} \text{ – [eq. (1)]}$$

1) Compressive strength of conventional M30 concrete.

The 7th day and 28th day compressive strength values of normal concrete mix is given in Table below.

Table. 1 Compressive strength of conventional M30 concrete

Mix designation	7th day compressive strength (N/mm^2)	28th day compressive strength (N/mm^2)
$M30_1$	27.58	41.04
$M30_2$	27.43	42.18
$M30_3$	27.10	40.16
Average value	27.37	41.12

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2) Compressive strength of fly ash blended M30 concrete.

The 7th day and 28th day compressive strength values of fly ash blended concrete mix is given in Table below.

Table. 2 Compressive strength of fly ash blended M30 concrete

Mix designation	7th day compressive strength (N/mm^2)	28th day compressive strength (N/mm^2)
M30	27.37	41.12
F_1M30 (08% Fly ash)	31.10	42.45
F_2M30 (10% Fly ash)	33.46	47.70
F_3M30 (12% Fly ash)	31.59	42.09

The partial replacement of cement by fly ash increased the compressive strength in all the considered cases and the maximum strength was obtained for 10% fly ash replacement at which the 28th day compressive strength. There is an increase of 16% from the value of control mix and the optimum value of fly ash blended concrete. There is a significant improvement in the compressive strength of the concrete as because of the pozzolanic nature of fly ash and its void filling ability (Ogale R.A and Snehal S.Shinde;2016) .

3) Compressive strength of fly ash-metakaolin blended M30 concrete

The 7th day and 28th day compressive strength values of fly ash-metakaolin blended concrete mix is given in Table 3. In fly ash-metakaolin blended concrete of M30 grade, optimum percentage of fly ash is replaced with 10, 15 and 20% of metakaolin and the results obtained on the 7th day and 28th day are as follows

Table. 3 Compressive strength of fly ash-metakaolin blended M30 concrete

Mix designation	7th day compressive strength (N/mm^2)	28th day compressive strength (N/mm^2)
M30	27.37	41.12
$F_2MK_{10}M30$	36.28	44.87
$F_2MK_{15}M30$	41.95	46.62
$F_2MK_{20}M30$	41.79	45.41

The replacement of fly ash with Metakaolin increased the compressive strength in all the considered cases and the maximum strength was obtained for 15% metakaolin replacement at which the 28th day compressive strength. There is an increase of 13.35% from the value of control mix and the optimum value of fly ash metakaolin blended concrete. The increase in the compressive strength could be due to the pozzolanic, void filling and cement hydration acceleration mechanisms of metakaolin by which the microstructure of fly ash-metakaolin blended concrete became more compact and denser [12].

4) Compressive strength of copper slag blended M30 concrete.

The 7th day and 28th day compressive strength values of copper slag blended concrete mix is given in Table 4. In the copper slag blended concrete of M30 grade, fine aggregate is replaced by copper slag with 30%, 40% and 50%. The obtained results on the 7th day and 28th day are as follows:

Table. 4 Compressive strength of copper slag blended M30 concrete

Mix designation	7th day compressive strength (N/mm^2)	28th day compressive strength (N/mm^2)
M30	27.37	41.12
$CS_{30}M30$	30.29	40.82
$CS_{40}M30$	34.24	45.94
$CS_{50}M30$	32.08	42.02

The compressive strength development of concrete containing different percent replacement of copper slag was conducted. According to the results obtained the compressive strength increased by using copper slag as fine aggregate replacing material. Due to the higher value of specific gravity its packing is more compact and also provides a better packing, leads to production of most efficient mix, the contents of cement, water, and coarse aggregate were kept constant while the percentages of copper slag as a replacement for fine aggregate varied from 30 to 50%. Results showed that replacement of 40% of fine aggregate with copper slag caused major changes on concrete strength, the strength increase about 11.72%.

B. Split Tensile Strength Test

The split tensile test was carried out as per IS 5816: 1999 (Reaffirmed 2008) by placing the cylindrical specimen horizontally between the loading surfaces of compression testing machine and then load was applied until the failure of the cylinder along the vertical diameter. This is an indirect method for determining the tensile strength of concrete. Cylindrical specimens of diameter 150 mm and height 300 mm were used for this test. The split tensile strength was calculated by,

$$\text{Tensile strength} = \frac{2P}{\pi DL} \text{ - [eq. (2)]}$$

Where,

P = applied load

D = diameter of the cylinder

L= length of the cylinder

The split tensile strength of concrete mixes was found using compression testing machine.

1) Split tensile strength of conventional M30 concrete.

The 7th day and 28th day split tensile strength values of normal concrete mix is given in Table below.

Table. 5 Split tensile strength of conventional M30 concrete

Mix designation	7^{th} day Split tensile strength (N/mm^2)	28^{th} day Split tensile strength (N/mm^2)
$M30_1$	2.44	3.30
$M30_2$	2.46	3.33
$M30_3$	2.40	3.31
Average value	2.43	3.313

2) Split Tensile strength of fly ash blended M30 concrete.

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The 7th day and 28th day Split Tensile strength values of fly ash blended concrete mix is given in Table 6. In the fly ash blended M30 grade concrete, 8, 10 and 12% replacement of cement with fly ash is done and the split tensile values obtained on the 7th day and 28th day are as follows:

Table. 6 Split Tensile strength of fly ash blended M30 concrete

Mix designation	7th day split tensile strength (N/mm^2)	28th day split Tensile strength (N/mm^2)
M30	2.43	3.31
F_1M30 (08% Fly ash)	2.47	3.35
F_2M30 (10% Fly ash)	2.51	3.42
F_3M30 (12% Fly ash)	2.42	3.29

The partial replacement of cement by fly ash increased the split tensile strength in all the considered cases and the maximum strength was obtained for 10% fly ash replacement at which the 28th day compressive strength. There is an increase of strength from the value of control mix and the optimum value of fly ash blended concrete. There is a significant improvement in the split tensile strength of the concrete as because of the pozzolanic nature of fly ash and its void filling ability.

3) Split Tensile strength of fly ash-metakaolin blended M30 concrete

The 7th day and 28th day split tensile strength values of fly ash-metakaolin blended concrete mix are given in Table 7. In the fly ash-metakaolin blended M30 grade concrete, optimum percentage of fly ash is replaced with 10, 15 and 20% of metakaolin and the split tensile strength results obtained on the 7th day and 28th day are as follows:

Table. 7 Split tensile strength of fly ash-metakaolin blended M30 concrete

Mix designation	7th day split tensile strength (N/mm^2)	28th day split tensile strength (N/mm^2)
M30	2.43	3.31
F_2MK_{10}M30	2.53	3.48
F_2MK_{15}M30	2.55	3.51
F_2MK_{20}M30	2.51	3.45

The replacement of fly ash with Metakaolin increased the split tensile strength in all the considered cases and the maximum strength was obtained for 15% metakaolin replacement at which the 28th day compressive strength. There is an increase of strength from the value of control mix and the optimum value of fly ash metakaolin blended concrete. The increase in the strength could be due to the pozzolanic, void filling and cement hydration acceleration mechanisms of metakaolin by which the microstructure of fly ash-metakaolin blended concrete became more compact and denser.

4) Split tensile strength of copper slag blended M30 concrete.

The 7th day and 28th day split tensile strength values of copper slag blended concrete mix is given in Table 8. In the copper slag blended M30 grade concrete, fine aggregate is replaced by copper slag with 30%, 40% and 50%. The obtained split tensile strength results on the 7th day and 28th day are as follows:

Table. 8 Split tensile strength of copper slag blended M30 concrete

Mix designation	7th day split tensile strength (N/mm^2)	28th day split tensile strength (N/mm^2)
M30	2.43	3.31
CS_{30}M30	2.41	3.28
CS_{40}M30	2.45	3.33
CS_{50}M30	2.43	3.30

The split tensile strength development of concrete containing different percent replacement of copper slag was conducted. According to the results obtained the split tensile strength slightly increased by using copper slag as fine aggregate replacing material than the control mix. Due to the higher value of specific gravity its packing is more compact and also provides a better packing, leads to production of most efficient mix, the contents of cement, water, and coarse aggregate were kept constant while the percentages of copper slag as a replacement for fine aggregate varied from 30 to 50%. Results showed that replacement of 40% of fine aggregate with copper slag caused changes on concrete strength.

RESULTS AND CONCLUSION

Experimental study on the effect of alternative materials such as fly ash, metakaolin and copper slag in the concrete was conducted. The fly ash replacement in concrete was done as 8%, 10% and 12% for cement by weight. The optimum of fly ash was replaced by Metakaolin from 10%, 15% and 20%. The fine aggregate was replaced by copper slag from 30, 40 and 50% in the concrete. The optimum percentage of fly ash was 10% when replaced with cement. The optimum percentage obtained for Metakaolin when replaced for the optimum percentage of fly ash was 15%. For copper slag when replaced to fine aggregate the optimum percentage obtained was 40%.

The compressive strength of the modified mixes was more than that of the normal mix. When the normal mix concrete is re-designed with alternative materials, for each replacement levels the strength characteristics was improved. The split tensile strength was also improved to an extent. Concerning the split tensile strength, the least strength was obtained when replaced with copper slag with fine aggregate. Apart from that the modified mix shows better results in case of compressive as well as the split tensile strength. The increase in the strength characteristic when alternative materials were used may because of the properties of fly ash, metakaolin and copper slag such as the pozzolanic nature, void filling and the cement hydration acceleration mechanism of fly ash and Metakaolin and the higher value of specific gravity of copper slag which makes the packing more compact to get efficient concrete mix

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