Experimental investigationon mechanical properties and characterization of steel fibre concrete with Bacillus subtilis

*Pooja*Damodaran[1], *and Lakshmi* Thangasamy[2*]

[1]Department of Civil Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, India - 602 105Email: poojad5008.sse@saveetha.com

[2]Department of Civil Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, India - 602 105Email: lakshmits.sse@saveetha.com

Abstract. Building cracks spoil the aesthetic view of the structure along with degrading the strength of the structure. It leads to the failure of the structure as a whole. Propagation of cracks in the concrete surface increases the chance of permeability due to moisture content in the atmosphere which might corrode the internal reinforcements. To overcome this situation, a solution in the form of fibre-reinforced self-healing concrete was suggested in this research work. Steel fibre was added by varying 0%,1%,2%,3%,4% and 5% interms of volume of concrete to prolong fatigue life and decrease the crack width under fatigue loading. Bacteria (*Bacillus subtilis*) are used to heal the cracks by producing calcium carbonate (CaCO3) as a result.Bacterial concrete with fibre (BCF) was cast by M30 mix as per Indian Standard Code. Studied concrete's mechanical and microstructural properties like compression strength test, flexural strength test, split tensile strength test, SEM images, EDS, XRD and FTIR methods.From microstructural studies, it is clear that there is sufficient self-healing material in broken concrete, hence the efficiency of BCF's self-healing property is commendable and the ability of the generated BCF concrete to regain strength.

Keywords-steel fibre, bacterial concrete, self-healing,cracks, reinforcements,permeability

1. INTRODUCTION

Plant and steel fibres have a lengthy history dating back to the beginning of human civilization, where natural fibres have been employed to reinforce construction materials and enhance the mechanical qualities of various materials. Natural fibres (like straw and horsehair) were combined with mud to create mud walls and mud roofs as early as the Egyptian era [1,2]. The need for environmentally friendly construction materials with high stiffness qualities is rising daily as a result of growing environmental problems [3-5]. In the building sector, concrete is the most widely utilised material. Unavoidable surface cracks

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brought on by a variety of circumstances may increase the permeability of concrete, making the entire structure more vulnerable to hostile surroundings over time.

Increasing numbers of natural fibres are being used to strengthen compound enhancers in place of chemical fibres, thanks to environmental consciousness and a limitation of energy supplies worldwide [6–10]. The progression of cracks in concrete is mostly influenced by changes in external loads, temperature, humidity, water, salt, and acids. The qualities of concrete are enhanced through the addition of various admixtures and additives that are provided to withstand challenging circumstances. Adding fibres to concrete is a practical way to enhance its mechanical qualities. Depending on their composition, various fibre kinds are used to accomplish the desired properties.

Natural fibres provide a few additional benefits over chemical fibres, in addition to being recyclable and regenerative [11,12]. These include low density, cost-effective processing, and high yield. Additionally, the natural fibre industry utilises and emits around 50% (weight%) more raw materials than other industries, and it contributes 30% of the world's carbon dioxide (CO_2) emissions[13]. In addition to consuming a lot of energy, typical Portland manufacturing also generates a considerable quantity of greenhouse emissions. Because of increased energy use and carbon density, the researcher has investigated alternative building materials. [12].

Self-healing concrete also referred to as bacterial concrete, fills up structural cracks caused by the bacterial response in the concrete after it has hardened. Bacterial concrete is prepared by adding the cultured bacteria in concrete with the required percentage. The usage of technology has raised construction standards to a new, high level in the modern era. To create a concrete structure that is excellent, sustainable, and affordable, several sorts of techniques, methods, and materials are employed. There are several solutions for this widespread issue of structure cracking both before and after the fracture. Self-Healing or bacterial concrete is one of the remedial techniques.

Natural fibres have long been preferred over synthetic fibres as reinforcing material for concrete due to growing environmental awareness and the development of environmentally friendly materials [14]. The new construction business is not sustainable, so there has been a lot of interest in finding substitute building materials. Consequently, natural fibres polymer nanocomposites have captured the interest of researchers from all over the world in recent years [11,15-18]. The use of natural fibre as reinforcement in the construction industry to produce an ecologically sustainable substance has received little attention from researchers[19,20].

Utilizing a variety of fibres, including coir, bamboo, sisal,husk, date,pineapple, or flax, steel reinforcement is created [21,22]. Furthermore, due to its benefits in building construction, the use of environmentally friendly materials in construction has grown significantly in recent years [23,24]. More subsequently, the Yunnan Province of China has an abundance of sisal fibres (such as different types of fibres), which are commonly utilised in the construction of buildings and dwellings due to their favourable environmental and economic qualities [25]. The term "hybrid fibre composites" refers to any supported structures that blend two or more different types of fibre to form a single matrix structure. [26–28]. The mechanical characteristics of natural fibres have been improved by many techniques up to this point, including fibre which was before, the use of hybrid composites or chemicals in the matrices, and the hybrid of organic [29,30].

The primary objectives of this research are to provide an efficient economic system while also increasing the stiffness of reinforced concrete sidewalks by varying 0%,1%,2%,3%,4% and 5% of steel fibres. This study explains the mechanical properties and microstructural characteristics of different percentages of steel fibres used in self-healing concrete.

2. MATERIALS AND METHODS

In this research, the steel fibre-reinforced bacterial concrete is influenced by the mechanical properties and microstructural behaviour of the concrete. It gives a brief description of the materials used and their properties used in the steel fibre-reinforced self-healing concrete. Also, it provides details of tests carried out on the material used in this research.

1.1 2.1 Materials Used

1.2 The followings are the materials used to make the fibre-reinforced bacterial concrete.

2.1.1 Cement

For this research, the OPC 53 was the grade cement used and the properties of cement are within limits of IS 12269-2013, which corresponds to the specific gravity of 3.12, initial setting time of cement is 45 mins and the final setting time of cement is 8hrs. Table 1. shows the chemical composition of cement.

Table 1. Chemical Composition of Cement.

Chemicals	CaO	Al_2O_3	Fe_2O_3	SiO_2	Na_2O	K_2O	TiO_2	MgO	Other	Total
OPC	65.29	4.73	3.95	20.93	0.29	0.36	0.19	1.43	2.83	100

2.1.2 Fine aggregate

For this research, locally available river sand was used by confirming Zone II as per requirements of IS 383 2016. The Fineness modulus is 3.02 and the specific gravity is 2.61.

2.1.3 Coarse aggregate

The crushed stone aggregate of size 12.5mm was used, As per requirements of IS 383 2016 the properties specified with the specific gravity of coarse aggregate is 2.87 and the fineness modulus is 7.24.

2.1.4 Water

Water is the agent of hydration of cement, hence, mixing and curing water must be free of deleterious substances and chemicals that can satisfy IS 456 2000.

2.1.5 Steel fibre

In this study, to increase the tensile strength of the concrete, reinforcement in the form of zigzag-shaped steel fibresFig. 1 with 30mm length and 0.5mm diameteris used by 0%,1%,2%,3%,4% and 5% of steel fibresinterms of volume of concrete. The properties of fibre have been listed in Table 2.

Fig.1. Steel Fibre.

Table 2. Properties of Steel Fibre

Properties	**Description**
Length (mm)	30
Diameter (mm)	0.5
Aspect ratio	60
Shape	Zig-Zag
Ultimate tensile strength (MPa)	900
Density (kg/m^3)	7850
Elastic modulus (GPa)	210

2.1.6 Bacteria Used

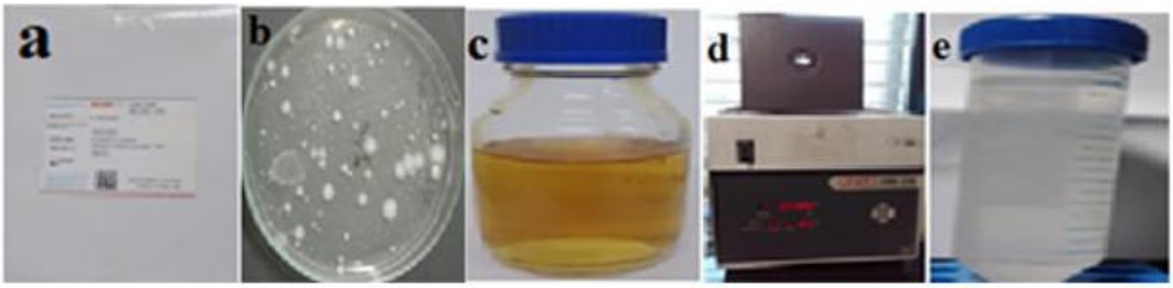
*Bacillus subtilis*was used, which is a gram-positive and rod-shaped bacillus. Table 3 shows the properties of *Bacillus subtilis*.

Table 3. Properties of *Bacillus subtilis*

Properties	**Specifications**
Size	0.3- 22 µm (width) 1.2- 7.0 µm (length)
Shape	Rod-shaped
Pigmentation	Brown
Staining properties	Gram-positive
Medium	Nutrient broth
Temperature	37°C
pH	7

2.1.7 Bacterial suspension preparation

The *Bacillus subtilis* spore strips were procured from Hi-media life sciences. One spore strip was introduced aseptically into 100 ml of clean nutrient broth solution, where it was incubated for 48 hours at 37°C. Following the 48-hour incubation phase, a loop full of inoculum was streaked on MYP agar and incubated at 37°C. That after the incubator time, the plates underwent a colony morphology examination. *Bacillus subtilis* was identified as the source of the large, pink, fired egg-like colonies with uneven edges. An inoculum from a single colony was added to 1000 ml of sterile nutrient broth solution, and the mixture was kept at 37°C for 48 hours. The sedimented bacterial cells were re-suspended in 250 ml of sterile distilled water as shown in Fig. 2. The bacterial load in the suspension was estimated by the standard plate count method and the population was confirmed as 10^7 cells/ml and used for further studies.



a) Spore strips b) Pure culture In solid media c) Broth media d) Centrifuger e) Purified bacterial cells in distilled water

Fig. 2. Processing of *Bacillus subtilis* bacteria

2.1.8 Superplasticizer

In this study, TEC-MIX 550 is used, to enhance water reduction properties resulting in improved workability and greatly reduced porosity of concrete. As per recommendation, 200-250g/50kg bag of cement.

2.1.9 Mix design

The mix proportion for the M30 grade of concrete was calculated as per IS code provision, mix ratio. As per IS 456-2000, the quantities used were tabulated below in Table4.

Table 4.Quantity Of Materials Used

Materials used	Quantity (kg/m^3)
Cement	380
Fine aggregate	660
Coarse aggregate	1200
Water	190
Steel fibre	0%,1%.2%,3%,4%,5%
Bacillus subtilis	3.8
Superplasticizer (Tec-mix)	1.52

2.2 Experimental methods

In this study, the cubes, cylinders and prisms were cast and cured in water for 28 days at room temperature. With that, the mechanical methods and microstructural techniques were carried out.

2.2.1 Mechanical method

The mechanical properties of concrete play a crucial role in its overall performance, and a range of mechanical methods are used to assess and improve these properties. In this research, as per the codal provisions, the concrete's mechanical properties were assessed by conducting compression strength tests, split tensile strength tests and flexural strength tests after the 7th, 14th and 28th day.

2.2.2 Microstructural techniques

Although concrete's particular behaviour is impossible to predict with any degree of accuracy, understanding its microstructural properties can help to manipulate the material's characteristics. The three phases of concrete microstructure are aggregate, hydrated cement and Interfacial Transition Zone (ITZ). The properties of these phases have a tremendous influence on the overall performance of the concrete. The Microstructure of the elements is studied through XRD,FTIR, SEM and EDS studies. Results of microstructural techniques carried out on the concrete samples made from different mixes using XRD,FTIR,SEM and EDS studies.

3. RESULTS AND DISCUSSION

3.1 Determination of compressive strength

Under IS 516:2018, cubical specimens 150 x 150 x150 mm in size were cast to assess the concrete's compression properties. To create the cubical specimens for the M30grade of concrete, the 0%,1%,2%,3%,4%, and 5% of steel fibre and 1% of *Bacillus subtilis* added by weight of cement, were taken into consideration. Enhancing the mechanical properties of composites to create efficient concrete structures [31–32]. To increase the mechanical properties of concrete, several fibres are hybridised [33]. Results for adding natural fibres to the matrices have been described as both favourable and unfavourable [34]. Additionally, some data show a decline in proportion. The samples were aged in water at room temperature for 28 days. After the curing phase, the specimens were tested using CTM at a loading rate of 4.5 kN/s in Fig. 3 Peak compressive strength values were identified and compared with conventional concrete.

Fig. 3. Compressive strength test on steel fibre in bacterial concrete

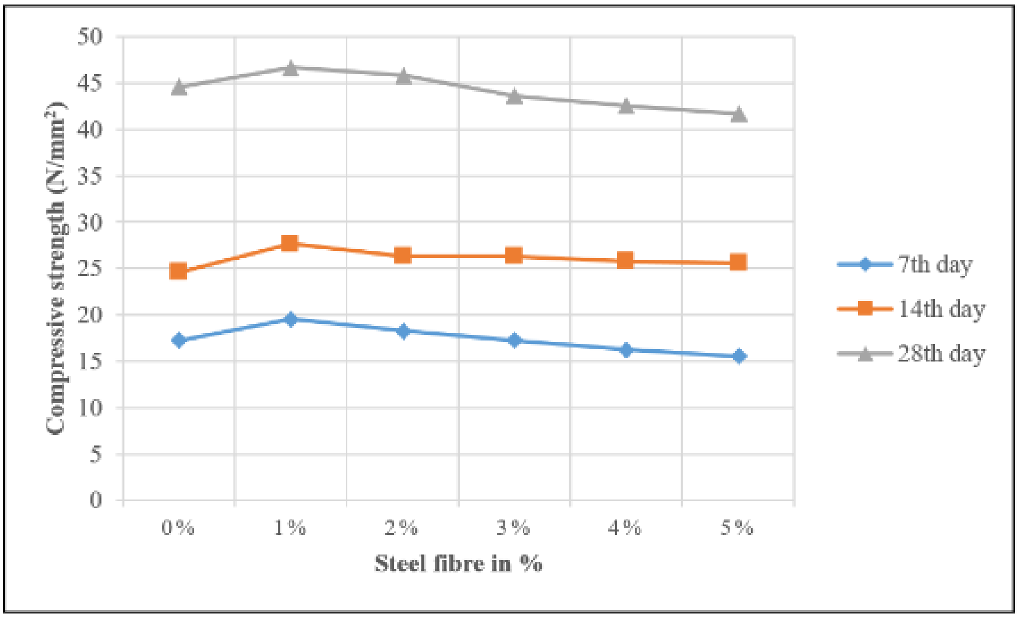


Fig. 4. Compressive strength on steel fibre in bacterial concrete

The results of the compressive strength test it has shown that the strength of concrete has been drastically increased with the addition of 1% steel fibre and 1% *Bacillus subtilis* bacterial culture. The strength increase was 13.5% on the 7th day, 12.3% on the 14th day and 4.7% on the 28th day. But the further increase of steel fibre concentration in the concrete has resulted in the gradual decrease of compressive strength of the concrete. In this study, upto 5% of steel fibre was used along with the bacterial culture. Based on the results it was confirmed that the increase of steel fibre beyond 1% has to reduce the concrete strength from 90% to 130% and as explained in Fig.4.

3.2 Determination of split tensile strength

Under IS 516:2018, cylinders of 200 mm inheight and 100 mm in diameter were cast. The addition of steel fibres and bacteria in conventional concrete was used to create the cylinders. The specimens were prepared and cured for 28 days in water at room temperature. After curing, the specimens underwent CTM testing with a loading rate of 2.5 kN/s as shown in Fig. 5.

Fig. 5. Split tensile strength test on steel fibre in bacterial concrete

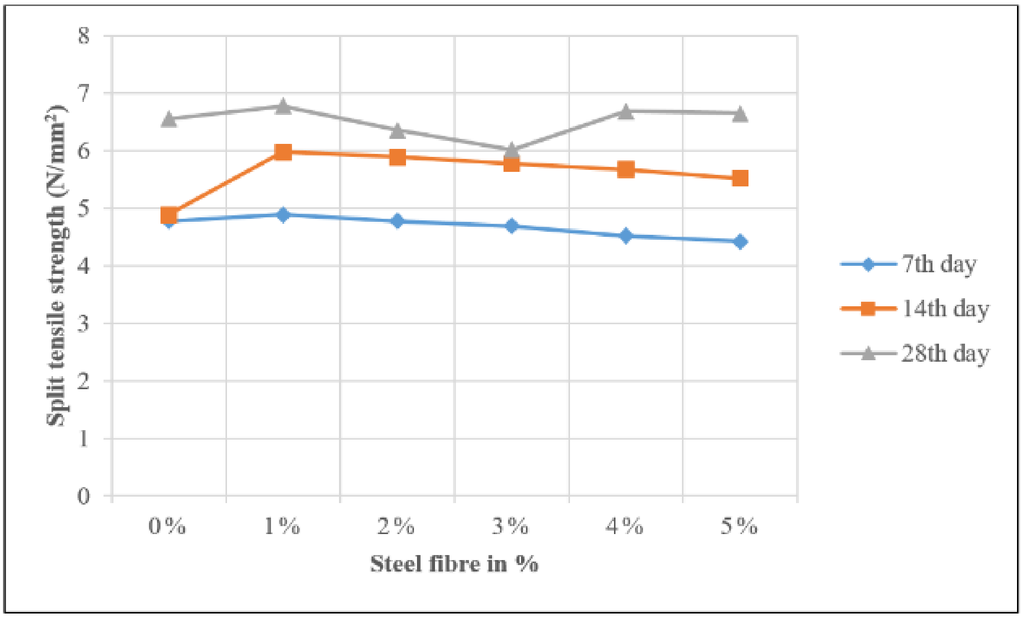


Fig. 6. Split tensile strength on steel fibre in bacterial concrete

The splitting tensile strength was determined on cylinders (100 x 200mm) with differing fibre loading (0%,1%, 2%, 3%,4%,5%), as shown graphically in Fig.6, and the highest possible strength was discovered to be at 1% steel fibre, and it is decreasing on the increase of steel fibre concentration upto 5%. The split tensile strength was reduced from 70% to 150% on an increase of steel fibre from 1% to 5%.

3.3 Determination of flexural strength

Under IS 516:2018, beams with dimensions of 100 x 100 x 500 mm were developed. With the addition of steel fibres and bacteria in conventional concrete, prismatic specimens were produced. The specimens were cured in water for 28 days at room temperature. After curing, the specimens were tested in a flexural strength machine with two-point loading consideration shown in Fig. 7.

Fig. 7. Flexural strength test on steel fibre in bacterial concrete

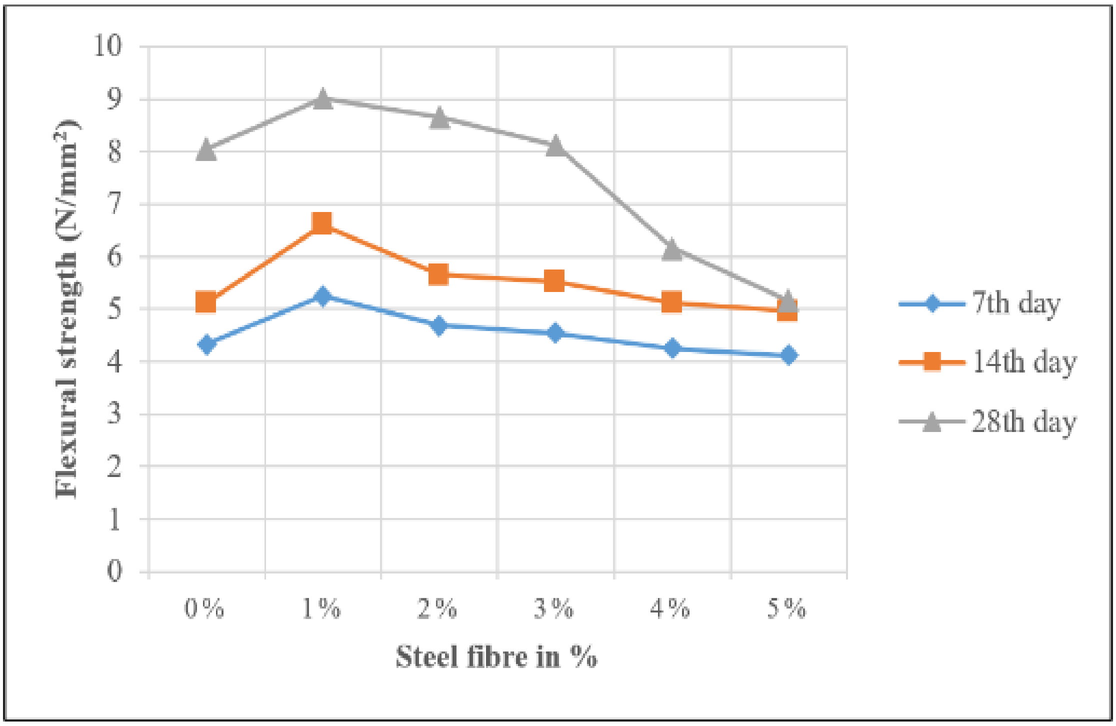


Fig. 8. Flexural strength on steel fibre in bacterial concrete

The study of flexural strength analysis of bacterial suspension incorporated concrete along with steel fibre has shown an increase of 20% to 28% flexural strength at 1% steel fibre concentration and it was explained in Fig. 8. The further increase of steel fibreup to 5% does not affect the flexural strength of the concrete. But the increase in steel fibre has resulted in a decrease inthe flexural strength of concrete from 70% to 160%.

3.4Mineralogical techniques

3.4.1 XRD analysis

As illustrated in Fig. 9, the X-ray diffraction analysis of microbially produced $CaCO_3$ reveals nine distinctive peaks labelled A at angles of 21, 29.5, 32, 36.4, 41, 48.2, 49, 56.5, and 60.9. By using XRD analysis and calcite (2 = 29.3), it was determined that the white precipitate was $CaCO_3$ is the polymorph that forms most frequently in bio-concrete samples. The literature reveals a comparable result [29].

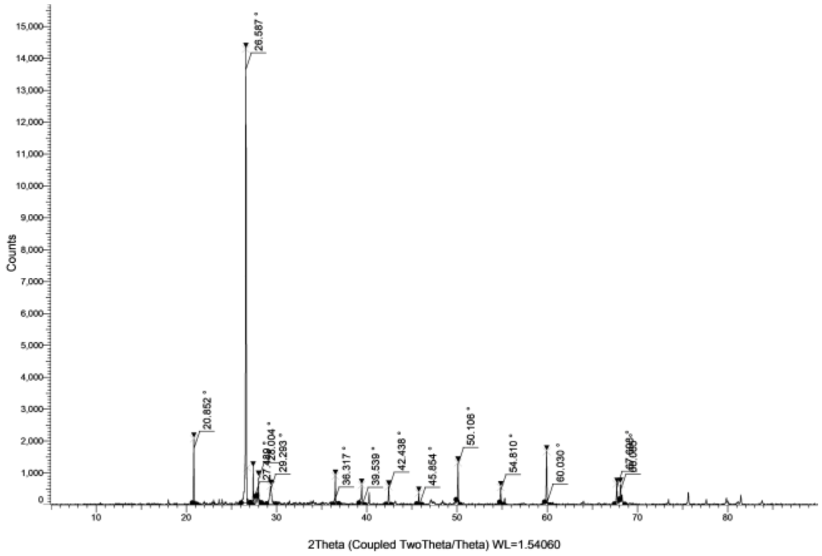


Fig. 9.XRD analysis of 1% steel fibre in bacterial concrete

3.4.2FTIR analysis

As seen in Fig. 10, the FTIR analysis of calcium carbonate generated by microbes in powder seems to be a helpful method for early identification.

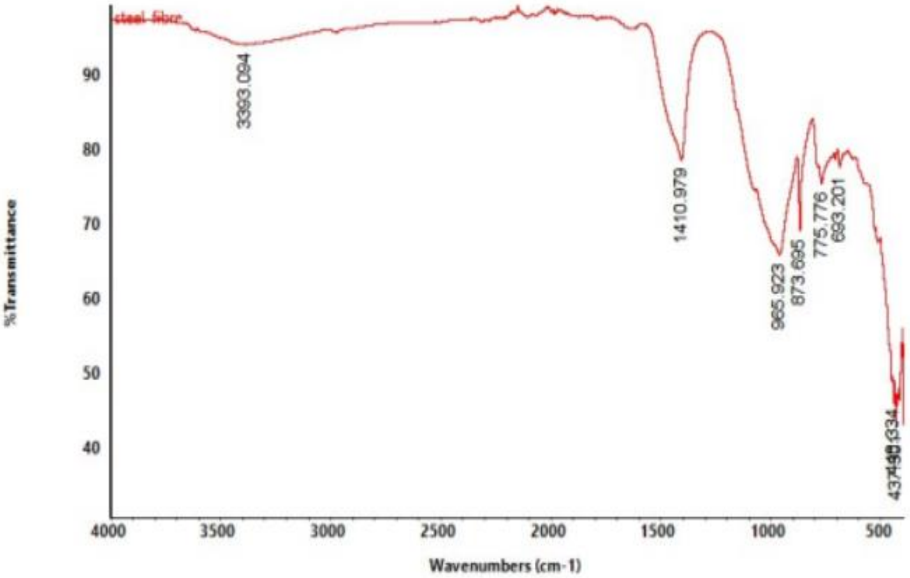


Fig. 10.FTIR analysis of 1% steel fibre in bacterial concrete

According to the intensity values of the bands at 863 $cm^{-1}$and 1758 to 1550 cm^{-1}, calcite was the most common mineral produced by *Bacillus subtilis* cells. Extremely evident acute stretching rings of calcites ranged in width from 1800 to 1550 cm^{-1} in the white precipitate that *Bacillus subtilis* left behind [39,40].

3.4.3SEM and EDS analysis

The cubical shape of the particles revealed by the SEM investigation of the microbial-produced $CaCO_3$ supports the geometry of calcite Fig. 11. In contrast to the other allotropic form of calcium carbonate, the calcite was in the solid region of the compound. The allotropic style's stability is a reliable indicator of the concrete's toughness. Precipitated calcite, an amorphous type of calcium carbonate, had higher water permeability and was insoluble in water because of its stronger binding. According to the research [38], the calcite is also thermo stable up to 5000°C. Additionally, it was discovered that the precipitating calcite was more tightly bound to the other components of the concrete during the fracture repair because it had fewer pores. A higher number and fewer holes cause less permeability. Additionally, it produced greater scores for compressive density and compression strength.

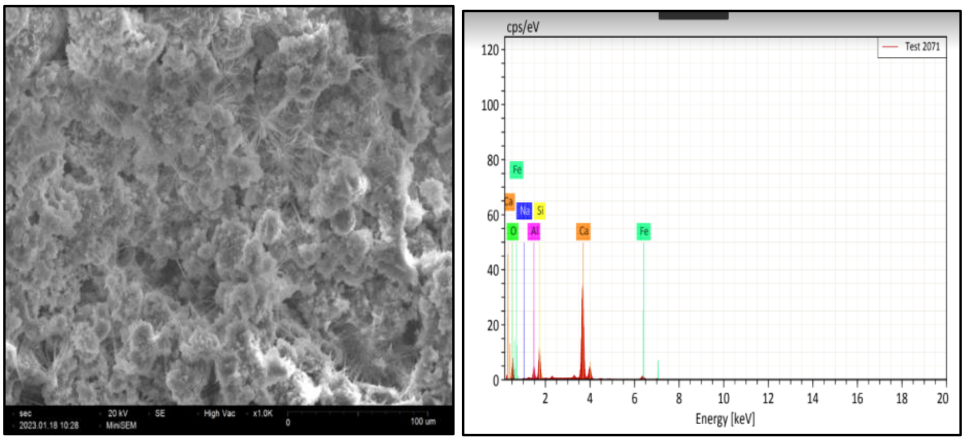


Fig. 11.SEM with EDS analysis of 1% steel fibre in bacterial concrete

4. CONCLUSION

Based onthe outcomes of this study it was concluded that the addition of steel fibre at 1% concentration to the bacterial concrete has played a progressive role in the increase of compressive strength, split tensile strength and flexural strength. The addition of steel fibre into the bacterial concrete beyond 1% does not affect the increase of concrete strength properties. But the increase of steel fibre concentration from 1% to 5% has reduced the concrete strength from 50% to 150%. Further, the concrete weight also increased with the addition of steel fibre. The addition of 1% *Bacillus subtilis* and 1% steel fibres in concrete can also improve the microstructural behaviour of the material. The SEM and XRD analyses suggest that the incorporation of *Bacillus subtilis* and steel fibres can result in a more homogeneous distribution of the fibres and bacterial cells within the concrete matrix. The total repair of micro-cracks demonstrates *Bacillus subtilis* microbes' significant ability to produce caco3 for healing nano /micro-scale structural/non-structural cracks in cementitious composites. From this study, it was concluded that the optimal concentration for the steel fibre concentration in bacterial concrete is 1%.

5. References

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