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European Journal of Advances in Engineering and Technology, 2018, 5(2): 136-141

Research Article ISSN: 2394 - 658X

Analysis of Mechanical and Durability Characteristics of Concrete using Granite Slurry Waste and Metakaolin as a Partial Replacement of Cement

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ABSTRACT

This study has been carried out and required specimens have been cast to check Workability and durability properties (abrasion resistance test and acid attack). From the results obtained by various studies, it can be concluded that by using granite slurry waste and metakaolin, modification in durability properties is noted at various replacement levels for water cement ratio of 0.45. The abrasion test results show that the abrasion loss for concrete decrease with increase in the percentage of granite slurry waste (GSW) *and metakaolin (MK). It is also seen that maximum loss of abrasion is less than 1 mm. Acid attack test is also influenced by the inclusion of granite slurry waste and metakaolin and it has been noted that the loss of compressive strength by the immersion of concrete specimens in acid is minimized by the influence of Granite slurry waste and Metakaolin at various replacement levels. All the results give the conclusion that the partial replacement of cement by granite slurry waste and metakaolin proves to be good for both economic and environmental point of view.*

Key words: Metakaolin, Granite slurry waste, Workability, Abrasion resistance, Acid attack, Durability

INTRODUCTION

Concrete is the major component of construction industries used extensively as a building material. Cement is one of the basic component of concrete used as binding material. With the increasing demand of concrete demand of cement is also increasing throughout the world. Cement production consumes a large amount of energy and different types of harmful gases are emitted during its manufacturing process. Replacement of natural resources in the production of cement is an important issue in the present construction scenario due to limited availability of stock of these resources. At the same time, cement industry is one of the principle producers of carbon dioxides. Granite is a widely used construction stone which generates granite slurry which is responsible for creating environmental problems. Metakaolin is also a cementitious material used as an admixture to produce high strength concrete and is used for maintaining the consistency of concrete.

Concrete is the most widely used material in civil engineering and is the primary component in most infrastructures. According to Portland cement association about 3.8 billion m^3 concrete is produced annually. Cement is a main binding material which is used in concrete production. With increasing demand of concrete, demand of cement is also increasing in all over the world. Portland cement production is one of the major cause of CO_2 and oxides of other harmful gases emission in environment [1-2]. The reason behind this reflects population growth, the universal development of infrastructure and the extra-ordinary properties like mechanical and durability, which is provided by concrete. These oxides emission in the cement production is due to the calcinations of $CaCO_3$ and combustion of fossil fuels [3]. Moreover, a large amount of energy is also consumed in the cement production [4]. There is required to produce sustainable concrete by using other pozzolonic materials. Strength of concrete is most important, it is also very much needed that the concrete should be durable, workable and provide a good service life [5]. There are various cementitious materials which can be used to reduce the consumption of cement and improve the various properties of concrete.

Granite slurry waste is a fine material, which is easily carried away by air and cause nuisance causing health problems and environmental pollution. These wastes are disposed openly which directly pollute the environment and cause health hazard. To reduce the impact of granite waste on environment this waste should be made sufficiently and left over residue be used innovatively to produce new products or should be used as filler material in concrete so that the natural resources are used effectively and hence environmental waste can be reduced. The utilization of this waste will offer an alternative material which leads to cost reduction and energy saving in addition to the benefit of environment friendly material. Increase in concrete strength and further saving can be done if some suitable supplementary cementing material is use in the production of concrete.

Metakaolin is a pozzolanic material which is derived from natural mineral and manufactured specially for cementing applications [6]. Metakaolin is an artificial pozzolanic material which is obtained from thermal treatment or calcinations of kaolin clay at temperature around 700-850ºC [7]. Due to its high pozzolanic activity, the inclusion of metakaolin improves the mechanical and durability properties [8]. When metakaolin is used in concrete as a partial replacement of cement it reacts with $Ca(OH)_2$ which is by-product of hydration reaction of cement and results in additional CSH gel which results in increased strength [9]. It is generally noticed that metakaolin make adverse effects on the workability of concrete. Jain ting dong *et al* observed the effect of metakaolin and silica fume and it noticed that metakaolin offered a much better workability than silica fume for a given mixture proportion [10]. Slump was increase up-to 10% when replacement level was 10%. Concrete mixtures modified by metakaolin less high-range water reduction admixture than silica fume mixtures to achieve similar workability at same W/C ratio [11]. Metakaolin decrease the workability of concrete.

EXPERIMENTAL INVESTIGATIONS

Based on the preliminary investigations carried out, the experimental investigation is planned as under:

Physical and Chemical Properties of Materials

The Physical and Chemical properties of various materials like cement, Granite, Metakaolin etc. is shown in table 1-3.

Table -1 Chemical Characteristics of Cement, Granite and Metakaolin

Chemical Composition	Cement	Granite	Metakaolin
SiO_2 (Silica)	18.70%	71.22%	57.08%
Fe_2O_3 (Ferric oxide)	3.55%	0.56%	1.42%
Al_2O_3 (Alumina)	8.31%	12.48%	32.72%
TiO_2 (Titanium oxide)	-	0.16%	0.16%
CaO (Calcium oxide)	61.60%	1.40%	0.56%
MgO (Magnesium oxide)	0.80%	0.81%	0.20%
LOI (Loss on Ignition)	3.34%	1.20%	5.60%
Na_2O (Sodium oxide)	-	6.16%	1.45%
K_2O (Potassium oxide)	-	4.56%	0.37%

Table -2 Physical Properties of Cement

Physical properties	Requirement as per IS 8112: 2013	Test results
Consistency	-	32%
Initial setting time Final setting time	30 minutes (min.) 600 minutes (max.)	130 minutes 213 minutes
Specific gravity	-	3.12
7 days compressive strength 28 days compressive strength	33 MPa 43 MPa	34.95 MPa 45.29 MPa

Table -3 Physical Properties of Granite and Metakaolin

Characteristics	Granite	Metakaolin
Form	Fine Powder	Fine Powder
Colour	Red	Off white
Water Absorption	7.6%	-
Consistency	37%	45%
Soundness	-	2.5 mm
Specific Gravity	2.17	2.40

Specimens and Curing

The following specimens were cast for each mixture as shown in table 4 below:

Table -4 Concrete Testing Sample Details

Test	Shape and Dimensions of the Specimens	Time Duration(in days)	No. of Specimens
Abrasion Resistance	Cube: 100mm×100mm×100mm	28	48
Acid Attack	Cube: 100mm×100mm×100mm	28 (after 28 days of normal curing)	48

All the specimens were cast on mechanical vibration table. After casting, all the specimens were left at room temperature for 24 hours. The specimens were demolded after 24 hours of casting and were then cured in water at approximately 27 ^{0}C until the testing day.

EXPERIMENTAL PROCEDURES

1. Workability of the fresh concrete was measured by using standard slump cone test apparatus.
2. Abrasion resistance test is used to determine the thickness of wear under various exposures condition like skidding, rubbing and sliding. Test was performed on the prepared specimens of size 100mmx100mmx100mm after standard curing as per recommended guide lines of IS: 1237: 2012. The weight of the specimen was noted to nearest 0.1 gram before to the abrasion test. The grinding path of the disc of the abrasion testing machine was evenly spread with 20 gm of abrasive powder. The specimen was then fixed in the holding device and loaded at the center with 600 N. After every 22 revolutions, the disc was stopped, the abrasive powder was removed from the disc, and 20 gm fresh abrasive powder was applied and the specimen was turned 90° in the clockwise direction. This was repeated nine times thereby giving a total 220 number of revolutions. The abrasion resistance testing machine is shown in figure 1. After completion of the test, the specimen was weighed again and depth of wear was obtained by the following equation:

$$t = (W_1\text{-}W_2) \times V_1 / W_1 \times A \quad (1)$$

Here t = Average loss in thickness in mm, W_1= Initial mass of the specimen in gm, W_2= Final mass of the abraded specimen in gm, V_1= Initial volume of the specimen in mm^3 and A = Surface area of the specimen in mm^2.

3. Acid attack was determined by immersing test specimens of size 100 mm cubes in 5% H_2SO_4. After 28 days of curing, the specimens were submerged for 28 days in sulphuric acid (as shown in figure 2) and the compressive strength was found. The compressive strength was calculated by breaking cubical concrete specimens in a compression testing machine. The compressive strength was calculated from the failure load divided by the cross-sectional area resisting the load. This test was performed on a compressive testing machine (CTM). Other specimens of same casting were submerged for 28 days in sulphuric acid (5% H_2SO_4) then compression strength test was performed again for each interval. The loss of compressive strength was calculated from following formula: -

$$\text{Loss in \%} = [f_{c(28\ days)}\text{-}f_{c(t\ days)}]/fc_{\ (28\ Days)} \quad (2)$$

Where, fc (28 Days) = Compressive strength of concrete cube specimens at 28 days.
fc (t Days) = Compressive strength of concrete cube specimens after `t `days of immersion in H_2SO_4 solution

Fig. 1 Abrasion resistance testing machine

Fig. 2 Acid tank

RESULTS AND DISCUSSIONS

Tests were carried out in the laboratory to investigate various properties such as workability, compressive strength, flexural strength of the concrete containing granite slurry waste and metakaolin as a partial replacement of cement whose results are discussed below:

Workability

Workability is the prime factor for acceptance of any material for its probable use in the production of concrete. In this study, slump cone test was used to derermine the workability of the fresh concrere. Fig. 3 shows the slump values of concrete for w/c ratio 0.45 with replacement of cement by combination of granite slurry and metakaolin. It can be seen from fig. 3, that the slump value has been decreased with the increase % of granite slurry waste and metakaolin in concrete. Ding et al. (2002) also reported the decrease in slump value with addition of metakaolin. The reduction in workability may be due to the filler effect of the metakaolin and granite slurry waste. Slump value for conventional concrete was observed as 80mm. The slump value for 5%, 10% and 15% replacement of cement with granite slurry waste was observed as 75mm, 70mm and 65mm. Similarly, the slump value for 5%, 10% and 15% replacement of cement with metakaolin and Granite Slurry was found and is shown in the Fig. 3.

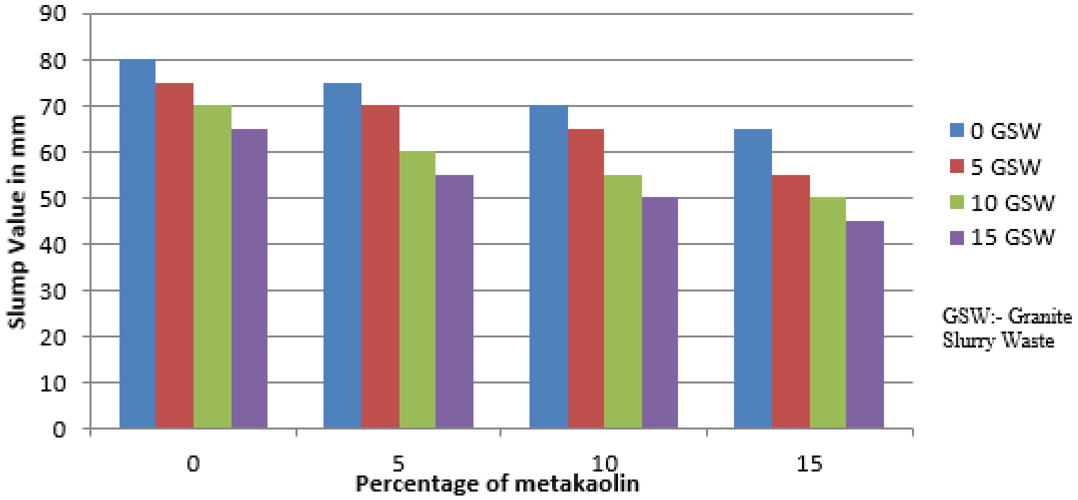

Fig. 3 Slump values of concrete containing granite slurry waste and metakaolin

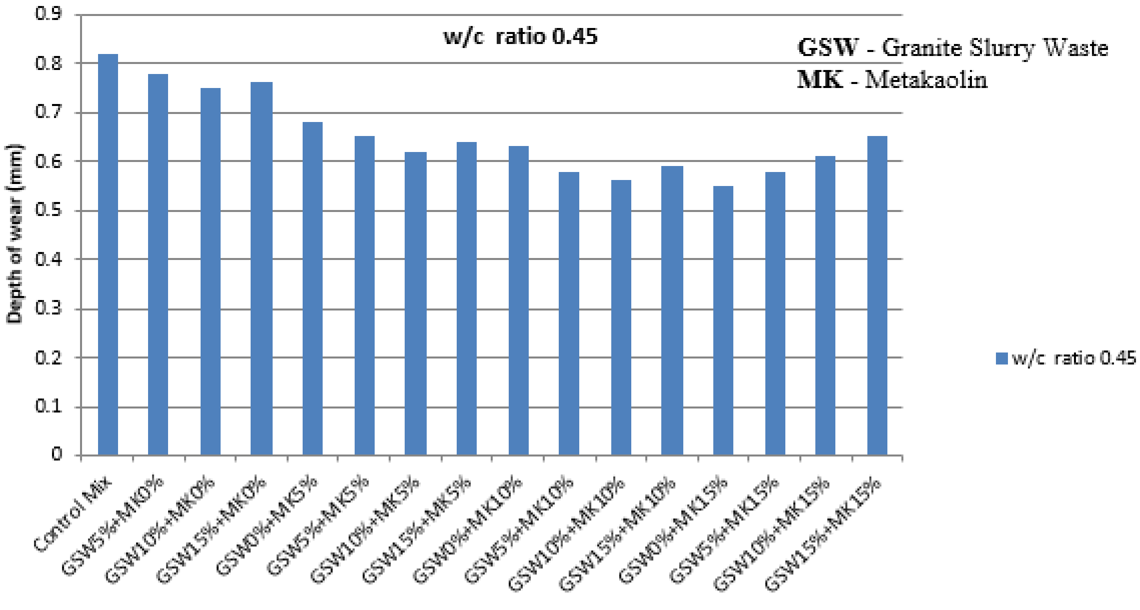

Fig. 4 Depth of wear of concrete with granite slurry waste and Metakaolin

Abrasion Test

Deterioration of concrete may take place due to abrasion caused by various exposures (skidding, rubbing, or sliding) on the concrete surface. Abrasion resistance is measured in the terms of depth of wear of concrete under standard testing conditions [IS 1237:1980]. The variation in abrasion resistance of concrete containing granite slurry waste and metakaolin is shown in fig.4 for w/c ratios 0.45. It was observed that the depth of wear of concrete decreased with the increasing percentage of granite slurry waste and metakaolin. Depth of wear was found to be 0.82mm for conventional concrete. Depth of wear for the combination of GSW10% + MK10% was found to be 0.75mm.

It was observed that the depth of wear decrease with increase in the percentage of metakaolin and the decrease in depth of wear was obtained to 0.68mm at 5% replacement level of metakaolin as compare to control mix (0.82mm). Whereas depth of wear marginally increases to 0.56mm with additional 5% replacement of cement with metakaolin along with 10% granite slurry waste. Minimum depth of wear 0.55mmwas observed for the combination of GSW0%+MK15%. Depth of wear for the combination GSW10%+MK10% was observed as 0.56mm which was less than the desirable limit. So it is advisable to use this combination. Decrease in depth of wear for the concrete is due to higher compressive strength of concrete. It can be also seen from the results for varied w/c ratios and replacement levels that the depth of wear observed in at all replacement levels are less than the permissible limits [IS 1237:1980].

According to IS-1237, the limit for general purpose concrete tiles is 3.5mm and depth of wear should not exceed 2mm for heavy duty applications.

Acid Attack

Figure 5 and table 5 shows the loss of compressive strength of concrete for w/c ratio 0.45 with partial replacement of cement at different percentage of granite slurry waste and metakaolin tested for 28 days after submerged in 5% H_2SO_4 acid solution. Loss of compressive strength for conventional concrete was obtained as 12.44% after 28 days of acid. Loss in compressive strength increases with an increase in the percentage of granite slurry waste and the loss of compressive strength at 10% replacement of cement with granite slurry waste was observed as 23.51% which was more than control mix (12. 44%).Increase in loss of acid attack was due to increase the permeability of water through the grains of granite slurry waste.

Loss in compressive strength decreases with increase in metakaolin content up to 5% replacement. With the additional 5% replacement along with 10% granite slurry waste leads to decrease the loss to 16.47% at 28 days of acid. Further increment in metakaolin in 10% granite slurry waste concrete increase in loss of compressive strength was obtained. Compressive strength loss for the concrete containing GSW10%+MK10% was observed as 19.86%. The minimum loss of compressive strength was observed as 10.12% for the combination (GSW0%+MK5%).

Table -5 Loss of Compressive Strength of Concrete for Granite Slurry Waste and Metakaolin

Combination	28 days Compressive strength (N/mm^2)	Compressive strength after 28 days of acid (N/mm^2)	Loss of compressive strength after 28 days of acid (%)
Control Mix	22.5	19.70	12.44
GSW5%+MK0%	23.6	19.15	18.86
GSW10%+MK0%	23.9	18.28	23.51
GSW15%+MK0%	23.2	17.15	26.45
GSW0%+MK5%	24.6	22.12	10.12
GSW5%+MK5%	25.8	22.17	14.07
GSW10%+MK5%	26.4	22.05	16.47
GSW15%+MK5%	25.1	20.52	18.25
GSW0%+MK10%	26.8	22.75	15.10
GSW5%+MK10%	27.2	22.54	17.05
GSW10%+MK10%	28.4	22.76	19.86
GSW15%+MK10%	27.2	21.40	21.32
GSW0%+MK15%	28.6	24.32	14.96
GSW5%+MK15%	27.5	22.10	19.64
GSW10%+MK15%	26.4	20.35	22.91
GSW15%+MK15%	26.1	19.82	24.06

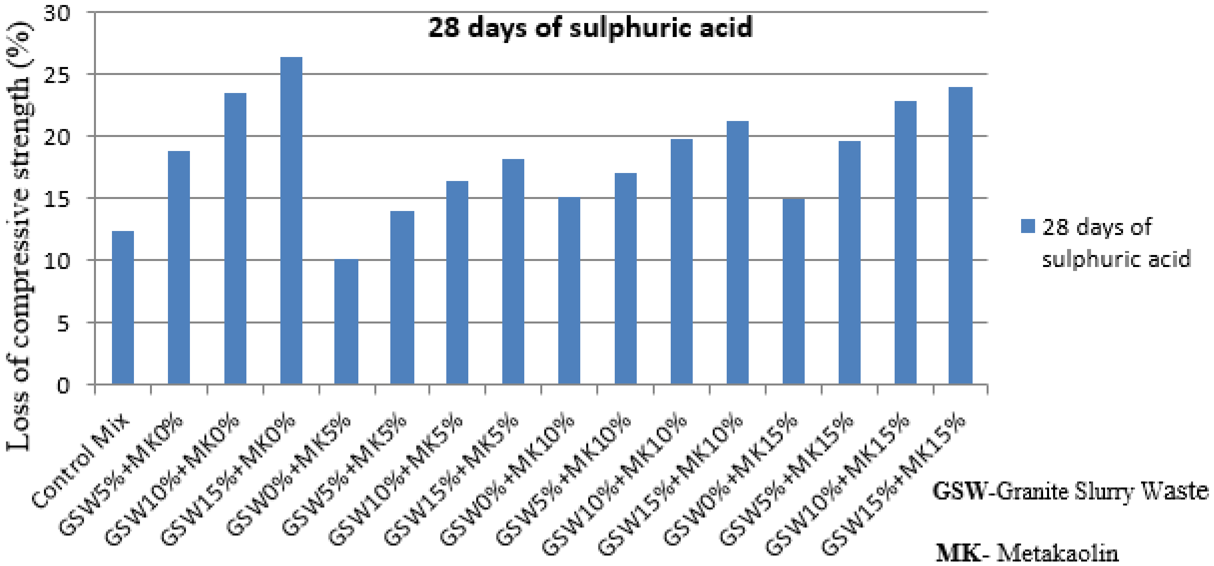

Fig.5 Loss of compressive strength of concrete for granite slurry waste and metakaolin

CONCLUSION

Cement was partially replaced by granite slurry waste and metakaolin at varied replacement level ranging (0%, 5%, 10% and 15%). The behaviour of concrete for the combination of both materials GSW and MK was investigated and following conclusions can be drawn from the current study:

a) The Slump value of concrete decreased with the increasing percentage of granite slurry waste. Further decrease in the workability was also observed with increasing percentage of metakaolin.
b) The value of Abrasion loss was gradually decreased with addition of varied replacement levels of granite slurry waste as a partial replacement of cement. Depth of wear found to be decreased with increase in the percentage of metakaolin. It is also seen that the depth of wear for all combination was less than the conventional concrete. Depth of wear for the combination GSW10%+MK0% was found to be 0.75mm. Minimum depth of wear 0.55mm was observed for combination of GSW0%+MK15%. It can be also seen from the results for varied replacement levels that the depth of wear observed in at all replacement levels are less than the permissible limits [IS 1237:1980].
c) The value of Abrasion loss was gradually decreased with addition of varied replacement levels of granite slurry waste as a partial replacement of cement. Depth of wear found to be decreased with increase in the percentage of metakaolin. It is also seen that the depth of wear for all combination was less than the conventional concrete. Depth of wear for the combination GSW10%+MK0% was found to be 0.75mm. Minimum depth of wear 0.55mm was observed for combination of GSW0%+MK15%. It can be also seen from the results for varied replacement levels that the depth of wear observed in at all replacement levels are less than the permissible limits [IS 1237:1980].

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