Strength Assessment of Concrete Made with Metakaolin and M-Sand

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***Abstract*— Concrete is a fundamental component of the construction industry. Cement production has expanded dramatically, and it is linked to CO_2 emissions, resulting in a slew of environmental issues. The high energy costs connected with cement manufacture, as well as the environmental difficulties related with carbon dioxide emissions, have pushed for the use of supplemental materials to reduce cement use. River sand is also in low supply today. As a result, different concrete materials such as fine aggregate and coarse aggregate should be considered. The ongoing project tries to manage these materials. Supplementary materials like as metakaolin are employed as a partial replacement for cement in this article, and river sand and manufactured sand are used as fine aggregates. Concrete with a compressive strength of 20 MPa was employed in this experiment. The mechanical parameters of modified concrete were compared to compressive strength, splitting tensile strength, and flexural strength of normal concrete. Non-destructive testing methods such as Rebound Hammer and ultrasonic pulse velocity were also used to assess the amended concrete. Durability paramaters such as acid resistance, salt resistance and sulphaye resistance were also done on metakaolin based concrete. As a result, it was discovered that modified metakaolin concrete is superior to regular concrete.**

Keywords*— *Metakaolin, Manufactured sand, Compressive Strength, Split Tensile Strength, Flexural Strength, Rebound hammer, Ultrasonic Pulse Velocity.

I. INTRODUCTION

Concrete is the foremost extensively used construction material within the world. It is only second to water because of its huge consumption [1]. The majority of the cementitious binders employed in concrete are based on Portland cement clinker, the manufacture of which is an energy-intensive process. Additionally, it produces an outsized amount of gas emissions, mostly CO_2, resulting from release of CO_2 from limestone within the pyro-processing of clinker. So as to scale back energy consumption, CO_2 emission and increase production, cement plants produce blended cements, comprised of supplementary cementitious materials like metakaolin, silica fume, natural pozzolan, fly-ash and limestone. In recent years, many studies were done on Metakaolin (MK) because of its high pozzolanic properties [2–5]. Not like other pozzolans, it is a primary product, not a secondary product or by-product, which is formed by the dehydroxylation of kaolin precursor upon heating temperature range of 700–800 °C [6,7]. The stuff input in the manufacture of metakaolin ($Al_2Si_2O_7$) is kaolin. Metakaolin on reaction with Ca $(OH)_2$, produces C–S–H gel at ambient temperature and reacts with CH to supply alumina containing phases, including C_4AH_{13}, C_2ASH_8, and C_3AH_6 [8,9]. Larbi [10] showed that caustic lime will be virtually eliminated from the cement matrix by using sufficient adapted metakaolin concentrations. Metakaolin is increasingly getting used to provide high-strength, high-performance concrete with improved durability. Extensive research is reported within the literature concerning different properties of MK paste and concrete like porosity, pore size distribution, pozzolanic reaction, compressive and durability of MK concrete [11–13].

II. MATERIALS AND METHODS

Ordinary Portland Cement of 53 grade was used confirming to IS: 12269 – 1987 and the specific gravity of cement was found to be 3.13. Locally available River sand having bulk density of 1.71 kg/m^3 was used with a specific gravity is 2.65. The Fineness modulus of river sand is 2.44. The bulk density of Manufactured sand was 1.75 kg/m^3, specific gravity and fineness modulus was found to be 2.73 and 2.87, respectively. Crushed angular aggregate with maximum grain size of 20 mm was used with a bulk density of 1.38 kg/m^3. The specific gravity and fineness modulus of coarse aggregate was found to be 2.82 and 7 respectively. Fresh portable water, which is free from acid and organic substance, was used for mixing the concrete. Metakaolin is a dehydroxylated form of clay mineral kaolinite which was brought from Aastra Chemicals, Chennai, whose specific gravity was 2.26. Concrete mix for M20 grade was designed as per the guidelines specified in IS 10262-2009 and IS 456-2000 with a ratio of 1: 1.9: 3.2. For determining mechanical properties, eight different types of mixes were used as described in Table 1.

TABLE 1 MIX DESIGNATION AND COMBINATIONS

S.No.	Mix Designation	Mix Combinations
1.	C	(River Sand + Metakaolin 0%)
2.	CMK5	(River Sand+ Metakaolin 5%)
3.	CMK10	(River Sand + Metakaolin 10%)
4.	CMK15	(River Sand + Metakaolin 15%)
5.	CMS	(M- sand + Metakaolin 0%)
6.	CMSMK5	(M- Sand + Metakaolin 5%)
7.	CMSMK10	(M- Sand + Metakaolin 10%)
8.	CMSMK15	(M- Sand + Metakaolin 15%)

TABLE 2 MECHANICAL PROPERTIES OF ALL SAMPLES

S. No	Mix Designation	Compressive Strength, MPa	Split Tensile Strength, MPa	Flexural Strength, MPa	Elastic Modulus, MPa
1.	C	26.75	2.06	3.62	2.13×10^4
2.	CMK5	28.72	2.20	3.81	2.25×10^4
3.	CMK10	32.03	2.59	3.91	2.47×10^4
4.	CMK15	31.11	2.45	3.86	2.32×10^4
5.	CMS	27.75	2.12	3.74	2.19×10^4
6.	CMSMK5	29.53	2.30	3.89	2.32×10^4
7.	CMSMK10	33.50	2.67	4.05	2.51×10^4
8.	CMSMK15	32.76	2.55	3.95	2.40×10^4

Control Specimens were cast and verified for their "compressive strength, flexural strength, split tensile strength and Elastic Modulus". In addition to this, Non-Destructive testing such as Rebound Hammer and Ultrasonic Pulse Velocity were also performed. Various Durability test such as acid resistance test, salt resistance test and sulphate resistance test were also conducted to assess the concrete performance.

Fig.1 Compressive Strength Test Setup

Fig.2 Splitting Tensile Strength Test Setup

Fig.3 Flexural Strength Test Setup

Fig.4 Elastic Modulus Test Setup

III. RESULTS AND DISCUSSIONS

A. Mechanical Properties

The mechanical properties of all samples were presented in Table 2. The 15 % replacement MK mixture had exhibited lower strengths comparatively than the other MK percentages, but comparable strengths at all the ages to that of control concrete. All the concretes including the control had achieved their target strength of 20 MPa at 28 days. It can be seen that the strength was highest for the CMSMK10 mixtures at 28 days. This clearly shows that the replacement level of 10 % was the optimum as far as the strength is concerned. The main reason for improving the strength in concrete with metakaolin is because of silica present in metakaolin will reacts with Calcium hydroxide and it forms the extra Calcium Silicate Hydrate (C-S-H) gel which is main gel for the event of strength. This process will continue till the saturation (i.e.10%) beyond this metakaolin will act as a filler material only.

The reduction in compressive strength for Metakaolin 15% is because of a clinker dilution effect. The dilution effect may be a result of replacing an element of cement by the equivalent quantity of MK. In MK concrete, the filler effect, pozzolanic reaction of MK with caustic lime and compounding effect (synergetic effect of mineral admixture) react opposite of the dilution effects [23]. For this very reason, there was an optimum MK replacement for MK concrete. With time, the compressive strength differences between the MK mixtures and OPC concrete becomes smaller. This might be due to the actual fact that all cementitious materials reactions were near completion, or had stopped; mainly because the reactions between MK and OPC mixtures were over-involved with time [11].

B. Non-Destructive Testing

The rebound hammer test was administered in accordance with IS 13311. The test can provide a reasonably accurate estimate of concrete compressive strength. The cube specimens were tested as per the standard guideline procedure. The test results of Rebound Hammer Test are in accord with the compression test results. Ultrasonic Pulse Velocity (UPV) testing of concrete is based on the pulse velocity method which provides information on the concrete uniformity, cavities, defects and cracks. The pulse velocity passing through the specimen depends on its density and its elastic properties which sequentially related to the quality and the compressive strength of the concrete. Therefore, it is possible to obtain information about the properties of components by sonic investigations. The test was carried out as per IS 13311(Part 2): 1992. Table 3 shows the values of Rebound number and ultrasonic pulse velocity for different mixes. From this test, the strength of concrete increases as the percentage of Metakaolin increases up to 10%.

TABLE 3 REBOUND NUMBER AND ULTRASONIC PULSE VELOCITY FOR DIFFERENT MIXES

S. No	Mix Designation	Rebound Number	Ultrasonic Pulse Velocity in m/sec
1.	C	38	4120
2.	CMK5	40	4143
3.	CMK10	43	4170
4.	CMK15	41	4159
5.	CMS	39	4130
6.	CMSMK5	43	4152
7.	CMSMK10	46	4179
8.	CMSMK15	44	4164

Fig.5 Rebound Hammer Test Setup

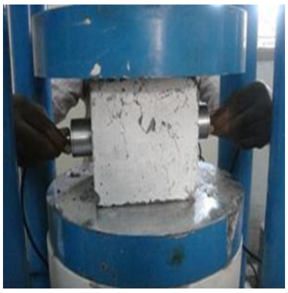

Fig.6 Ultrasonic Pulse Velocity Test Setup

The rebound hammer and ultrasonic pulse velocity tests further authorized that the modified concrete specimens although being sound and of good quality have increased strength when compared to the control concrete.

C. Acid Resistance Test

After 28days curing 150mmx150x150mm cube specimens were immersed in 5 % H_2So_4 solution. The solution was kept at room temperature and solution was stirred regularly, at least twice a day to maintain uniformity. After removing the specimens from solution, the surface was cleaned with a soft nylon wired brush under running tape water to remove weak product and loose material from the surface. The specimens were allowed to surface dry and the compressive strength of specimens was found out and the average percentage of loss of weight and compressive strength were calculated and presented in the Table 4.

TABLE 4 TEST RESULTS OF ACID RESISTANCE FOR DIFFERENT MIXES

S. No	Mix Designation	Compressive Strength after immersion in H_2SO_4, N/mm^2	Strength loss in %	Weight loss in %
1.	C	22.91	17	5.0
2.	CMK5	25.33	13	4.7
3.	CMK10	28.86	11	4.0
4.	CMK15	28.09	12	4.2
5.	CMS	23.65	15	4.6
6.	CMSMK5	26.37	12	4.2
7.	CMSMK10	30.45	10	3.8
8.	CMSMK15	29.51	11	4.0

The calcium compounds of cement paste generated in concrete during the hydration process, as well as the calcium in the calcareous aggregate, are leached away by the acid attack. Acid attack degrades the structural integrity of concrete, reducing its durability and service life. When compared to all mixes, concrete with 10% replacement of Metakaolin shows less strength loss and weight loss for both river sand and M-Sand. The mix CMSMK10 shows a strength loss and weight loss of 10% and 3.1% whereas CMK10 shows a strength loss of 11% and weight loss of 4% respectively. Therefore, concrete with Metakaolin 10% has given a good resistance against acid attack.

D. Salt Resistance Test

Salt water immersion test was performed to evaluate the resistance of the concrete cubes subjected to salt water attack which might have resulted from Nacl. The volume of expansion induces stresses which may generate internal cracks and ultimately load to failure. The concrete specimen cubes of 150x150x150mm size were cast for finding the weight loss and strength loss due to the salt attack. The cubes were cured for 28 days. After measuring the weight of the specimen, they were immersed in water diluted with 3% sodium chloride After 28 days of continuous immersion the cubes were taken out and dried at room temperature for 24 hours then they were lightly brushed to remove the debris from the surface before weighing. The specimens were allowed to surface dry and the compressive strength of specimens was found out and the average percentage loss of weight and loss of strength were calculated and presented in the Table 5.

TABLE 5 TEST RESULTS OF SALT RESISTANCE FOR DIFFERENT MIXES

S. No	Mix Designation	Compressive Strength after immersion in NaCl, N/mm^2	Strength loss in %	Weight loss in %
1.	C	23.67	12.1	3.8
2.	CMK5	25.74	10.5	3.6
3.	CMK10	29.12	9.0	2.2
4.	CMK15	28.05	9.8	2.9
5.	CMS	24.43	11.3	3.4
6.	CMSMK5	26.9	9.7	2.9
7.	CMSMK10	31.28	7.1	1.2
8.	CMSMK15	30.2	8.3	1.6

The chlorides travel through the pore water through diffusion. Ionic diffusion takes place when pore water combines with hydrated cement paste. The chemical tri-calcium aluminate, which is found in cement, can bind chloride ions, creating calcium chloro-aluminate, which lowers chloride ion mobility. Metakaolin also contains alumina oxides, which have the ability to bind chloride ions. The mix CMSMK10 shows a strength loss and weight loss of 7.1% and 1.2% whereas CMK10 shows a strength loss of 9% and weight loss of 2.2% respectively. Therefore, CMSMK10 exhibits less strength loss and weight loss when compared with other mixes.

E. Sulphate Resistance Test

. After 28 days of curing, 150 mm cube specimens are allowed to dry before the initial weight were measured. Cube specimens were immersed completely in a 5 percent Magnesium Sulphate ($MgSO_4$) solution for 28 days.

TABLE 6 TEST RESULTS OF SULPHATE RESISTANCE FOR DIFFERENT MIXES

S. No	Mix Designation	Compressive Strength after immersion in $MgSo_4$, N/mm^2	Strength loss in %	Weight loss in %
1.	C	26.31	1.3	2.8
2.	CMK5	28.41	1.1	1.9
3.	CMK10	31.20	0.9	1.2
4.	CMK15	30.82	1.0	1.5
5.	CMS	27.39	1.2	2.6
6.	CMSMK5	29.23	1.0	1.7
7.	CMSMK10	31.73	0.7	1.1
8.	CMSMK15	30.06	0.9	1.3

To maintain a homogenous mix, the solution is set aside at room temperature and stirred constantly, at least twice a day. The cube specimens were removed from the sulphate solution after 28 days and dried. The specimens are then weighed to determine the percentage of weight loss and compressive strength. Table 6 shows the strength loss and weight loss in percentage for different mixes. Sulphate attack can result in concrete expansion, loss of compressive strength, and weight loss. It may be due to the formation of ettringites and gypsum. Metakaolin Concrete exhibited no cracks or spalling after 28 days of immersion in a sulphate solution. When compared to normal concrete, Metakaolin concrete has a lower percentage loss in strength and weight. The mix CMSMK10 shows a strength loss and weight loss of 0.7% and 1.1% whereas CMK10 shows a strength loss of 0.9% and weight loss of 1.2% respectively. Therefore, CMSMK10 exhibits less strength loss and weight loss when compared with other mixes.

IV. CONCLUSIONS

From the experimental investigation the following conclusions can be drawn.

- The strength of all Metakaolin admixed concrete mixes overshoot the strength of OPC.
- Mix with 10% metakaolin is superior to all other mixes.
- The increase in metakaolin content improves the compressive strength, Split Tensile Strength, Flexural Strength and Elastic Modulus upto 10% replacement.
- There is a good correlation between Non-Destructive tests and Destructive tests.
- The addition of Metakaolin in concrete shows a good resistance capacity under acid, salt and sulphate medium.
- The results encourage the use of Metakaolin, as pozzolanic material for partial cement replacement in producing high strength concrete.
- The utilization of supplementary cementitious material like Metakaolin concrete can compensate for environmental, technical and economic issues caused by cement production.
- Inclusion of Metakaolin serves as an invaluable means to protect environmental resources, which may result in more viable constructions in the future.

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