

Microstructural Study And Durability Characteristics Of Alccofine-Concrete Reinforced With Polypropylene Fibre

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Abstract

The addition of cementitious materials as a replacement for Ordinary Portland Cement (OPC) is the most common solution to reduce carbon emissions. Research studies have involved various cementitious materials and examined their properties. However, cementitious concrete exhibits greater brittleness, and its durability remains an area of ongoing study. In the present work, the concrete mix is developed with cement and alccofine reinforced by polypropylene fibre at the weight fraction of 0.1% to 0.4%. The developed concretes are tested for their durability through water absorption tests, acid resistance tests (H₂SO₄), and porosity tests. The concrete specimens are prepared and tested based on the test standards. The microstructural study is carried out on the concrete samples through SEM and EDAX images. The experimental study showed that the cement-alccofine mixture with 0.2% polypropylene fiber showed better durability characteristics with less water absorption, lower weight loss, and less change in dimension than the control mix.

Keywords: Alccofine, Polypropylene, acid resistance test, water absorption test, microstructural study.

INTRODUCTION

Concrete has been the most prevalent material used in the construction industry for centuries. The concrete is generally a combination of cement, aggregates, and water, along with some additives. Cement is the major component in concrete, and its production results in the emission of carbon dioxide and sulphur, which are harmful to the environment (Farhan et al. 2018). Additionally, the concretes show brittleness with less tensile strength, which is the major drawback for the structural applications (Chandratilaka et al. 2021). For reducing the usage of cement in concrete, several cementitious materials are added, such as fly ash, GGBS, and metakaolin. The alccofine 1203 is one of the replacement materials for cement that is used for producing concrete. The alccofine 1203 is a highly reactive slag-based product produced through the granulation process (Jayaswal & Mungule, 2022). The issue of strength in the concrete is addressed through the application of fibres. The fibre addition in the concrete generally results in bridging the cracks that lead to premature failure of it. The addition of fibre improves the load-bearing capacity of concrete, which increases the mechanical properties (Amin et al. 2017).

Generally, steel fibres are used for reinforcing concrete to enhance mechanical properties with a high ratio of strength to cost. However, concrete reinforced with steel fibres shows poor performance in durability and fire resistance (Frazao et al., 2015). For enhancing the durability performance of the concrete, synthetic and natural fibres are employed in it. The synthetic fibres showed enhanced durability performance than natural fibre-reinforced concrete. Among the different synthetic fibres, polypropylene fibres (PF) are widely used to reinforce concrete. The polypropylene fibres have less strength than steel fibres, but it has better chemical and heat resistance. PF has tensile strength in the range of 200-900 MPa, and its modulus of elasticity is about 5-12 GPa (Parkavan & Ozbakkaloglu, 2019).

The water absorption test is carried out on the concrete that was reinforced using the fibres of glass and polypropylene. The concrete with polypropylene showed more water absorption than that of the control mix at a dosage of 0.45% and more than all the concrete with glass fibre. The lower water absorption is observed at lower dosages of polypropylene fibre than in the control mixes due to the hydrophobic nature of PF. The

excessive addition of PF in concrete results in internal structure inhomogeneity that leads to excessive water absorption (Yuan & Jia, 2021). The test for capillary water absorption for the fly ash and slag-based concrete reinforced with PF. The study involved the PF with a length and diameter of 12mm and 0.035mm to reinforce the concrete at a volume fraction up to 1.35 kg/m³. The water absorption for the concrete reduces with an increase in PF volume because of lower porosity (Liu et al., 2019). The high-strength concrete is developed with PF with a diameter and length of 0.022 mm and 12 mm. The PF is added to the concrete at the volume content of 0.15%, 0.30%, and 0.45%. The study revealed that the addition of PF decreased water absorption (Afroughsabet and Ozbakkaloglu, 2015).

The expansion rate study is employed to characterize the impact of sodium sulphate solution on the concrete reinforced with PF. The PF is added to the concrete mix at different volume fractions of 0.4%, 0.8% and 1%. The study showed that the concrete mix with 1% PF has the maximum rate of expansion, and the least expansion is observed at 0.8% PF-reinforced concrete (Mardani et al.2018). The impact of aging on PF-reinforced concrete immersed in the 5% sodium sulphate solution is studied for 30 days, 60 days, and 90 days. The compressive strength loss is observed to be minimum with the addition of 1.5% of PF in the concrete. The compressive strength loss on the PF-reinforced concrete initially showed a decreasing trend and increased with the increase in PF content (Ranjith et al. 2017).

The acid and sulphate resistance of waste PF-reinforced concrete is studied. The waste PF is added in the concrete with the volume fraction ranging from 0 to 1.25% and the length of the PF is about 30 mm. The study reported that with the usage of PF in the concrete, the acid and sulphate resistance is improved by 28.47% and 30.39% respectively (Mohammadhosseini et al. 2024). The macro-PF is employed in the concrete at the volume fraction of 0-1.5% and its durability study was performed. The PF addition improved the acid resistance of the concrete. At the 92nd day examination, the strength of the concrete is reduced by 24% with 1% of PF which is the optimum performance observed in the study (Chen et al. 2024).

The sorptivity test was carried out on the arccosine-nano silica-concrete reinforced with PF. The study showed that with the increase of PF in concrete, the sorptivity coefficient decreased. The optimum performance on the sorptivity test is observed for the concrete with 0.3% PF (Jamenraja et al. 2023). The durability of the concrete reinforced with the PF is studied on the parameters of water absorption, chloride penetrations, and sorptivity. The obtained results showed that the inclusion of PF improved concrete performance on sorptivity and water absorption, whereas no impact on chloride penetration (Rashid 2020).

2. MATERIALS AND METHODOLOGY

2.1 Ordinary Portland Cement (OPC)

For the study, the grade 53 OPC is used, which conforms to IS 12269:2013. The OPC used has a 3.15 specific gravity. The initial and final setting times for the OPC are about 56 minutes and 383 minutes, respectively.

2.2 Coarse Aggregate

The crushed granite in angular shape was used as the coarse aggregate that conforms to IS383:2016 with 20 mm particle size (maximum). The specific gravity and water absorption of the selected coarse aggregate is about 2.83 and 0.8, respectively.

2.3 Fine Aggregate

The fine aggregate for the study is the river sand that conforms to IS 383:2016. The size of the river sand particles is determined through the sieve analysis. The maximum weight of the fine aggregate falls under the size category of 300µm (41.9%), followed by the size category of 600µm (32.2%). The least percentage of fine aggregate is found in the pan, i.e., 0.2%.

2.4 Super Plasticizer

The super-plasticizer in the form of Conplast SP 430 is added to the concrete mix, which is an admixture of sulfonated naphthalene polymer, and it is also a chloride-free compound. The major role of the selected superplasticizer is to dissolve the water in the concrete mix instantly.

2.5. Alccofine 1203

The alccofine is added at a constant proportion of 20% to replace the cement in the concrete mix. The alccofine generally contains a high level of silicon dioxide (35.6%), followed by Calcium oxide (33.6%), along with alumina and magnesium oxide at 21.4% and 7.98% respectively.

2.6 Polypropylene Fibre

The triangular-shaped fibres of polypropylene with a length of 12 mm and an effective diameter of 40 μm are used. The PF used has a tensile strength and modulus of elasticity of about 4 GPa.

2.7 Experimental study

The concrete control mix (CM) is prepared with a mix proportion of 1:1.88:2.87 using cement at 350 kg, coarse aggregate at 525 kg, and fine aggregate at 1050 kg. The alccofine is added to replace the cement in the control mix at 20% to form the Concrete-Alccofine (CA) mix. The PF is added to the CA mix at a weight percentage of 0.1 to 0.4 %. The cubical specimens are prepared using the CM, A20, and CA-Polypropylene fibre mix (A20PX) with a size of 150x150x150. In total, 72 cubical specimens are developed to carry out the durability test based on water absorption, acid attack, and Permeability. The microstructural study is carried out on the specimens that underwent failure in the initial compression test. Additionally, 12 specimens are used to determine compressive strength before the acid test, and a microstructural study is carried out on the specimens. The schematic diagram for the experimentation is given in Figure 1. The details of the test are given below:

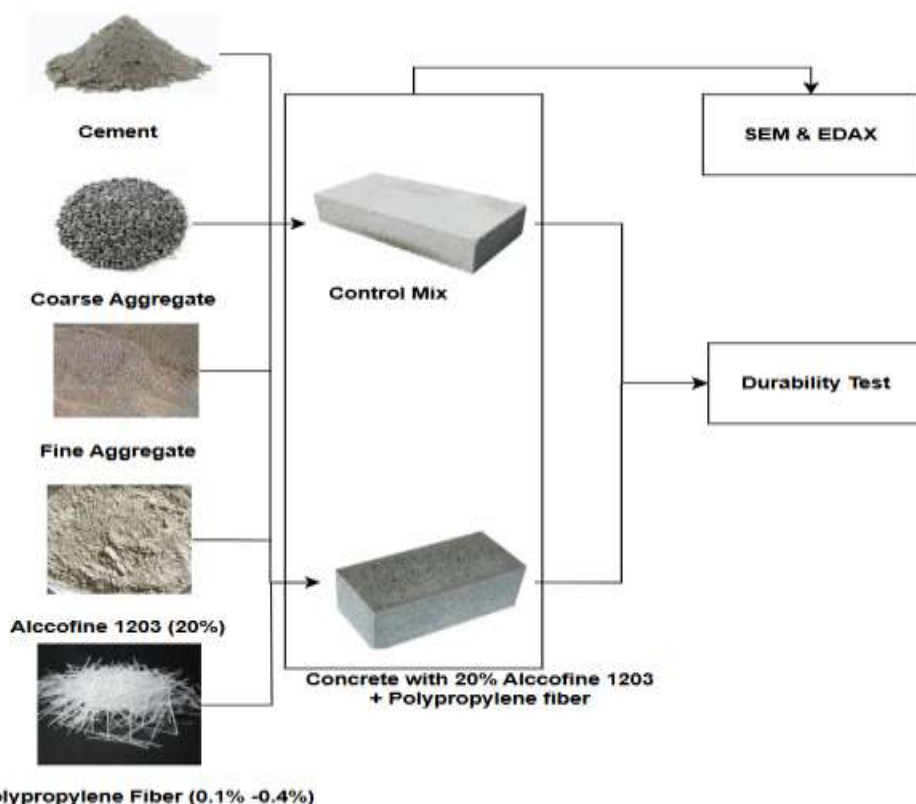


Figure 1. Schematic diagram for the study

2.7.1 Water Absorption and Permeability Test

Among the 72 cube specimens, 18 specimens from six different concrete mixes, i.e., three each from the distinct mix, are subjected to a water absorption test conforming to ASTM C642-97. All the specimens are initially weighted and noted as W_i . The specimens were immersed in the water for 48 hours, and the weight

of the concrete was measured again, which is noted as W_f . The water absorption is measured through the following formula:

$$\text{Water absorption (\%)} = \left(\frac{W_f - W_i}{W_i} \right) \times 100$$

$$\text{Porosity void \%} = \left(\frac{\text{Voids volume}}{\text{Total Volume}} \right) \times 100$$

2.7.2 Compression Strength Test

The compression test is carried out using the 18 specimens conforming to the IS 516-5919. The compression strength values are recorded for each concrete mix as C_i , which can be used for comparing with the strength of concretes that are subjected to acid and sulphate attacks.

2.7.3 Acid attack test

The next set of 18 cubical specimens is subjected to the acid attack test conforming to the ASTM C1012. Similar to the water absorption test, the weight of the concrete is measured initially as C_i (MPa) and recorded as W_i . The specimens were kept in the H_2SO_4 acid solution, which is at 5% concentration. The specimens are removed from the H_2SO_4 acid bath after 28 days of immersion and weighed again, which is recorded as W_f . The specimens were subjected to a compressive test to determine their strength as C_f (MPa).

$$\text{Weight loss \% (acid)} = \left(\frac{W_i - W_f (g)}{W_i (g)} \right) \times 100$$

$$\text{Strength loss \% (acid)} = \left(\frac{C_i - C_f}{C_i} \right) \times 100$$

2.7.4 Microstructural study

The samples of concrete with size 10 x 10 x 5 mm were cut from the concrete specimens with different concrete mixes. The obtained samples were used for performing SEM analysis and EDAX analysis.

3. RESULT AND DISCUSSION

The developed concrete specimens are subjected to the different durability tests mentioned in the previous section, and the measurements are carried out as per the standards. The obtained results are given as follows:

3.1 Compressive strength

The compressive strength of the developed specimen is determined out and the obtained results are shown in Figure 2. The average compression strength of the CM is observed at 24.59 MPa. Among the developed concrete mixes, the A20, A20 P1, A20P2, A20P3, and A20P4 have a compressive strength of 39.94 MPa, 40.97 MPa, 43.55 MPa, 40.92 MPa, and 39.04 MPa. The concrete with 20% Alccofine and 0.2% PF showed maximum compressive strength. The obtained strength values are used to analyse the impact of acid on these concretes.

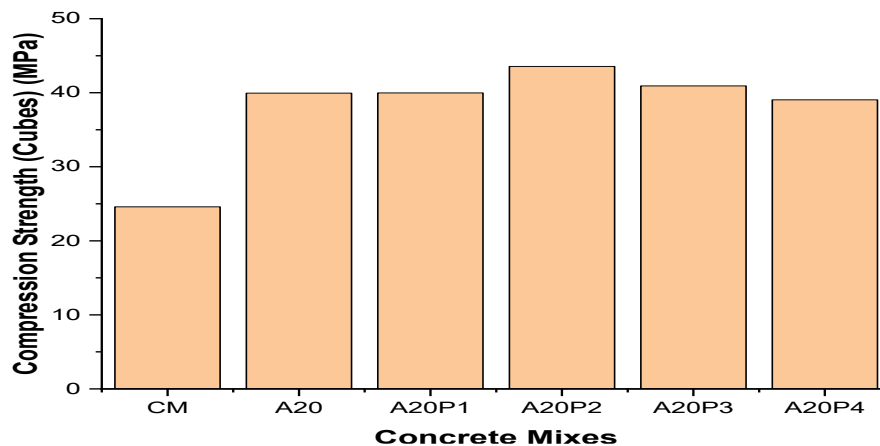


Figure 2. Compressive strength of Concrete mix

3.3. Water Absorption Test

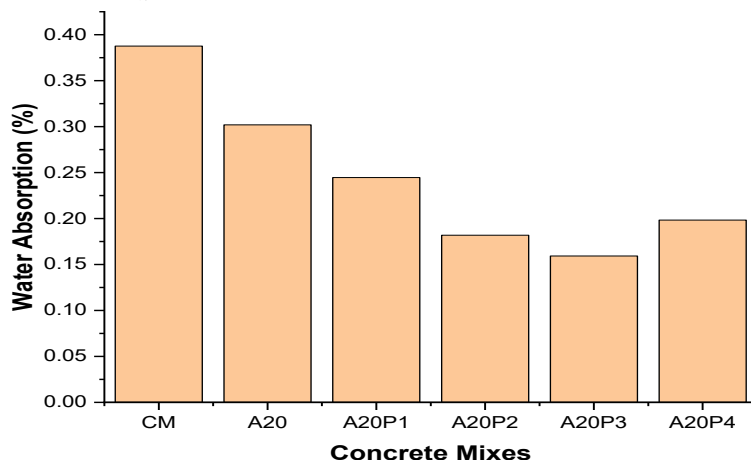


Figure 3. Water absorption in concrete mix

The results obtained from the water absorption test and porosity are given in Figure 3 and 4. The results showed that all concrete mixes showed an increase in weight after absorbing the water. The CM concrete showed maximum water absorption of 0.39% and the least water absorption was observed for the A20P3 concrete mix with a weight increase of 0.16%. The concrete mixes of A20, A20P1, A20P2, and A20P4 showed an increase in weight by 0.30%, 0.24%, 0.18%, and 0.2% respectively. The A20 concrete showed maximum porosity of 1.5% and the least water absorption was observed for the A20P2 concrete mix with a porosity of 1.12%. The concrete mixes of CM, A20P1, A20P3, and A20P4 showed porosity of 1.3%, 1.32%, 1.16%, and 1.24% respectively. The agglomeration of PF resulted in increased water absorption for the concrete mix of A20P2 (Gayathri et al., 2022b). The uniform distribution of the PF in the concrete matrix, along with the lower porosity, reduced the water absorption as observed by Liu et al. (2019).

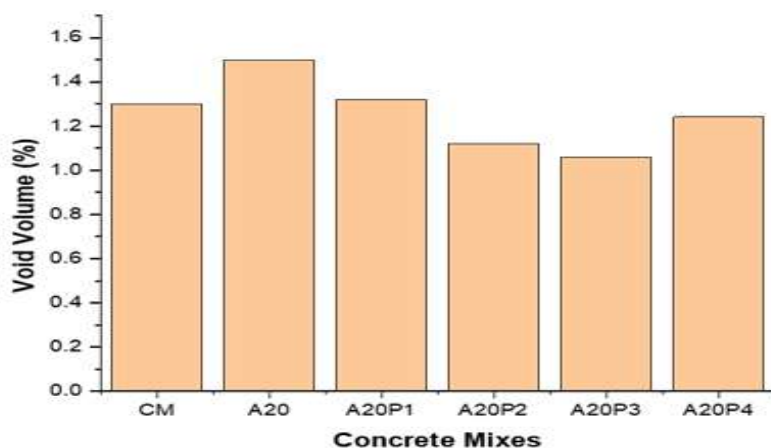


Figure 4. Porosity in concrete mix

3.4 Acid Resistance Test

The concrete specimen mixes are subjected to acid attack for 28 days. The acid attacks are measured by weight and strength loss on the concrete mix. The obtained results are given in Figures 5 and 6. The CM concrete showed maximum weight loss on acid attacks with a reduction of 6.38%. The addition of alccofine and PF reduced the weight loss in other concrete mixes. The weight loss due to acid is found to be minimum for A20P2 concrete with a loss percentage of 4%. The PF showed resistance to corrosion and prevented chemical attacks, resulting in a decrease in weight loss.

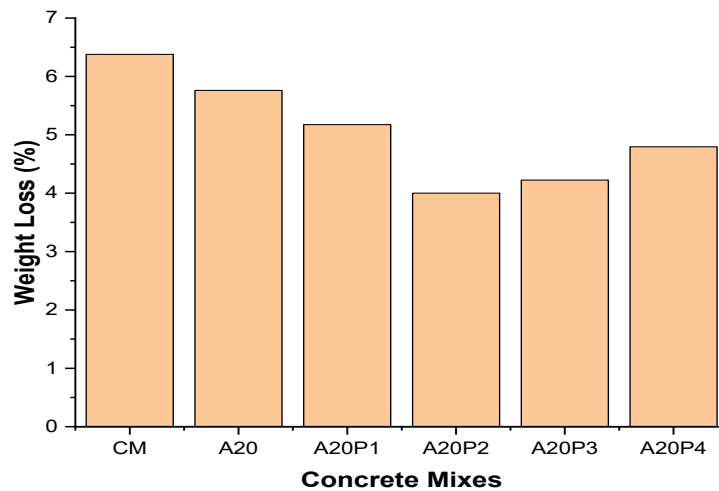


Figure 5. Weight loss in concrete mix

Similar to the weight loss, the strength loss is found to be maximum for the CM, and the least loss is observed for the A20P2 concrete mix. The A20P2 concrete achieved a reduction in strength of about 1.05% when subjected to acid attacks. All the developed concrete specimens exhibited less weight and strength loss than the control mix. The decrease in porosity resulted in lower acid penetration. However, an increase in weight and strength loss is observed due to excessive dosage of PF at 0.04% (Guo et al., 2020).

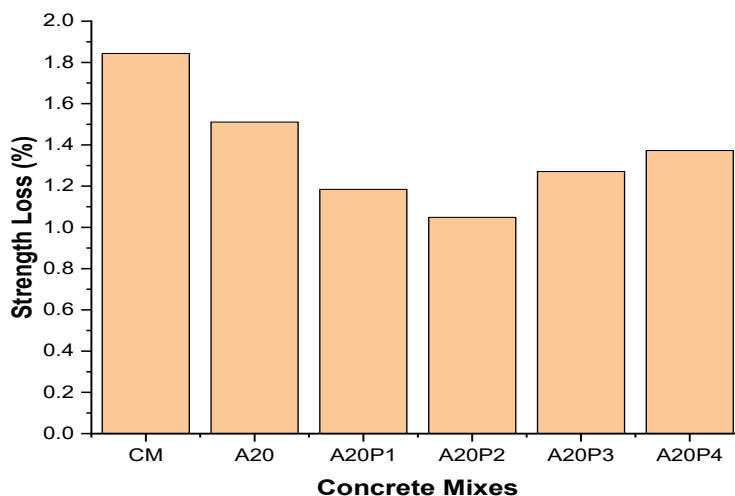


Figure 6. Strength loss in concrete

3.5 Microstructural Analysis

The SEM images of control concrete, along with the concrete with alccofine and Polypropylene fibres, are shown in Figure 7. The SEM images showed dense crystalline structures, which are formed due to the hydrolysis of calcium and silicates. The SEM image of the control concrete showed fewer voids than the other concrete mixes. With the addition of alccofine, the voids seem to appear in the concrete matrix. The addition of PP fibres provided effective bonding between the concrete matrix and ensured better performance than the concrete mixes without PP fibres. The addition of PPF in concrete reduced the pores, which reduced the crack propagation to a greater extent.

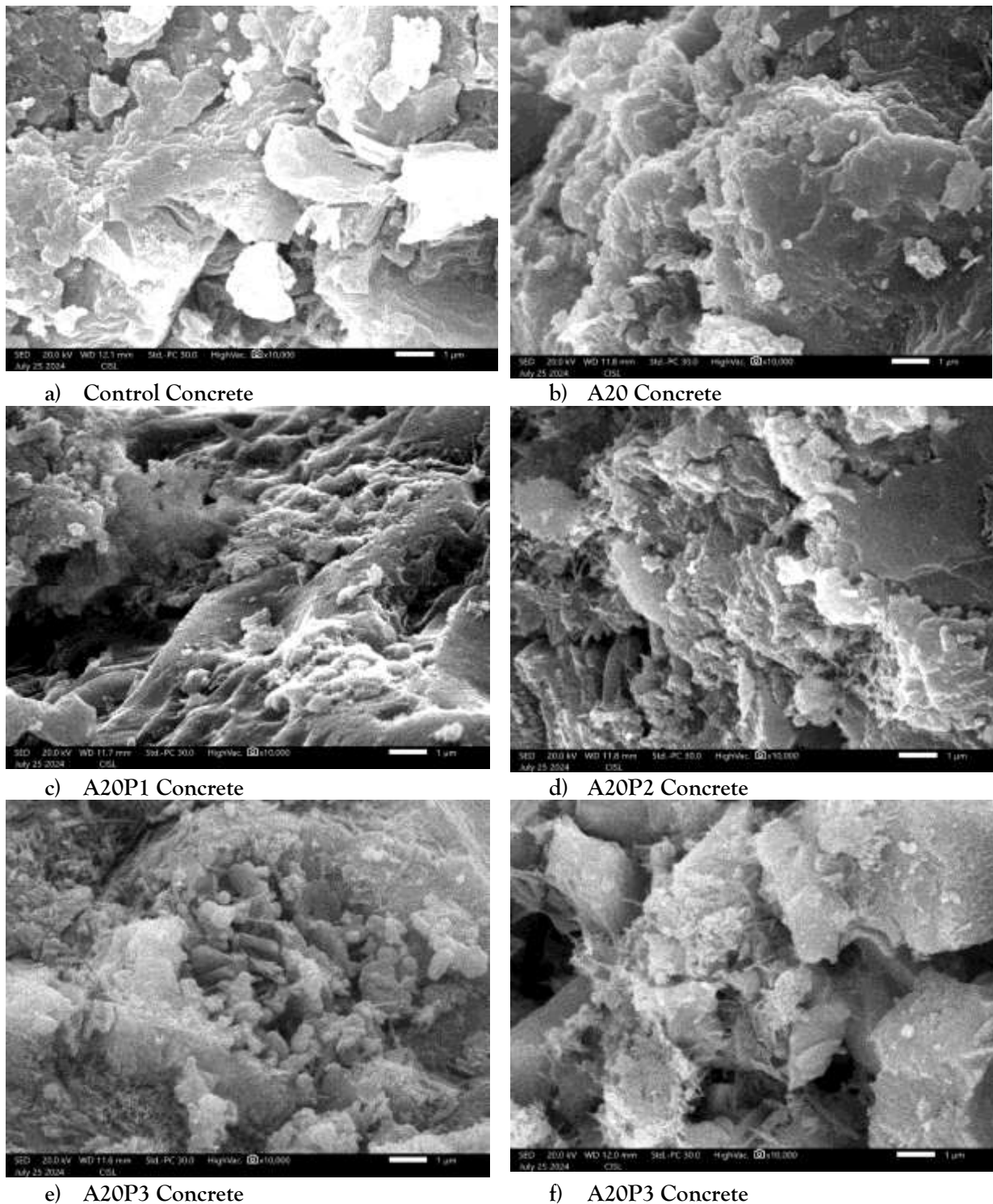


Figure 7. SEM images of concrete mixes

The EDAX techniques are employed on the sample specimens of different concrete mixes to understand the elemental composition. The elemental composition of each concrete sample, along with the mass% and atom%, is given in Figure 8-13.

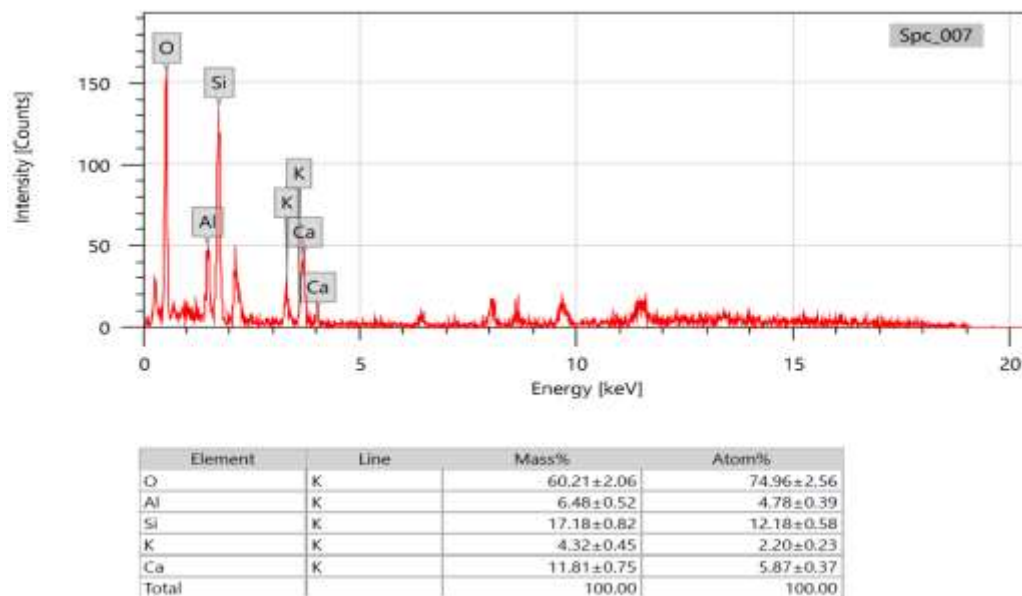


Figure 8. EDAX for Control concrete

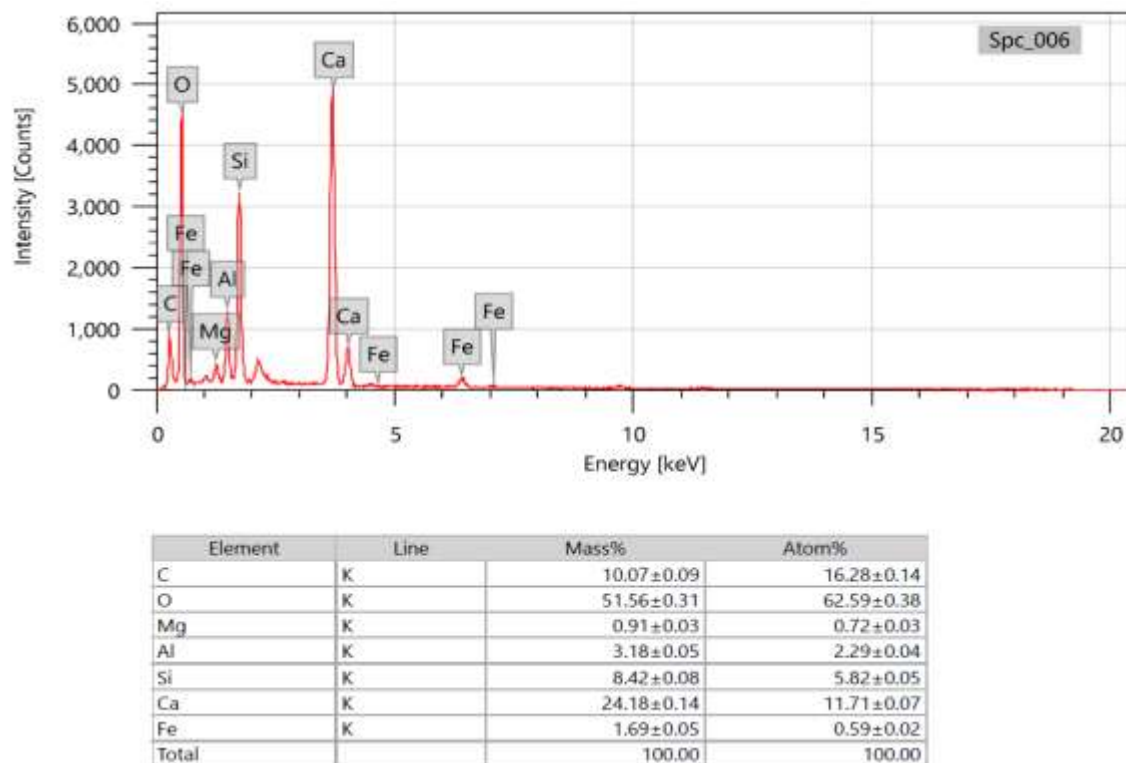


Figure 9. EDAX for A20 mix

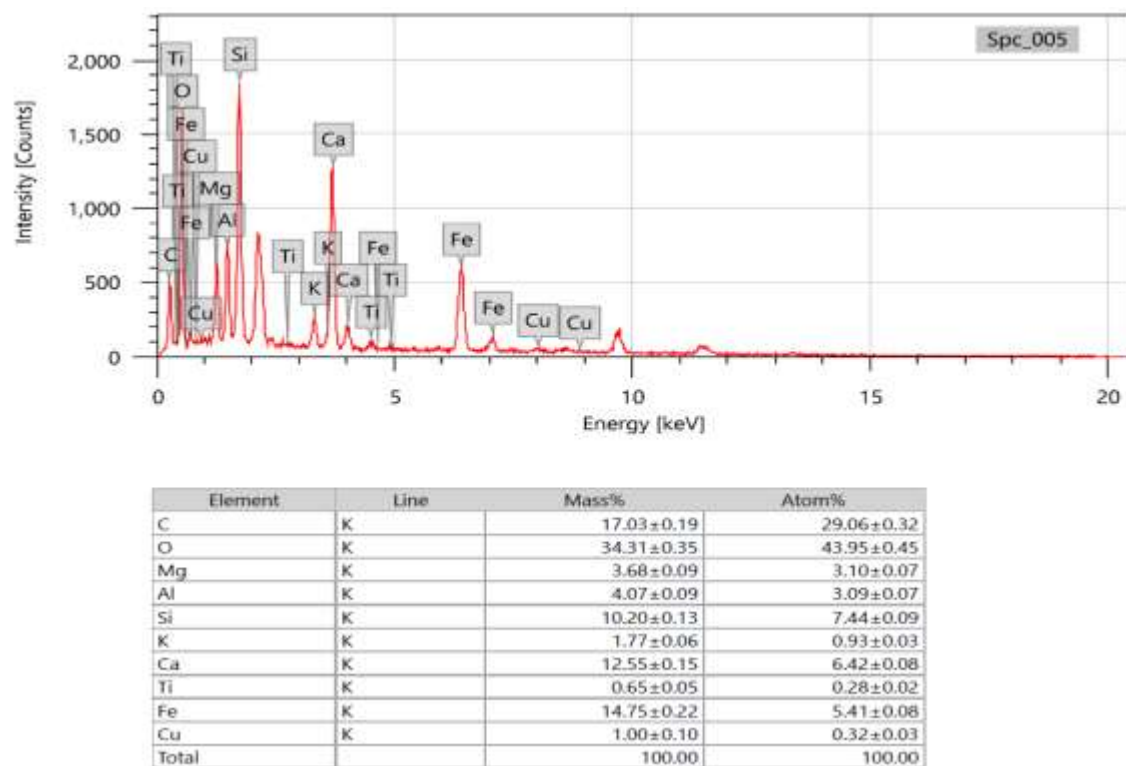


Figure 10. EDAX for A20P1 mix

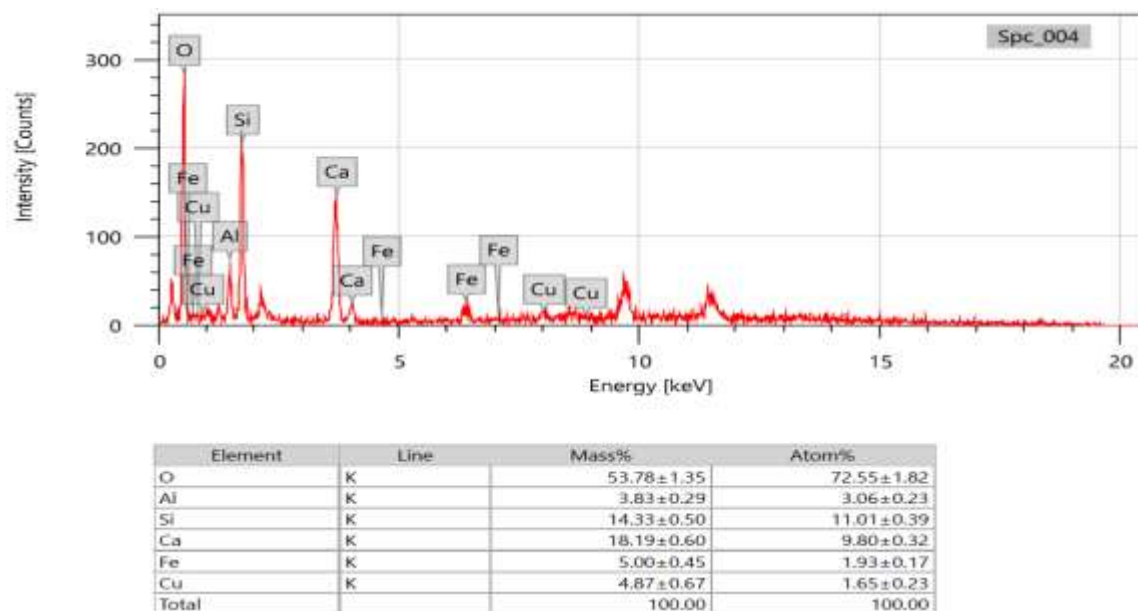


Figure 11. EDAX for A20P2 mix

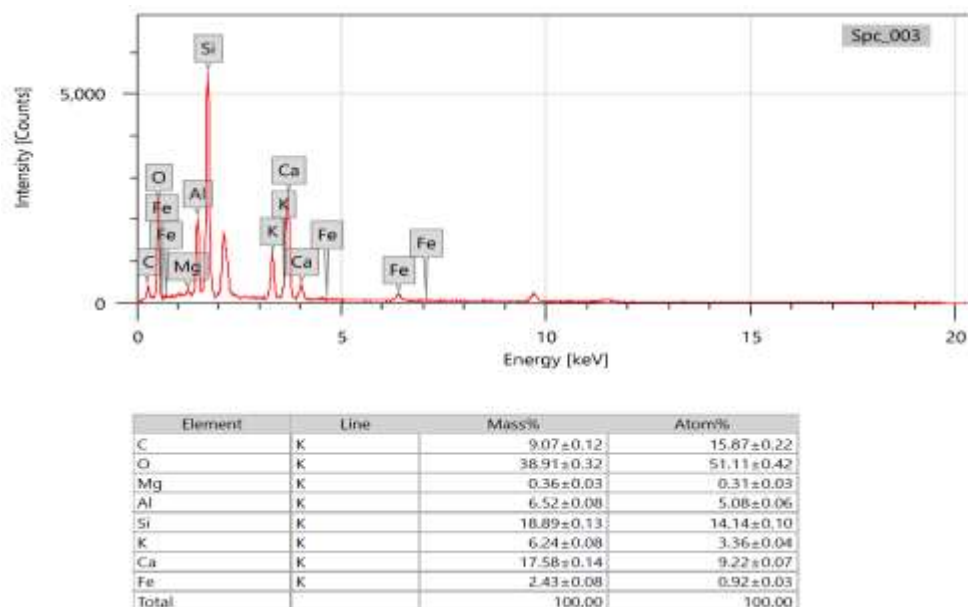


Figure 12. EDAX for A20P3 concrete

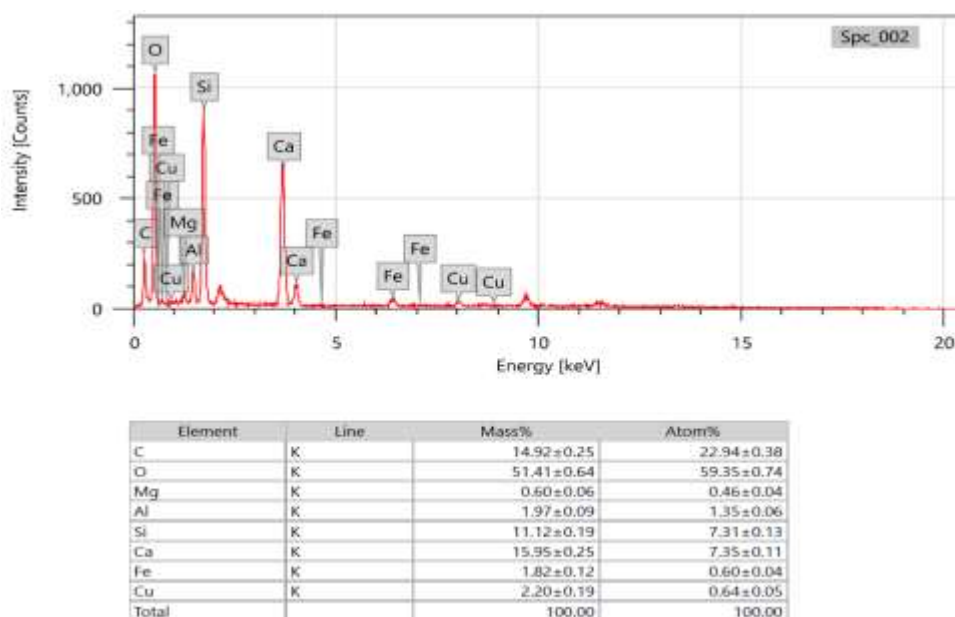


Figure 13. EDAX for A20P4 concrete

4. CONCLUSION

The concrete specimens are fabricated, adhering to international standards using Alcofine and polypropylene fibers. The fabricated concretes are tested for their durability based on the acid test, water absorption, and porosity. The microstructural study of the concrete specimens is carried out through SEM and EDAX analysis. The SEM images showed effective bonding between the cement-alcofine matrix, along

with PP fibres. The EDAX analysis showed the elemental composition of each concrete mix in particularly calcium and silicon. The durability study showed the following results:

- The control concrete showed maximum weight loss of 6.38% due to its interaction with the acid, whereas A20P2 concrete showed a minimum weight loss of 4% than other concrete mixes.
- The strength loss during the acid test is observed to be maximum for control concrete and minimum for A20P2 concrete, which is about 1.84% and 1.05%, respectively.
- The A20P3 concrete showed less water absorption of 0.16%, whereas the control concrete showed maximum water absorption of 0.39%.
- The porosity of the fabricated concrete mix is observed to be a minimum of 1.12% for A20P2, whereas the A20 concrete showed a maximum porosity of 1.5%.

Further studies can be established using other industrial waste, similar to alccofine, to enhance the performance of concrete. The fibre with different configurations and orientations can be employed to analyse their impact on the performance of concrete.

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