JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

# EXPERIMENTAL STUDY ON PARTIAL REPLACEMENT OF CEMENT BY METAKAOLIN POWDER IN CONCRETE

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**ABSTRACT :** The overall production of the cement has greatly increased which results lots of problems in environment as it involves the emission of $CO_2$ gas. Environmental concerns, stemming from the high energy expense and carbon dioxide emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials. Materials such as Metakaolin have good pozzolanic activity. To achieve sustainability in construction world, number of substitution materials are used. Metakaolin is widely used green pozzolana. Metakaolin is calcined clay (koalite). It is obtained from raw material i.e. Kaolin Clay (very fine, white). There is very little emission of carbon dioxide whiles the production of Metakaolin as compared to cement hence it is called as green pozzolana. The chemical properties of cement were compared with Metakaolin, so that we can replace cement with Metakaolin. It also solve ecological and environmental problems because cheaper production of Metakaolin and more durable. Therefore this paper provides a scope for more research which is required for green and durable concrete

**KEY WORDS:** Metakaolin powder,Compressive strength, Split Tensile Strength, Flexural strength.

## I.INTRODUCTION

In the manufacture of cement, the clinker production process requires a great amount of energy and emits a large amount of carbon dioxide ($CO_2$) into the atmosphere. The increase in $CO_2$ emissions has led to the greenhouse effect and an increase in the temperature of the Earth. To reduce the environmental problems, industrial and agricultural by-products such as fly ash, rice husk ash, silica fume metakaolin, granulated blast furnace slag, *etc*., have been used as supplementary cementing material to reduce the production of cement, thus reducing the emission of $CO_2$ and the use of energy. Moreover, the incorporation of these cement replacement materials in concretes has been reported to improve the mechanical properties and penetration resistance of the concrete

The cement concrete is a mixture of cement, sand, pebbles or crushed rocks and water. The cement concrete has attained the status of a major building material in the modern construction. Although Portland cement demands are decreasing in industrial nations, it is increasing dramatically in developing countries. Cement demand projections shows that by the year 2050 it will reach 6000 million tons. Portland cement production leads to major $CO_2$ emissions accounting for almost 0.7 tonnes of $CO_2$ per ton of cement, which represents almost 7% of the total $CO_2$ world emissions. Not only $CO_2$ releases from cement manufacture but also $SO_3$ and $NO_3$ which can cause the greenhouse effect and acid rain.

The addition of metakaolin in concrete will affect the properties of concrete both in the fresh and hardened states. In fresh state the properties that always been highlight is workability and setting time. Workability is defined as how easy the fresh concrete can be handled, placed, compacted and finished. The setting time is been divided into two which initial and final set that show how fast the metakaolin can be hydrated. For hardened state the properties that always been highlight is compressive strength and flexural strength test because these properties of the quality of the concrete.

The raw material in the manufacture of Metakaolin is kaolin clay. Kaolin is a fine , white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolins are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer silicate mineral. The Meta prefix in the term is used to denote change. In case of Metakaolin , the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time. Dehydroxylation is a reaction of decomposition of kaolinite crystals to a partially disordered structure.

The results of isothermal firing shows that the dehydroxylation begins at 4200°C. At about 100-2000°C clay minerals lose most of their adsorbed water. The temperature at which kaolite loses water by dehydroxilization is in the range 500-800$^0$C. This thermal activation of a mineral is also referred to as calcining. Beyond the temperature of dehydroxylization, kaolinite retains two dimensional order in the crystal structure and the product is termed Metakaolin.

Metakaolin is white, amorphous, highly reactive aluminium silicate pozzolan forming stabile hydrates after mixing with lime stone in water and providing mortar with hydraulic properties. Heating up of clay with kaolinite $Al_2O_3.2SiO_2.2H_2O$ as the basic mineral component to the temperature of 500 °C - 600°C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form – so-called metakaolinite.The chemical equations describing this process is **$Al_2O_3.2SiO_2.2H_2O$ = $Al_2O3.\ 2SiO_2 + 2H_2O$**

**Objectives**

- To investigate the effect of curing condition of concrete based on normal, exposed and high temperature curing
- To investigate the mechanical properties of concrete containing metakaolin based on compressive and flexural strength test

- To investigate the physical properties of the metakolin cement paste based on workability, setting time and soundness test
- To investigate the optimum replacement for metakaolin in concrete from 5%, 10% and 15%.

## II.EXPERIMENTAL INVESTIGATION

### MATERIALS

### CEMENT:

Ordinary Portland cement (OPC) 53 grade of cement available in market manufactured by super tech was used for the experiment. The cement was tested for various properties as per: IS 12269:1970 properties such as consistency, specific gravity, setting time were determined. Cement is a binder, a substance used in construction that sets and hardened and can bind other material is together. Cement is a fine, grey powder. Cement is mixed with water and materials such as sand, gravel, and crushed stone to make concrete.

**Table 1 Properties of Cement**

| **Properties of cement** | | | | |
|---|---|---|---|---|
| **Standard consistency** | **Specific gravity of cement** | **Fineness test** | **Initial setting time** | **Final setting time** |
| 32% | 3.16 | 7.11% | 60 minutes | 400 minutes |

### FINE AGGREGATE:

Aggregate are the important constituents in concrete. They give body to the concrete, reduce shrinkage and effect economy. They occupy about 70-80 percent of the volume of the concrete. Aggregates shall consist of naturally occurring (crushed or uncrushed) stones, gravel and sand or combination of aggregates. They shall be hard, strong, durable, clear and free from veins and adherent coating; and free from injurious amounts of disintegrated pieces, alkali, vegetable matter and other deleterious substances.

**Table 2 Properties of Fine Aggregate**

| **Properties of fine aggregate** | | | | |
|---|---|---|---|---|
| **Sieve analysis of river sand** | **Sieve analysis of M-sand** | **Specific gravity of river sand** | **Sieve analysis of M-sand** | **Water absorption test** |
| 2.58 | 2.84 | 2.63 | 2.73 | 0.5% |

**COARSE AGGREGATE:**

IS 383-1970 defines coarse aggregates as Aggregates most of which is retained on 4.75mm IS Sieve and containing only so much finer material are

1. Uncrushed gravel or stone which results from natural disintegration of rock,
2. Crushed gravel or stone when it results from crushing of gravel or hard stone
3. Partially crushed gravel or stone when it is a product of the blending of uncrushed gravel or stone and crushed gravel or stone

**Table 3 Properties of Coarse aggregate**

| Properties of coarse aggregate | | | | |
|---|---|---|---|---|
| **Sieve analysis of coarse aggregate** | **Specific gravity of Coarse aggregate** | **Water absorption test** | **Impact test** | **Abrasion test** |
| 7.33 | 2.65 | 0.98 | 10,28 | 10.8 |

**METAKAOLIN POWDER**

The manufacture of Metakaoline is kaolin clay. Kaolin is a fine , white, clay mineral that has been traditionally used in the manufacture of porcelain. Kaolins are classifications of clay minerals, which like all clays, are phyllosilicates, i.e. a layer silicate mineral. The Meta prefix in the term is used to denote change. In case of Metakaolin , the change that is taking place is dehydroxylization, brought on by the application of heat over a defined period of time. Dehydroxylation is a reaction of decomposition of kaolinite crystals to a partially disordered structure. The results of isothermal firing shows that the dehydroxylation begins at 4200° C.

**Table 4 properties of metakaolin powder**

| Specific gravity | Fineness moudulus | Water absorption |
|---|---|---|
| 3.21 | 3.0 | 1.5% |

**MIX PROPORTIONING:**

Concrete mix design in this experiment was designed as per the guidelines in IS 10262-2009. All the samples were prepared using design mix. M30 grade of concrete was used for the present investigation. Mix design was done based on I.S 10262-2009. The table 5 shows mix proportion of concrete (Kg/m$^3$).

**Table 5 mix proportion of concrete**

| | CEMENT | FINE AGGREGATE (River sand)(kg) | M-SAND | COARSE AGGREGATE | WATER | ZEOLITE POWDER |
|---|---|---|---|---|---|---|
| C.C | 425.73 | 647.11 | - | 1110.21 | 191.58 | - |
| C.CM | 425.73 | 647.11 | 639.73 | 1110.21 | 191.58 | - |
| C.M.ZP 5% | 424.81 | 647.11 | 639.73 | 1110.21 | 191.58 | 0.916 |
| C.M.ZP 10% | 423.90 | 647.11 | 639.73 | 1110.21 | 191.58 | 1.829 |
| C.M.ZP 15% | 423.18 | 647.11 | 639.73 | 1110.21 | 191.58 | 2.544 |
| C.C= Conventional concrete , C.CM= Conventional concrete with M-sand, C.M.ZP= Conventional concrete with zeolite powder | | | | | | |

**FRESH CONCRETE PROPERTIES:**

The following tests were conducted to determine the fresh concrete properties.

**Test on fresh concrete**

1. Slump cone Test
2. Compacting Factor test

**Slump cone Test:**

This test is performed to measure the workability of fresh concrete as per IS 1199-1959. Slump cone test is the most commonly used method of measuring consistency of concrete. It is used conveniently as a control test and gives an indication of the uniformity of concrete. Additional information on workability and quality of concrete can be obtained by observing the manner in which concrete slump. The apparatus for conducting the slump test essentially consist of a metallic mould in the form of frustum of the cone having the internal dimension of bottom diameter 20cm, top diameter 10cm, and a height of 30cm. Slump cone = 30 cm height

Slump = 15 cm

**Fig 1: Slump cone Test**

**Compacting Factor test:**

Compaction factor test is the workability test for concrete conducted in laboratory. The compaction factor is the ratio of weights of partially compacted to fully compacted concrete. It was developed by Road Research Laboratory in United Kingdom and is used to determine the workability of concrete as per IS1199:1959 Compaction factor test apparatus consists of two conical hoppers and a bottom cylinder which is arranged as shown in Fig, steel rod of1.6cm Diameter with a length of 61cm is used to tamp the concrete and a weightbalance is used to weight the concrete.

**Compaction factor = (W2-W1)/ (W3-W1)**

**Table 7 Workability of fresh concrete**

| **Workability** | |
|---|---|
| **Slump cone Test** | **Compacting Factor test** |
| 76 | 0.83 |

**Fig 2: Compacting Factor test**

## HARDENED CONCRETE PROPERTIES:

The various strength properties of M-sand concrete are discussed below.

**Test on Hardened concrete**

1. Compressive strength test
2. Split tensile strength test
3. Flexural strength test

**Compressive strength test**

150 mm cube specimens were tested under compressive load in the respective to the age of curing. All the specimens were tested in saturated surface dry condition, after wiping out the surface moisture. For each mix combination, three identical specimens were tested at the ages of 7, 14, 28 days using compression testing machine of 2000 KN capacity under a uniform rate ofloading of 140 kg/cm$^2$/min. and the compressive strength was calculated as per IS: 516 – 1959.

$$\textbf{Compressive Strength (f) = (P/A) N/mm}^2$$

Where,

P = Load at which specimen fails in Newton,

A = Area over which the load is applied in mm$^2$

f = Compressive Stress in N/mm$^2$

**Fig 3:Compressive strength test apparatus**

**Split tensile strength test**

This is an indirect test to determine the tensile strength of cylindrical specimens. Split tensile strength tests were carried out on 100 mm dia.x200 mm high cylindrical specimen at the ages of 28 days of moist curing, using compression testing machine of 2000 N capacity as per IS 5816-1999.

Split tensile strength (ft) is estimated from the expression

$$T = 2P / \pi DL \ \ N/mm^2$$

Where,

T = Split tensile strength of concrete

P = Ultimate Load (Newton)

D = Diameter of cylinder (mm)

L= Length of cylinder (mm)

**Fig 4: Split tensile strength test apparatus**

**Flexural strength test**

In order to determine the flexural strength of concrete, prismatic specimens of a size 100 mm x 100 mm x 500 mm were cast with various proportions of all the concrete mixtures. After 28 days of moist curing the specimens were tested in flexural testing machine under a uniform rate of loadingof 180 $kg/cm^2$/min. Flexural strength of specimens expressed as the modulus of rupture (fb) is then calculated using the formula and procedure given in IS: 516- 1959.

When the distance between the line of fracture and the nearer support, measured on centre line of the tension side of specimen ('a' in mm) is greater than133 mm for prism of size 100 mm x 100 mm x 500 mm, the modulus of rupture (fb) is then calculated from the Equations.

$$(fb) = Pl / bd^2$$

For 'a' is less than 133 mm but greater than 110 mm for prismspecimen, then modulus of rupture is calculated from the formula.

$$(f_b) = 3Pa / bd$$

where,

b = Width of the specimen (mm)

d = Depth of the specimen (mm)

l = Length of the specimen (mm) on which specimen isSupported (span)

P = Maximum load (Newton) applied on the specimen

a = The distance between the line of fracture and the nearer support, measured on the centre line of the tensile side of the specimen.


**Fig 5: Beam testing machine**

## III.EXPERIMENTAL PROCEDURE

The specimen of standard cube of (150mmx150mmx150mm) and standard cylinders of (200mmx100mm) and beam of (100mmx100mmx500mm) were used to determine the compressive strength, split tensile strength and flexural strength of concrete. Three specimens were tested for 7,14&28 days before crushing.

The following experiments are conducted on the specimen is the compressive strength test, split tensile strength test and flexural strength test.

## RESULTS AND DISCUSSION:

The normal concrete are tested for their performance by determining their compressive strength, splitting tensile strength and flexure strength development at different ages of $7^{th}$, $14^{th}$ and $28^{th}$ days. The results obtained are discussed in detail in the following sections.

## COMPRESSIVE STRENGTH TEST:

Compressive strength test is done as Per IS 516-1959. The test is conducted on Compression testing machine of capacity 2000 KN. Mechanical behaviour of concrete was studied for M30 grade of cubes were casted and cured for 7,14 and 28days. using compression testing machine of 2000 KN capacity under a uniform rate of loading of 140 kg/cm2/min. and the compressive strength was calculated as per IS: 516 – 1959.

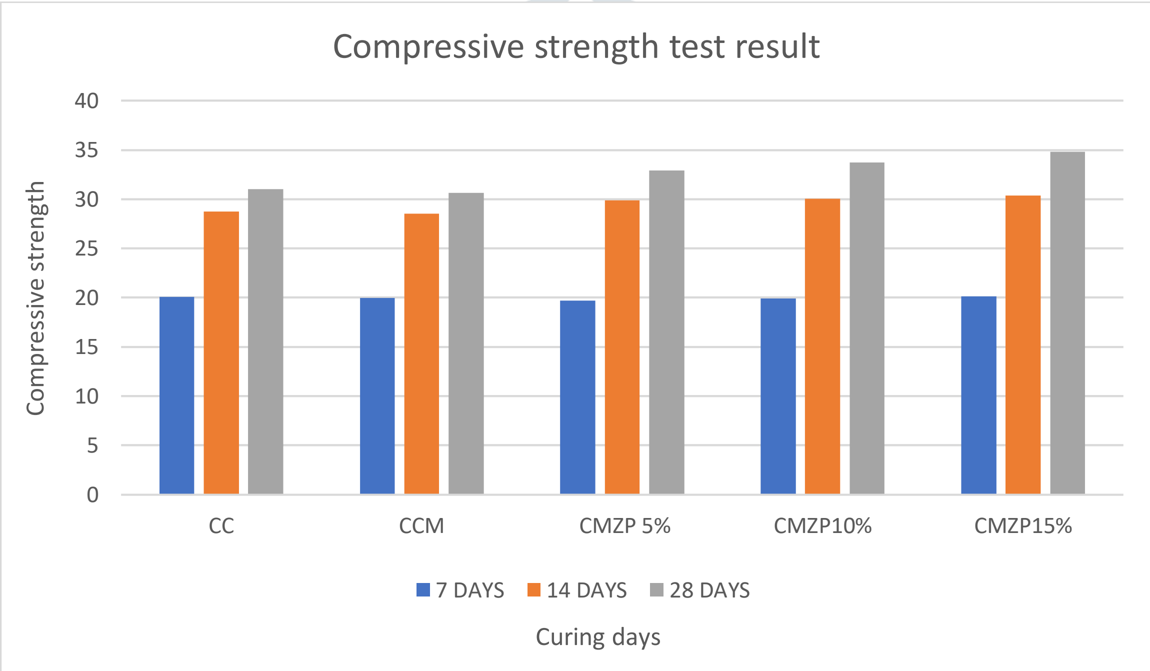
**Compressive Strength (f) = (P/A) N/mm$^2$**

Where,

P = Load at which specimen fails in Newton,

A = Area over which the load is applied in mm2

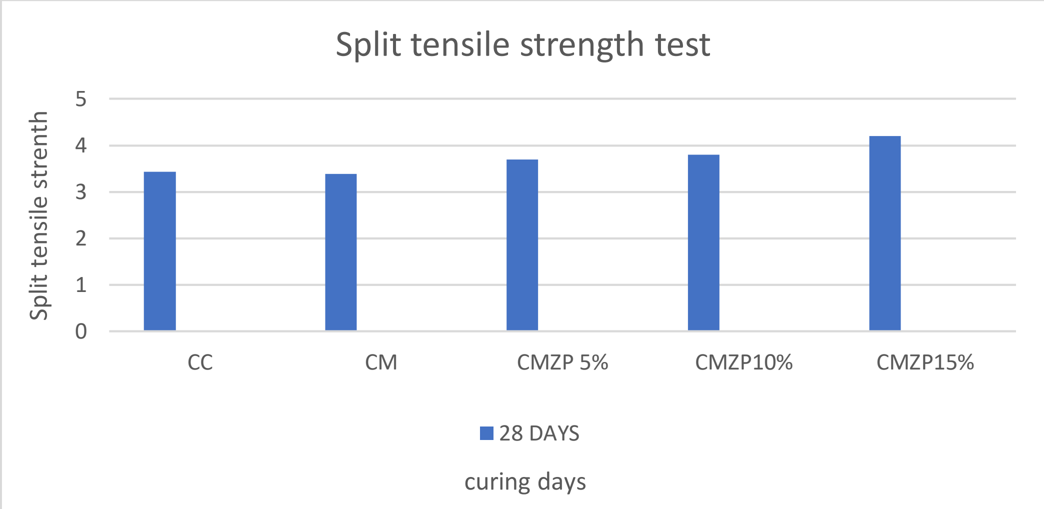
f = Compressive Stress in N/mm2




**Split Tensile Strength test result:**

This is an indirect test to determine the tensile strength of cylindrical specimens. Split tensile strength tests were carried out on 100 mm dia. x200 mm high cylindrical specimen at the ages of 28 days of moist curing, using compression testing machine of 2000 N capacity as per IS 5816-1999.

$$T = 2P / \pi DL \text{ N/mm2}$$




**Flexural strength test result:**

In order to determine the flexural strength of concrete, prismatic specimens of a size 100 mm x 100 mm x 500 mm were cast with various proportions of all the concrete mixtures. After 28 days of moist curing the specimens were tested in flexural testing machine under a uniform rate of loading of 180 kg/cm2/min. Flexural strength of specimens expressed as the modulus of rupture (fb) is then calculated using the formula and procedure given in IS: 516- 1959.

When the distance between the line of fracture and the nearer support, measured on centerline of the tension side of specimen (‘a’ in mm) is greater than 133 mm for prism of size 100 mm x 100 mm x 500 mm, the modulus of rupture (fb) is then calculated from the Equations

**(fb) = Pl/ bd$^2$**

For ‘a’ is less than 133 mm but greater than 110 mm for a100mm specimen, then modulus of rupture is calculated from the formula.

**(fb) = 3Pa / bd**

where,

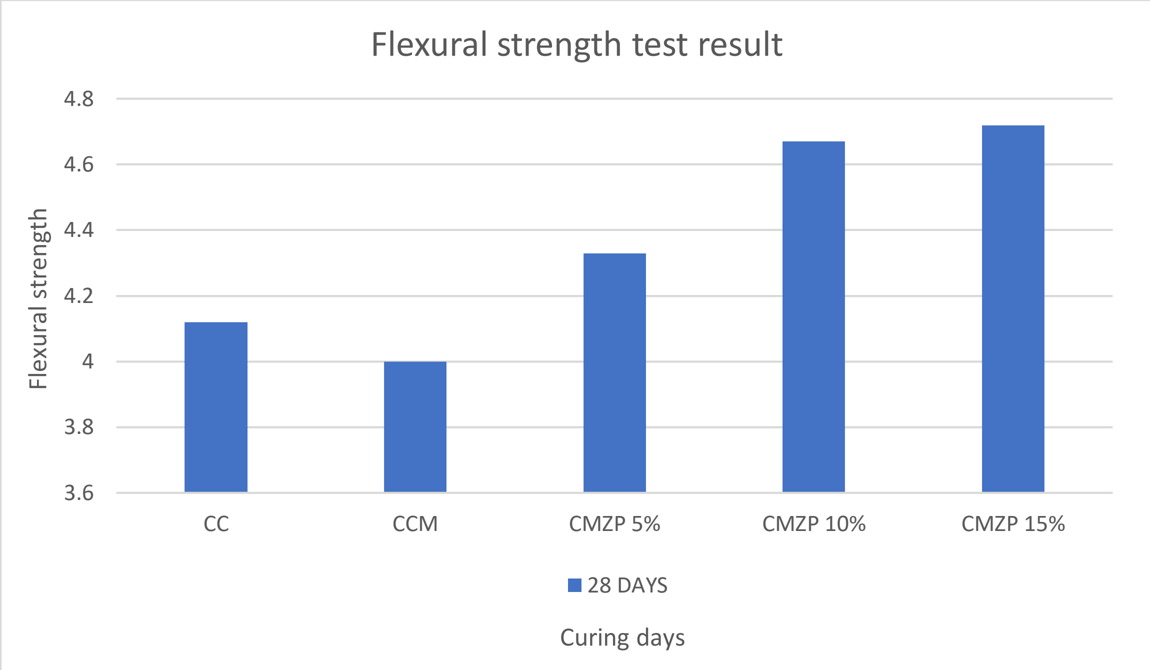
b= Width of the specimen (mm)

d= Depth of the specimen

l= Length of the specimen (mm) on which specimen is Supported (span)

P = Maximum load (Newton) applied on the specimen

a = the distance between the line of fracture and the nearer support, measured on the center line of the tensile side of the specimen




**SCANNING ELECTRON MICROSCOPE (SEM):**

The SEM technique can only be used for the evaluation of surface morphology like roughness, homogeneity of dispersion of nanomaterials in the polymer matrix. SEM is a method for high resolution surface imaging. The SEM uses electrons for imaging, much as light microscopy uses visible light. The advantages of SEM over light microscopy include greater magnification (up to 100,000X) and much greater depth of field. Different elements and surface topography emit different amounts of electrons; the varying amount of electrons are responsible for the contrast in the electron micrograph (picture).

**Benefits of SEM testing include:**

- Digital image resolution as low as 15 nanometers
- Magnification for all imaging is calibrated to a traceable standard. Image analysis for coating thicknesses, grain size determinations and particle sizing can be applied to the saved images.
- Qualitative elemental analysis, standardless quantitative analysis, x-ray line scans and mapping can be performed on both of the SEM systems.

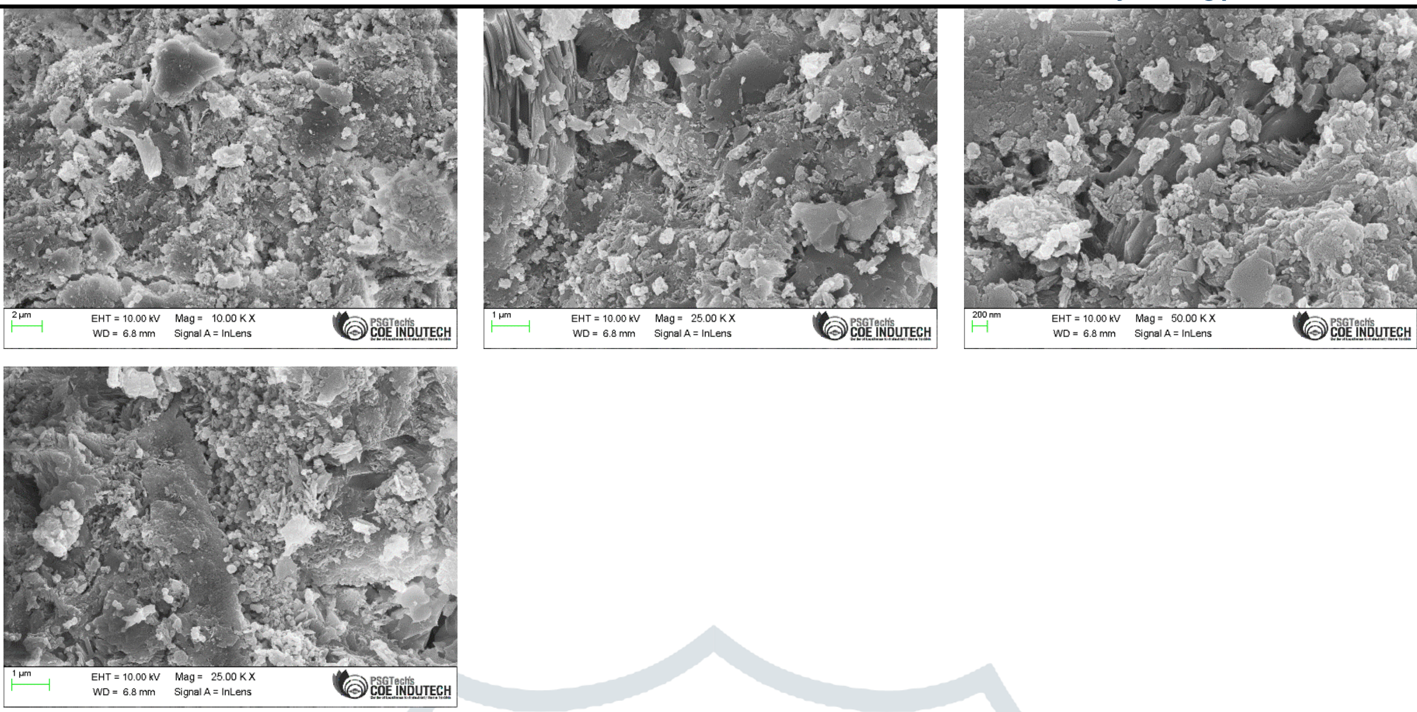



Figure:6 SEM analysis ,these images are scanned in nano microscope(nm).

## IV.CONCLUSION

The strength of metakaolin modified cement concrete mixes shoot the strength of ordinary Portland cement (OPC). The strength of concrete in compression increases up to 15 % replacement of cement in concrete by metakaolin and further increasing of metakaolin leads to decrease in strength of concrete. Thus it is evaluated that optimum percentage replacement of metakaolin with cement in concrete and it is almost 15% for cubes.Compressive strength 34.82 N/mm2,Split tensile 4.2 N/mm2,Fleural strength4.72 N/mm2 at 28 days of curing

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