Ternary Blended Concrete with Bagasse Ash and Metakaolin

Miss. Bini M J
PG student, Dept. of Civil Engg.
MA College of Engg, Kothamangalam
Ernakulam, Kerala, India

Mr. Shibi Varghese
Asso. Professor Dept. of Civil Engg.
MA College of Engg, Kothamangalam
Ernakulam, Kerala, India

Abstract: **The utilization of industrial and agricultural wastes produced by industrial processes has been the focus of waste reduction research for economical, 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. This paper presents the results of an experimental investigation dealing with concrete incorporating Bagasse ash and Metakaolin replacing Ordinary Portland Cement in concrete with various percentages of Bagasse ash (0%, 5%, 10%, 15% and 20%) and constant percentage of Metakaolin (5%). Tests were conducted for workability of fresh concrete (Slump test), strength of hardened concrete (Compressive strength, Split tensile strength and Flexural strength) and durability properties of concrete (Chloride resistance and Sulphate resistance). Based on present study, definite conclusions have been arrived and suggestions for further works have also been given. 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.**

Keywords: Bagasse ash, Metakaolin, Compressive strength, Split tensile strength, Flexural strength, Durability.

I. INTRODUCTION

Concrete is one of the most commonly used construction material in the world. Every year concrete consumes 12.6 billion tons of natural raw materials. This huge consumption rate of natural raw materials creates several ecological problems. More economical and environmental-friendly supplementary cementing materials have extended interest in partial cement replacement materials. Ground granulated blast furnace slag (GGBS), pulverized fly ash, silica fume, metakaolin, etc have been successfully used for this purpose.

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. With the country's plan to boost the sugar production to over 3 million tons by the end of 2015, the disposal of the bagasse ash will be of a serious concern.

Metakaolin is a supplementary cementing material which is produced from carefully calcining kaolin clay between 600 and 800oC to make it reactive. Metakaolin is composed mainly of alumina and silica phases, which can vary by approximately 10% and 8% respectively depending on the kaolin source. Metakaolin has the general form $Al_2O_3SiO_2$. When blended with Portland cement in appropriate amounts, typically below 10%, it will enhance the strength and durability of the concrete.

Replacement of Portland cement by sugarcane bagasse ash and metakaolin on weight basis seems to be very suitable for Indian construction industry due to abundant availability of bagasse ash and metakaolin at cheap cost.

II. EXPERIMENTAL INVESTIGATION

In this experimental work, cubes, cylinders and beams were casted. The standard size of cube 150mm×150mm×150mm, cylinder 150 mm diameters x 300mm height and beam 100mm x 100mm x 500mm are used. The mix design of concrete was done according to Indian Standard guidelines for M 30 grade.

Based upon the quantities of ingredient of the mixes, the quantities of BA for 0, 5, 10, 15 and 20% replacement by weight were estimated. The ingredients of concrete were thoroughly mixed in mixer machine till uniform consistency was achieved. Before casting, machine oil was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the mould and compacted thoroughly and the top surface was finished by means of a trowel. The specimens were removed from the mould after 24h and then cured under water for a period of 7, 28, 56 and 90 days. The specimens were taken out from the curing tank just prior to the test. The tests were conducted as per the relevant Indian Standard specifications.

A. Material Details

The materials used in this investigation are:

Cement: The OPC Cement of 53 grade was used with fineness 5% and standard consistency 32%.

Fine Aggregate: Basalt stone crushed sand is used as fine aggregate. In the present study the sand conforms to zone II as per the Indian standards. The specific gravity of sand is 2.5 and fineness modulus is 2.79.

Coarse Aggregates: The crushed granite stone aggregates used were 12mm and 20mm nominal size and are tested as per Indian standards and results are within the permissible limit. The specific gravity of aggregate is 2.67 and fineness modulus is 2.239.

Water: Water available in the campus conforming to the requirements of water for concreting and curing as per IS: 456-2009.

Superplasticizer: The superplasticizer used in this study was MasterRheobuild 1125. It is a high-range, retarding, superplasticising admixture for concrete. It is a sulphonated naphthalene polymer based superplasticizer having slump retaining capabilities. It shall comply with IS: 9103 and shall be of type G when tested to ASTM C-494.

Sugarcane Bagasse Ash: Sugarcane bagasse ash was collected during the cleaning operation of a boiler operating in the Sakthi Sugar Factory, located in the city of Sathyamangalam, Tamilnadu, India.

Metakaolin: Metakaolin obtained from Ashapura Minechem Ltd, Trivandrum, India was used for the present investigation. The specific gravity of the metakaolin sample was 2.5. Table 1 shows the chemical composition of BA, Metakaolin and Cement.

TABLE 1. Chemical composition of Bagasse ash, Metakaolin and OPC

COMPONENT	BA MASS%	METAKAOLIN MASS%	CEMENT MASS %
SiO_2	78.34	60-65	20.85
Al_2O_3	8.55	30-34	4.23
Fe_2O_3	3.61	1.00	5.25
CaO	2.15	0.2-0.8	63.49
Na_2O	0.12	0.5-1.2	0.16
K_2O	3.46	-	0.4
P_2O_5	1.07	-	-
LOSS OF IGNITION	0.42	<1.4	1.05

TABLE 2. Mix proportion for M30 concrete

Mix Designation	NC	MB 0	MB 5	MB 10	MB 15	MB 20
Metakaolin %	0	5	5	5	5	5
Bagasse ash %	0	0	5	10	15	20
Superplasticizer %	1	1	1	1	1	1
Cement (kg/m^3)	360	342	324	306	288	270
Metakaolin (kg/m^3)	0	18	18	18	18	18
Bagasse ash (kg/m^3)	0	0	18	36	54	72
Fine aggregate (kg/m^3)	629	629	629	629	629	629
Coarse aggregate (kg/m^3)	1223	1223	1223	1223	1223	1223
Water (kg/m^3)	144	144	144	144	144	144
Superplasticizer (kg/m^3)	3.6	3.6	3.6	3.6	3.6	3.6

B. Concrete tests

Slump test: Workability of fresh concrete was measured using slump test. Slump test was conducted as per IS 516:1959.

Compression test: Compressive strength test was conducted at 7 and 28 days on 150mm cubes as per IS 516:1959.

Cylinder splitting tension test: Cylinder splitting tension test was conducted at 28 days on 150mm diameter x 300mm height cylinders as per IS 516:1959.

Flexure test: Flexure test was conducted at 28 days on 100mm x 100mm x 500mm height beams as per IS 516:1959.

Sulphate attack: Cube specimens of size 150mm were cast and after 7 days of water curing were taken out and dried in air and then kept immersed in $MgSO_4$ solution for a period of 28, 56 and 90 days. The concentration of $MgSO_4$ solution used is 20 g/lit. Compressive strengths of modified concrete mixes were compared with that of control mix.

Chloride attack: Cube specimens of size 150mm were cast and after 7 days of water curing were taken out and dried in air and then kept immersed in NaCl solution for a period of 28, 56 and 90 days. The concentration of NaCl solution used is 100 g/lit. Compressive strengths of modified concrete mixes were compared with that of control mix.

C. Experimental Results

The strength results obtained from the experimental investigations are showed in Table 3. The durability results obtained from the experimental investigations are showed in Table 4. All the values are the average of the three trails in each case in the testing program of this study. The results are discussed as follows.

TABLE 3. 7 & 28 day cube compressive strength, 28 day cylinder split tensile strength and 28 day flexural strength

Mix	Slump (mm)	7 day cube compressive strength (MPa)	28 day cube compressive strength (MPa)	28 day cylinder split tensile strength (MPa)	28 day flexural strength (MPa)
NC	80	26.13	38.67	2.7	3.6
MB 0	70	31.2	42.44	3.03	4.4
MB 5	80	37.16	43.85	3.41	4.8
MB 10	100	30.04	38.81	3.13	4.4
MB 15	105	25.87	33.41	2.81	4.0
MB 20	110	23.73	31.11	2.43	3.6

TABLE 4. Cube compressive strength after 28, 56 & 90 days in $MgSO_4$ and NaCl solution

Mix	Compressive strength after 28, 56 & 90 days in $MgSO_4$ solution (MPa)			Compressive strength after 28, 56 & 90 days in NaCl solution (MPa)		
	28 days	56 days	90 days	28 days	56 days	90 days
NC	31.78	34.89	39.11	35.33	36.22	42.67
MB 0	41.11	48.00	49.33	43.11	45.33	46.67
MB 5	38.67	42.67	43.56	38.22	39.78	43.56
MB 10	33.33	35.11	36.00	31.33	35.78	37.11
MB 15	30.89	32.00	34.67	31.11	34.00	34.44
MB 20	29.33	32.00	32.89	31.11	32.44	33.33

The silica content of pozzolans reacts with free lime released during the hydration of cement and forms additional calcium silicate hydrate (CSH) as new hydration products, which improved the compressive strength, flexural strength and split tensile strength of concrete. When quantity of bagasse ash and metakaolin in mix is higher than the amount required to combine with the liberated lime during the process of hydration, leading to excess silica leaching out, causes a reduction in strength as it replaces part of the cementitious material but does not contribute to strength.

III. CONCLUSION

The results show that the workability of the modified concrete increases with increase in bagasse ash percentage when metakaolin percentage is kept constant. So use of superplasticizer is not essential. The replacement of cement with bagasse ash and metakaolin increases the compressive strength, flexural strength and splitting tensile strength upto 15% replacement. Maximum compressive strength, flexural strength and splitting tensile strength occur at 5% metakaolin and 5% bagasse ash replacement. Durability decreases with increase in bagasse ash content. Optimum strength is obtained for 5% metakaolin and 0% bagasse ash replacement

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