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Original Article

Strength and Reliability Performance of Wollastonite in Concrete as Part Replace of Cement with Metakaolin as Admixture

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Abstract - *This study examines the long-term reliability of concrete that has metakaolin added as an admixture and wollastonite used in part instead of cement in the concrete grade of M30. In recent times, wollastonite—a naturally found element with pozzolanic qualities—has drawn interest because of its potential to improve the qualities of concrete and lessen its negative effects on the environment. Metakaolin, a supplementary cementitious material, is known for its ability to improve concrete strength and durability, used to increase the adhesiveness act as admixture. In this research, various concrete ratios were made on different proportions of wollastonite to assess their impact on the reliability of concrete. The research effort involves assessing the mechanical strength and long-term reliability of concrete mixes containing various proportions of wollastonite and metakaolin as an admixture of 3%. Tests are conducted following standard procedures to evaluate the mechanical strength and resistance to adverse environmental conditions, including chloride ion penetration and sulfate attack. Using Scanning Electron Microscopy (SEM) examination, the effects of wollastonite and metakaolin on the microstructure of concrete are also investigated. The research outcomes are compared with normal concrete to analyze the effectiveness of wollastonite and metakaolin in enhancing concrete durability. The research's conclusion delivers beneficial insights into the feasibility and effectiveness of utilizing wollastonite and metakaolin as sustainable alternatives in concrete production, contributing to the development of durable and eco-friendly construction materials.*

Keywords - *Wollastonite, Metakaolin, Admixture, Concrete tests, Compressive test, Split tensile, SEM & XRD analysis.*

1. Introduction

Concrete is one of the most frequently used building materials in the world, with two billion tons utilized yearly. Since the production of cement accounts for around 2.5% of all industrial emissions worldwide, the environmental effects of cement are cause for worry. While the need for Portland cement is declining in developed nations, it is rising sharply in emerging nations. Some writers discuss 5%. This is particularly risky in light of the current condition of climate change brought on by emissions of carbon dioxide into the atmosphere, which is causing sea levels to rise and the world economy to collapse. With 10 billion tons produced yearly, concrete is the most important building material on Earth. As such, partial substitution of portland cement with pozzolanic by-products and mineral additives would allow for considerable reductions in carbon dioxide emissions. Studies on the pozzolanic properties of calcined clays, calcined agricultural wastes, and fly ash have already been conducted. The building of infrastructure has seen a sharp rise in investments as a result of the growing economy. Construction of roads, buildings, bridges, dams, and undersea constructions all require a large volume of concrete. The main component of concrete products, Portland cement, is acknowledged across the world as one of the most crucial building materials for infrastructure. A comparable amount of carbon dioxide is released as a byproduct of the manufacture of Portland cement, which is a major global concern and a big contributor to the "greenhouse" effect. Wollastonite and metakaolin show promise as alternatives because of their pozzolanic characteristics. Wollastonite, which is frequently utilized in the creation of low-heat cement, is well known for its capacity to improve the qualities of concrete that has been hardened as well as fresh. Because of its advantageous qualities and minimal ecological impact, it is an environmentally friendly choice for the manufacturing of concrete. Using wollastonite in the production of concrete is a step toward ecologically friendly methods. Preserving the functionality of concrete structures is crucial, especially for those exposed to harsh weather conditions, so that they may fulfil their intended function for a long time. Metakaolin, a dehydroxylated form of kaolinite, is commonly used in ceramic production and as a cement replacement in concrete. Pozzolanic materials are needed to enhance concrete's durability and decrease the amount of cement used in its production. Additionally, the

Water-Cement ratio (W/C) was altered to ascertain the many ways that whiskers may be strengthened and toughened [26]. Concrete's brittleness, or poor flexural strength, is a major problem that may be solved by adding fibers to the concrete to boost its tensile strength. We will go into great detail on wollastonite and how it affects concrete when it is used in place of some of the cement. Wollastonite mines are located in Tamil Nadu, Uttarakhand, Andhra Pradesh, and Rajasthan. India surpassed China as the world's top producer of wollastonite in 2017. Because wollastonite is utilized as microfiber, the concrete's flexural strength is increased. Due to sulfate attack, it also lessens water absorption, abrasion loss, drying, and shrinkage. It improves the reliability of concrete. The ultimate durability and strength of concrete are dictated by the elements' quantities, interactions, placement, curing process, and working environment. Any concrete material's capacity to withstand physical and chemical attacks determines how long it will last [25].

1.1. Objectives of Study

The study aims to explore the impact of varying wollastonite percentages and metakaolin as admixture on the workability, compressive, split tensile strength of concrete, and the resistance to acid and sulphate attack, SEM and XRD analysis in M30 grade concrete.

2. About Wollastonite

Wollastonite is a white to yellowish-brown calcium silicate mineral which develops naturally. It is known for its strength, fire ability, and ability to reduce crazing in materials. Despite its pure composition, it may contain trace metal ions. Wollastonite is composed of calcium, silicon, and oxygen, with the chemical formula CaSiO3. Several materials, including metakaolin, fly ash, silica fume, stone refuse, rubber tire, copper slag and wollastonite, have been investigated for use in the production of durable concrete. Wollastonite, a mineral called calcium meta-silicate with granules a comparable size to cement, has not been well studied in terms of its influence on concrete. It is a naturally occurring calcium silicate mineral found in metamorphic rocks formed by limestone metamorphism. Its unique needle-like or fibrous crystal structure makes it useful in various industrial applications due to its unique properties. It is formedby two processes. The first occurs when silica and limestone are raised to a temperature of 400°–450°C, either because of deep burial (regional metamorphism) or by being baked because of their proximity to an igneous intrusion (skarn deposits), forming wollastonite and giving off carbon dioxide:

$$SiO_2 + CaCO_3 = CaSiO_3 + CO_2$$

The second way wollastonite forms is by direct crystallization from molten rock (magma) that is unusually high in carbon content. The origin of these magmas is controversial, but current thinking is that they probably originate in the lower crust and upper mantle. The rocks they form, called carbonatites,are scattered throughout the world, but they have not been exploited for commercial purposes. These deposits differ in their basic mineralogy, reflecting both differences in geologic conditions during formation and host rock composition.

Table 1. Chemical composite of wollastonite powder

Chemical Oxide	Wollastonite Powder (%)
Lime	51.2-60
Silica	46.4-50
Alumina	0.79-2
Iron Oxide	0.52-2
Magnetia	0.70-2
Soda Or Potash	0.5-1
Sulphur Trioxide	0.1-0.7

3. Research Significance

Under normal circumstances, concrete generally exhibits durability. However, problems occur when some components of concrete that were thought to be innocuous turn out to be hazardous. Since some of metakaolin's durability qualities have been previously established and supported in other contexts, it is being contemplated as a cement substitute in the creation of concrete. The purpose of this study is to evaluate the durability characteristics of a Wollastonite and Metakaolin (WC) mixture that is used to produce concrete instead of cement. The goal is to evaluate the wollastonite-infused concrete's durability performance.

Furthermore, Conventional Concrete (CC) is used in this investigation to provide a comparative evaluation of outcomes. The sorptivity, water permeability, acid resistant test, pH test and Rapid Chloride Penetrability Test (RCPT) are among the durability criteria that are examined. These tests are performed on the NC and WC specimens after curing durations of 7, 28, 56, 90, and 180 days in order to evaluate their performance throughout time fully. Samples of wollastonite sand that are cured in the CO_2 environment acquire a rather high compressive strength (10–15 MPa). It was found that the sample's compressive strength greatly increased with increases in the binding substance quantity, compaction pressure, and CO_2 exposure period. The specifications for the belite and unique low-heat cement are satisfied by these values [24].

4. Experimental Program

According to IS 516: 1959 requirements, cube specimens of 150 × 150 × 150 mm were cast and their compressive strength was evaluated at 7, 28, 56, 90, and 180 days intervals. Furthermore, 100 mm in diameter (υ) and 200 mm in height cylindrical specimens were prepared and cured for 7, 28, 56, 90, and 180 days to support different durability property tests, such as sorptivity, Acid Resistant test and Rapid Chloride Penetrability Test (RCPT). Water replenishment had to be done strictly once a week. At ages 7, 28, 56, 90 and 180 days, the effect on durability parameters such as water absorption, VPV, sorptivity, and RCPT was examined using a traditional curing technique. The surrounding air temperature was 29°C ± 7°C, while the relative humidity was kept between 40 and 80%.

5. Materials Used

The materials used to manufacture concrete during this examination comprised wollastonite, metakaolin, river sand, OPC grade 53 cement, and water. The cement utilized in the concrete specimens complies with Indian Standard specification 12269:2013's OPC grade 53 requirements. In order to start the hydration process, this cement serves as the concrete mixture's binding agent has to come into complete contact with water. With most of the particles in concrete being smaller than 4.75 mm, fine aggregates are important. Serving as structural fillers, they take up a significant amount of the concrete mixture, giving it stability and affecting how quickly it hardens. For aggregate specifications, Indian Standard 383:2016 is the code that is used. The presence of coarse aggregate enhances the concrete mixture's strength, hardness, and durability. The aggregate requirements follow Indian Standard 383:2016. Metakaolin is used as an admixture of 3% at all concrete mix ratios. It also improves workability, meaning that less water is needed to get the desired strength properties. The main chemical components of wollastonite, a mineral that occurs naturally, are calcium, silicon, and oxygen. It develops as a result of high temperatures and pressures altering limestone or other high-calcium rocks, frequently in the presence of silica-rich fluids seen in metamorphic rocks.

Table 2. Chemical composite of cement powder

Particulars	Percentage of chemical composition (%)
Lime (CaO)	61.33
Silica (SiO_2)	21.01
Iron oxide (Fe_2O_3)	3.12
Alumina oxide (Al_2O_3)	6.40
Magnesia (MgO)	3.02
Sulfuric anhydride (SO_3)	2.30

6. Durability Properties

For the benefit of readers, standard references are listed in this work, even if the testing processes are not covered in detail because they have already been explained in previous publications. The ASTM C 1202 [2] method was followed for sorptivity testing, and the ASTM C 1585 [3] method's suggested protocols were followed for the Rapid Chloride Penetrability Test (RCPT).

Tests for absorption and the Volume of Permeable Voids (VPV) were carried out in compliance with ASTM C 642 (2013) [4]. Curing periods of 7, 28, 56, 90, and 180 days, specimens from Conventional Concrete (CC) and concrete with cement replacement (WC) were used in these experiments.

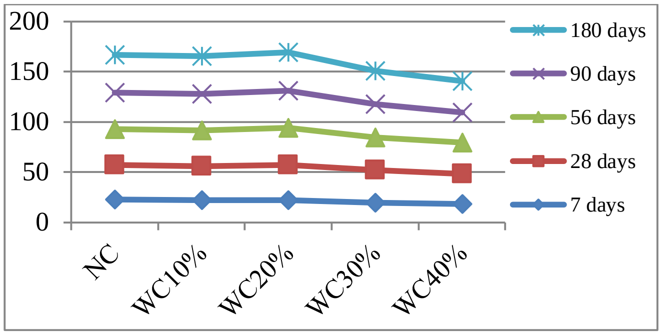

Fig. 1 Compressive strength

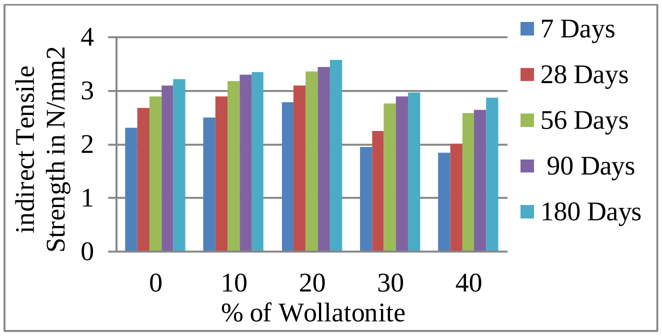

Fig. 2 Indirect tensile strength test

6.1. Compressive Strength

Figure 1 shows the compressive strengths of concrete with cement replacement (WC) and Normal Concrete (NC) cubes maximum of 180 days under normal curing. This analysis demonstrates that the bulk of compressive strengthening occurs during the early stages and increases with curing time, which is in line with findings from other studies [2, 3]. Crucially, the research shows that the mixtures that contain wollastonite show strength increases even after 180 days.

6.2. Indirect Tensile Test

The cylinders are casted and cured for the size of 150mm diameter and 300mm long. The cylinders are taken out from the curing and dried out for some time. Then, the cylinders are tested for split tensile strength.

6.3. Rapid Chloride Permeability Test (RCPT)

The Rapid Chloride Permeability Test (RCPT) results for Conventional Concrete (CC) and concrete with Cement Replacement (CRC) mixtures during normal curing at various ages are shown in Figure 3. According to the ASHTO (T259 80) Rapid Chloride Permeability Test (RCPT) results [1], the RCPT values for the Conventional Concrete (CC) mix varied from around 3000 to 2800 coulombs. The RCPT values for the CRC mixes with different cement replacement percentages displayed comparable trends: 10% CRC mix: RCPT varied between about 3100 and 2800 coulombs.20% CRC mix: RCPT varied between about 3240 and 3065 coulombs. Mix CRC 30%: RCPT varied between about 3740 and 3255 coulombs.40% CRC mix: RCPT varied between about 3800 and 3650 coulombs. These results were noted throughout trials that lasted from three days to 180 days. After 28 days, moderate penetrability of chloride ions was found in all combinations. Age-related decreases in the charge transmitted were seen, which is consistent with data from an earlier investigation and suggests moderate chloride permeability [4]. This implies that the pore structure inside the concrete matrix will gradually get better. Concrete mixes containing wollastonite and metakaolin demonstrated higher resistance against the penetration of chloride ions in comparison to those that did not. This is explained by the replacement materials' chemical particles filling up the pores in the concrete, increasing its strength and decreasing its permeability. Thus, the RCPT research provides more evidence that using wollastonite instead of cement improves the quality of concrete produced.

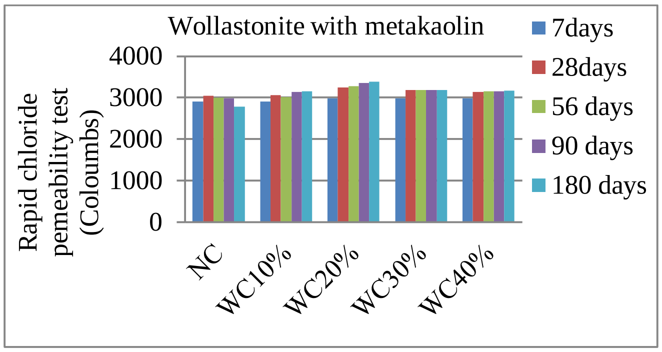

Fig. 3 Rapid chloride penetration test

**NC – Normal Concrete*

**WC – Wollastonite Concrete*

6.4. Acid Test

Through the use of a corrosive test, the cubes are evaluated based on their endurance. The cubes undergo a 28-day acid soak to verify their condition before being put through a durability test. The durability is evaluated by comparing the quantity of weight differences. The OPC resistance to acid attack is rather low, with the exception of specimens submerged in solutions containing sulfuric acid. The decrease in weight of these samples is caused by the interaction between the acid and the calcium hydroxide that is present on their surface. Hydrochloric acid treatment of OPC specimens results in the most detrimental possible situation.

6.5. Sorptivity Test

The sorptivity findings during conventional curing at various ages for Normal Concrete (NC) and Concrete Mixes with 10%, 20%, 30%, and 40% cement replacement (WC) are shown in Figure 4. Based on sorptivity test results the sorptivity measurements for the CC mix varied from 0.081 to 0.04 mm/min 5. The sorptivity measurements for the WC 10% mix varied from 0.096 to 0.046 mm/min 5. The sorptivity measurements for the WC 20% mix varied from 0.145 to 0.067 mm/min 5. The sorptivity measurements for the WC 30% mix varied from 0.153 to 0.064 mm/min 5.

6.6. Scanning Electron Microscopic Analysis

High-resolution pictures of concrete microstructures are provided by Scanning Electron Microscopy (SEM), which makes it easier to see morphological traits and organize extra components like fibers, aggregates, and cement particles. Energy-Dispersive X-ray Spectroscopy (EDS) and SEM work together to allow elemental composition in different stages of the concrete matrix to be analyzed. When analyzing the morphology, surface properties, and structural elements of metakaolin in cement-replaced concrete, it is very helpful [12]. Through the use of SEM analysis, scientists are able to learn more about the ways in which metakaolin and wollastonite interact with the concrete matrix to affect the material's durability characteristics. Through this analysis, scientists may explore how the substitute materials and the concrete matrix interact, providing insight into the mechanisms that underlie the improvement in durability traits. As seen in Figures 5 to 9, these insights support the creation of robust and sustainable building materials by enabling well-informed choices about material design and optimization.

Table 3. Sorptivity Test

S. No.	Curing Days	% of Wollastonite	Initial Weight of the Cube, W_1 (kg)	Final Weight after Immersion, W_2 (kg)	Difference in Weight, W_1-W_2 (kg)
1	7 days	0	8.02	7.787	0.233
		10	7.84	7.535	0.305
		20	8.26	8.05	0.21
		30	8.10	7.52	0.58
		40	8.04	7.12	0.92
2	28 days	0	8.20	7.943	0.257
		10	7.80	7.54	0.26
		20	8.13	7.952	0.178
		30	8.04	7.71	0.33
		40	7.84	7.62	0.22
3	60 days	0	8.10	7.80	0.30
		10	7.86	7.503	0.357
		20	8.21	7.93	0.28
		30	8.04	7.62	0.42
		40	8.02	7.54	0.48

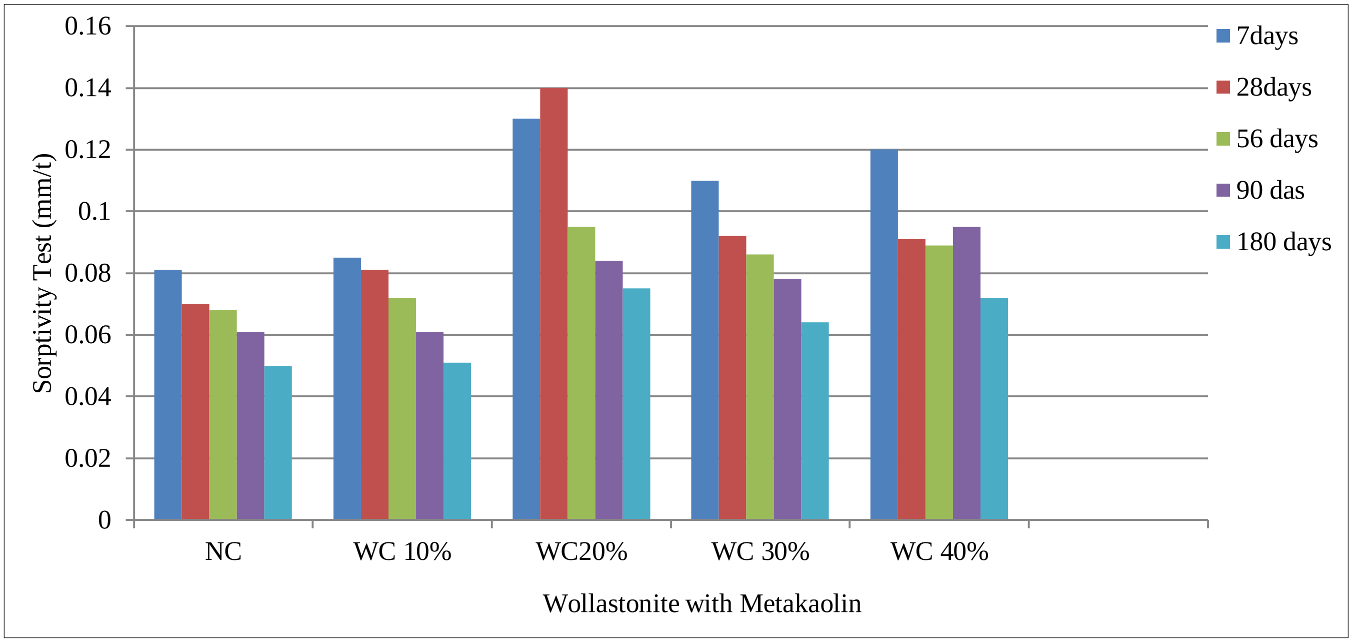

Fig. 4 Sorptivity test

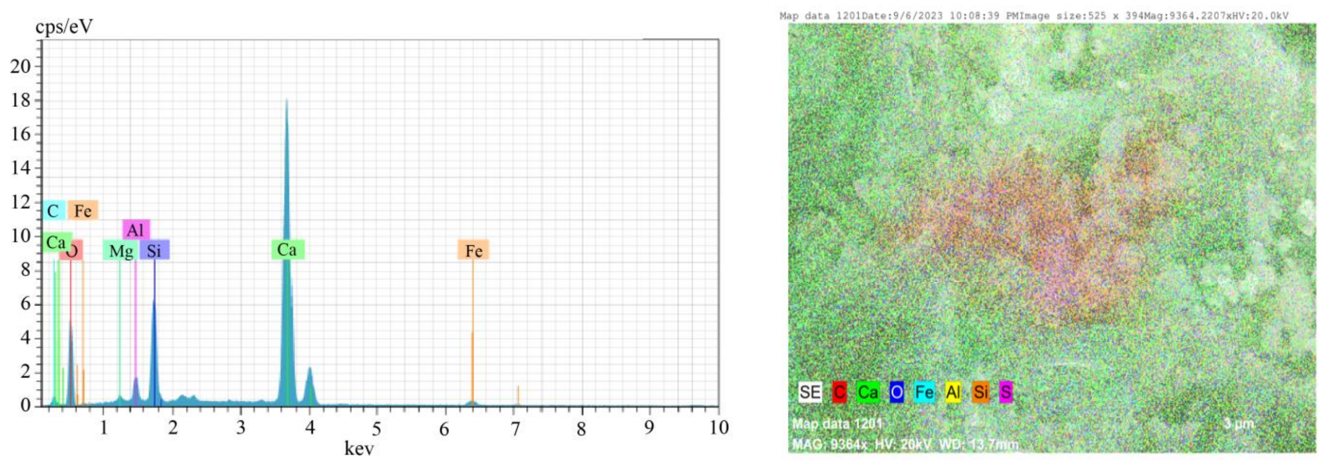

Fig. 5 EDS analysis and mapping of 20% wollastonite powder

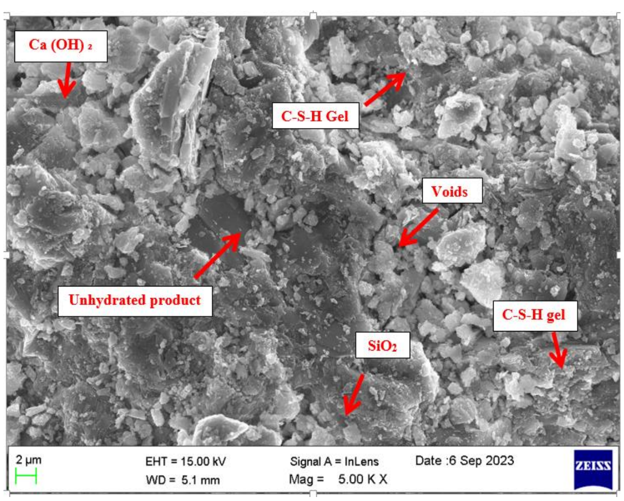

Fig. 6 SEM analysis & mapping of normal concrete

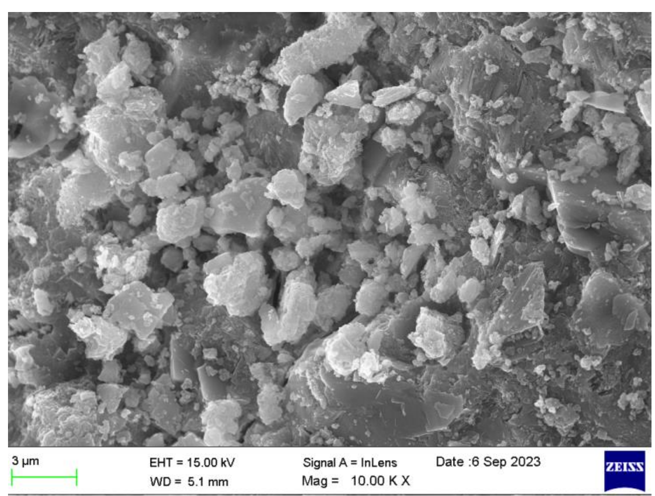

Fig. 7 SEM analysis

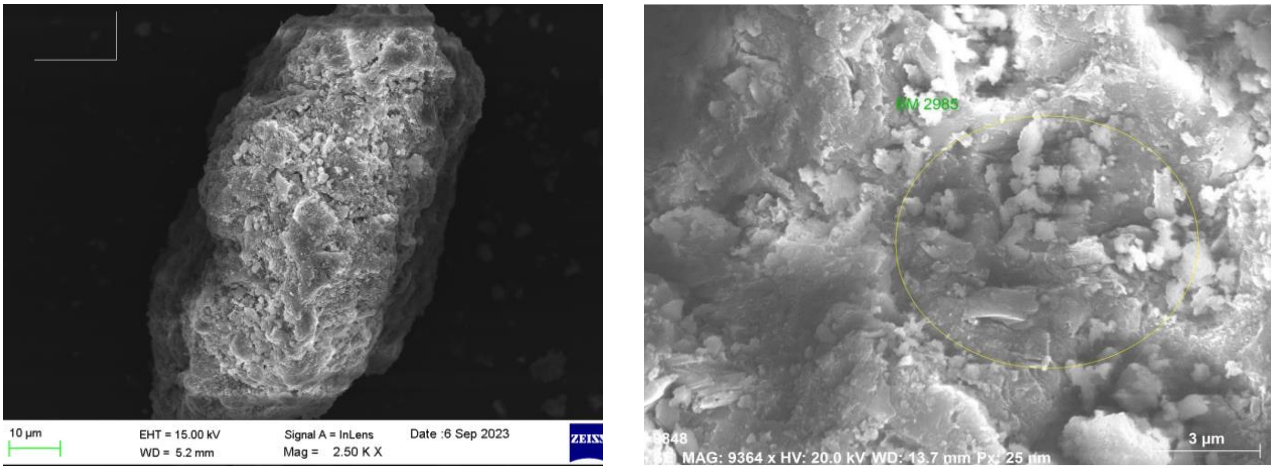

Fig. 8 SEM analysis

6.7. XRD Phase Analysis

X-ray Diffraction (XRD) stands out as a powerful analytical technique for scrutinizing a material's crystalline structure. In the context of concrete fortified with wollastonite and fly ash, XRD yields valuable insights into the characteristics and behaviors of the concrete matrix. Through XRD analysis, the mineralogical composition of the concrete matrix becomes discernible.

Important components, including Calcium Silicate Hydrates (C-S-H), portlandite (Ca (OH)2), and different types of crystallized and amorphous silica, have a big impact on how strong and long-lasting concrete is. XRD elucidates the crystalline structure of these components and furnishes information on the orientation and arrangement of molecules within the concrete. Additionally, XRD analysis enables the identification of new crystalline phases generated by the alkaline environment of concrete, as well as any chemical reactions or interactions occurring between wollastonite and fly ash in the concrete matrix.

Distinct hydration forms emerge during the concrete curing process, with XRD capable of distinguishing ettringite and portlandite phases, thereby offering insights into both the evolution of the concrete's microstructure and the progression of the hydration process [13].

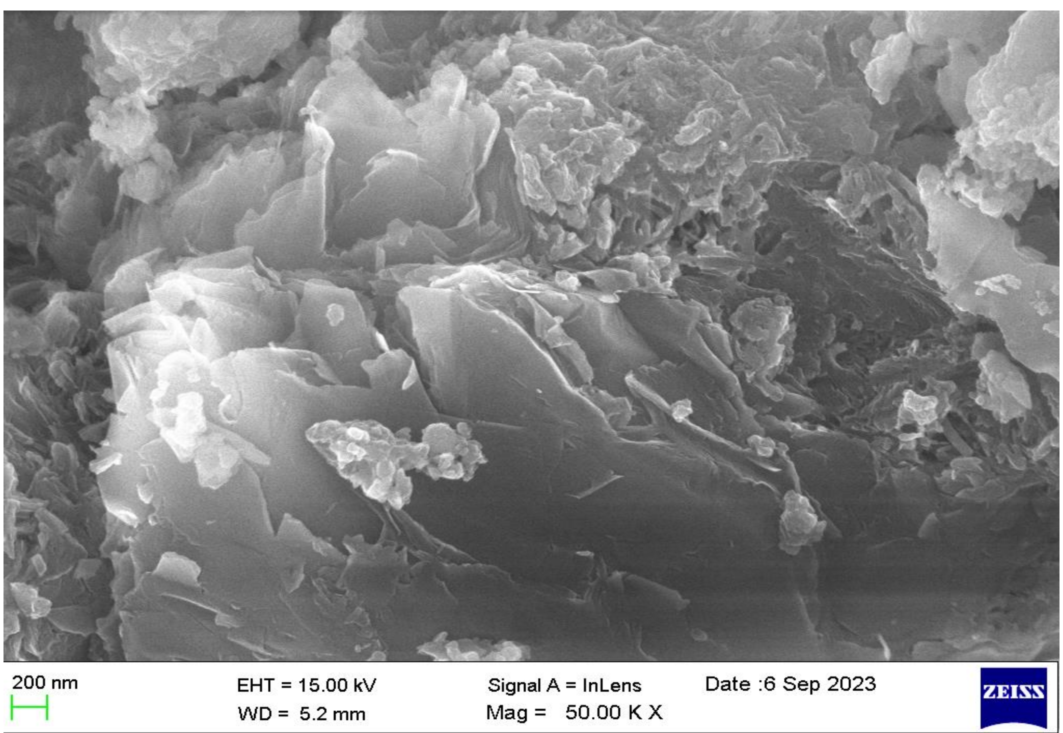

Fig. 9 XRD analysis

7. Conclusion

Wollastonite is combined with ordinary concrete to generate M30 grade concrete. The proper proportions of wollastonite improve the durability properties of both types of concrete. The durability and mechanical strength were tested and compared with normal concrete.

There was a discernible increase in wollastonite replacement of up to 20% when wollastonite was added to the concrete at dosages of 10%, 20%, 30%, and 40% in comparison to ordinary concrete. This improvement shows that wollastonite, when used as an admixture with 3% metakaolin, helps to improve the durability of concrete's performance by 12%. It is achieved by the property of wollastonite used to increase the strength and durability of concrete due to the fibrous property of wollastonite as naturally present in it. Therefore, the optimum percentage of wollastonite with 20% replacement of cement gives better results in comparison to the normal one. The ultimate goal of this research is to replace cement as much as possible with wollastonite, taking into account the material's endurance and microstructural characteristics.

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