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MECHANICAL BEHAVIOUR FOR METAKAOLIN BASED CONCRETE

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Abstract

Supplementary cementing materials (SCMs) are additives used to modify or enhance the properties of cement. These materials can either occur naturally or be generated as by-products of industrial processes. Wide range of SCM's is available in the market. Each being made available at a economical production and efficient utilization in the construction industry. Metakaolin is one among them, produced by calcining kaolin clay at high temperatures. It has the unique ability to generate calcium silicate hydrate gel due to the reaction between the calcium hydroxide and water. C-S-H produced is the primary binder in cementitious materials. The resulting C-S-H gel fills the voids in the concrete matrix, improving its durability and strength. In this study, the authors provide an overview of their experimental work that involved partially replacing cement with metakaolin in concrete. The report on various concrete samples with different levels of substitution has been represented in this article. It is found that the inclusion of metakaolin into the concrete mix has influenced the workability in fresh state along with altering the strength parameters in the hardened state.

Keywords: *Metakaolin, Workability, Slump Value, Compressive Strength, Split Tensile Strength*.

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INTRODUCTION

Metakaolin is a pozzolanic material that is produced by calcining kaolin clay at temperatures between 600 – 800 ^{O}C. Metakaolin is an amorphous, white, and fine powder that does not have a well-defined crystal structure. However, it is primarily composed of the mineral kaolinite, which has a layered crystal structure consisting of a tetrahedral sheet of silica and an octahedral sheet of alumina.During the calcination process, the kaolinite structure is destroyed, and the alumina and silica are transformed into a more reactive form. The resulting metakaolin has a high surface area and contains amorphous silica and alumina in a non-crystalline form. Metakaolin particles are typically small, with a size range between 0.1 to 10 micrometers. They have a high specific surface area and a porous structure that allows them to react quickly with calcium hydroxide and water when mixed with cement. Metakaolin is commonly used as a supplementary cementitious material in the construction industry. As an SSM, it reacts with the calcium hydroxide and water present in cement to form calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) compounds. These compounds are responsible for the strength and durability of concrete. The reaction of metakaolin in concrete is a slow process, and it continues over time as long as there is unreacted calcium hydroxide and water present in the cement. This ensures that the strength and durability of the concrete continue to improve even after the initial setting and hardening. Apart, from the engineering advantageous, the utilization of SSM's has gained popularity in the construction industry due to its availability ti improve productivity and reduce labor cost.

Metakaolin is a supplementary cementitious material that has been widely used in the production of high-performance and sustainable concrete due to its pozzolanic properties. Zhang et al. [1] investigated the effect of metakaolin on the durability properties of high-performance concrete and found that the inclusion of metakaolin improved the resistance to chloride ion penetration and enhanced the microstructure of the concrete. Topçu and Şahmaran [7] examined the effects of metakaolin on the mechanical and durability properties of concrete and reported that metakaolin increased the compressive and flexural strength of the concrete and reduced the water absorption and chloride ion penetration. Sharifi et al. [3] conducted a review on the mechanical and durability properties of metakaolin-based geopolymer concrete and found that metakaolin improved the strength, durability, and microstructure of the concrete. Abdullah et al. [4] investigated the use of metakaolin as a cementitious material in concrete and observed that the reactive aggregate type had a significant effect on the mechanical and durability properties of the concrete. Nath and Gupta [5] reviewed the effect of metakaolin on various properties of concrete and concluded that metakaolin improved the compressive strength, flexural strength, and durability of the concrete. Bicer et al. [6] investigated the effect of metakaolin and fly ash on the properties of self-compacting concrete and found that the combination of these materials improved the fresh and hardened properties of the concrete. Kabir et al. [8] studied the influence of metakaolin on the workability, strength, and microstructure of fly ash-based geopolymer concrete and reported that metakaolin enhanced the workability, strength, and microstructure of the concrete. Taha et al. [9] investigated the effect of metakaolin on the mechanical and microstructural properties of self-compacting concrete and found that the addition of metakaolin improved the compressive strength and microstructure of the concrete. Kolay and Bandyopadhyay [10] conducted a review on the effect of metakaolin on the fresh and hardened properties of concrete and concluded that metakaolin improved the workability, strength, and durability of the concrete. Torgal et al. [11] investigated the influence of metakaolin and fly ash on the performance of fiber-reinforced self-compacting concrete and found that the combination of these materials improved the mechanical properties of the concrete.

The objective of this research paper is to investigate the effect of metakaolin on the properties of modified concrete. The paper will present the results of laboratory experiments conducted to evaluate the fresh and hardened properties of different mix containing different percentages of metakaolin. The fresh properties and the hardened properties are some of the some of the parameters which will be evaluated. The microstructure review of the designed modified concrete will also be reviewed. This article aims to contribute to the understanding of the use of metakaolin in concrete and to provide guidance for engineers and expertise in the construction industry who are interested in using metakaolin in their projects.

RESEARCH SIGNIFICANCE

The investigation of the impact of metakaolin replacement of cement in concrete holds significant research significance due to its potential to address sustainability and durability issues in the construction industry. Metakaolin, a pozzolanic material, can be used as a partial replacement for cement in concrete, resulting in improved mechanical properties, reduced carbon footprint, and enhanced resistance to aggressive environments. Understanding the impact of metakaolin on the properties of concrete can help in developing sustainable and durable construction practices, reducing the environmental impact of cement production, and promoting resource conservation. Therefore, this research holds significant importance in the field of construction materials and can contribute to the development of sustainable and resilient infrastructure.

EXPERIMENT PROCEDURE

Materials

Concrete is a composite material made from a mixture of cement, water and aggregates such as sand or crushed stones. The properties of concrete can be modified by adjusting the ratios of its components and by adding admixtures such as plasticizers. In this experimental investigation a special supplementary cementitious metarial in the form of metakolin was also utilized. The cement used in concrete is typically Portland cement Grade 43 of Khyber Brand. A fine aggregate obtained from local river source and coarse aggregates of 20 mm nominal size available at the local crusher zone were utilized in this mix. The ordinary tap water supplied from municipal means was used for preparing the mix. Some of the basic testing of the constituent particles was carried out before preparing the mix design, in accordance to IS 10262 (2009). Superplastizer with the brand name of Auramix-400, a high performance superplasticiser was used for maintaining the required workability. Some of the characteristics. obtained during the initial material testing phase of the basic materials have been tabulated in Table – 1.

Cement : Khyber Brand OPC – 43 Grade	
Soundness	0.92 mm
Initial setting time	137 minutes
Final setting time	218 minutes
Compressive Strength	44.12 N/mm^2
Fine Sand : River Sand – Source River Sindh	
Zone	II
Fineness modulus	2.71

Specific gravity	2.65
Water absorption	1.02%
Silt content	2.12%
Clay content	0.67%
Coarse Aggregates : Cursed River Bed Boulders	
Size	20 mm Nominal
Fineness modulus	6.8
Specific gravity	2.6
Water absorption	0.82%
Flakiness index	20.31%
Elongation index	8.14%
Aggregate crushing value	21.67%
Water : Tap Water	
pH	7.2
Admixture : Auramix - 400	
Nature	High water reduction Long workability retention
Appearance	Light yellow coloured liquid

Table – 1, Basic Test Results for Raw materials

Supplementary Cementitious Material – Metakolin

Metakolin utilized in our experimental work was procured from Kaomin Industries LLP, Atladara, Vadodara, Gujrat in form of powder packed in 25Kg HPDE Laminated Bags. The supplied material was having properties as tabulated in Table -2, as per technical sheet received from the supplier with the material.

Physical Appearance	Powdered Form Off-white pink colour
Amorphous Content	>70%
Avg. Particle Size	1.5mircon to 2.5micron
Consistency	75

Table – 2, Properties of Metakaolin (as per TDS)

Material Mix Proportioning

Design Mix in accordance to IS 10262 (2009) were prepared for which the proportioning of the mix have been tabulated with the reference mix (Mix - REF). Following mix were prepared containing 0%, 5%, 10%, 15%, 20% and 25% as a replacement (by mass) for the cement fraction were used in this experimental investigation. The mix proportions are summarized in Table-3.

Mix	MK % (by weight of cement)	Cement (kg/m^3)	MK (Kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	Water (kg/m^3)	Plasticizer ($grams/m^3$)
REF	0	385	0	738	1175	154	2118
MK05	5	365.75	19.25	738	1175	154	2156
MK10	10	346.5	38.5	738	1175	154	2198
MK15	15	327.25	57.75	738	1175	154	2263
MK20	20	308	77	738	1175	154	2318
MK25	25	288.75	96.25	738	1175	154	2397

Table – 3, Concrete mix proportion used for the experimental investigation.

Production and Storage of specimens

The concrete specimens were produced and stored according to IS 456 (2000). The concrete mixes were produced by first mixing all the dry materials (viz Sand, Cement, Coarse aggregates, Metakaolin) in the laboratory mixer for 2-3 minutes, before the fraction of water along with superplastizer were added. The mixing was nontinued for another 5 minutes till a uniform consistency, colour and texture was achieved. The concrete was checked for slump followed by the filling in the moulds of cube, cylinder and beams. Moulds filled were placed on a vibrating table followed by finishing the the top surface by trowel. After 24 hours of casting the moulds were demoulded and kept for normal curing in the water curing bath. This was done for 28 days, in order to obtain the specimens coded with details of different mix proportions

Testing Procedures

The experimental investigations, over different concrete state, mode of test and the standards considered in the experimental investigations are summarized in Figure 1. The workability was investigated by slump values obtained with the fresh concrete. The mechanical properties were investigated after 7 and 28 days. The compressive strength and split tensile strength were tested with cubes and cylinder respectively. The microstructural analysis was performed using a Hitachi 3600 N Scanning electron microscope with a 5 axis motorized stage coupled with ultra dry Compact EDS Detector (Thermo Scientific™).

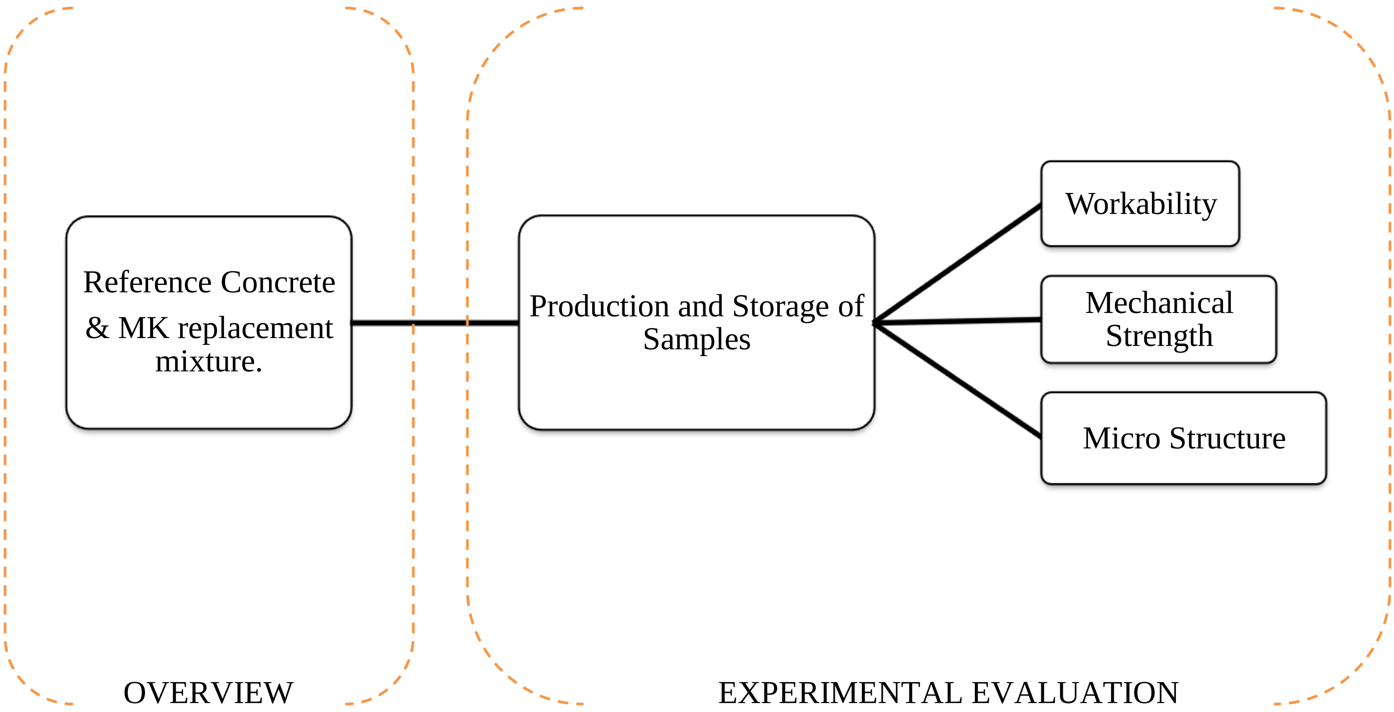

Figure – 1, Methodological processes used to assess the feasibility of metakaolin as an substitution for cement in concrete **.**

RESULTS & DISCUSSION

Workability

Metakaolin dosage, can affect the workability of the mix. As evident from the Figure 2, the workability of fresh concrete was altered by the addition of metakaolin. The increased demand of superplastizer with the increase in metakaolin content was noted in order to maintain the workability of the modified mix. In the fresh state the mix obtained by the incorporation of metakaolin showed no segregation or bleeding.

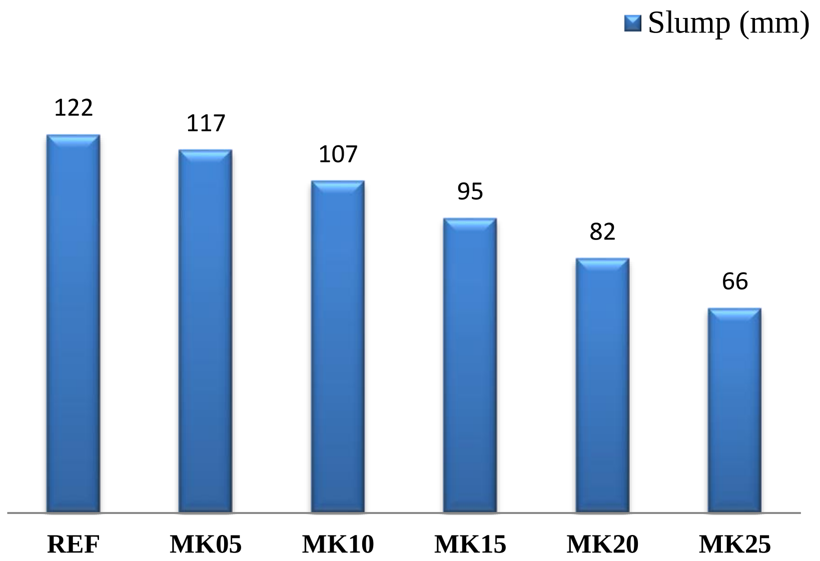

Figure – 2, Slump values for different mix

The slump value decreased with the addition of metakolin. As illustrated from Fig 2, at lower replacement there is not much variation with the slump values. However at higher concentration level there is abrupt drop in the slump.

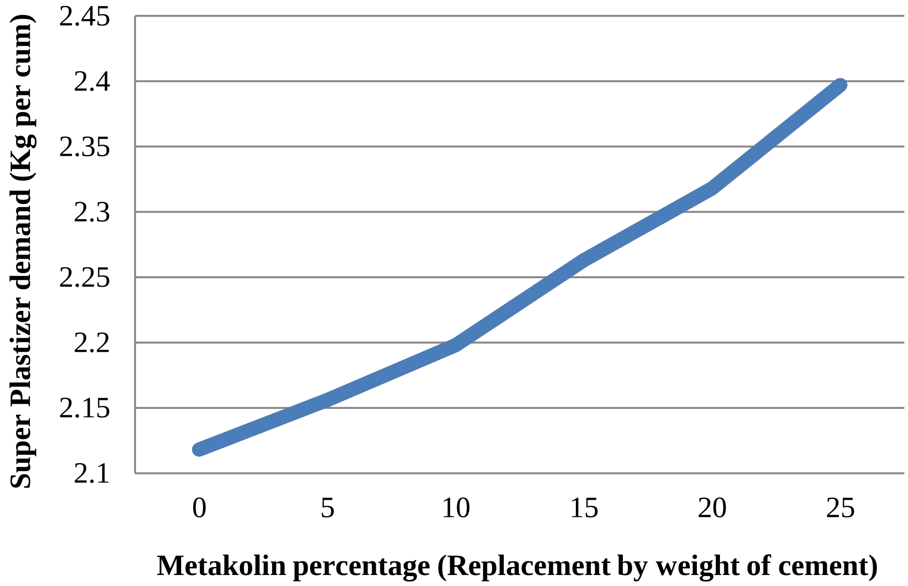

Figure – 3, Superplastizer demand with reference to MK % to maintain true slump values.

Fig-3 shows that the need of superplasticer increases with the increasing MK content. This modification with the design mix is carried out in order to compensate for the loss of workability of concrete.

Compressive Strength

Metakaolin's addition had an impact on the concrete's compressive strength. The alteration in the compressive strength values were noted with reference to the neat concrete. The additions made in the initial incremental values increased the compressive strength however at the higher percentage substitution levels, there was a negative impact over the compressive strength. Because of the improved micro-structure brought about by the inclusion of metakaolin, the compressive strength has increased. The extra calcium silicate hydrates (C-S-H) were created when calcium hydroxide, a by-product of cement hydration, was combined with metakaolin.

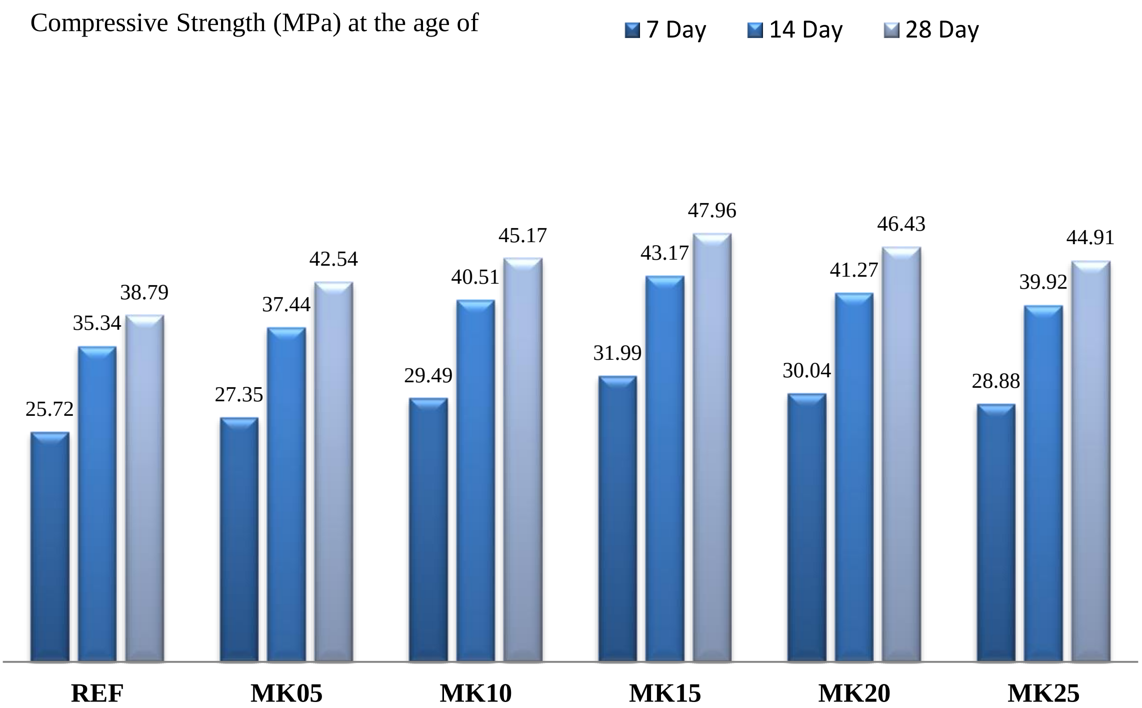

Figure – 4, Compressive Strength by different mix (N/mm^2).

Fig-4 illustrates the impact of metakaolin content over the compressive strength. As evident from the experimental findings, the variation in compressive strength is noted with reference to the neat concrete. At the substitution percentage level of 5%, 10%, 15%, 20% and 25% a marginal gain of 5.9%, 14.6%, 22.15%, 16.77% and 12.95 with reference to neat concrete. Moreover, it may be observed that the highest gain in strength may be noted with the replacement level of 15%. This overall enhancement in the compressive strength may also be attributed to the reduction in the amount of unreacted cement in the concrete mix, which in turn helps in decreasing the number of capillary pores. This reduction in capillary pores by the filling of smaller voids within the concrete matrix by metakaolin particles helps to improve the microstructure of the concrete. This improved microstructure helps to improve the overall strength for the modified concrete mix.

Split Tensile Strength

In case of split tensile strength (Figure-5) the 28 days value without metakaolin is 2.97 N/mm^2. With the addition of metakaolin, the split tensile strength was also altered. Overall, gain in split tensile strength was noted. With the addition of 5%, 10%, 15%, 20% and 25% of metakaolin the increase of 6.73%, 16.16%, 24.8%, 10.43% and 5.05% respectively. The highest gain was similarly noted at 15% substitutional level.

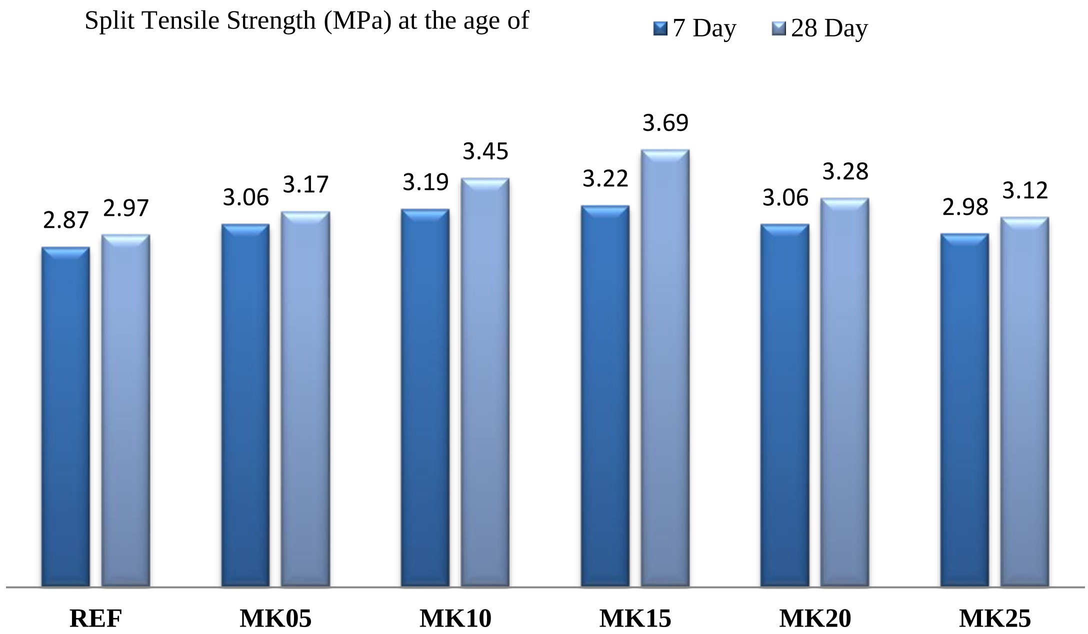

Figure – 5, Split Tensile Strength results by different mix (N/mm^2).

The enhancement in the split tensile strength may be attributed to the densification and compact microstructure arising due to the pozzolanic reaction, resulting in enhanced resistance to tensile forces. Thus the improved microstructure by the addition of metakaolin to the concrete is leading to a more uniform and interconnected network of C-S-H gel. This improved microstructure enhanced the bonding between the cement paste and aggregate particles, which can thus help to transfer tensile stresses between the two phases more effectively. This improved bonding ability also contributes to the enhancement of the split tensile strength.

Scan Electronic Microscopy

Scanning electron microscope, is most extensively used tool for determining the morphology of modified concrete with the metakaolin substitution. The morphological investigation serves as a useful material property for evaluating metakaolin's viability as a replacement cementitious material.

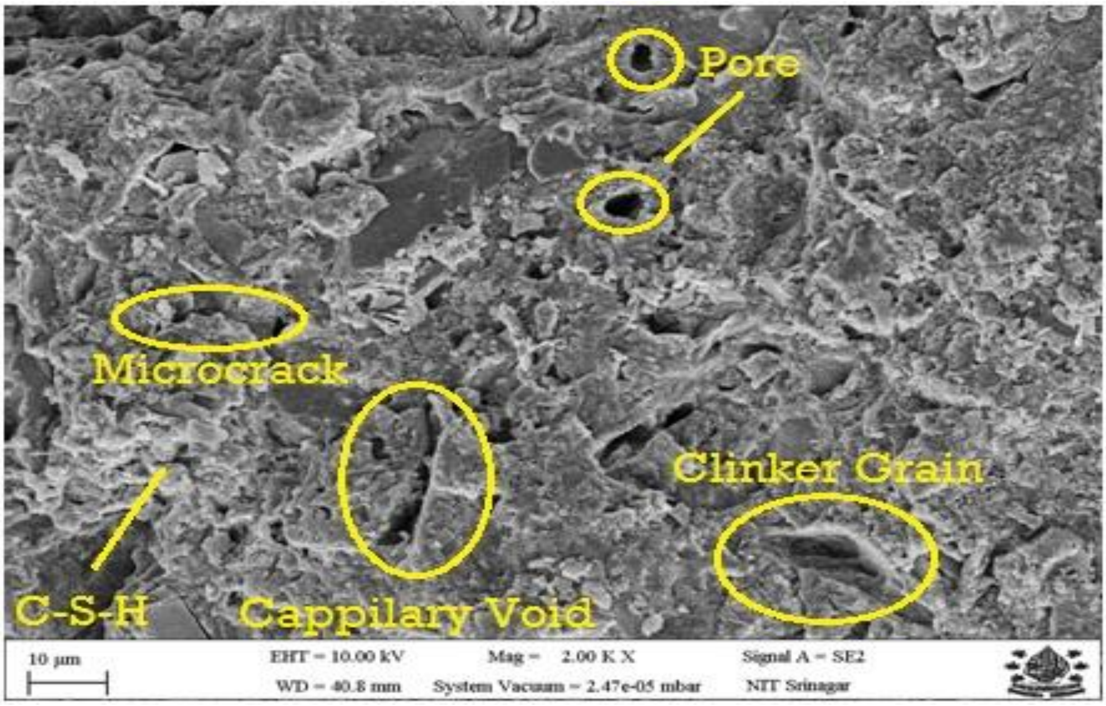

Figure – 6, SEM image of concrete with 15% metakaolin.

Figure 6 depicts the findings of the SEM investigations containing metakaolin (Mix : MK15). As can be seen from the photograph, there are a sizable number of large fragments, which can be classified as anhydrate clinker grains. These particles are associated to each other during the hydration process in which the dissolution of smaller clinker grains are followed by the bigger ones [12]. Observations, pertaining to the presence of tiny voids, circular holes and capillaries in haphazard manner are also noticed. The addition of metakaolin has considerably influenced the porous structure of concrete matrix at the microscopic level. The addition of metakaolin thus, markes its presence in these micro spaces. Thus due to this fact the metakaolin improving the porous structure of the concrete matrix. These findings may also be attributed to the improved interfacial transition zone (ITZ). All these factors arising due to the pozzolanic reactions and the filling up of voids by metakaolin resulting in a denser micro structure, ultimately improving the strength of the matrix.

CONCLUSION

- ✓ Inclusion of metakolin, influenced the fresh state of concrete. Workability of concrete with the incorporation of metakaolin decreased, thus increasing the demand of super plastizer quantity in order to maintain a workable true slump values.
- ✓ Pozzolanic activity of metakaolin is confirmed by the increased compressive strength, owing to increased CSH concentrations. The highest compressive strength capacity was obtained at a 15% substation of Metakolin which is about 22% more than the control sample (28 days). However, with the further incremental percentage of metakaolin the decreasing trend in the compressive strength was noted.
- ✓ The densification and compact microstructure arising due to pozzolanic reaction of the inducted metakaolin, enhanced the resistance to tensile forces. The split tensile strength was also improved by the addition of

metakaolin to the concrete, with an overall gain of 24% was noted at the optimum concentration level.

- ✓ Mechanical performance of the modified concrete is improved significantly with the inclusion of metakolin into the concrete mix. Thus the optimum amount of replacement by 15% of metakaolin by weight of cement is important.
- ✓ SEM results confirm that the micro structure is reframed by the inclusion of metakaloin, the micro pores or voids are filled by the metakaolin particles thus resulting into the densification of the concrete matrix.

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