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STUDY ON MECHANICAL AND MICROSTRUCTURE PROPERTIES OF CONCRETE PREPARED USING METAKAOLIN, SILICA FUME AND MANUFACTURED SAND

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ABSTRACT
The increased usage of traditional concrete tends to spoil the environment, i.e. the cement leads to greenhouse gas emission and sand to depletion of natural sources. This situation demands to find out suitable alternative/sustainable materials partially replacing the constituent materials of concrete for which the performance needs to be checked. The hydration period, mineral admixtures, composition of cement, amount of water used affects the microstructure of concrete. The present study describes an experimental program planned to investigate the effect of using Metakaolin, silica fume partially replacing cement and manufactured sand partially replacing river sand in preparation of concrete. The percentage replacement of cement by Metakaolin and silica fume considered in this study are 2,4, and 6% by weight of cement and sand by M-sand are 10,20,30%. The compressive and split tensile strength are analyzed for modified concretes, at the age of 7 and 28 days. Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) techniques are used to study topography and crystalline properties on conventional and modified concretes. The results of experimental investigations and microstructure study to examine the chance of using alternate materials for the production of concrete are presented in this paper.
Keywords: Metakaolin, Silica fume, Manufactured sand, SEM, XRD

INTRODUCTION
Portland cement is most commonly used as a binder material in building and construction. The production of cement will utilize some natural resource, consume high energy and generate a huge amount of carbon dioxide. Metakaolin, as the name suggests, is a mineral rich in kaolinite having a particle size smaller than cement. Metakaolin is a valuable admixture for concrete, so that it can act as high-performance concrete. Silica fume, an ultra-fine powder used as pozzolanic material in production of high-performance concrete is an amorphous polymorph of silicon dioxide and silica obtained as a by-product in the production of silicon and Ferro silicon alloy. Some of the research works performed earlier is described here. The best material for replacement of cement in concrete was studied.[1] The specimen was cast with M60 grade of concrete using OPC. Using Metakaolin as 5, 10, 15 and 20 % replacement of cement by its weight, the split tensile, compressive, flexural strength were examined. The compressive, split tensile and flexural strength increased up to 15% of replacement thus indicating that replacing cement by Metakaolin as a pozzolanic material will produce high-performance concrete. Silica fume as a partial replacement in cement was investigated.[2] Silica fume replaced cement at 0 to 15% with 5% increment. The study of the strength parameter of partial replacement of cement in concrete showed a rapid increase in strength of concrete with the increase of silica fume content. The optimum value of compressive and split tensile strength is obtained at 10% replacement. The effect on properties of concrete using Metakaolin and silica fume was investigated.[3] The specimen was cast by replacement of cement with 0,5,10 and 15% of Metakaolin or silica fume by keeping the water-cement ratio of 0.35. The concrete was examined for

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compressive strength, slump, restrained shrinkage cracking and free shrinkage. The result showed that the workability of concrete and compressive strength was increased in Metakaolin modified concrete than silica fume modified concrete. The usage of two admixtures reduces the restrained shrinkage cracking width and free drying shrinkage. The effect on strength properties of concrete by combinations of silica fume and Metakaolin was studied.[4] The specimens were cast with M30 grade concrete made by a combination of Metakaolin and silica fume by 0,5,10 and 15%. The compressive strength of silica fume and Metakaolin concrete is increased gradually up to 10% replacement. Similarly, the split tensile and flexural strength increased 19.69 and 22.44% respectively by 10% replacement of Metakaolin and silica fume in concrete compared to conventional concrete. The XRD, NMR Synchrotron spectroscopic, NEXAFS and IR studies of OPC/slag and OPC cement paste hydrates are studied.[5] This investigation was aimed at finding the fundamental similarities between OPC and OPC/slag paste hydrates. Investigation of OPC and 35% slag is done by using five techniques. The results of NMR show that there is no major difference between the silicate phase of OPC and 35% of slag paste. XRD result shows that the three main phases of OPC and in 35% of slag paste, no spectra were detected. IR spectra confirm that $CaOH_2$ present more in OPC compared to 35% of slag paste. NEXAFS results show that there is no difference between OPC and 35% of slag paste. The effect of the use of silica fume and natural volcanic ash as by micro and pore structural investigation using NMR, XRD, FTIR and X-Ray micro tomography was performed.[6] Volcanic ash, silica fume and Portland cement were tested using different pore and microstructures characterization techniques using multiple mix combination. The pore and microstructure were tested using XRD and FTIR with hardened cement paste cured after 28 days. The result shows that adding silica fume helped to reduce porosity and up to 40% of it can replace OPC. Similar studies were conducted in recent years.[7-12]

EXPERIMENTAL

The chemical properties of materials used, the mixture proportions used for conventional and modified concrete, the test procedure adopted for studying mechanical properties of concrete and microstructure study are included in this section.

Materials

Metakaolin and silica fume was collected from Astra chemicals, Chennai, India. Metakaolin is a pozzolan, which is more effective pozzolanic material used in concrete. It is an anhydrous calcined form of the clay minerals kaolinite. Silica fume is an ultra fine powder and can be used as pozzolanic material in the production of high-performance concrete. M-sand is sand made form rock by artificial processes, usually for construction purpose in concrete. It differs from river sand by being more angular and having different properties. The chemical properties of Metakaolin and silica fume are given in Table-1 and 2 respectively. The fine aggregate used was river sand and M-Sand. The crushed stone was used as coarse aggregate. Ordinary Portland cement was used in this research work.

Mixture Proportions

The mix proportions of non-conventional and conventional concrete are given in Table-3. The conventional concrete mixture was designed as per IS 10262-2009. Metakaolin and silica fume replacing cement by weight and M-Sand was replacing river sand by weight is used. The quantities of coarse aggregate i.e., 1170 kg/m^3 were used in all concrete samples. M40 grade of concrete was prepared with water cement ratio of 0.45.

Table-1: Chemical Properties of Metakaolin

Content	Percentage
SiO_2	52
Al_2O_3	46
Fe_2O_3	0.60
TiO_2	0.65
CaO	0.09
MgO	0.03

Na_2O	0.10
K_2O	0.03

Table-2: Chemical Properties of Silica Fume

Content	Percentage
SiO_2	99.886
Al_2O_3	0.043
Fe_2O_3	0.040
TiO_2	0.001
CaO	0.001
MgO	0.00
Na_2O	0.003
K_2O	0.001

Table-3: Mix Proportions of Concrete Mixtures

Mixture	Cement kg/m^3	Metakaolin kg/m^3	Silica fume kg/m^3	Sand kg/m^3	M-Sand kg/m^3	Coarse Aggregate kg/m^3
Control Mix	450	-	-	658	-	1170
2M2SF30MS	432	9	9	460	198	1170
4M4SF20MS	414	18	18	526	132	1170
6M6SF10MS	378	38	36	592	66	1170

M-Metakaolin, SF-Silica Fume, MS-M-Sand. The prefix indicates its % replacement.

Test Procedure

The compressive and split tensile strength of concrete was examined by casting and testing cubes and cylinders of size 150 mm× 150 mm×150 mm and 150 mm×300 mm respectively. The specimens were demoulded after 24 hrs and placed inside curing tank for curing up to required age for the test. The split tensile and compressive strength of concrete was measured at 7 and 28 days of curing period as per IS: 516-1959 and IS 5816-1999 respectively. Totally 24 cubes and 24 cylinders were cast and tested.

Microstructure study Using Abruker instrument model d2-phaser, XRD test was performed with different percentages of cement, Metakaolin, silica fume, M-Sand and river sand at a scanned rate of 2.5º/min using Cu-kα radiation through continuous scanning of within the 2-theta range of 0-90º. Perking Elmer 880 spectrometer was used for performing FTIR using KBr pellet technique. Scanning Electron Microscope (SEM) analyzer is an instrument used for the analysis of micro structural characteristics of the sample. The instrument can give the morphological structure of the specimen for various magnifications.

RESULTS AND DISCUSSION

Compressive Strength of Concrete

Figure-1 denotes the result of compressive strength tests. The strength development pattern of percentage replacement of material in concrete is depicted. From the results, it is found that the strength is increased in a different stage of the curing period. At 7 days of the curing period, the strength of 2M2S30MS, 4M4S20MS, and 6M6S10MS was increased by 5.1, 2.3 and 7.5% respectively and at 28 days of curing age, the strength of 2M2S30MS, 4M4S20MS and 6M6S10MS was increased by 8.1, 5.5 and 8.8% respectively compared to the conventional concrete. Comparing all the specimens, the specimen 6M6S10MS showed higher compressive strength.

Split Tensile Strength of Concrete

Figure-2 denotes the result of split tensile strength tests. The improvement of strength in concrete is shown in all curing stages. At 7 days of the curing period, the strength of 2M2S30MS, 6M6S10MS was increased by 0, 3.8% and 4M4S20MS was decreased by 7.6% respectively and at 28 days of curing age, the strength of 2M2S30MS, 4M4S20MS, 6M6S10MS was increased by 6.1,12.2, and 16.3% respectively compared to conventional concrete. Comparing all the specimens, the specimen 6M6S10MS showed higher split tensile strength.

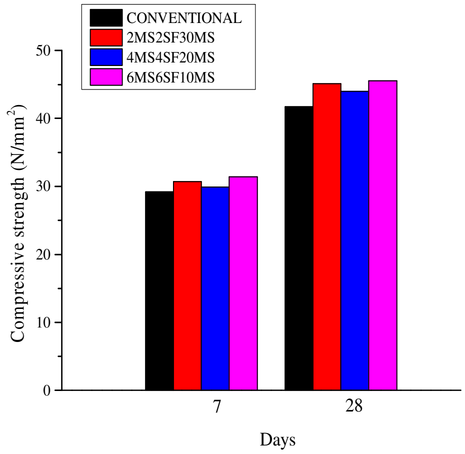


Fig.-1: Compressive Strength

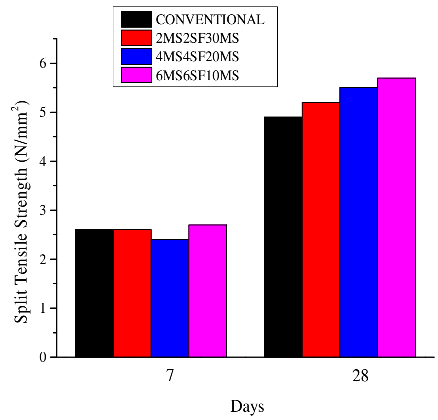


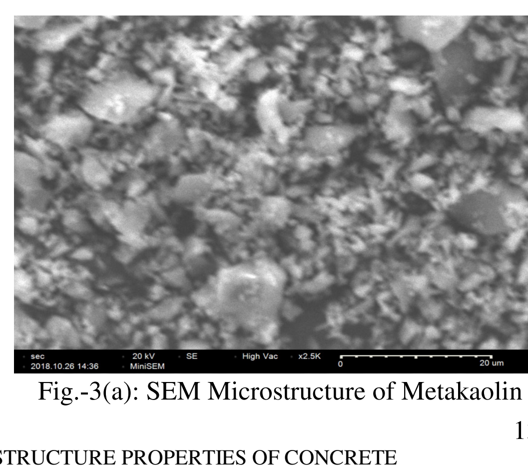
Fig.-2: Split Tensile Strength

SEM Analysis

The mechanical properties of material only depend upon its microstructure which is resolved using scanning electron microscopy (SEM). SEM analysis is used to find the surface area of the material. Scanning electron microscopy provides not only topographic but also compositional analysis of the material. The raw powder of Metakaolin and silica fume were placed on the SEM stub and image was taken in the form of SE image mode. SEM image in Fig.-3(a) shows the SEM microstructure of Metakaolin and Fig.-3(b) shows the SEM microstructure of silica fume. In order that it was a raw powder, there were no pores shown in the figure and it was denser and compact which increases the strength of concrete.

XRD Analysis

XRD Analysis is used to find out the qualitative minerals. This test was done to determine the presence of glass and crystalline components. This technique is mostly used to identify the intensity and structure of crystalline materials. The graph is drawn between 2θ and intensity. The XRD pattern of Metakaolin, silica fume and 20% M-Sand-80% fine aggregate 30% M-Sand-70% fine aggregate is shown in Fig.-4. According to XRD spectra of Metakaolin, the presence of quartz, calcium and alumina is observed. From silica fume XRD, the presence of quartz is observed. From 20MS80FA mix, it is seen that it represents quartz and alumina. In X-Ray pattern for pure Metakaloin, the first peak is observed at 2θ= 11.12 and second peak is observed at 2θ= 26.7. Also in silica fume, the first peak is observed at 2θ = 23.45 and the second peak is observed at 2θ = 27.5 and also in 20MS80FA, the first peak is observed at 2θ = 26.8 and the second peak is observed at 2θ = 60.15. The peak intensity was decreasing with decreasing replacement % of the material by weight. Compared to 20MS80FA mix, the peak intensity was high in 30MS80FA.



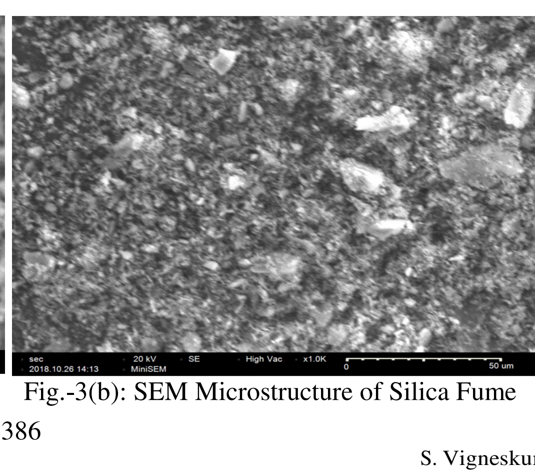
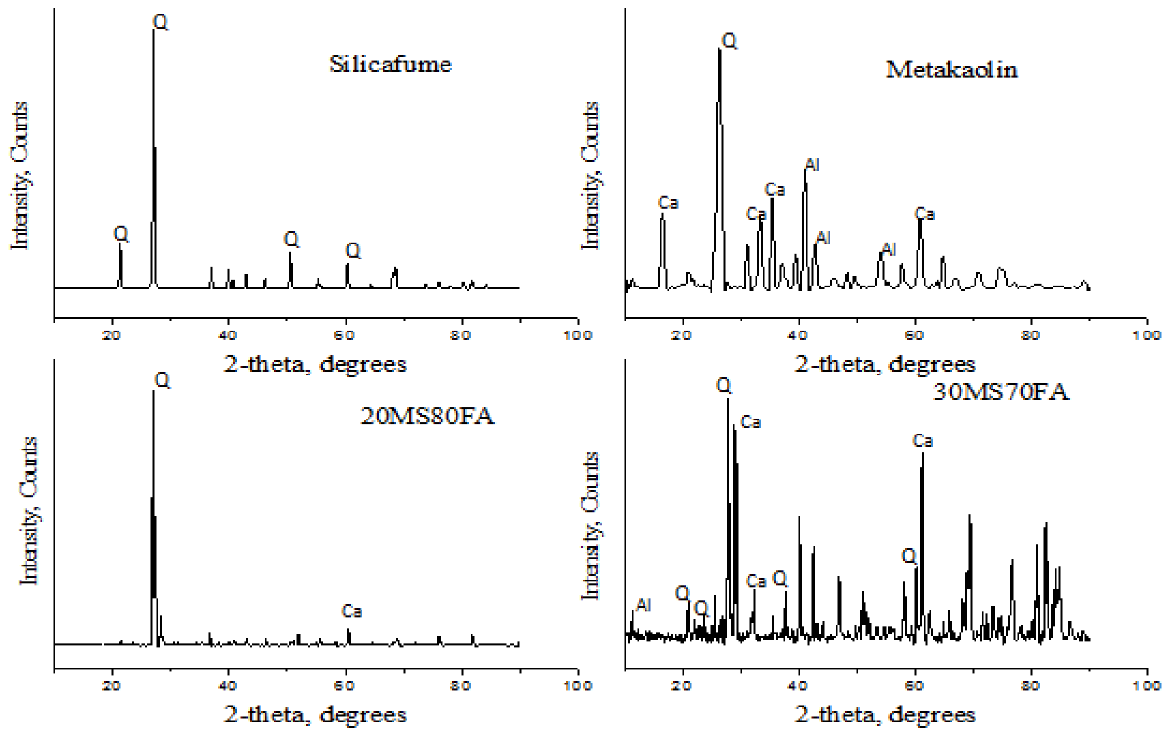


Fig.-3(a): SEM Microstructure of Metakaolin Fig.-3(b): SEM Microstructure of Silica Fume



Q-Quartz, Ca- Calcium, Al- Alumina
Fig.-4: XRD Pattern of Metakaolin, Silica Fume, 20MS80FA, 30MS70FA

FTIR Analysis

The FTIR spectra for Metakaolin, fine aggregate replaced with M-Sand and cement replaced with Metakaolin, silica fume is shown in figures. The results of Metakaolin with transmission band at 1092, 838, 734, 549 and 529 cm^{-1} is shown in Fig.-5(a). The main peaks are at 1092 and 838 cm^{-1}. The results of the replacement of material in cement and IR spectrum with the transmission band at 1847, 1458, 1409, 1097,879 cm^{-1} is shown in Fig.-5(b). The main peaks are at 1097 and 879 cm^{-1}. The result of the replacement of material in cement and IR spectrum with the transmission band at 3735, 1537, 1155, 1095, 711, 557 cm^{-1} is shown in Fig.-5(c). The main peaks are at 1537 and 1095 cm^{-1}.

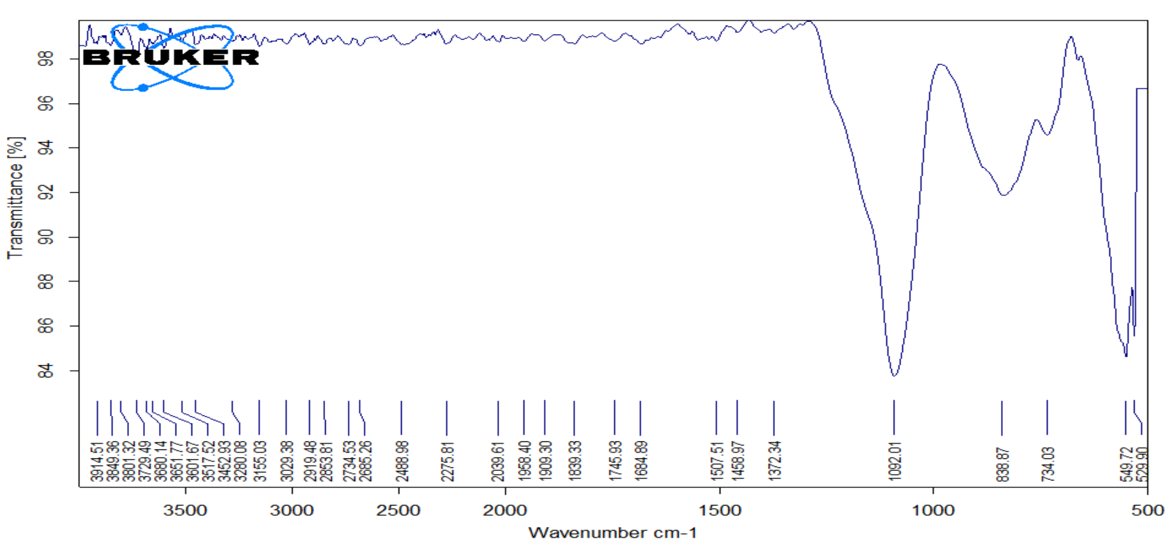


Fig.-5(a): FTIR Spectra of Metakaolin

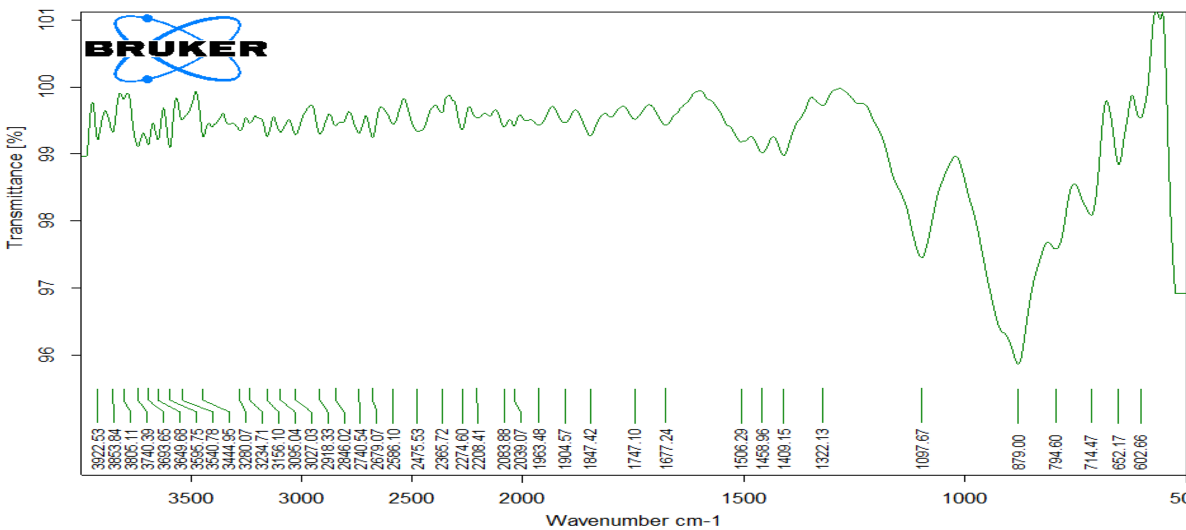


Fig.-5(b): FTIR Spectra of Material Replacement in Cement

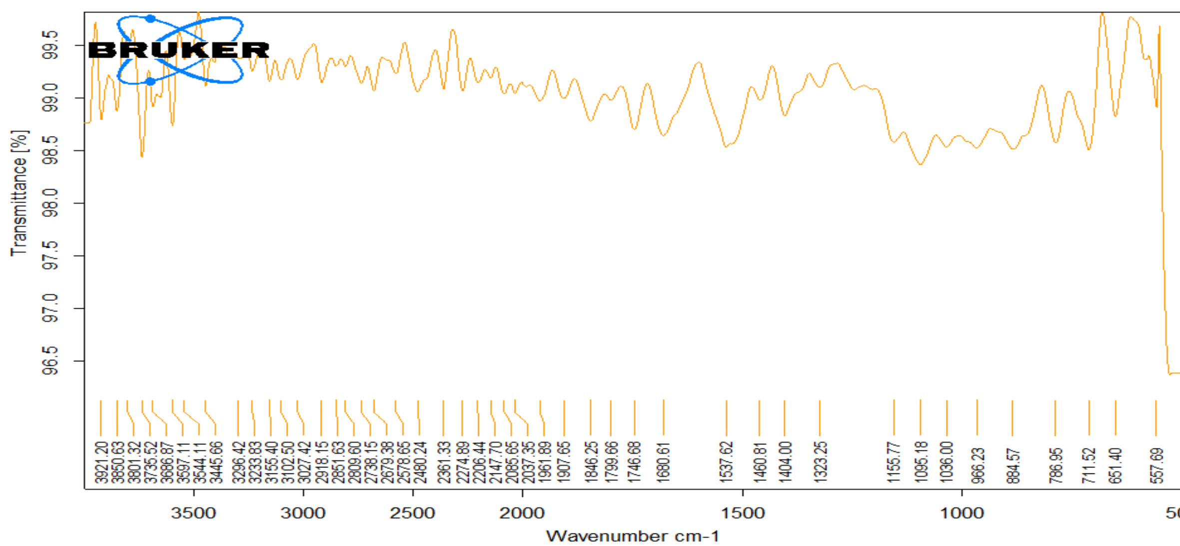


Fig5. (c)FTIR Spectra of Material Replaced in Fine Aggregate

CONCLUSION

The conclusions arrived from the experimental and microstructure study are listed below.

The compressive strength at 7 and 28 days shows that for the specimens 2M2S30MS, 4M4S20MS, 6M6S10MS, strength was increasing compared to conventional concrete. The split tensile strength at 7 days shows that for the specimen 2M2S30MS and 6M6S10MS, it was increasing and for the specimen 4M4S20MS it was decreasing and at 28 days, for the specimens, 2M2S30MS, 4M4S20MS and 6M6S10MS, strength was increasing compared to conventional concrete. From overall results, specimens with an increase in the percentage of replacement by Metakaolin, silica fume and with a decrease in the percentage of replacement by M-Sand gives high strength compared to all other specimens. XRD result shows that the peak intensity was decreasing with a decrease in the replacement of material by weight. SEM shows that the dense of the microstructure is responsible for the increase in compressive strength of concrete. The peak results are obtained using FTIR analysis.

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