EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT WITH METAKAOLIN AND BAGASSE ASH FOR PERFORMANCE IMPROVEMENT

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Abstract - *The utilization of industrial and agricultural wastes produced by industrial processes has been the focus of waste reduction research for economic, environmental, and technical reasons. Bagasse is a by-product from sugar industries, which is burnt to generate power required for different activities in the factory. The burning of bagasse leaves bagasse ash (BA) as a waste. Bagasse ash has pozzolanic property and it can be used as a cement replacement material. Bagasse ash mainly contains alumina and silica. Improvement in the packing density of the cement by blending with cementitious materials plays a major role in enhancement of particle distribution, reduction of thermal cracks and in improving mechanical properties of high-performance concrete. In the present experimental study, Puntke test conducted to determine the packing density of cement and cementitious material combinations to evaluate optimization in mortar paste. The optimization of different mixes evaluated based on the packing density. Test results indicated that the use of Bagasse ash and Metakaolin as partial replacement of cement in concrete resulted in improvement in workability, mechanical strengths and durability properties and can be effectively used in structural concrete. It is observed that, Puntke test gives a good indication of optimum packing and significantly helps in designing the mix proportion of the binder materials for high performance concrete. Further, the fresh concrete was studied by slump test, V funnel test, L box Test and U box test and the hardened concrete was studied for compressive strength of M70 grade of high- performance concrete was determined from 1, 3, 7 and 28 days and, split tensile and flexural strength of concrete are also done.*

Keywords: *Metakaolin, Sugarcane bagasse ash, Puntke test, Compressive strength, Flexural strength, Split tensile strength.*

1. INTRODUCTION

The advent of Prestressed Concrete Technology Techniques has given impetus for making concrete of higher strength. In India, there are cases of using high strength concrete for prestressed concrete bridges. The first prestressed concrete bridge was built in 1949 for the Assam Rail Link at Siliguri. In fifty's a number of prestressed concrete structures were built using concrete of strength from 35 MPa to 45 MPa. But strength of concrete more than 35 MPa was not commonly used in general construction practices. Probably concrete of strength more than 35 MPa was used in large scale in Konkan Railway project during early 90's and concretization of Mumbai Municipal Corporation Roads. It is only during 90's use of high strength concrete has taken its due place in Indian construction scenario. Of late concrete of strength varying from 45 MPa to 60 MPa has been used in high rise buildings at Mumbai, Delhi and other Metropolitan cities. Similarly, high strength concrete was employed in bridges and flyovers. Presently (year 2000) in India, concrete of strength 75 MPa is being used for the first time in one of the flyovers at Mumbai. Other notable example of using high strength concrete in India is in the construction of containment Dome at Kaiga Power Project.

1.1 HIGH PERFORMANCE CONCRETE

Recently a new term "High performance concrete" is used for concrete mixture which possess high workability, high strength, high modulus of elasticity, high density, high dimensional stability, low permeability and resistance to chemical attack. There is a little controversy between the terms high-strength and high-performance concrete. High-performance concrete is also, a high-strength concrete but it has a few more attributes specifically designed as mentioned above. It is, therefore, logical to describe by the more widely embracing term "High Performance Concrete" (HPC). To improve the qualities of transition zone, use of silica fume is also found to be necessary. Silica fumes becomes a necessary ingredient for strength above to 80 MPa. The best quality fly ash and GGBS may be used for other nominal benefits. In spite of the fact that these pozzolanic materials increase the water demand, their benefits will outweigh the disadvantages. The crux of whole problem lies in using very low w/c ratio, consistent with high workability at the time of placing and compacting. Neville opines that the lowest w/c ratio that could be used is 0.22. Adopting w/c ratio in the range of 0.25 to 0.3 and getting a high slump is possible only with the use of superplasticizer.

1.2 AGGREGATES FOR HPC

In normal strength concrete, the strengths of aggregate by itself plays a minor role. Any aggregate available at the site could be used with little modification of their grading. The situation is rather different with HPC, where the bond between aggregate and hydrated cement paste is so strong that it results in significant transfer of stress across the transition zone. At the same time, the strength of the cement paste phase, on account very low w/c ratio is so high that sometimes it is higher than the strength of aggregate particles. Observation of fractured surface in HPC has shown that they pass through the coarse aggregate particles as often as, if not more often than, through the cement paste itself. Indeed in many instances, the strength of aggregate particles has been found to be the factor that limits the compressive strength of HPC.

1.3 PARTICAL PACKING DENSITY

Particle packing density of concrete mixtures has several advantages for concrete properties in the wet as well as in the hardened state. With a high packing density in the mixture, cement and other particles are close to each other, reducing the space that needs to be filled by hydration products. It has been learnt that the improvement in the packing density of the cementitious materials by blending cement with mineral admixture plays a major role in enhancement of the properties of the mortar produced. Research in the past has provided clear understanding about the significant role of particle packing on the properties of concrete. it conducted study on partial replacement of mineral admixtures on a volume basis to determine packing density using Puntke test. the material is apprehended that higher packing densities reduces the water /cement ratio and increases the strength of concrete mixtures. The water demand varies with different composition of cementitious materials using Puntke test. Present work on the optimization of cement, metakaolin and bagasse ash in the cement paste for a high- performance concrete.

2. MATERIAL ANALYSIS AND MIX PROPORTION

2.1 MATERIAL SECTION

ORDINARY PORTLAND CEMENT: Ordinary Portland cement is composed of calcium silicates and aluminate and aluminon ferrite. It is obtained by blending predetermined proportions limestone clay and other minerals in small quantities which is pulverized and heated at high temperature – around 1500 deg centigrade to produce “clinker”. The clinker is then ground with small quantities of gypsum to produce a fine powder called Ordinary Portland Cement (OPC). When mixed with water, sand and stone, it combines slowly with the water to form a hard mass called concrete. Cement is a hygroscopic material meaning that it absorbs moisture in presence of moisture it undergoes chemical reaction termed as hydration. Therefore, cement remains in good condition as long as it does not come in contact with moisture.

COARSE AGGREGATE: Coarse aggregate for the works should be river gravel or crushed stone. It should be hard, strong, dense, durable, clean, and free from clay or loamy admixtures or quarry refuse or vegetable matter. The pieces of aggregates should be cubical, or rounded shaped and should have granular or crystalline or smooth (but not glossy) non-powdery surfaces. Aggregates should be 10 properly screened and if necessary washed clean before use. Coarse aggregates containing flat, elongated or flaky pieces or mica should be rejected. Aggregates should be stored in such a way as to prevent segregation of sizes and avoid contamination with fines.

FINE AGGREGATE: Aggregate which is passed through 4.75 IS Sieve is termed as fine aggregate. Fine aggregate is added to concrete to assist workability and to bring uniformity in mixture. Usually, the natural river sand is used as fine aggregate. Grading of natural sand or crushed stone i.e. fine aggregates shall be such that not more than 5 percent shall exceed 5 mm in size, not more than 10% shall IS sieve No. 150 not less than 45% or more than 85% shall pass IS sieve No. 1.18 mm and not less than 25% or more than 60% shall pass IS sieve No. 600 micron.

WATER: Water is an important ingredient of concrete as it actually participates in the chemical reaction with cement. Since it helps to from the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Since quality of water affect the strength, it is necessary for us to go into the purity and quality of water.

METAKAOLIN: Considerable research has been done on natural pozzolans, namely on thermally activated ordinary clay and kaolinitic clay. These unpurified materials have often been called “Metakaolin”. Highly reactive metakaolin is made by water processing to remove unreactive impurities to make 100% reactive pozzolan.

SUGARCANE BAGASSE ASH: Bagasse was packed in graphite crucible air tight and placed inside electric control furnace. Burnt at temperature of 1200^{O}C for 5hrs to obtain black ash. This bagasse ash is used in the research. This carbonated bagasse was collected and burned for 6hours at 600^{O}C. After burn a layer of light-colored ash was observed on the surface.

CHEMICAL ADMIXTURE: The superplasticizer is practiced for production of flowing,self-levelling, self-compacting and for the production of high strength and high-performance concrete. The mechanism of action of superplasticizer are more or less same as explained earlier in case of ordinary plasticizer. It is use of superplasticizer which has made it possible to use w/c as low as 0.25 or even lower and yet to make flowing concrete to obtain strength of the order 120 Mpa or more.

2.2 TEST ON CEMENT

2.2.1 SPECIFIC GRAVITY TEST

Specific gravity of aggregate is required in calculating the compacting factor in connection with the workability measurements. It may vary from 2.6-2.8. The pycnometer of about 1-liter capacity having a metal conical screw top with a 6mm hole at its apex with a water tight screw top was used in the determination of specific gravity of soil sample.

$$G=(w2-w1)/[(w2-w1)-(w3-w4)]$$

W1 = Mass of empty pycnometer.

W2 = Mass of empty pycnometer + aggregate.

W3 = Mass of empty pycnometer + aggregate + water. W4 = Mass of empty pycnometer + water.

Table-1: Specific Gravity Test

Material	Values
Cement	3.15
M. sand	2.74
Coarse aggregate	2.6
Metakaolin	2.77
Sugarcane Bagasse Ash	2.67

2.2.2 CEMENT STANDARD CONSISTANCY TEST

Weight of cement taken (g) = 400 g

Initial percentage of water added to cement = 26%

Quantity of water added to cement = 118 ml

Depth of penetration = 6 mm

Standard Consistency of Cement **=** (Quantity of water for 5-7 mm penetration/Weight of cement) X 100

= 118 x 400 = 29.5 %

Standard Consistency of Cement = 29.5 %

Table- 2: Test on Cement Result

S.No	Property	Value
1	Specific gravity	3.15
2	Fineness	225 m^2/kg
3	Initial setting time	30 min
4	Final setting time	600 min

2.2.3 TEST ON FINE AGGREGATE

Weight of sample: 500g

Sieve analysis is conducted to determine the particle size distribution in a sample of aggregate which we call gradation. The aggregate fraction ranging from 4.75mm – 150 microns are termed as fine aggregate.

Weight of fine aggregate = 500g

Table- 3: Sieve Analysis Result of Fine Aggregate

IS Sieve No	Weight retained (g)	Cumulative weight	Cumulative percentage	Cumulative percentage
4.75 mm	0	0	0.00	100.00
2.36 mm	0	0	0.00	100.00
1.18 mm	58	58	11.60	88.40
700 microns	164	222	44.40	55.60
600 microns	90	312	62.40	37.60
300 microns	96	408	81.60	18.40
150 microns	74	482	96.40	3.60
Pan	14	496	99.20	0.80

The values obtained are conforming to Zone II as per IS 383:1970

Fineness modulus **=*Sum of cumulative* % *weight retained*/100 =** 2.73

Fineness Modulus = 2.73

2.2.4 WATER ABSORPTION TEST

The sample shall be completely immersed in clean water a room temperature for 24 hours. The sample shall be removed from the water and allowed to drain for one minute by placing them on a coarser wire mesh, visible surface water being removed with a damp cloth, the saturated and surface dry sample immediately weighed. The water absorption calculates as:

Absorption percentage =$(A−B)/BX$ 100

where, A = Wet mass of sample in Kg. B = Dry mass of sample in Kg.

Table- 4: Water Absorption Test

Materials	Water absorption (%)
Coarse aggregate	0.5
Fine aggregate	0.5

2.3 PUNTKE TEST

Dry mix of selected volume of solid materials are mixed minimum four times for homogenization. Calculated increment of potable water added to the dry mixture with continuous manual mixing and simultaneous pressing of mixture against the sides of the container wall. Twenty times the container needs to be tapped by keeping on the flow table. This procedure needs to repeat for addition of each increment of water until the saturation point (shinning/glossy surface) is reached. The experiment is done in three stages to get the least water required to achieve saturation.

Packing density =1-((Vw) / (Vp + Vw))

Vw = Volume of water (cm3)

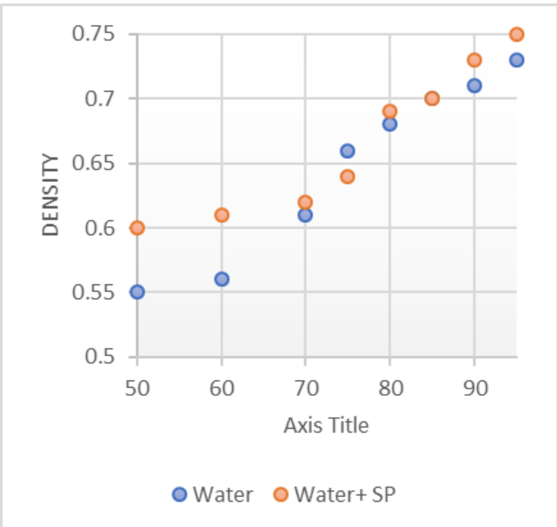
Vp = Volume of Particle (cm3)

Table- 5: Puntke Test

Trial No	Cement (g)	MK (g)	BA (g)	Water (ml)	Water +SP (ml)	Packing Density	
						Water	Water+ SP
1	95	3	2	35	35	0.73	0.75
2	90	6	4	40	39	0.71	0.73
3	85	10	5	42	42	0.70	0.70
4	80	12	8	44	45	0.68	0.69
5	75	15	10	54	56	0.66	0.64
6	70	18	12	61	63	0.61	0.62
7	60	26	14	62	76	0.56	0.61
8	50	35	15	65	80	0.55	0.60

From the above table of trails, trail no 3 gives the optimum ratio. Therefore, this project the mis design is further proceeded with optimum ratio obtained. The wet combination of 85 percentage of cement, 10 percentage of metakaolin and 6 percentage of sugarcane bagasse ash required less water and attained maximum packing density. Graph 1 indicates the various packing density with different combination of cement, metakaolin and sugarcane bagasse ash.

Graph:1



2.4 MIX PROPORTION

2.4.1 MIX DESIGN AND PROPORTION OF M70 GRADE

1. The mix design procedure is done with IS 10262-2019.
2. Grade of concrete is taken as **M70** for high performance concrete.
3. Degree of workability is taken as high based on slump value **150 to 200.**

Table- 6: Mix Proportion

MATERIAL NAME	Control Mix (%)	MIX (%)
CEMENT	100	85
METAKAOLIN	-	5
SUGARCANE BAGASSE AHS	-	10
M- SAND	100	100
COARSE AGGREGATE (20mm)	60	60
COARSE AGGREGATE (12.5mm)	40	40
WATER CEMENT RATIO	0.3	0.3
SUPERPLASTICIZER	0.70	0.70

3. RESULT AND DISCUSSION

3.1 FRESH CONCRETE TEST

SLUMP TEST: The slump flow test is done to assess the horizontal flow of concrete in the absence of obstructions. It is a most commonly used test and gives good assessment of filling ability. It can be used at site. The test also indicates the resistance to segregation.

Table- 7: Slump Test

Concrete Grade	Slump mm
M70	165
	182
	175
Average	174

V-FUNNEL TEST: This test was developed in Japan. The equipment consists of a V-shaped funnel shown in diagram below. The V-funnel test is used to determine the filling ability (flowability) of the concrete with a maximum size of aggregate 20mm size. The funnel is filled with about 12 liters of concrete. Find the time taken for it to flow down. After this the funnel can be filled with concrete and left for 5 minutes to settle. If the concrete shows segregation then the flow time will increase significantly.

Table-8: V Funnel Test

Concrete grade	V funnel sec	V funnel at T5 min sec
M70	148	269
	135	254
	122	225
Average	135	249

L BOX TEST: This test is developed in japan. The test assesses the flow of concrete and also the extent to which the concrete is subjected to blocking by reinforcement.

Table-9: L Box Test

Concrete grade	h2/h1 mm
M70	0.92
	0.88
	0.94
Average	0.91

U BOX TEST: Introduction. The test was developed in Japan. The test is used to measure the filling ability of self-compacting concrete. The apparatus consists of a vessel that is divided by a middle wall into two compartments by R1 and R2. An opening with a sliding gate is filled between the two compartments. Reinforcing bars with nominal diameter of 13 mm are installed at the gate with center to center distance of 50 mm. This creates a clear spacing of 35 mm between the bars. The left-hand section is filled with about 20 liters of concrete. The gate is then lifted and the concrete flows to the other section. The height of concrete in both the sections is measured.

Table-10: U Box Test

Concrete grade	h2-h1 mm
M70	23
	16
	20
Average	19

3.2. TESTING OF HARDENED CONCRETE

3.2.1 COMPRESSIVE STRENGTH TEST:

Compressive strength test was conducted at 1, 3, 7 and 28 days on 150mm cubes on M70 grade of concrete.

Table-11: Compressive Strength of Cube

AREA mm²	COMPERSSION STRENGTH (N/mm²)			
	1 DAY	3 DAY	7 DAY	28 DAY
150*150*150	10.80	28.36	46.99	68.5
150*150*150	11.82	29.59	44.84	71.6
150*150*150	11.27	28.6	44.22	70.8
AVERAGE	11.27	28.85	45.35	70.3

3.2.2 SPLIT TENSILE TEST:

Split tension test was conducted at 1, 3, 7 and 28 days on 150mm diameter x 300mm height cylinders on M70 grade on concrete.

Table-12: Split Tensile of Cylinder

AREA mm²	SPLIT TENSILE STRENGTH (N/mm²)			
	1 DAY	3 DAY	7 DAY	28 DAY
150*300	0.73	2.81	3.29	4.04
150*300	0.87	2.74	3.8	4.86
150*300	0.84	2.6	3.06	4.45
AVERAGE	0.81	2.7	10.15	4.45

3.2.3 FLEXURE TEST

Flexure test was conducted at 1, 3, 7 and 28 days on 100mm x 100mm x 500mm height beams M70 grade on concrete.

Table-13: Flexure Strength of Prism

AREA mm²	FLEXURE STRENGTH (N/mm²)			
	1 DAY	3 DAY	7 DAY	28 DAY
500*100*100	0.297	1.26	2.88	4.2
500*100*100	0.104	1.64	3.26	3.6
500*100*100	0.146	1.34	2.86	3.5
AVERAGE	0.18	1.4	3	3.8

4. CONCLUSION

In high performance concrete it is extremely necessary to ensure the use of fine and ultrafine, Puntke test provide the experimental solution to find the best combination of cement, metakaolin and sugarcane bagasse ash among different combination. Based on experimental result following conclusion has been drawn. Then optimum ratio is taken as cement:85%, metakaolin:10%, bagasse ash:5%, water cement ratio:0.3, super plasticizer:0.7% are proceeded with mix design for M70 grade of concrete. Based on test results on 1, 3, 7 and 28 days, it is concluded that characteristic compressive strength of the concrete is achieved. Split-tensile and Flexural strength are also obtained.

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