Journal of
Composites Science

*Article*

# Development of Basalt Fiber Reinforced Fine-Grained Cementitious Composites for Textile Reinforcements

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**Abstract:** Cementitious composites have been the prevalent field of research in recent eras due to their excellent bending and high strains. However, textile reinforcement requires materials with fine grain size to make proper binding between the yarns in the textile reinforcement and improve the strength characteristics. This concern has led to the development of fine-grained cementitious composites by dispersing chopped basalt fiber to improve strain-hardening capabilities with reduced voids. The basalt fiber content is varied by 0, 0.2, 0.4, 0.5 and 1% to the volume of the cementitious matrix. Various testing methods have evaluated the mechanical and microstructural properties of fine-grained cementitious composites with basalt fiber. Adding basalt fiber up to 0.4% to the volume of the matrix improves the compressive, split tensile, flexural strength and dynamic modulus of elasticity compared to the controlled cementitious matrix. Also, higher fiber content escalated the impact resistance and degree of carbonation. From the results, obtained basalt fiber reinforced fine-grained cementitious composites have higher mechanical characteristics, and the particles are densely packed compared to cementitious composites. Thus it provides good bonding between the textile reinforcement and helps to construct thin structural elements.

**Keywords:** fine-grained cementitious composites; basalt fiber; optimum; mechanical properties; microstructure

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**Citation:** Sudhakar, A.J.; Muthusubramanian, B. Development of Basalt Fiber Reinforced Fine-Grained Cementitious Composites for Textile Reinforcements. *J. Compos. Sci.* **2022**, *6*, 396. https://doi.org/10.3390/jcs6120396

Academic Editor: Francesco Tornabene

Received: 28 November 2022
Accepted: 13 December 2022
Published: 19 December 2022



## 1. Introduction

Fine-grained cementitious composites are an advancement in engineering cementitious composites with fine grain size materials. The fineness of materials reduces the air voids in the matrix by dense packing. It also possesses high tensile strength and strain than conventional concrete [1]. These fine-grained cementitious composites have a major application in textile-reinforced composite construction. It helps in constructing thin and complex constructions. When the grain size of the sand decreases, it reduces the air voids and makes proper binding between the yarns in the textile reinforcement, increasing the strength characteristics [2]. It resists permeability through the voids and reduces corrosion with improved durability [3]. The finer particles impregnate easily between the yarns and create good bonding between the textile fiber and cementitious composite. The workability of fine-grained cementitious composites is higher due to their fineness [4]. Despite being densely packed, it shows shrinkage due to the absence of coarse aggregates and due to its fineness. The shrinkage can be reduced by introducing fibers in fine-grained cementitious composites [5]. The flexural and tensile characteristics of cementitious composites can be improved further by adding fibers. It also reduces air voids and makes the matrix more densely packed [6]. Leasovik et al. [7] have developed fine-grained cementitious composites for textile-reinforced concrete and report that concrete, and cement mortars reinforced with dispersed reinforcement reduce shrinkage cracks and increase fire resistance and impact resistance. Klyuev et al. [8] suggest that the dispersion of fibers in the concrete helps to reduce the shrinkage cracks. Fiber-reinforced fine-grained concrete exhibit excellent bending property [9].

Fiber-reinforced concrete (FRC) is not new in the research field, but it is still commonly used due to its good flexural characteristics. The length of fiber dispersed and the yarn count influences its behavior. Recently, it has been discovered that basalt fibers, made from igneous basalt rock, are extensively used in concrete constructions domestically and internationally [10]. Researchers have been applying intense effort to cementitious composites in the past decade, leading to strong, ductile and energy-absorbing composites with high compressive and tensile strengths and high ductility [11]. The composites industry has been paying close attention to basalt fibers (BF) because of their chemical stability and excellent mechanical and thermal properties [12,13]. BF has many applications in polymer industries and construction sectors for its reduced economy [14]. Basalt fiber-reinforced engineering cementitious composites show higher strength when compared with other types of fibers and possess superior ductile characteristics [15]. In addition, it is well known that basalt fiber reinforced concrete (BFRC) achieves better mechanical performance with an increasing amount of basalt fibers; however, the fiber-matrix interface is another critical factor affecting the durability of such composites [12]. In addition, higher fiber content lowers the pore size [16] and has a low impact on water resistance [17]. Chopped basalt fiber is available in different lengths, among which 12 mm basalt fiber showed higher strength when compared to other chopped lengths [18]. Ahmad and Chen [19] observed that adding basalt fiber enhanced the flexural response after failure, but its effect on compression was insignificant. Using a multiscale simulation of the fundamental mechanical characteristics, Sun et al. [20] evaluated the influence of the length of basalt fiber and its content. Progressive damage theory and Mori-Tanaka homogenization theory were used in developing a constitutive damage model to predict the properties of Basalt fiber-reinforced concrete. The variation in mechanical properties was observed with the length of the fiber and percentage variation in the matrix. The comparative performance of alkali-resistant basalt fiber and basalt fiber assessed by Li et al. [21] revealed that it also helps enhance mechanical characteristics, including compression, split tensile and flexure. In the compression of concrete, the strength decreases with an increase in fiber content regardless of the length of the fibers and cement consumption equality, which corresponds to an increase in the water:cement ratio to maintain the given mobility. For the same conditions, a concrete's flexural strength increases with fiber content to a certain level that corresponds to its optimal fiber content. However, there is an equal decrease in flexural strength as fiber quantity increases. Flexural strength is also positively impacted by fiber length growth. Concrete's composition and the length of the reinforcing fibers determine the optimal content of these fibers. Reinforcing fiber content exerts a dominant influence on the flexural strength of the concrete by providing high tensile strength and a decrease in strength of equitant as a result of increasing water-to-cement ratio.

Past research shows that the construction industry focuses on sustainable, thin and complex structures. Thus, there is a need for evolving sustainable and thin construction materials with excellent performance. The performance of engineering cementitious composites increases by reducing the grain sizes and is known as fine-grained cementitious composites. Only limited work has been carried out so far on fine-grained cementitious composites, and the major drawback found in engineering cementitious composites is that it contains voids between the particles, and due to the grain size, they could not impregnate between the textiles and make the proper binding. Therefore, to overcome the challenges, the study's first aim is to investigate the mechanical and microstructural characteristics of fine-grained cementitious composites with basalt fiber. Other researchers have carried out characteristics of fine-grained cementitious composites with synthetic fibers like polypropylene fiber, glass fiber, etc. Basalt fiber made from natural rock shows superior strength and durability and is more cost-effective than other fibers. By using the fine aggregate of less than 2.36 mm, the voids are reduced due to the fineness, and chopped basalt fiber occupies the voids resulting in a dense matrix. Among the chopped basalt fibers of different available lengths, 12 mm fiber gave excellent mechanical and microstructural characteristics, as evident from the literature on fiber-reinforced concrete. Thus, chopped basalt fiber of 12 mm is used in this study in fine-grained cementitious composites, among other lengths. The addition of fibers also helps to reduce air voids and make the composite more densely packed due to its flexibility. The characteristics of fine-grained cementitious composites are studied from mechanical and microstructural studies.

## 2. Materials and Methods

### 2.1. Materials

The materials used for preparing basalt fiber-reinforced fine-grained cementitious composites (BFRFGC) conform to the IS standards. The cement of OPC 53 grade was used and conforming to IS 12269: 2013 [22] with major calcium and silica content of 65% and 20%, respectively. Manufactured sand used as fine aggregate was as per IS 383–2016 [23]. Manufactured sand of grain size less than 2.36 mm was used in this study with a specific gravity of 2.65 and a fineness modulus of 2.6. No coarse aggregate was used in this study. The chopped basalt fiber of length 12 mm was added as an additive. The addition of basalt fiber helps in reducing shrinkage cracks and improves strain hardening. A sulfonated naphthalene-based superplasticizer was used to improve the workability without increasing the water content. The properties of the materials used are shown in Tables 1 and 2.

**Table 1.** Properties of Materials.

| Properties | Cement | Fine Aggregate | Superplasticizer |
|---|---|---|---|
| Specific gravity | 3.1 | 2.74 | 1.18 |
| Grading of M-sand | - | Zone III (slightly fine) | - |
| Density (kg/m$^3$) | 1420 | 1790 | - |

**Table 2.** Properties of basalt fiber.

| Property | Values |
|---|---|
| Density | 2.68 (g/cm$^3$) |
| Length | 12 mm |
| Fiber diameter | 16 µm |
| Aspect ratio | 705 |
| Tensile strength | 3.57 GPa |
| Elastic modulus | 88 GPa |
| Elongation at break | 3.16% |

### 2.2. Specimen Preparation

The basalt fiber-reinforced fine-grained cementitious composites were prepared with a binder to the aggregate ratio of 1:3 and a water-cement ratio of 0.45. The appropriate mix required water content and superplasticizer percentage were decided based on a trial and error method to achieve a target strength of 30 N/mm$^2$. A sulfonated naphthalene-based superplasticizer of 1% to the weight of cement was added as a water-reducing agent. The basalt fiber was added in varying percentages to the mix volume, say, 0%, 0.2%, 0.4%, 0.5% and 1%, to obtain the optimum percentage of fiber to be added to the mix. From the literature on using basalt fibers in concrete specimens with coarse aggregate, basalt fiber of 0%, 0.5%, 1%, 1.5% and 2% to the volume of the mix is used. With that reference, in this study, 0%, 0.5% and 1% were chosen, but while testing the specimens for compression, the strength was reduced beyond 0.5% dosage. Thus, intermediate percentages like 0.2% and 0.4% are adopted to fix the optimum basalt fiber content. As no coarse aggregates are used in this study and a fine aggregate of size less than 2.36 mm is used, it makes the dense mix with a reduced volume of voids leading to lower fiber addition. M0, M1, M2, M3 and M4 are the mix codes indicating that 0%, 0.2%, 0.4%, 0.5% and 1% of basalt fiber are added to the concrete mix. The specimens were tested after 7, 14 and 28 days of water curing. Three specimens are tested for each day of curing, and the average values are obtained for each mix. The details of the materials used in each mix with mix id are given in Table 3.

**Table 3.** Mix details.

| Mix ID | % Basalt Fiber | Cement (kg/m$^3$) | Fine Aggregate (kg/m$^3$) | Water (kg/m$^3$) | Basalt Fiber (kg/m$^3$) | Super Plasticizer (kg/m$^3$) |
|---|---|---|---|---|---|---|
| M0 | 0 | 454.8 | 1654.35 | 191.55 | - | 4.54 |
| M1 | 0.2 | | | | 2.67 | |
| M2 | 0.4 | | | | 5.34 | |
| M3 | 0.5 | | | | 6.68 | |
| M4 | 1 | | | | 13.35 | |

## 2.3. Methods

The tests performed for studying the mechanical and microstructural characteristics of fine-grained cementitious composites and the procedure followed are explained in this section.

### 2.3.1. Fresh Properties

A flow table test was used to determine the flowing ability of concrete with the addition of fiber. A flow table test was done for fine-grained cementitious composites to check their flowing ability as per ASTM C1437–15 [24]. The mix prepared was placed in the conical mold of the flow table in three equal layers, and each layer was compacted using a tamping rod 20 times per layer, then the excessive layer was removed. The flow table was raised and dropped 25 times after removing the mold, and the diameter of the flow was measured using the steel scale.

### 2.3.2. Mechanical Properties

It is desired to determine the main mechanical characteristics of the cementitious mix to check its suitability in different application areas. In this study, fine-grained cementitious composites are developed with the main moto of applying them in textile-reinforced structural elements to obtain thin, lightweight and complex structural elements with proper bonding between textile fibers and matrix. Hence the mechanical characteristics of fine-grained cementitious composites were performed using compression, split tensile, flexural test, impact resistance and the dynamic modulus of elasticity for 7, 14 and 28 days of water curing.

#### Compressive Strength Test

The fine-grained cementitious composites were cast using different percentages of basalt fibers to the volume of the matrix, and to determine the compressive strength, 45 specimens were cast, and three were tested at each age of curing for each mix. Cubes of 70.6 mm were cast and immersed in water for curing. After the required days of curing, the specimens are air-dried and tested after 7, 14 and 28 days. The compression test was performed in a Compression Testing Machine (CTM) with a 2000 kN loading capacity with a 2 mm/min loading rate.

#### Split Tensile Test

In this article, forty-five fine-grained cementitious composite cubes are cast with different percentages of basalt fiber addition to determine the split tensile characteristics. The split tensile test was performed using cube specimens of 70.6 mm as per IS 5816: 1999 [25] by loading them diagonally in a compression testing machine, with a load rate of 1.5 mm/min for 7, 14 and 28 days of water curing.

#### Flexural Test

The flexural response of fine-grained cementitious composites for different percentage addition of basalt fiber was studied using forty-five prism specimens of

160 mm × 40 mm × 40 mm as per ASTM C348-02 [26]. Four-point bending is preferred over three-point bending due to zero shear between the loading points.

Impact Resistance Test

The impact resistance of fiber-reinforced fine-grained cementitious composites was determined using a drop weight impact test as per ACI 544 -2R [27]. Forty-five specimens are cast, and three are tested for each 7, 14 and 28 days of water curing. The specimens were prepared of 152.4 mm diameter and 63 mm thickness with different percentages of basalt fiber. After the required age of curing, the specimen is tested by placing a steel ball at its center and dropping a hammer from a height of 450 mm of 4.5 kg. The hammer should be dropped freely as a gravitational fall. The number of blows required for the specimens in initializing the crack and final crack was counted, and from which the impact energy absorbed by the fiber-reinforced fine-grained cementitious composites can be determined.

Dynamic Modulus of Elasticity

The dynamic modulus of the fine-grained cementitious composites with basalt fiber can be studied using the UPV test, increasing with time [28]. Depending on the thickness of interfacial zones near the aggregate surface, the normal value of dynamic modulus changes based on its porosity [29]. A mortar's interfacial zone is measured by its moduli after being mixed. In addition to estimating the interfacial zones, they can also estimate the bulk cement paste consistency [30]. The dynamic modulus can be obtained from the UPV results using a formula mentioned in Equation (1) as per IS 13311 (Part 2): 1992 [31]. The same prism specimens cast to determine the flexure can be used to study the UPV effect as it is a non-destructive method.

$$E_d = \rho\left[(1+\mu)(1-\mu)V^2\right]\Big|[1-2\mu] \quad (1)$$

where $E_d$ = Dynamic modulus of elasticity.

$\mu$ = Poisson ratio of concrete, assumed 0.17.

$\rho$ = Mass density (g/cm$^3$).

$V$ = Speed rate of wave in specimen m/micro sec [28].

The dynamic modulus of elasticity values is compared with a static modulus of elasticity values obtained from $E_c = 5000\sqrt{f_{ck}}$, as per IS 456: 2000. $f_{ck}$: characteristic compressive strength of concrete after 28 days of curing.

2.3.3. Microstructural Characteristics

The collected specimen is washed with ethanol three times in the microstructural analysis to stop the hydration. SEM analysis under a vacuum helps to obtain the microscale and nanoscale images by passing the beam of electrons. The vacuum chamber controls the beam of electrons. The image was captured by loading the sample in a vacuum chamber and bypassing scattered electrons at low vacuum conditions. EDS is a quantitative analysis studied by passing the electron spectrum. FTIR spectroscopy was carried out to determine the functional groups present in the sample. The wavenumber ranging from 400 to 4000 cm$^{-1}$ was carried out in this study. The powdered concrete samples are mixed with potassium bromide, and a detector is used to identify the absorbed frequencies.

## 3. Results and Discussion

This section presents and discusses the outcome obtained through various experiments in this article.

### *3.1. Fresh Properties-Flow Table Test*

The workability of the fine-grained cementitious composites determined by of flow table test reduced by 4%, 7.42%, 10.85 and 19.42% with the basalt fiber addition of 0.2%, 0.4%, 0.5% and 1%, respectively and is represented graphically in Figure 1. Flow properties decrease slightly upon the addition of fibers. The mix's flowability reduced with the fiber content's increase due to the water absorption of the fibers in BFRFGC and was similar to the results obtained by Girgin and Yildirim [32] and Ozkan and Demir [33] in basalt fiber-reinforced engineering cementitious composites. The workability reduced with the increase in fiber content but was higher than engineering cementitious composites in fine-grained cementitious composites due to the finer aggregates. Thus, when the fiber content is increased, it absorbs more water and reduces workability, and the fine grain size particles improve the workability.

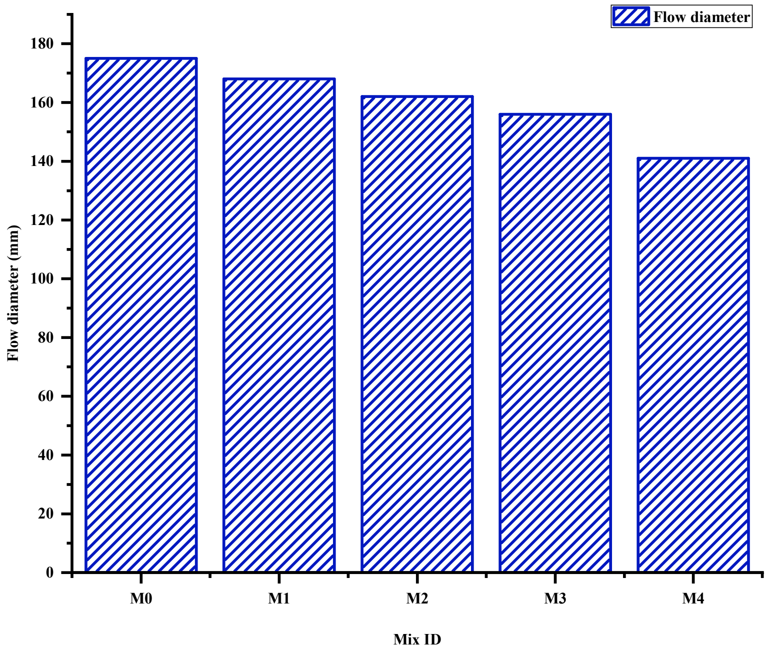


**Figure 1.** Flow diameter of BFRFGC for five different mixes.

### *3.2. Mechanical Properties*

#### 3.2.1. Compressive Strength

Conventional fine-grained cementitious composites and BFRFGC specimens showed brittle and ductile failure, respectively. The graphical representation of the compressive strength of BFRFGC for different days of curing is shown in Figure 2 and is an average of three cubical specimens as per IS 4031-6 (1988) [34]. The percentage increase in compressive strength of 13.77, 22.72 on 0.2 and 0.4% addition of basalt fiber was reduced by 14.15 and 21.61% from the optimum percentage on further increase in fiber content. The maximum compressive strength of 22.72% increased for the mix's 0.4% basalt fiber addition. The mechanical properties of basalt fiber-reinforced fine-grained cementitious composites deteriorate when their volume fraction exceeds their optimum volume fraction [35]. The change in failure pattern upon basalt fiber addition in fine-grained cementitious composites from brittle to ductile nature was similar to the failure pattern observed by Rafiei et al. [36] on basalt fiber reinforced engineering cementitious composites. Thus by incorporating basalt fiber in fine-grained cementitious composites, brittle failure is changed to ductile failure. A good binding nature between basalt fiber and concrete was judged from the failure characteristics of fibers in the failure section. Therefore, the 0.4% addition of BFRFGC gives greater compressive strength and is considered as optimum fiber percentage.

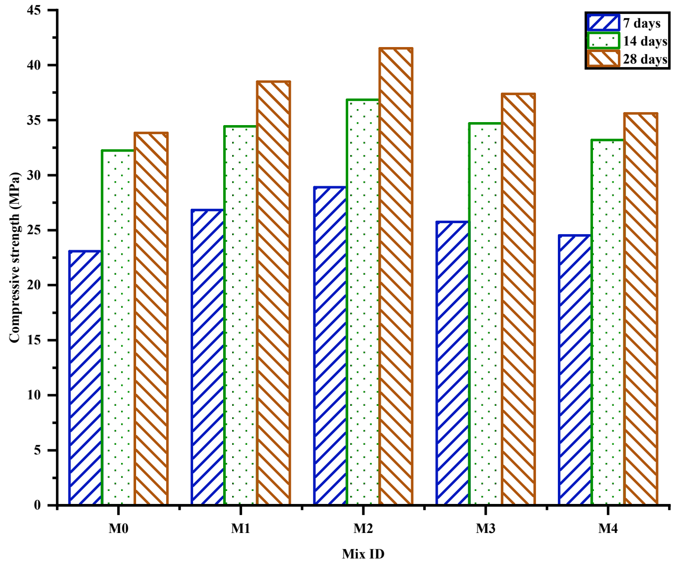


**Figure 2.** The compressive stress of fine-grained cementitious composites for five different mixes.

### 3.2.2. Split Tensile Strength

The split tensile strength of fine-grained cementitious composites was determined using an indirect method using cube specimens by placing them diagonally. The split tensile strength of the fine-grained cementitious composites with basalt fiber increased with fiber content. The variation in split tensile strength value is shown in Figure 3 for different days of curing. The failure occurred clearly along the diagonal of the specimen. The percentage increase of 38.39%, 51.47%, 53.58% and 50.21% for different percentage addition of fiber. The maximum increase in split tensile strength is for 0.5% of basalt fiber in the matrix. The tensile strength increases with fiber content were higher than the split tensile strength noticed by Qiang et al. [37] on basalt fiber-reinforced engineering cementitious composites. When the particle size decreases along with fibers, it improves the stiffness, which is the reason for higher split tensile strength [38]. The split tensile strength showed a slight decrease after the 0.5% addition of basalt fiber and could resist cracking and spallation along the failure plane, thus improving ductility. However, tensile strength increased with fiber content.

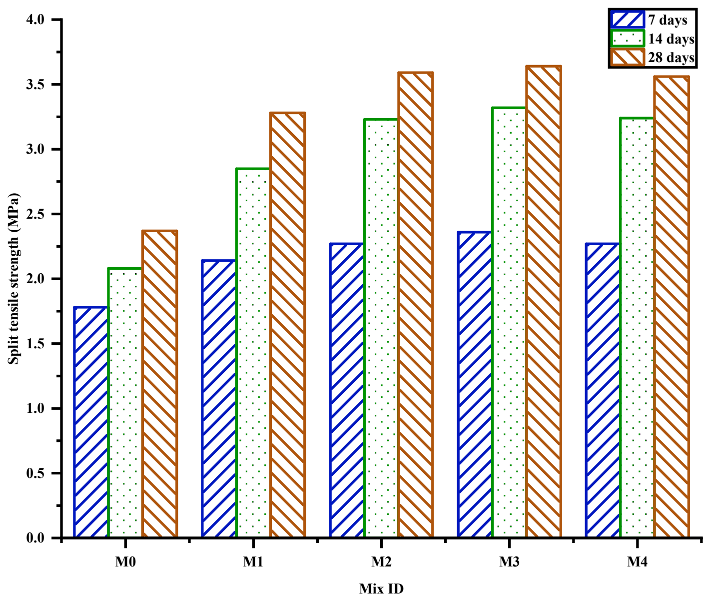


**Figure 3.** Split tensile strength of fine-grained cementitious composites for five different mixes.

#### 3.2.3. Flexural Strength

Generally, the fiber-reinforced specimens show excellent flexural performance, so it is vital to determine the flexural properties of basalt fiber-reinforced fine-grained cementitious composites.

The flexural strength of fine-grained cementitious composites increased by 26.69%, 47.48%, 49.01% and 44.2% percentages for different percentages of basalt fiber addition, as shown in Figure 4. The maximum flexural strength of about 6.74 N/mm$^2$ was achieved for 0.5% basalt fiber addition. The flexural strength increased with fiber content and was similar to Rafiei et al. [36] on engineering cementitious composites. However, the flexural strength values are higher for fine-grained engineering cementitious composites. Flexural strength increases with finer grain particles as it improves the toughness and bending ability [38]. Thus, finer particles and higher fiber content improve flexural strength.

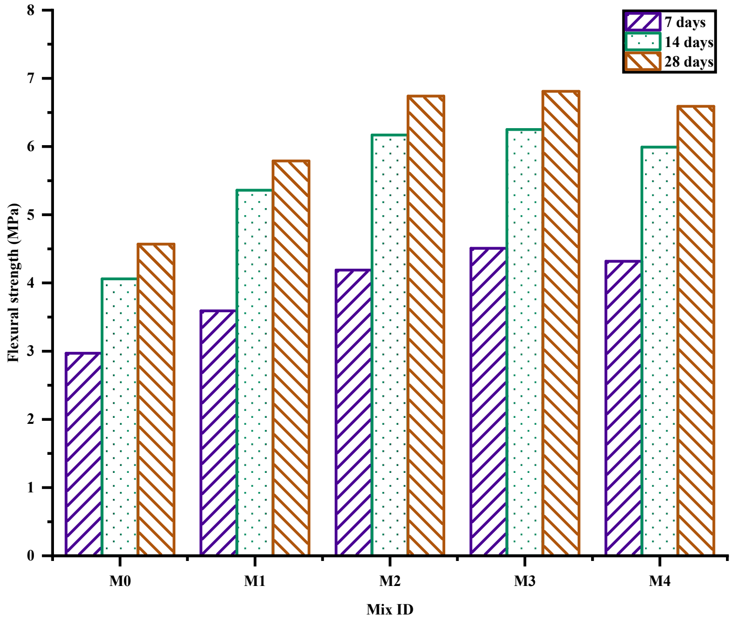


**Figure 4.** Flexural strength of fine-grained cementitious composites with different percentages of fibers for five different mixes.

#### 3.2.4. Impact Resistance

The impact resistance of BFRFGC was studied by performing a drop weight impact test. The impact energy absorbed by fine-grained cementitious composites with basalt fiber addition is shown graphically in Figure 5. By adding basalt fiber to the concrete, energy absorption was increased by 1, 2.48, 3.32 and 3.71 times on 0.2%, 0.4%, 0.5% and 1%. The graph shows an increase in the addition of basalt fiber to the cementitious composites shows excellent resistance to impact load. The fibers hold the matrix and delay the formation of initial and final cracks formed by absorbing the energy.

Higher impact resistance was absorbed with days of curing and for 1% fine-grained cementitious composites. Impact test on fiber-reinforced concrete by Nia et al. [39] found it more resistant to the initiation of cracks and the final fracture under the impact, which led to greater energy absorption capacity in FRC and similarly in BFRFGC, the initiation of cracks got delayed and held higher energy absorption characteristics with increased fiber addition. The resistance depends on the length, tensile strength and other fiber properties.

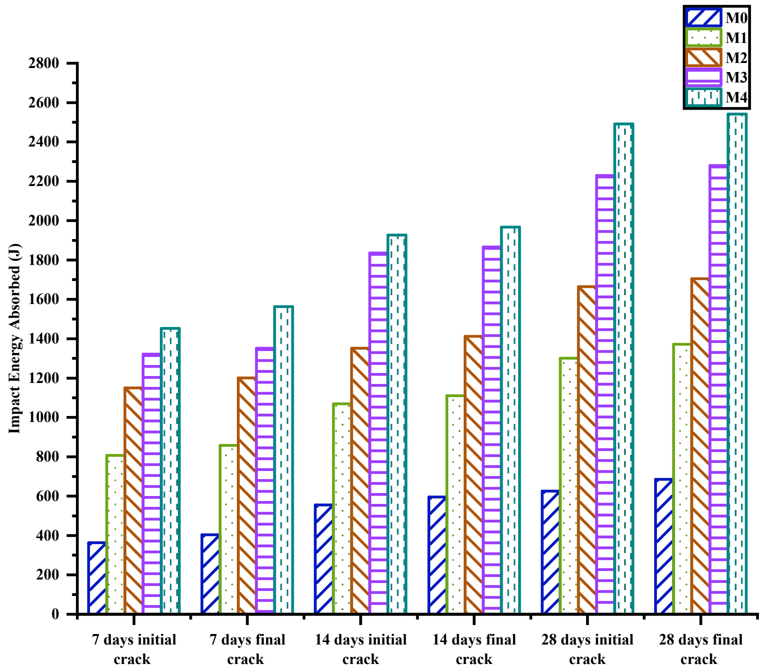


**Figure 5.** Energy absorption of basalt fiber reinforced fine-grained cementitious composites for five different mixes.

### 3.2.5. Dynamic Modulus of Elasticity

The dynamic modulus of elasticity is higher with days of curing, which is visible in Figure 6. The dynamic modulus is higher for a 0.4% addition of basalt fiber in fine-grained cementitious composites, and only a slight variation in results for higher percentage addition of basalt fiber.

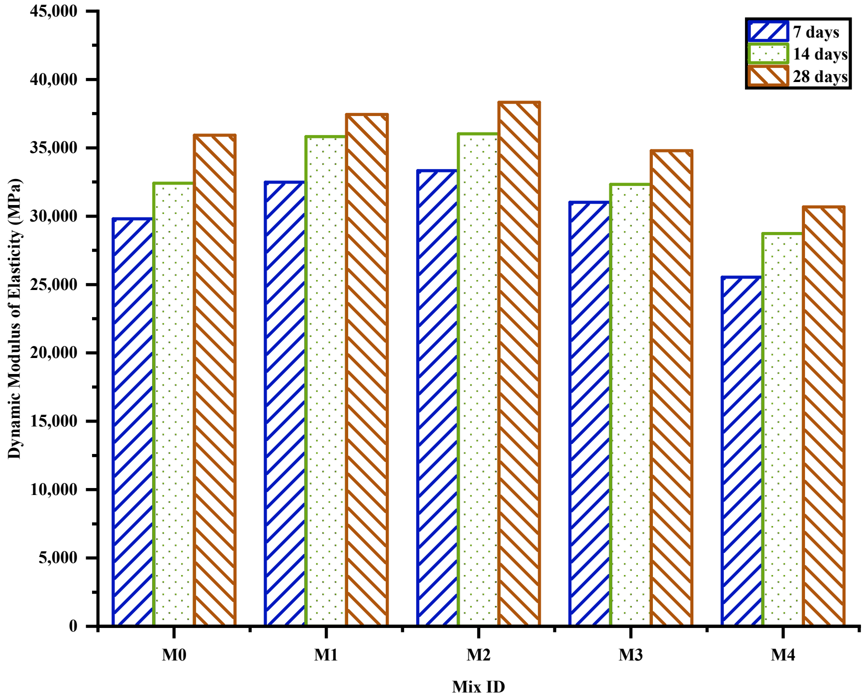


**Figure 6.** Dynamic modulus of elasticity of fine-grained cementitious composites for five different mixes.

From the comparative graph, as shown in Figure 7, there is a difference between static and dynamic modulus of elasticity. The static moduli were less when compared to dynamic moduli. The percentage of fiber added affects the dynamic modulus [40] is found in basalt fiber-reinforced concrete and is similar to BFRFGC. The dynamic modulus of elasticity differs from the static modulus of elasticity as static is obtained from stress-strain data, and dynamic modulus is found from wave velocity [41]. Because the overall differences in the dynamic modulus of elasticity were less than 17%, the volume content and type fibers affect the dynamic modulus of elasticity.

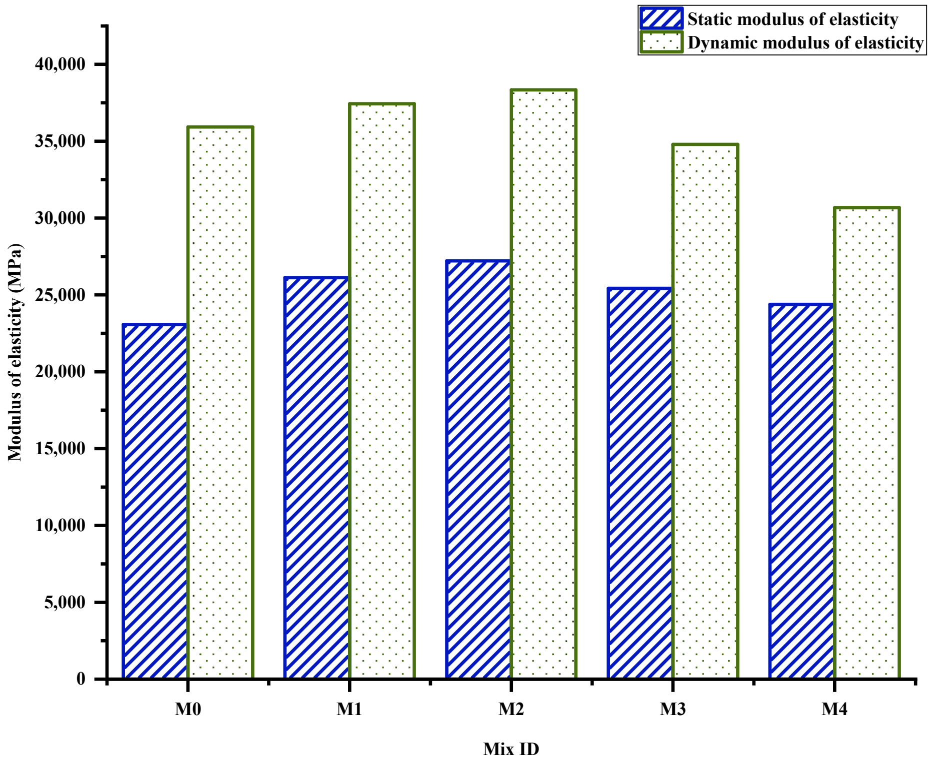


**Figure 7.** Comparison between static and dynamic modulus of elasticity of fine-grained cementitious composites for five different mixes.

### *3.3. Microstructural Properties*

#### 3.3.1. SEM with EDS

The SEM analysis obtained for basalt fiber-reinforced fine-grained cementitious composites is represented in Figure 8. It helps in analyzing the binding nature, porosity and cracks generated. Figure 8 indicates the formation of C-S-H gel, the brightest part is the hydrated cement, and the unhydrated part is dark in color. M0, M3 and M4 mix show more unhydrated cement than M1 and M2. C-S-H is the significant part present in M1 and M2. Ettringite is evenly dispersed like a needle projection in less quantity but higher in the case of M3 as a bundle. M0 samples show higher shrinkage and got reduced upon basalt fiber addition. When mixed with fiber, the concrete sample resists the formation of cracks. From the SEM images obtained, M1 and M2 can give higher strength characteristics due to the higher hydrated cement content and C-S-H formation. Voids are noted in the case of M0 and got reduced upon basalt fiber addition. The ITZ (Interfacial transition zone) in SEM images with basalt fiber shows proper binding between the basalt fiber and the fine-grained cementitious composite matrix.

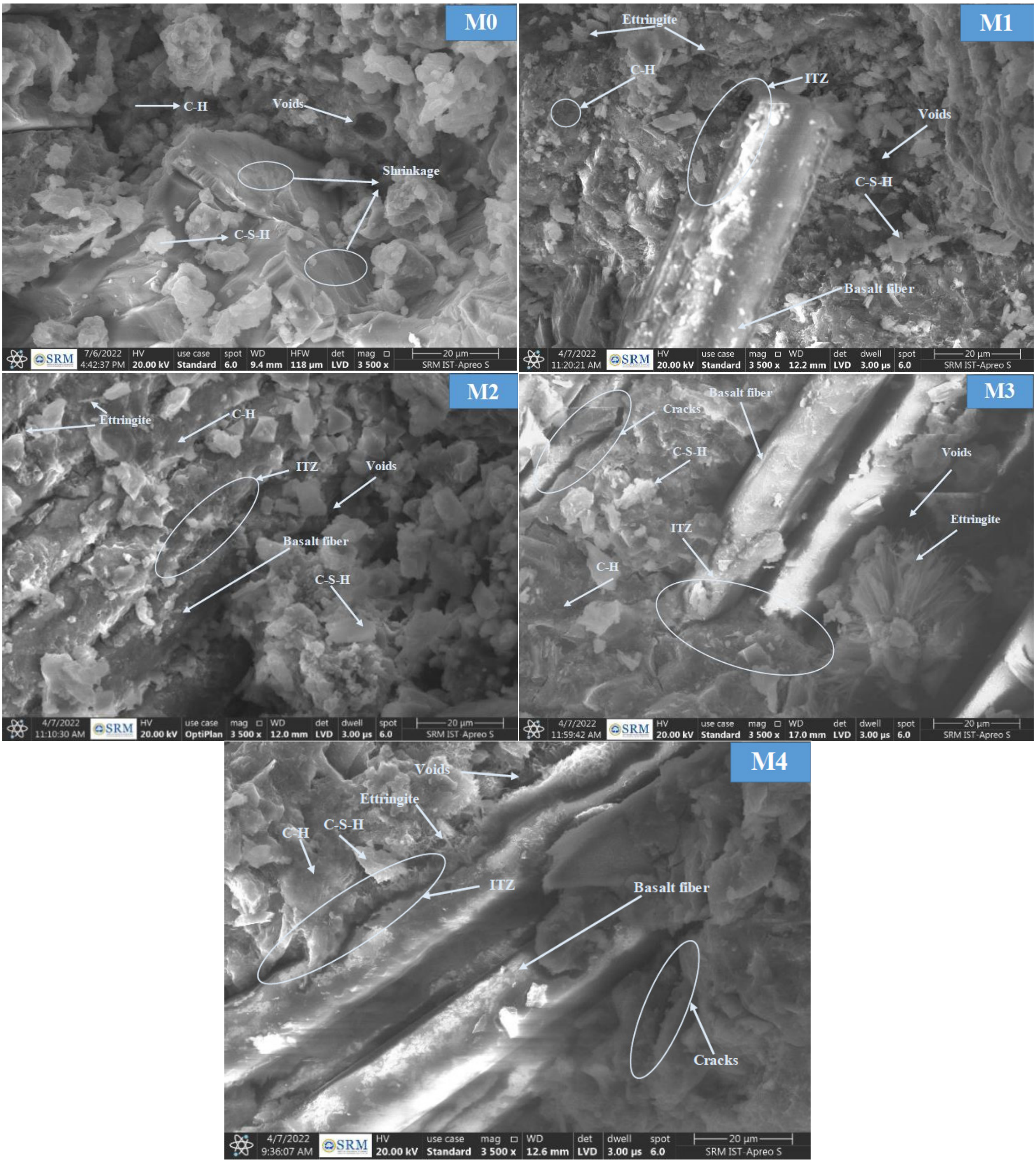


**Figure 8.** SEM Analysis of BFRFGC for five different mixes.

Figure 9 shows the elements present in all the mixes of BFRFGC with different percentages of basalt fiber content. All the mixes contain calcium and silica as a prominent peak confirming the presence of calcium silica hydra-gel. The other elements are carbon, oxygen, iron, sodium, magnesium, alumina, sulfur and potassium. The presence of calcium, alumina, sulfur and oxygen indicates the presence of ettringite. Ettringite is common in all cementitious materials and eliminates upon complete hydration.

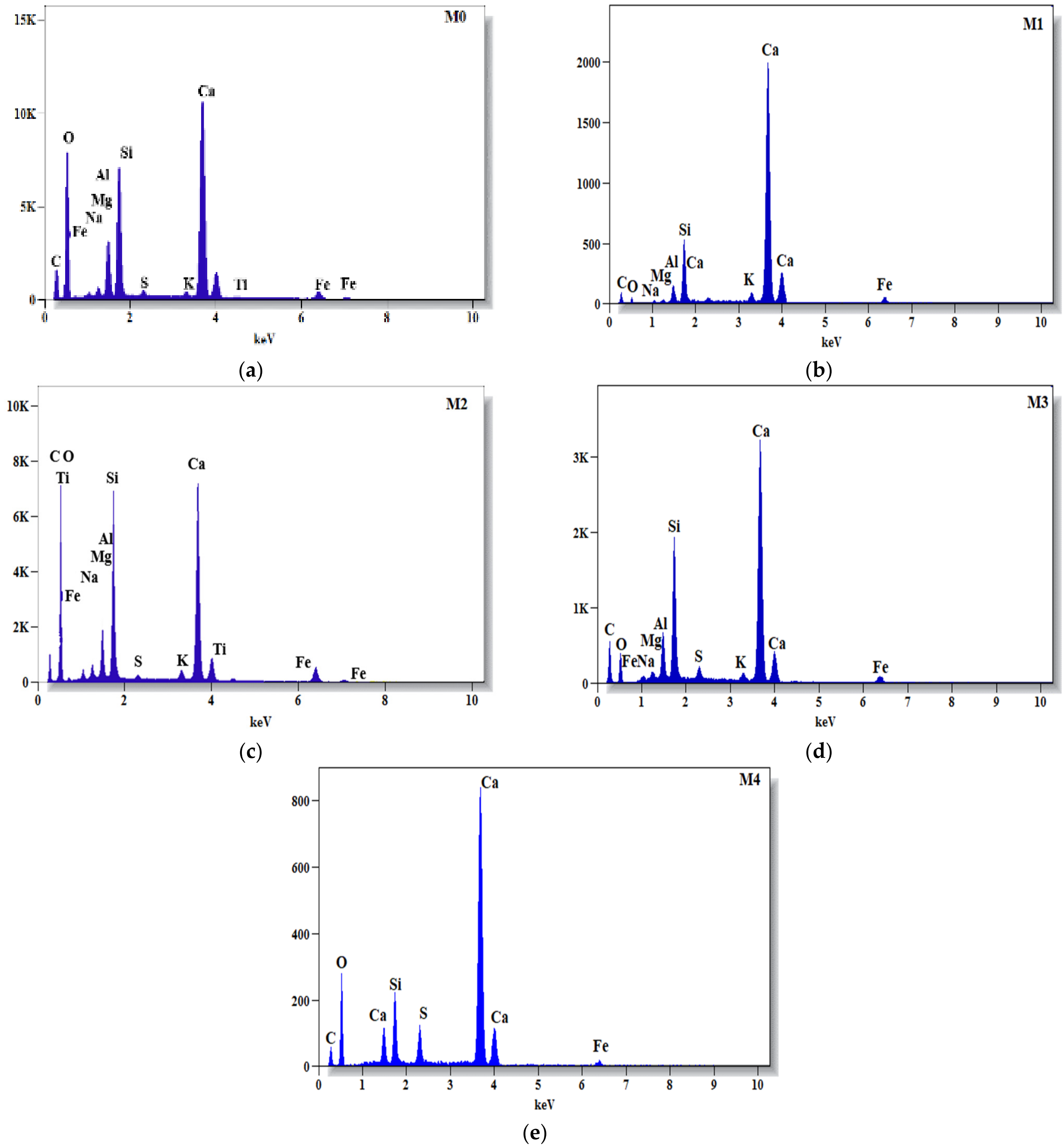


**Figure 9.** EDS spectrum of BFRFGC for five different mixes. (**a**) M0; (**b**) M1; (**c**) M2; (**d**) M3; (**e**) M4.

In addition, EDS helps identify the elements present in mixes and their composition. Basalt fiber and cement systems exhibited good bonding behavior, and the finer threads indicate ettringite formation and are eliminated upon complete hydration [42]. The fibers partly act in the form of micro aggregate and help in enhancing the compression [43]. The weight fraction of calcium and silica present in the optimum mix M2 was higher as the focusing point while collecting EDAX was on basalt fiber, and it is clear from the SEM image obtained for M2 shows a higher number of yarns when compared to others. As only fiber is added in different percentages and it is an inert material no variation in chemical composition between the samples. The microstructure obtained for BFRFGC was similar to the basalt fiber reinforced engineering cementitious composites, and the voids are less in the case of BFRFGC due to the finer materials. Thus, proper hydration leads to C-S-H gel formation, and M2 can perform better than other concrete mixes.

### 3.3.2. FTIR

The FTIR spectra obtained were similar for all the mixes. The peaks obtained in the range of wavenumber 960–975 $cm^{-1}$ indicate the presence of C=C bonds. The wave range of 1400–1425 $cm^{-1}$ [44] indicates the presence of an O-H bond. Si–O stretching bonds are identified near the wavenumber range of 1000 $cm^{-1}$ for all mixes, but the intensity varies. Figure 10, it is clear about the formation of the calcium-silica-hydra gel. The calcium silica hydra-gel formation phase was on all the BFRFGC samples with different percentage fiber addition, but the intensity of the peaks varies. The carbon compound is present in the wave range of 960–975 $cm^{-1}$, and the peak of this range is of lower intensity in the control mix. The same functional group of elements as of basalt fiber reinforced engineering cementitious composites as observed by Punurai et al. [37] is found, but the carbonation depth increased in the case of BFRFGC as peak intensity increased, and these results were contradictory. Thus, BFRFGC has C=C, Si–O and O-H bonds and forms a hydra-gel compound. Adding fibers ameliorates the intensity of the carbon peaks, resulting in increased carbonation.

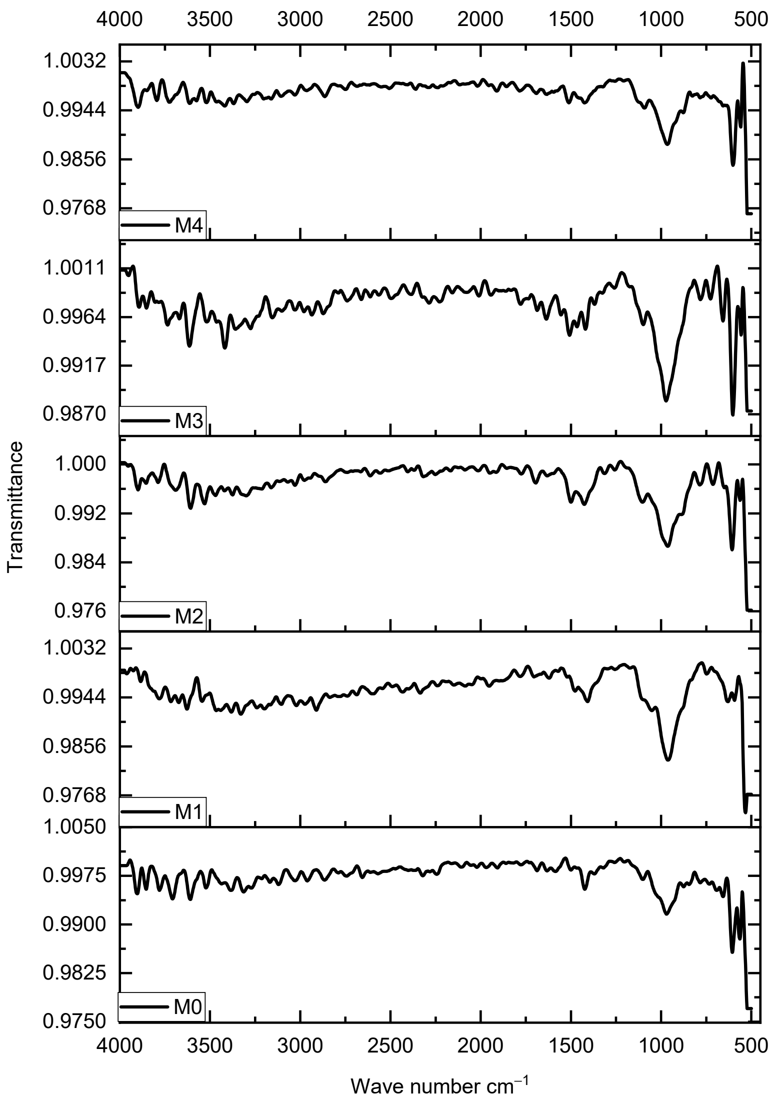


**Figure 10.** FTIR pattern of BFRFGC for five different mixes.

## 4. Conclusions

Fine-grained cementitious composites are used as a matrix material to construct thin and complex structural elements. As the maximum aggregate size is 2.36 mm, it makes proper bonding between the reinforcement and matrix for even smaller mesh sizes by impregnating through the yarns. By adding basalt fiber, a greener material, sustainable fine-grained cementitious composites can be produced. The reason behind saying this as sustainable green concrete material is not only due to the addition of basalt fiber, as no coarse aggregate is added, and the same strength is achieved by using the fine aggregate. It protects mother earth and helps in thin, lightweight and complex structural constructions.

The workability of fine-grained cementitious composites reduces with the addition of basalt fiber by about 19.42 percent. The higher water-cement ratio must be considered to maintain the required workability, or the required percentage of superplasticizer must be added. The compressive strength varies with increased fiber percentage addition. Not much variation in compressive strength was obtained, but upon the addition of basalt fiber and maximum of 22.72% increase was observed. The failure pattern was ductile upon fiber addition. Not much variation in split tensile test and flexural strength and a maximum of 53.58 and 49.05 percent addition of basalt fiber. The nature of fiber-reinforced concrete is that it has good resistance to impact loading. From the results, it is clear that basalt fiber, when reinforced with fine-grained cementitious composites, possesses excellent impact resistance with an increase in fiber percentage addition. It can observe 3.7 times the energy than cementitious composite without fiber upon 1% fiber addition. The more excellent resistance results from fibers holding the matrix and delays the formation of cracks by absorbing more energy. Upon higher percentage addition, a slight reduction in UPV value is obtained, and the same is reflected in the dynamic modulus of BFRFGC as calculated from UPV values. It is clear that fiber gives good binding nature, and not many voids are created due to higher UPV and dynamic modulus of elasticity. The difference in static to dynamic moduli ranged from 1.1 to 1.48. The interfacial transition zone of BFRFGC between basalt fiber and fine-grained cementitious shows proper binding and reduced voids. Carbonation depth increased with higher fiber content.

The comprehensive studies performed by basalt fiber addition in fine-grained cementitious composites with different percentages help to analyze its characteristics. The addition of 0.4% basalt fiber has better performance and is the optimum percentage of fiber addition. But the major drawback is that the carbonation depth increased with the increased addition of fiber, and even after adding fiber, small pores are noticed in the SEM image. However, the finer the particle size higher compressive, split and flexural strength is observed than engineering cementitious composites. Thus fine-grained cementitious composites with basalt fiber can be used as a matrix for textile reinforcement as it impregnates easily between the yarns resulting in proper binding between textile and matrix. The basalt fiber-reinforced fine-grained cementitious composites improve the strain hardening of textile-reinforced concrete. It also helps construct thin, lightweight and complex structures with better performance than engineering cementitious composites.

**Author Contributions:** Conceptualization, A.J.S. and B.M.; methodology, A.J.S.; validation; A.J.S. and B.M.; investigation, A.J.S.; writing—original draft preparation, A.J.S.; writing—review and editing, A.J.S. and B.M.; visualization, A.J.S.; supervision, B.M.; project administration, B.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author.

**Acknowledgments:** The authors greatly acknowledge the Analytical services of the SCIF and Department of Physics and Nanotechnology, SRM Institute of Science and Technology, Kattankulathur, for providing the instrumental facilities.

**Conflicts of Interest:** The authors declare no conflict of interest.

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