Performance Appraisal of M40 Concrete with Partial Substitution of GGBS and Metakaolin to Cement with Addition of Polypropylene Fibres

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***Abstract:** The experimental investigation deals with the study of combined effect of GGBS and Metakaolin in M40 grade of concrete reinforced with polypropylene fibres. The cement is replaced up to 40% by GGBS and metakaolin. The addition of polypropylene fibres is fixed as 1% of volume of concrete. The aim of the experimental program is to find the optimum dosage of GGBS and Metakaolin. To achieve so various tests are performed which includes Compression, split tensile and flexural tests at 3,7,28 days of curing of the sample specimens. The aim further extends to know the durability property of the fibre reinforced concrete produced by partially replacing cement by GGBS and Metakaolin. The results revealed that the mix M20G20 i.e., cement replaced with Metakaolin 20% and GGBS 20% showed better results than any mix. The quantum of increase in compressive strength for this optimum mix was 7.15% when compared to conventional concrete. Also the mix M20G20 was found to have greater resistance against acid than the conventional mix.*

***IndexTerms** - GGBS, Metakaolin, Polypropylene fibre, Mechanical properties.*

I. INTRODUCTION

The infrastructural development of India is rising at a rapid rate, which requires huge amount of construction materials specially cement. The production of cement consumes a large volume of energy and produces large amount of gases which are harmful for the environment. It is also said that for producing a cement of quantity one ton, the same magnitude of CO_2 is released into the atmosphere. The concrete's availability, its durability, economy, and sustainability made it the world's utmost utilized construction material. Concrete is made by mingling aggregates, cement, water and admixtures in different proportions to obtain different grades. This cement can also be replaced by other materials which bear certain pozzolanic property. Generally, concrete resists compressive load to a greater point when compared to tensile load. Hence, in this experimental exploration an effort is made to replace cement by waste materials like MK & GGBS and to know the concrete strength. Additionally, this blended concrete is reinforced with polypropylene fibres, to arrest the crack propagation and to provide better ductility to tensile loads. The byproduct obtained while producing iron by blast furnace gives GGBS. The ore of iron, limestone and coke are served into the furnace which results in formation of molten slag, which glides on the molted iron at about 1500° to 1600°C temperature. This molten slag comprises of about 30-40% of silicon di oxide & 40% of Calcium oxide which closely resembles the components of cement. The molten slag after being separated from the molten iron is cooled with high pressure water jets which produces granules upon complete drying. Those granules are further grinded to produce fine glassy material called as GGBS. GGBS mainly comprises of silica and alumina, which helps in utilizing it as an alternate cementitious material. The incorporation of GGBS in concrete helps in various aspects like enhancement in workability and compaction characteristics, reduced permeability, increase in durability, rise in concrete strength, greater resistance to acids, appealing surface finishing.[1]

Several researchers conducted study on concrete made with GGBS from 20-40% of cement. The results revealed that there was an increase in concrete strength by including 20% GGBS also the workability was normal for GGBS up to 40%. Thus utilization of GGBS is an ecofriendly option which not only reduces the load on cement production but also makes use of by product achieved from industries. [2]

Metakaolin, unlike other cementitious materials (silica fume, GGBS, fly ash) isn't a byproduct of any industrial process. Metakaolin is specifically produced by burning the clay called kaolin for heat stretching from 600°- 900°C, this process is termed as calcination. The calcination process destroys the crystalline structure and expels the chemically bound water, further upon the screening and grinding operation produces a fine pozzolanic material called as metakaolin. The major components of metakaolin are silicon di oxide and alumina oxide. The utilization of metakaolin in the concrete helps in improving the concrete's hardened properties as well as helps in the reduction of CO_2 emissions. Researchers have also stated that the combination of MK as a binding material enhances the workability, durability, permeability.

An investigation done on concrete produced by replacing OPC with 10 and 20% metakaolin, and concluded that not only the concrete strength is enhanced but also the concrete was more impervious and was resistant against drying shrinkage.[3]

The polypropylene fibres (PP) are made from homo polymer polypropylene resins in different shapes and sizes, and with varying properties. The main advantage of these fibres is the resistance against the alkali's, high melting point and the lower market price. In this study, short discrete PP fibres are used intended to reduce the crack propagation and to improve the ductility.

II. OBJECTIVES

- To conduct feasibility study of producing concrete with Metakaolin and GGBS combination as cement's partial replacement & with the addition of PP fibres.
- To study & compare strength parameters of concrete, replacing cement by Metakaolin and GGBS combination for grade of concrete of M40 after curing for 3, 7 & 28 days.
- To study concrete properties in fresh and hardened state by replacing cement upto 40% by different percentage of Metakaolin (0%, 10%, 20%, 30% and 40%) and GGBS (40%, 30%, 20%, 10%, and 0%).
- To study the durability characteristics of the GGBS and Metakaolin based fibre reinforced concrete.

III. LITERATURE REVIEW

1. E Guneyisiet. al have carried studies on the strength properties, shrinkage and concrete structure using MK. Two replacement levels of 10% and 20% MK by cement weight were engaged in study. Plain PCMK concretes were considered at two w/c ratios-0.35 & 0.55. The result exposed that presence of MK bizarrely condensed the shrinkage strain, but amplified concrete strength in changing amounts, reliant largely on substitution of MK, age of testing, and w/c ratio. They also stated that the presence of ultrafine MK improved considerably the concrete pores & restricted the damaging pores, which ended up with more durability of concrete, specifically at 20% substitution level. [3]

2. J M Khatibet. al conducted study on concrete properties combining MK & slag. The effect of adding them in concrete was explored. The OPC was partially substituted with those materials separately. The w/c ratio was kept fixed as 0.50 for all the mix variations.MK was replaced 0-20% while GGBS 0-80%. The MK existence grounds an upsurge in strength, particularly in the initial period. On the other hand, the utilization of GGBS as partial substitution of cement reduces concrete strength for the initial 28 days of curing. After the completion of this period, concrete strength enhances with existence of slag up to 60% substitution. Inclusion of metakaolin compensates the reduction in strength in the initial period of this mix. Addition of metakaolin in mix enclosing slag doesn't grounds a fall in long-term strength. Addition of more than 10% of Metakaolin in concretes having GGBS up to 12% doesn't pay to additional rise in crushing value. [4]

3. Zhu Ding et. al conducted study on the physical and the mechanical assets of cement comprising MK, grouping of slag & MK and suitability within both the materials & SP. The subsequent inferences were drawn:
By including 10% MK & 20%-30% slag conjointly in cement, the consistency of intermingled cements was upgraded, and compression resistance was boosted. MK as stated before is extremely vigorous pozzolanic material, which might hurry up cement hydration process, reduce the hardening time, surge water demand and escalate consistency dropping of fresh mix. Nevertheless, GGBS can postpone the reaction of hydration & prolong hardening of cement. [5]

4. S N Patilet. al focused on utilization of MK which has decent pozzolanic action & has a potential to create concrete of great strengths. They concluded that the optimum dosage of metakaolin is in the range of 7% to 15% of replacement of cement. It was found that, for 15% metakaolin replacement the compressive strength of such concrete after 28 days was increased by 20% when compared with conventional concrete. It was concluded that the addition of 15% of metakaolin causes decrease in the workability, thus the dosage of super plasticizer should be at the higher level. [6]

5. KasuNaveenaet. al studied the mechanical properties concrete by replacing up to 30% of cement by GGBS and Metakaolin starting from 10%. The results showed that 30% of replacement is the most optimum combined replacement of cement. The strength obtained after 28days of curing was remarkably high than the conventional concrete. [7]

6. KamaldeepKauret. al
The examination was conducted on concrete comprising MK and PP with several magnitudes of 0.0%, 7.0%, 8.0% and 9.0% of MK & 0.0%, 0.20%, 0.50% and 0.80% of PP. Fly ash 10% & super plasticizer 0.7% were used in a sense to increase consistency at a fixed percentage. It was witnessed; presence of MK & PP displayed huge development of concrete strength. Additionally, it was witnessed that 8% MK & 0.8% PP showed best gain in strength. [8]
7. Niya Susan Varghese et. al
PP fibres were added to the concrete at 0.5%, 1%, 2% and 4% with respect to the volume of concrete. The replacement of cement by pozzolanic material, byproduct from steel manufacturing industry known as GGBS. They studied the mechanical properties of GGBS as incomplete cement replacement in micro and macro polypropylene fibre reinforced concrete. Cement replaced with 40% GGBFS with 1% micro polypropylene fibre and 2% macro polypropylene fibre showed higher compressive strength. [9]

IV. MATERIALS USED

4.1 Cement:
Locally obtainable OPC 53-grade of UltraTech cement conforming to ISI standards was been procured, and utilized throughout the study. The SG of cement was 3.12 and other cement properties are described in table below.

Table 1: Shows the Characteristics of Cement

Sl.No	Property	Obtained test values
1	Consistency	36%
2	Specific gravity	3.12
3	Fineness	5%
4	Initial Setting	60mins
5	Final Setting	250mins

4.2 Fine Aggregate:
For fine aggregates natural sand provided with maximum size of 4.75 mm. locally accessible river sand, not containing any kind of organic matter is used. Properties of FA used are enumerated in Table 2.

Table 2: Shows the Properties of FA

Sl.No	Property	Test Value
1	Specific gravity	2.63

2	Water absorption	1.4%
3	Bulk density	1.54 g/cc (Loose)
		1.63 g/cc (Compacted)

4.3 Coarse Aggregates:

Coarse aggregates are used with size between 20mm-4.75mm. IS 383:1970 was used in determining quantity of mix of CA, consisting 60% 12.5mm & 40% 20mm. The specific-gravity of the CA was 2.70. The physical properties investigated are publicized in Table 3.4 whereas the Sieve analysis outcomes are indicated in Table 3.

Table 3: Shows the Properties of CA

Sl.No	Property	Test Value
1.	Specific gravity	2.73
2.	Water absorption	1.1%
3.	Bulk density	1.52 g/cc (Loose)
		1.59 g/cc (Compacted)

4.4 GGBS:

GGBS is granulated material made when molten iron blast furnace slag is hastily chilled by immersion of water. GGBS with very less crystal formation is a granular material, and pulverized for matching cement fineness, & the hydration resembles cement. For present investigation it was supplied from Beyond mind materials canvassers, Bangalore. The specific-gravity of GGBS was 2.78. The chemical composition of the obtained GGBS was as shown in Table 4. The Figure 1 below spectacles GGBS sample used in investigation.

Table 4: Shows the Composition of GGBS provided by Supplier

Sl.No	Ingredient	%age
1	Magnesia	7.75
2	SulphideSulphur	0.45
3	Sulphite	0.32
4	Loss on Ignition	0.30
5	Chloride content	0.009
6	Glass	92

Figure 1: Shows sample of GGBS used

4.5 Metakaolin:

It is the anhydrous calcined form of the clay mineral kaolinite. The fineness of MK is higher than cement , yet fewer fine than silica-fume. MK reacts with $Ca(OH)_2$, yields CSH gel at 500-800°C temperature. For the present investigation metakaolin was procured from Royal Mineral, Madhapar, Gujarat. The specific-gravity of metakaolin used was 2.60. The chemical constituents of MK are indicated in Table 5 & Figure 2 below displays MK fraction utilized in program.

Table 5: Shows the Constituents of Metakaolin provided by Supplier

Constituent	%age
SiO_2	52.00-54.00
Al_2O_3	44.00-46.00
Fe_2O_3	0.60-1.20
TiO_2	0.65
CaO	0.09
MgO	0.03
Na_2O	0.10
K_2O	0.03

Figure 2: Shows sample of Metakaolin used

4.6 Polypropylene Fibres:

Fibrillated 12mm length PP fibres are used for the investigation and were procured from Dolphin Floats private limited, Pune.

Figure 3: Shows Polypropylene Fibres

4.7 Super plasticizer:
Fosroc-Conplast SP-430 is being utilized for increasing consistency. The SG was determined to be 1.22.

V. EXPERIMENTAL PROGRAM

5.1 GENERAL

The experimental investigation deals with casting of 54 cubes, 54 cylinders and 54 beams for the destructive tests conducted after a period of 3, 7 and 28 days. Apart from these the mix which gives the optimum value, 3 more cubes are casted to carry out the durability study and to compare it with conventional concrete.The Table 6 below shows the various proportions of GGBS and MK replaced with cement and the mix designation used.

Table 6: Shows the Designations for various mixes

Mix Designation	Cement	MK	GGBS	PP
CC	100	-	-	-
M0G40	60	0	40	1%
M10G30	60	10	30	1%
M20G20	60	20	20	1%
M30G10	60	30	10	1%
M40G0	60	40	0	1%

Table 7: Mix Proportion

Water/cement	Cement	FA	CA
0.42	1	2.16	3.06

The various operations involved in the casting of the different specimens are;
1. Batching: The term batching here refers to weighing of different ingredients present in concrete which include water, cement, FA, admixtures, CA. All these materials are weighed according to the mix proportions obtained in Table 7 and as per the material calculations shown in the previous section.
2. Mixing: The batched materials are taken in a water tight platform. Initially, cementitious material mixed in the dry form. After thorough mixing of cementitious material, it is mixed with the sand and this mixture is spread on the 20mm and 12mm size CA. Eventually water is added along with the admixture and is mixed thoroughly, while mixing the required amount of PP fibres is spread over the mixture. The mixing is continued until a uniform mix is achieved.

Figure 4: Shows Mixing of Concrete

3. Casting: Upon the thorough mixing of the concrete, it is immediately transferred into the moulds which are lubricated prior to filling of concrete. The moulds are filled up in 3 deposits, wherein every deposit is stuffed with rod 25 times. The intent of tamping is to make sure the concrete is compacted and to make concrete denser. The exterior surface is trimmed off to remove excess concrete. The casted specimens are kept for 24 hours undisturbed as shown in figure 5 below.

Figure 5: Shows Casted specimens before de-moulding

4. Curing: The hydration process of cement requires water, especially at the early age. For this purpose the casted specimens after 24 hours are de-moulded and are immersed in water. They are removed from water before two hours when supposed for testing. In the present investigation they are removed after 3 days or 7 days or 28 days. The figure 6 spectacles the concrete specimens immersed in water tank for the purpose of Curing.

Figure 6: Shows Concrete specimens subjected to curing

5.2 TEST & RESULTS

1. Slump cone test

This test decides the workability or consistency of concrete. The test was performed for all the mixes which are shown in Table 6. The results show that the concrete is moderately workable having the slump value of 80mm for CC mix. There was an increase with use of GGBS only. However, when cement was replaced with metakaolin, workability started to reduce. This reduction in workability was also due to the presence of fibres. The Table 8 below shows the workability results.

Table 8: Shows the Slump test results

Sl.No	Mix designation	Slump value (mm)
1.	CC	80
2.	M0G40	84
3.	M10G30	82
4.	M20G20	78
5.	M30G10	72
6.	M40G0	66

2. Compressive-strength

It is done on all cubes at 3 different periods. The results reveal that there was an upsurge in cube strength due to combined effect of MK and GGBS. Presence of 40% of MK presented decline in strength. However, when metakaolin is replaced by 20% there was a remarkable increase in strength. The utilization of PP fibre adds an extra advantage in resisting the load after the occurrence of first crack. The tables and charts below indicate the test results of compression conducted at various days.

Table 9: Shows the Compressive-strength

Sl.No	Mix Designation	Average Comp. Strength (N/mm^2)		
		3 days	7 days	28 days
1.	CC	19.78	30.89	49.23
2.	M0G40	19.86	31.04	50.45
3.	M10G30	20.14	31.72	51.06
4.	M20G20	20.42	32.13	52.75
5.	M30G10	19.93	31.78	51.57
6.	M40G0	19.87	31.20	50.32

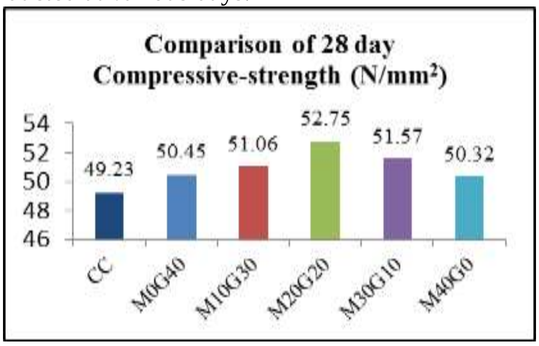

Chart 1: Shows Comparison of 28 days Compressive-strength

3. Split-tensile strength

This test was conducted on all cylindrical specimens to calculate the indirect tensile-resistance. Due to presence of metakaolin, GGBS and especially PP fibres there was an enhancement in strength parameter. The tables and charts below shows the Split-tensile test results.

Table 10: Shows Tensile-strength

S.No	Mix Designation	Average Split Tensile-Strength (N/mm^2)		
		3 days	7 days	28 days
1.	CC	2.16	2.72	4.22
2.	M0G40	2.30	2.80	4.67
3.	M10G30	2.42	2.92	4.85
4.	M20G20	2.68	3.10	5.16
5.	M30G10	2.72	2.98	5.04
6.	M40G0	2.56	2.84	4.89

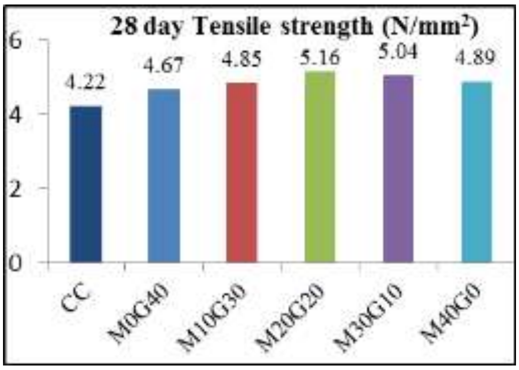

Chart 2: Shows Comparison of 28 days Split-Tensile Strength

4. Flexural test

This examination is also conducted to determine tensile-strength but in direct manner. The test is conducted on prisms having 500 x 100 x 100 mm size. The results stayed improved due to the presence of PP fibres. As they were supposed to counteract the crack propagation, which was initiated just before the occurrence of failure load P. The tables & charts below shows the test results of flexure.

Table 11: Shows Flexural-Strength

Sl.No	Mix Designation	Average Flexural-Strength (N/mm^2)		
		3 days	7 days	28 days
1.	CC	2.58	3.09	4.80
2.	M0G40	2.76	3.16	4.92
3.	M10G30	2.84	3.28	5.06
4.	M20G20	2.90	3.37	5.26
5.	M30G10	2.93	3.30	5.18
6.	M40G0	2.86	3.24	5.09

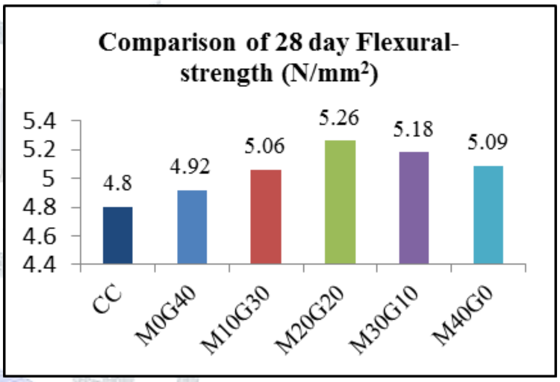

Chart 3: Shows Comparison of 28 days Flexural-Strength

5. Durability test

The cube specimens after the completion of 7 day immersion in Sodium Sulphate gets deteriorated and loses its physical properties like shape, weight and texture. The loss in weight is measured and is used to study the durability property. The more the loss in weight, the less durable is the concrete. The addition of GGBS, MK increases the water demand, which may lead to absorption of water from the sulphate solution. Thus it was found that, concrete produced by utilizing GGBS and MK showed greater resistance to acid. The Table 12 below shows the percentage weight loss of cube specimens. The figure 7 shows the loss in physical property of the cube due to the aggression of acid solution. Chart 4 compares the average percentage weight loss of CC and M20G20 mix. The average percentage weight loss for Mix CC was 4.57% while that for Mix M20G20 was 3.57%

Figure 7: Shows loss in physical property

Table 12: Shows Durability Test results

Sl.No	Mix	Cube weight measured before immersing	Cube weight measured after 7 days of immersion	Weight Loss %
1	CC	8.432	8.023	4.85
		8.997	8.572	4.72
		9.325	8.867	4.91
2	M20 G20	9.002	8.723	3.09
		8.765	8.456	3.52
		9.398	9.010	4.12

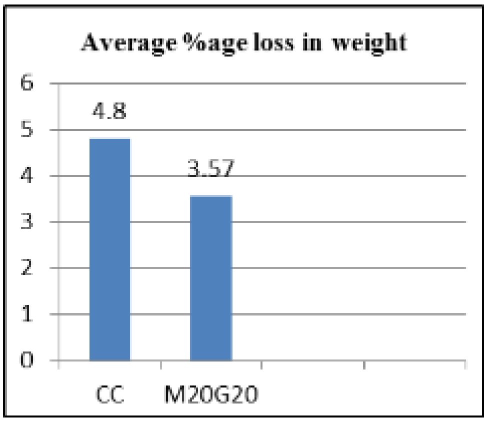

Chart 4: Shows %age weight loss

VI. CONCLUSIONS

1. The workability is reduced to a limited extent due to the addition of MK and PP fibre. The utilization of GGBS by 40% increases the workability of concrete. However, magnitude of reduction is not large and can be compensated by extra dosage of admixtures.
2. Amongst the five altered mixes, the optimum mix was which replaced cement by 20% MK and 20% GGBS i.e., M20G20.
3. The addition of MK & GGBS improves the Compressive-strength considerably. Highest increase was found by 7.15% for mix M20G20, when compared to mix CC. Further addition and reduction of MK & GGBS imparts adverse effects on strength parameter.
4. The utilization of PP fibres in MK & GGBS blended concrete enhanced Split-Tensile strength. The optimum mix was M20G20, which displays an increase of 22% against the mix CC. Similar is the case when MK content is higher than 20%
5. Flexure-strength was remarkably improved with the addition of PP fibre to this altered concrete. The best combination was that which replaced cement by MK 20% and GGBS 20% as the magnitude of increase when compared to CC was 9.6%
6. The durability of concrete with utilization of GGBS and MK was found to increase. The percentage weight loss was lesser when the Mix M20G20 was compared with Mix CC. The average percentage weight loss for mix M20G20 was 3.57% whereas that for mix CC was 4.8%

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