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Experimental study on Strength of Concrete by using Metakaolin and M-Sand

P. Jaishankar* and Vayugundlachenchu Eswara Rao

School of Civil Engineering, SASTRA University, Thanjavur, Tamilnadu, 613402, India.

Abstract : Concrete is that pourable mix of cement, water, sand, and gravel that hardens into a super-strong building material**.** Supplementary cementing materials (SCM) have become an integral part of concrete mix design. These may be naturally occurring materials, industrial wastes or, by products or the ones requiring less energy to manufacture. Some of the commonly used SCM are fly ash, silica fume (SF), GGBS, rice husk ash and metakaolin (MK), etc. Metakaolin is obtained by the calcination of kaolinite. It is being used very commonly as pozzolanic material and has exhibited considerable influence in enhancing the mechanical and durability properties of concrete. M-sand is crushed aggregates produced from hard granite stone which is cubically shaped with grounded edges, washed and graded with consistency to be used as a substitute of river sand. Usage of M-Sand can overcome the defects occurring in concrete such as honey combing, segregation, voids, capillary, etc. In this project, experimental study was carried out on M-30 grade of concrete. In this concrete mixes sand was replaced by M-sand by a constant percentage and cement was replaced by metakolin in various percentages such as 5%, 10%, 15% and 20%. Concrete specimens containing metakaolin were studied for their compressive, split tensile and flexural strengths according to Bureau of Indian standards. The results thus obtained were compared and examined with respect to the control specimen. From the test results, it was found that 15% of the Ordinary Portland cement could be beneficially replaced with themetakaolin to improve compressive, split tensile and flexural strengths of concrete.
Keywords: M-Sand, Metakaolin, Compressive, Split tensile, Flexural strength.

1. Introduction

Concrete is probably the most extensively used construction material in the world[14-27]. It is an artificial material in which the aggregates are bonded together by the cement when mixed with water. With the advancement of technology and increased field of application of concrete and mortars, the strength, workability, durability and other characteristics of the ordinary concrete can be made suitable for any situation. For this, definite proportions of cement, water, fine aggregate, coarse aggregate, mineral admixtures and chemical admixtures are required. The demand for Portland cement is increasing dramatically in developing countries. Portland cement production is one of the major reasons for CO_2 emissions into atmosphere. Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with $Ca(OH)_2$ one of the by-products of hydration reaction of cement and results in additional C-S-H gel which results in increased strength. Metakaolin is obtained by thermal activation of kaolin clay. This activation will cause a substantial loss of water in its constitution causing a rearrangement of its structure. To obtain an adequate thermal activation, the temperature range should be established between 600 to 750ºC. The principal reasons for the use of clay-based pozzolans in mortar and concrete have been due to availability of materials and durability enhancement. In addition, it depends on the calcining temperature and clay type. It is also possible to obtain enhancement in strength, particularly during the strength of curing. The very early strength enhancement is due to a combination of the filler effect and acceleration of cement hydration. [1]Dinakar et al. investigated the effect of using local calcined kaolin or MK obtained commercially as pozzolan on the development of high strength and permeability/durability characteristics of concrete designed for a very low w/b ratio of 0.3. [2]Nova John investigated the effect of partial replacement of cement by metakaolin on the properties of concrete. Supplementary cementing materials (SCMs) have been widely used all over the world in concrete due to their economic and environmental benefits. Hence, they have drawn much attention in recent years. [3]Poon et al. investigated the porosity and pore size distribution of high performance cement paste blended with metakaolin and compared them with silica fume (SF) or fly ash (FA) blended cement pastes. This present study was concerned with the MK-blended cement pastes at lower w/b ratios. The cement pastes prepared were MK blended pastes with MK contents of 5, 10, and 20%, SF-blended pastes with SF contents of 5 and 10%, an FA blended paste with a FA content of 20%, and a control PC paste without any pozzolanic replacement. The w/b ratio for all the pastes was 0.3.

2. Materials[4-14]

2.1 Cement

Cement is a binder, a substance that sets and hardens and can bind other materials together. The word "cement" traces to the Romans, who used the term opus caementicium to describe masonry resembling modern concrete that was made from crushed rock with burnt lime as binder. These are available in many grades, namely 33 grade, 43 grade, 53 grade etc. If 28 day strength is not less than 33N/mm^2 then it is called 33 grade cements. If 28 day strength is not less than 43N/mm^2 then it is called 43 grade cements. Use of higher grade cement offers many advantageous for making stronger concrete. Although they are little costlier than the low grade cement, they offer 10 to 20% saving in the cement consumption and also they offer many other hidden benefits. One of the most important benefits is the faster rate of development of the strength. Used for the ordinary works. Ordinary Portland cement conforming to IS 269-1976 and IS 4031-1968 was adopted in this work. Ordinary Portland cement used is grade 53 having a specific gravity of 3.15 was used for this research. The chemical configuration of cement was found using X-ray fluorescence analysis and has the following properties are given in table1.

Table 1: Chemical composition of Cement

Formula	Concentration (%)
Lime (CaO)	64
Silica (SiO_2)	22
Alumina (Al_2O_3)	6
Iron oxide (Fe_2O_3)	3
Magnesia (MgO)	2
Sulphur trioxide (SO_3)	2
Soda and/or Potash (Na_2O+K_2O)	1

2.2 Fine Aggregate

Natural sand which is easily available and low in price was used in the work. It has cubical or rounded shape with smooth surface texture. Being cubical, roundedand smooth texture it give good workability. Specific gravity of aggregate is 2.61. Sand which is used here is River Sand. Aggregate most of which passes 4.75mm IS sieve is used.

2.3 Coarse Aggregate

The fractions from 20 mm to 4.75 mm are used as coarse aggregate. The aggregate used in this project mainly of Granite rock which comes under normal weight category. The aggregates are locally available. Specific gravity of aggregate is 2.65. Aggregates are the most mined material in the world.

2.4 Water

Water should be easily available and it should be clear and tap water also sufficient to mix the ingredients and it should not be any alkali and should be free from more chlorides of calcium and magnesium.

2.5 Super plasticizer

To obtain the workable concrete mix, CONPLAST SP 430 a commonly available super plasticizer obtained from FOSROC Company was used fully in this research work. Conplast SP 430 is free of chloride & low alkali. It is compatible with all types of cements.

2.6 Metakaolin

Metakaolin is a chemical phase that forms upon thermal treatment of kaolinite. Kaolinite's chemical composition is Al_2O_3:$2SiO_2$. $2H_2O$ and as a result of thermal treatment in the range of 400-500^oC, the water is driven away to form an amorphous aluminosilicate called metakaolin. Metakaolin is white in colour and acts as a pozzolanic material. The reactivity of the metakaolin may also be affected by grinding to a finer particle size. The properties of Metakaolin are given in Table 2.

Table 2 Chemical composition of Metakaolin

Formula	Concentration (%)
Silica (SiO_2)	53
Alumina (Al_2O_3)	45
Iron oxide (Fe_2O_3)	1.1
Titania (TiO_2)	0.65
Lime (CaO)	0.09
Magnesia (MgO)	0.03
Soda (Na_2O)	0.10
Potash (K_2O)	0.03

2.7 M-sand

Manufactured sand (4.75mm to 75 micron) was used for partial replacement to natural sand. It was available at a place which was nearer to SASTRA university. Natural and manufactured sand are from zone II (IS 383).The artificial sand produced by proper machines can be a better substitute to river sand. The sand must be of proper gradation (it should have particles from 150 microns to 4.75 mm in proper proportion). When fine particles are in proper proportion, the sand will have fewer voids. The cement quantity required will be less. Such sand will be more economical. Demand for manufactured fine aggregates for making concrete is increasing day by day as river sand cannot meet the rising demand of construction sector. Natural river sand takes millions of years to form and is not replenishable.Because of its limited supply, the cost of Natural River sand has sky rocketed and its consistent supply cannot be guaranteed. Under this circumstances use of manufactured sand becomes inevitable.River sand in many parts of the country is not graded properly and has excessive silt and organic impurities and these can be detrimental to durability of steel in concrete whereas manufactured sand has no silt or organic impurities.

3. Experimental Program[4-14]

3.1 Concrete Mix design

M30 grade with nominal mix as per IS: 456-2000 was used. The concrete mix proportion (cement: fine aggregate: coarse aggregate) is 1:1.46:2.46 by volume and a water cement ratio of 0.38. It was proposed to investigate the properties of concrete, cast with partial replacement of sand with 50% of manufactured sand and cement content was replaced with 5%, 10%, 15% and 20% of proportions of metakaolin.

3.2 Casting Details

Total number of 45 cubes of size 150mm X 150mm X 150mm was casted for compressive strength. For split tensile strength 5 cylindrical specimens of diameter 150 mm and height of 300 mm were casted. For flexural strength 2 beam specimens of width, depth and length of the beam were 100mm, 150mm and 1200mm were casted and reinforcement shown in figure 1. Metakaolin was added in concrete in step of 5% (5%, 10%, 15% and 20%) and manufactured sand replaced the sand by 50% which is constant for all cubes and cylinders.

Figure 1. Reinforcement of the beam

For each percentage of metakoiln replacing cement, 3 cubes were casted for 7 days, 14 days and 28 days, 1 cylinder was casted for 28 days. One of the beams was casted for nominal mix concrete and another for optimum replacement percentage of metakaolin which was 15%. All the specimens were cast and cured for 28 days.

3.3 Testing

3.3.1 Compressive strength test

The compressive strength test is the most common test conducted because most of the desirable characteristic properties of concrete and the structural design purpose are qualitatively related to compressive strength. The test was conducted in compression testing machine of 3000kN capacity for different ages of concrete viz.7, 14 and 28 days as per the specifications given in IS 5816: 1999 under normal room temperature and figure 2 shown in experimental setup of compression, spilt tension, flexural strength.

Figure 2. Test setup for Compressive, Spilt tension, Flexural strength

3.3.2 Split tensile strength test

This is an indirect test to determine the tensile strength of cylindrical specimens. Splitting tensile strength tests were carried out at the age of 28 days for the concrete cylinder specimens of size 150 mm diameter and 300 mm length, using compression testing machine of 3000kN capacity as per IS:5816-1999. The load was applied gradually till the specimen splits and readings were noted.

3.3.3 Flexural strength test

Flexure test was done on beam with universal testing machine (UTM) at a loading rate of 1.8 KN/min. The test was done at the age of 28 days for the casted beams. The flexural strength test was determined using the relationship $F_b = \frac{PL}{BD^2}$

4. Results and Discussions

4.1 Compressive strength test

The test was carried out according to Indian Standards in order to obtain the compressive strength of concrete at 7, 14 and 28 days. Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete works. The compressive strength, as one of the most important properties of hardened concrete, in general is the characteristic material value for classification of concrete. Specimens were tested using 3000kN capacity Compressive Testing Machine (CTM). The 28 days compressive strength of conventional concrete, MK5, MK10 and MK20 concrete 32.55%, 22.8%, 12.94% and 9.89% of compressive strength was reduced when compared to MK15 concrete. From the table 3 was observed that the compressive strength of MK10 and MK20 were more or less same. It was observed that percentage increase for MK5 and MK10 is very less form 14 days. The increasing in compressive strength is not only by replacing cement with MK but it was also due to replacing sand with 50% of M-Sand.

Table 3. Compressive, Split tensile strength results

Mix Designation	Compressive strength (N/mm^2)			Split tensile strength (N/mm^2)
	7 days	14 days	28 days	28 days
CC	19.15	27.23	32.25	3.4
MK5	21.58	31.35	34.8	3.33
MK10	23.87	34.225	37.85	3.62
MK15	27.71	35.165	42.75	4.07
MK20	26.81	33.82	38.9	3.44

4.2 Split tensile strength test

This is an indirect test to determine the tensile strength of cylindrical specimens. Splitting tensile strength tests were carried out at the age of 28 days for the concrete cylinder specimens. Test was conducted using compression testing machine of 3000kN capacity as per IS: 516-1959. The load was applied gradually till the specimen breaks and readings were noted. The 28 days split tensile strength of conventional concrete, MK5, MK10 and MK20 concrete 19.7%, 22.22%, 12.43% and 18.31% of split tensile strength was reduced when compared to MK15 concrete. From the table it was observed that the split tensile strength of conventional concrete and MK20 were more or less same. From results it was observed that cement replaced with 15% of metakaolin was given more split tensile strength compare to other replacement percentages.

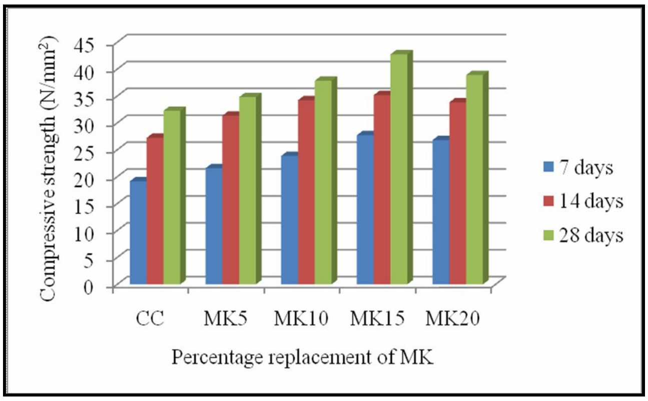

Figure 3. Compressive strength of examined specimens

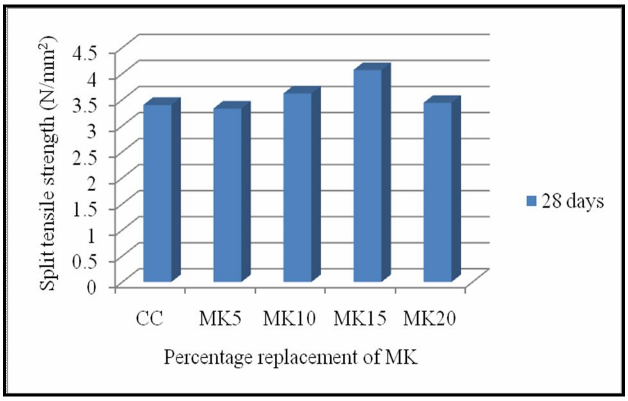

Figure 4. Split tensile strength at 28 days

4.3 Flexural strength test

The flexural strength of normal conventional concrete and optimum replacement of metakaolin beams were tested using Universal testing machine (UTM) and the strength results at the age of 28 days were noted. The beam was reinforced with steel bars having diameter of 12mm as main reinforcement, 8mm as secondary reinforcement and for stirrups 6mm diameter bar was used. Clear cover was given as 25mm. Control mix beam and beam replaced with MK15 proportion were tested failed in flexure with crushing of concrete in the compression zone at the failure stage after the development of flexural cracks. The first visible cracks formed between the locations of the two point loads in the region of maximum bending moment. The flexural strength test on beams results show that the ultimate load carrying capacity of the beam increases by 20% for MK15 and table 4 shown clear result in flexural strength.

Table 4. Flexural strength at 28 days

S.No	Mix Designation	Flexural strength (N/mm^2) 28 days
1	CC	23.6
2	MK15	28.42

5. Conclusions

Based on the results obtained in this experimental study the following conclusions were made

- The compressive, split tensile and flexural strengths using M-Sand and metakaolin were measured in the laboratory. Compressive strength and split tensile strength was found to increase with age as for normal concrete.
- The compressive strength values were increased with metakaolin content if cement was replaced with metakaolin upto 15%. After this replacement percentage the strength was reduced even after increase in replacement of metakaolin content.
- From the comparison of the compressive strength test results at 7, 14 and 28 days, it was observed that MK15 (15%MK & 50% M-Sand) showed maximum strength compare to other replacement percentage.
- MK15 showed there was 32.55% increase in compressive strength at 28 days compared to normal concrete.
- Splitting tensile strengths results have also followed the same trend to that of compressive strength results showing the highest values at 15% replacement.
- From the results it is concluded that the M-Sand can be used as a replacement for fine aggregate. It was found that 50% replacement of fine aggregate by M-Sand give maximum result in strength.

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