Durability Aspects of Basalt Fiber Reinforced Concrete

Subjects: Engineering, Civil

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The creation of sustainable composites reinforced with natural fibers has drawn the interest of both industrial and academics. Basalt fiber (BF) stands out as the most intriguing among the natural fibers that may be utilized as reinforcement due to their characteristics. Numerous academics have conducted many tests on the strength, durability, temperature, and microstructure characteristics of concrete reinforced with BF and have found promising results. However, because the information is dispersed, readers find it problematic to assess the advantages of BF reinforced concrete, which limits its applications.

basalt fibers shrinkage thermal properties

1. Introduction

In recent years, there have been increased demands for strength and durability features due to the construction of large-scale infrastructure in several challenging service settings [1][2][3][4]. Contrarily, concrete has several unfavorable characteristics, including brittleness, low impact resistance, and excessive weight. Consequently, there is a need to improve tensile capacity [5][6][7][8]. One of the current hot topics for building materials research is the use of fiber-reinforced technology to boost the durability of concrete [9][10][11]. Traditional concrete is typically strong in compression, but not in tension [12][13][14]. Reinforcement bars are frequently utilized in concrete to compensate for the tensile stresses. In fiber-reinforced concrete, a specific type of concrete, fibers are added to increase the necessary tensile capacity of concrete [15][16].

Since ancient times, many parts of the world have been using fibers in construction materials. The motivation for this effort was to boost the tensile strain of the concrete’s “perceived” delicate properties. In the 20th century, this technique was employed to produce fiber-reinforced concrete, which has grown in popularity and apply in construction sector due to its improved strength. The components of concrete are reinforced with a variety of fibers, including biological and inorganic fibers. The surface of the fibers, length, elastic modulus, and the material from which they are made all perform a role in determining the type of fibers used in concrete to increase tensile strength. Additionally, it is uncertain to what degree these fibers affect the functionality of concrete [17]. Metallic and nonmetallic fibers are the two categories into which fibers are frequently categorized. The capacity of metallic fibers to conduct electricity sets them apart from nonmetallic fibers. Steel fibers make up the majority of metallic fibers, whilst nonmetallic fibers are made of materials like steel fiber [18], propylene [19], carbon [20], jute fiber [21], glass fibers [22] and other similar ones [23]. Concrete brittleness may be reduced by adding fiber, and its strength and durability can be increased [13][24][25][26][27].

BFs are made from genuine basalt ore using hot melting and wire drawing techniques at high temperatures [28]. When the chemical composition is examined, it can be shown that SiO_2 is the primary component and Al_2O_3 is the second, as indicated in **Figure 1**.

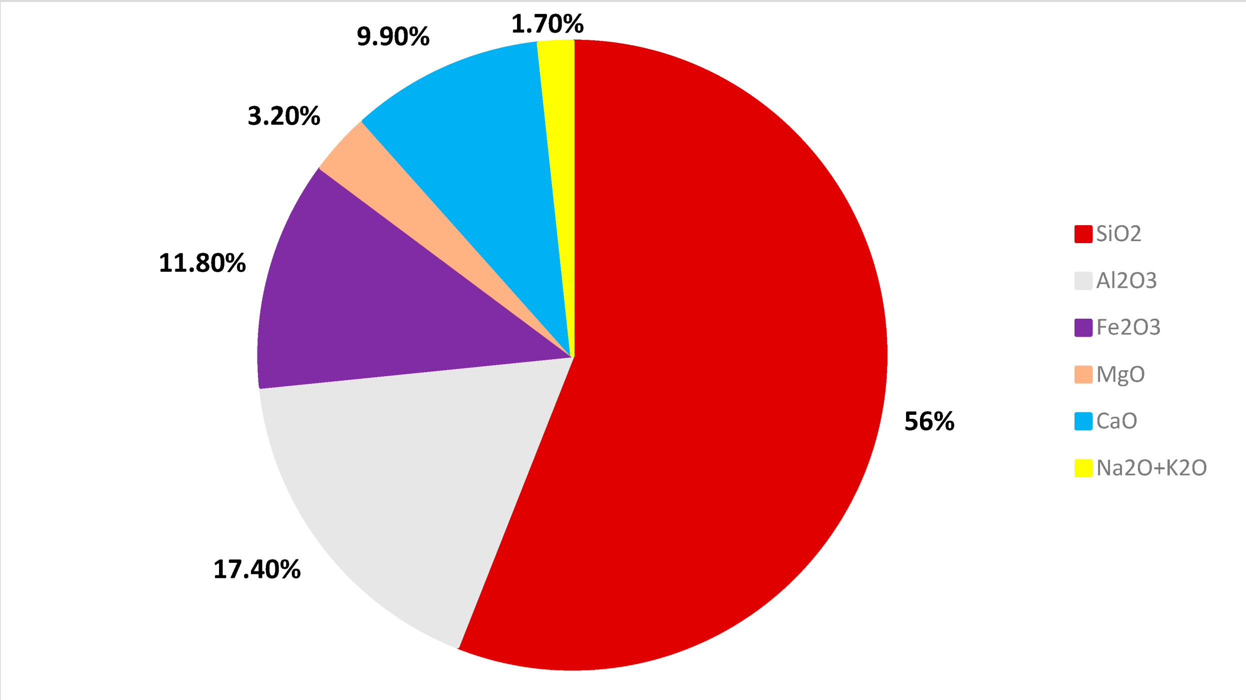


Figure 1. Chemical composition of BF [29].

The kind, quality, and production method of the raw materials, as well as the qualities of the finished product, all influence the base cost of BFs. The chemical and mechanical qualities are influenced by the composition of the raw materials, much like the price. Variations in composition and element concentration result in variations in thermal and chemical stability as well as favorable strength and basic qualities. Generally, the production of this type of fiber is comparable to that of glass fiber (GF), but it uses less energy and does not include any additives, making it less expensive than GF or carbon fiber (CF). Basalt rock from volcanic eruptions is used as the raw material to make BF, which is then molten in a kiln at 1450–1500 °C. The heated substance is then driven through a platinum/rhodium crucible bushing to produce fibers. Constant spinning is a technique that may provide reinforcing material in the form of continuous fibers or chopped fibers for use in the manufacture of textiles and has a lot of potential users in composite materials. Along with being simple to handle using standard procedures, it also has significant cost advantages [30]. The advantages of BF used in concrete are shown in **Figure 2**.

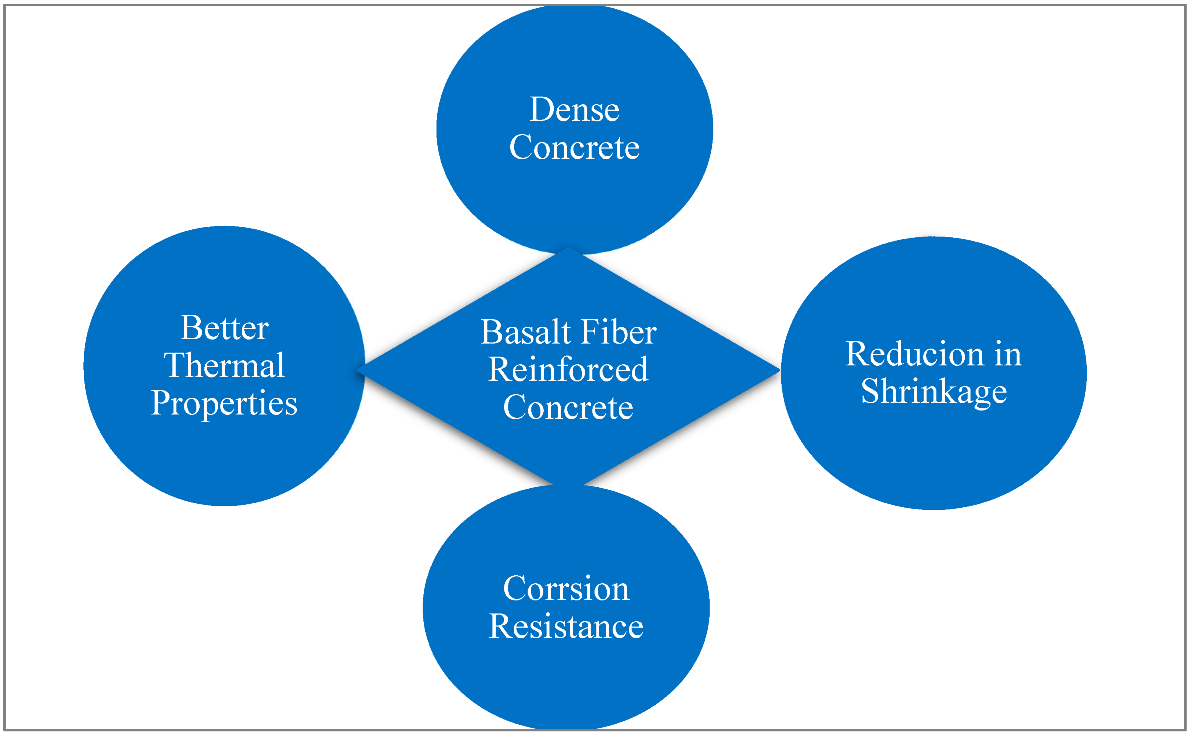


Figure 2. Benefits of BF.

A new class of inorganic fiber called BF has several benefits, including strength, stability, insulation, corrosion resistance, simple production, cheap cost, and high compatibility [31]. The insulating capabilities and anti-corrosion of BF make it further appropriate for extreme-speed rail and road engineering than those of metal fiber. BF is an eco-friendly material as well [32].

2. Apparent Density

Figure 3 displays each mixture's apparent density. The findings demonstrate a declining tendency in perceived density with boosting BF percentages. The density of concrete reduces with increasing BF percentage even though BF has a slightly greater density than concrete. The following is a summary of the causes: First, BF may result in a weak matrix across the fiber and reduce compatibility. Second, the BF network configuration produced prevents cement paste from separation and movement, making it more difficult to remove voids and bubbles with shaking. Third, BF needs an additional plasticizer to sustain the target slump, and the plasticizer can cause more air cavities because it includes the elements of the air-entrain. All of these factors cause more air spaces to exist in concrete, and this fact plays a significant role in determining the material's apparent density [25].

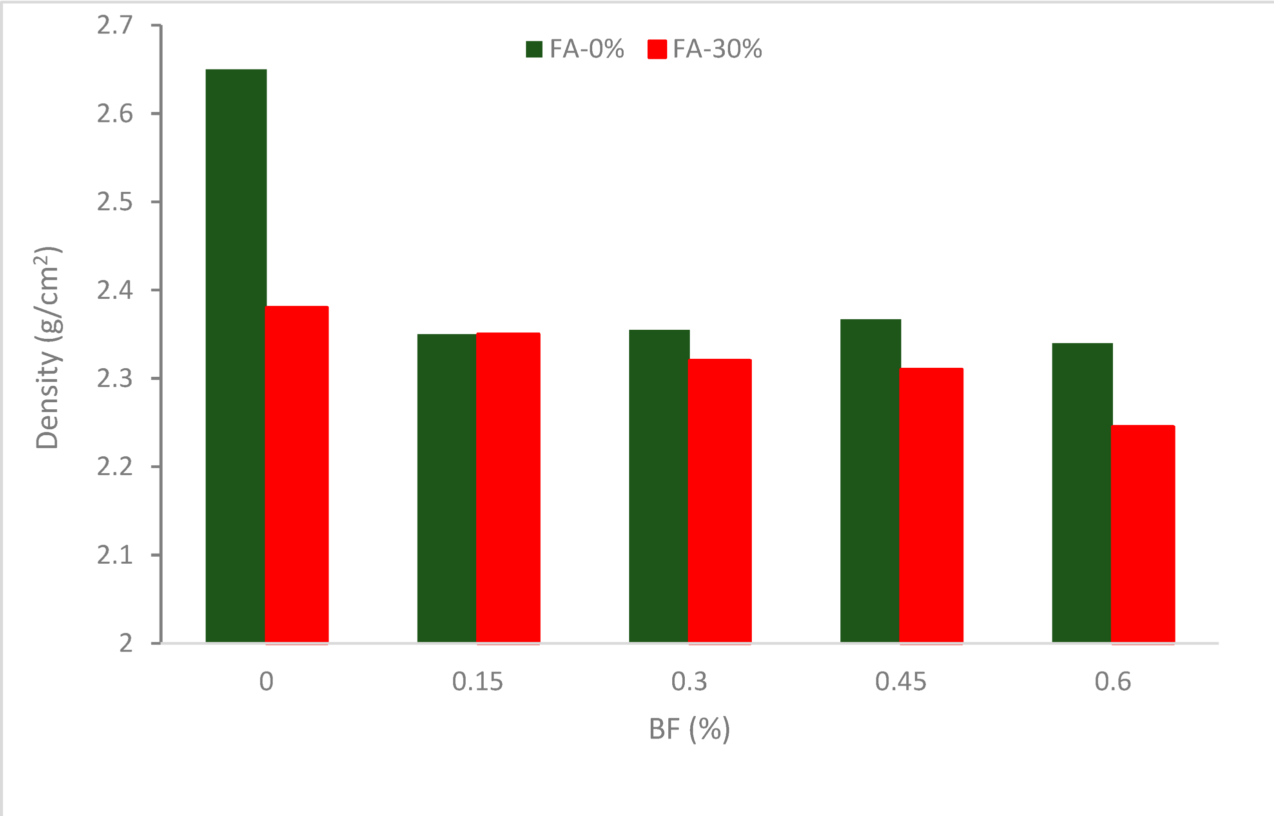


Figure 3. Density of basalt fiber (BF) reinforced concrete [33].

Additionally, BF creates a network structure that boosts the matrix's internal binding force and prevents cement paste from flowing or segregating. Therefore, the presence of BF causes concrete's flowability to decrease [34], making it difficult to fill up gaps in concrete using vibration. Due to this, the interior sponginess rises and the compatibility falls, which lowers the apparent density. Furthermore, with the same fiber content, the density of a combination containing secondary cementitious materials (SCM) is constantly smaller than it would be without them. This may be attributable to cement's greater specific gravity than fly ashes. A lower fresh concrete density and porous concrete are the results of higher fiber dosages (4.0%), which makes the compaction activity additional challenging. Concrete gains density by around 15% when 1.5 percent of its volume is added to fibers [35]. Research revealed that the permeability coefficient of concrete is decreased by the addition of BF. The permeability coefficient reduces by 86.3, 85.5, and 84.3 percent when the volume content of BF is 0.1, 0.2, and 0.3 percent, respectively [36].

It can be concluded that the density of concrete decreased with the addition of BF. However, with the substitution of cementitious materials such as fly ash, a slightly decreased in density was observed up to 0.45% addition of BF, further addition of BF (0.6%) results in considerably decreased density.

3. Permeability

3.1. Sorptivity

Hazardous chemicals like chloride and sulphate ions may penetrate construction materials via water infiltration. Diffusion and capillary action are the two major methods of transporting chloride and sulphate ions through the material, although transformation by itself is a very sluggish procedure. Consequently, particularly close to the unsaturated concrete surface, capillary action could be the primary transport pathway. Understanding how concrete transports moisture is crucial for determining its service life and enhancing its value as a construction material [37].

The total water absorption over 6 h and 8 days, respectively, was used to calculate the initial and secondary sorptivity. **Figure 4** displays the sorptivity coefficients of concrete. A similar pattern can be seen in both the primary and secondary sorptivity of all concrete mixtures. BF5 (0.05%) has the lowest sorptivity, while BF20 (0.20%) has the maximum. The initial and secondary sorptivity of the specimen with 0.05 percent t o0.15 percent BF was lowered, falling by 2.75 to 20.97 percent, and 5.39 to 16.78 percent, respectively, associated with the control concrete. The initial and secondary sorptivity are boosted by 19.35 and 20.52 percent, respectively, by a BF concentration of 0.2 percent. It is determined that lowering water absorption and sorptivity depends significantly on the presence of suitable BF. When steel slag is replaced with zigzag-shaped fibers, the porosity of the concrete is reduced, which reduces capillary action in steel slag concrete and improves the resistance of the movement of water through it.

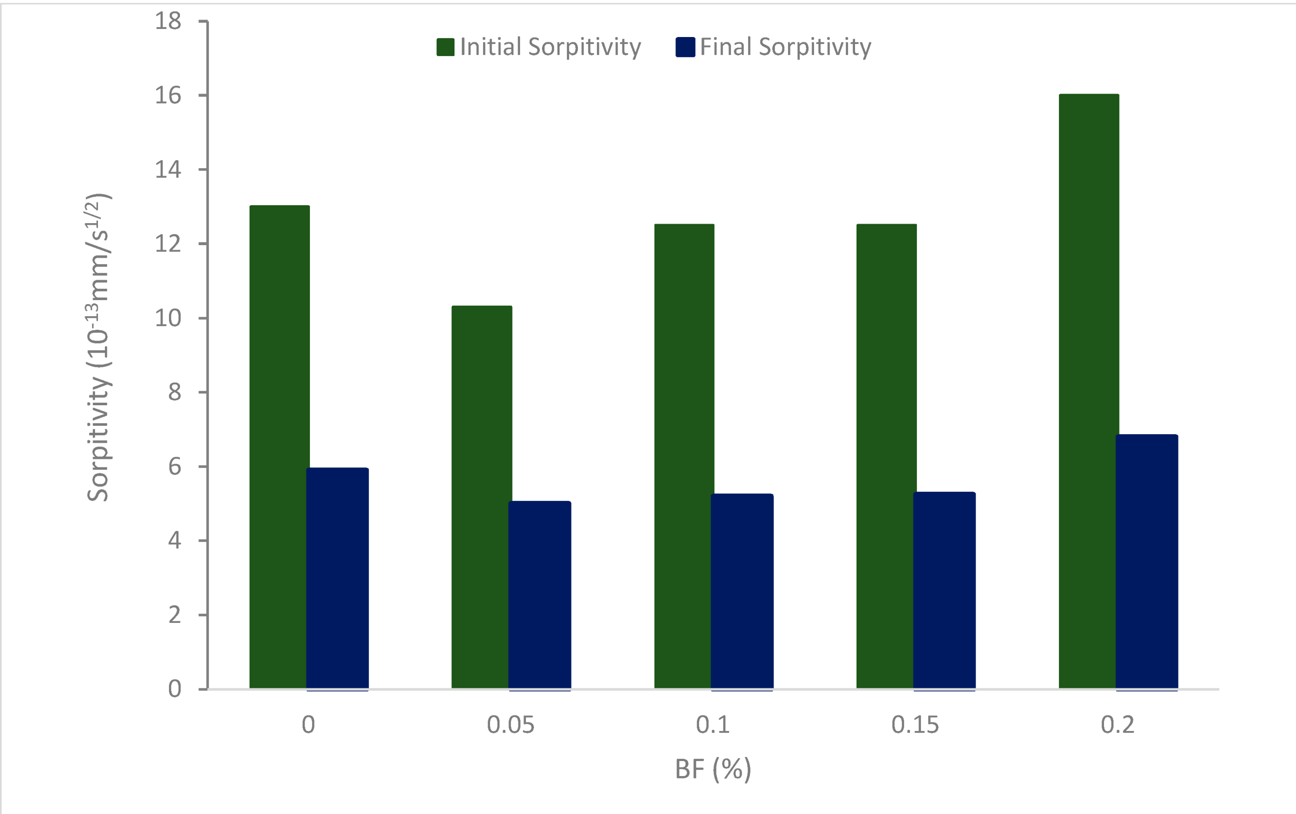


Figure 4. Sorpitivity of BF reinforced concrete [38].

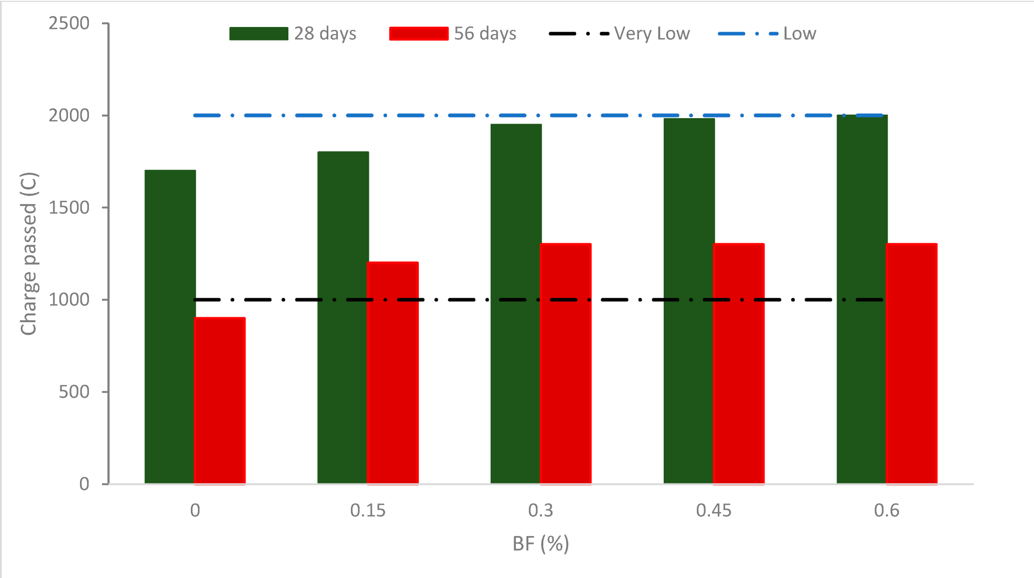
3.2. Water Absorption (WA)

Concrete must have both compressive strength and long-term durability. The density of concrete has an impact on its long-lasting qualities. Compact (dense) concrete has more load carrying capacity and has fewer voids and pores. Concrete with fewer voids is less porous to liquid chemicals and water. As a result, this kind of concrete will last longer, and less WA or other harmful chemicals will penetrate.

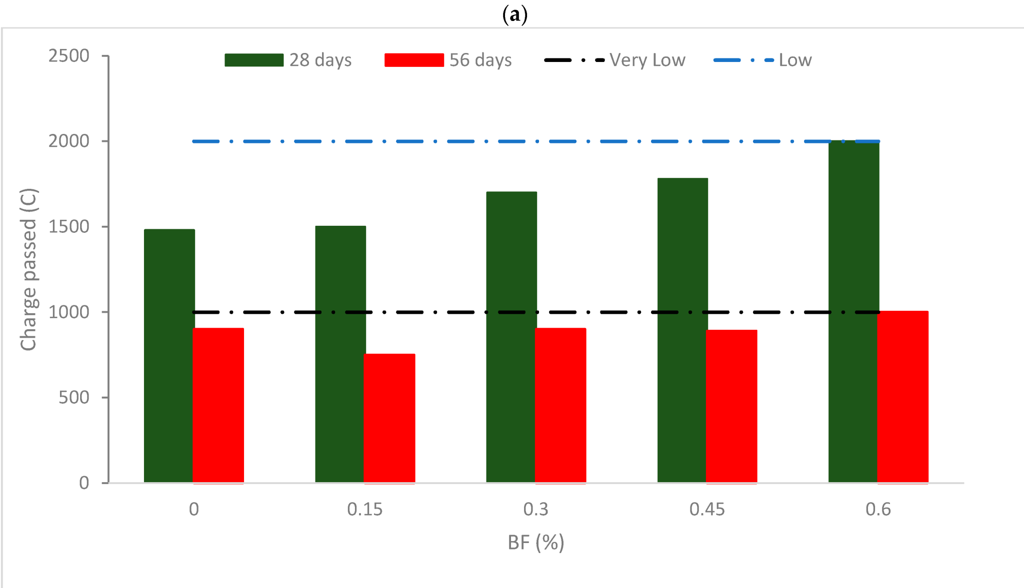
The statistics on water absorption show that increasing the fiber content somewhat improves the WA as associated to reference SCC. Nevertheless, the water absorption values of all fiber-reinforced SCC were within 2% of one another. Concrete has less water penetration because of a more compact pore structure as a consequence of the GF's tight bond with cement particles. The endurance of the concrete is increased by the introduction of GF [39]. It was known that the least amount of WA was attained at 2.0% steel fiber [40]. Regular concrete has a lower MOE than fiber concrete. Fibers would improve the tensile strain properties of concrete, reducing the development and spread of early fractures [41]. Therefore, BF addition decreased water absorption penetration due to crack prevention. Furthermore, the substitution of secondary cementitious materials such as silica fume considerably due to combined pozzolanic and micro filling effects.

3.3. Rapid Chloride Ions Penetrability

Figure 5 displays the outcomes of the charge after it was run through all combinations that were aged between 28 and 56 days. The outcomes show that adding BF raises the charge of the concrete. For the same series, a greater charge is obtained in the blends with greater BF (0.60 percent). According to a study [34], the inclusion of BFs in cementitious mixtures leads to a reduction in electrical resistivity, making electrical resistivity more apparent as fiber volume increases. Results from the electrical resistivity test have been altered by the percentages and composition of pores and the chemical composition of the pore mixture. Therefore, specimens containing 15% silica fume do not necessarily have higher performance or durability because of their higher specific electrical resistivity.



(**a**)



(**b**)

Figure 5. Charge pass of BF reinforced concrete (**a**) 0% fly ash and (**b**) 30% fly ash [33].

4. Shrinkage

Shrinkage is seen in the early hours after casting, however, it may be prevented by improving the blend mix and proper curing. Carbon dioxide and solidified cement paste combine to induce carbonation shrinkage [42].

According to the experimental findings, depending on the fiber content, using BFs greatly reduced concrete shrinkage and increased efficiency. **Figure 6** depicts the shrinkage reduction impact of BF after 7 days of concrete curing. The findings demonstrated that concrete shrinkage dramatically reduced as the fiber concentration rose. The shrinkage reduction efficiency in concrete employing 0.5 percent fiber compared to the control achieved 40% in the first week. The shrinkage reduction impact of concrete is quite strong, reaching 84 percent in comparison to the control when employing fibers up to 1.0 percent. The effectiveness of concrete shrinkage reduction reached 98 percent when the fiber content was raised to 1.75 percent.

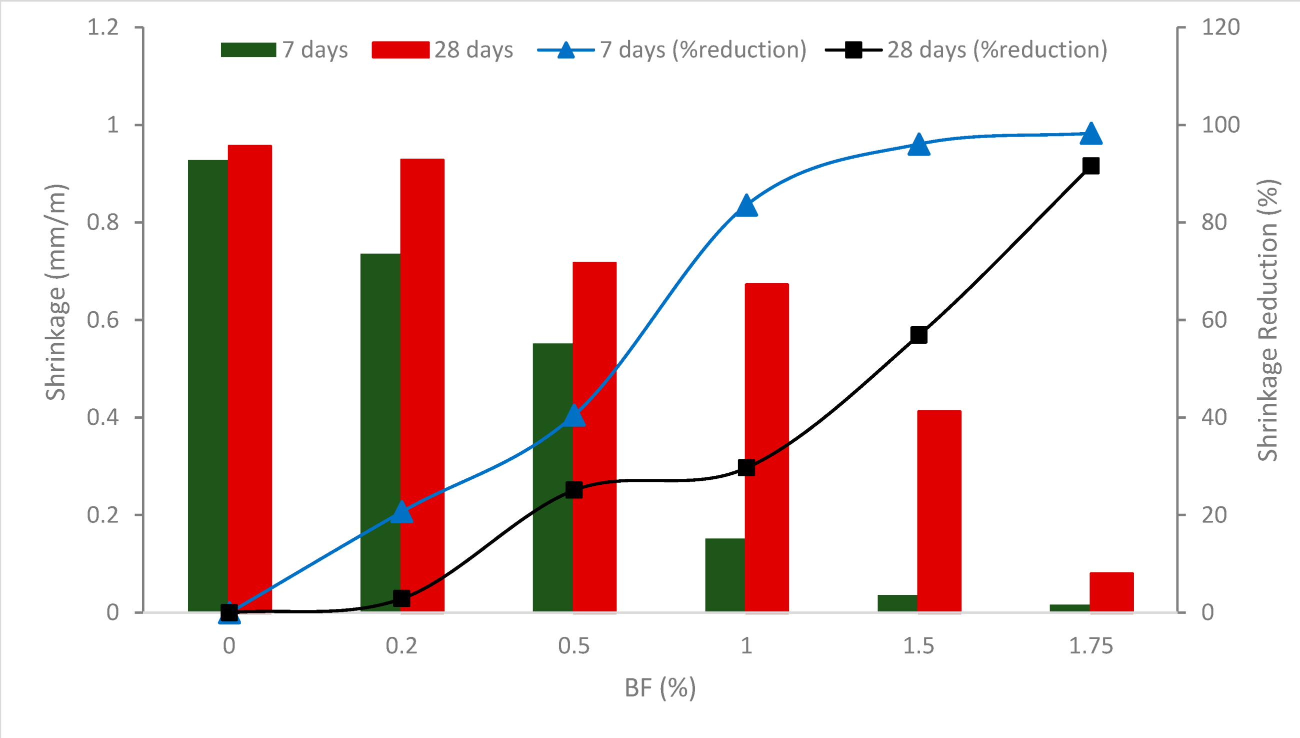


Figure 6. Shrinkage of BF reinforced concrete [43].

The concrete shrinks by 0.716 mm/m, which is 25% less than the control sample, when the fiber content is utilized at 0.5 percent. The shrinkage will be reduced by 56.9% and 91.6 percent, respectively, associated with the reference, with the fiber content raised to 1.5 and 1.75 percent. When fibers are added to concrete mixtures, shrinkage in concrete is improved. A reduction in the amount of moisture in the concrete and shrinkage of the concrete will occur along with the hydration of the cement. However, the fiber will play a role as a bridge to transport stress throughout the concrete in the presence of micro-sized BF, considerably decreasing shrinkage. A study also reported that carbon nanotubes delay the propagation of micro-cracks and strengthen the interfacial transition zone [44]. However, the shrinkage reduction impact for concrete does not significantly improve when the fiber percentage is increased from 1.5 to 1.75 percent. When the fibers have a propensity to group to create yarn balls, this may be explained by raising the fiber content utilized to a certain value. As a result, the fiber distribution in concrete will be less even, which will lessen the impact of lowering fiber shrinkage [43]. In comparison to plain concrete specimens, all fiber-reinforced concrete samples with blended fibers showed considerably reduced shrinkage values up to 180 days. Fibers stop the development of microcracks on the concrete's surface, which stops the movement of dangerous components in samples. As a consequence, the detrimental effects of shrinkage are minimized and the fracture density and size are decreased [45].

5. Electric Resistivity

The possibility of electrical charge transport through the composite is made clear by the material feature known as specific electrical resistivity. It often relies on the chemical makeup of the cementitious material, the kind and form of the pores, and the composition of the pore solution [46].

Figure 7 demonstrates that BF results in a decline in the penetrability of chloride ions (>12 kW/cm) for all combinations (w/c = 0.35) and a decline in the penetrability of chloride ions up to a 0.30% percent fiber for specimens with w/c = 0.45. Research also found that the presence of water and steel fiber clusters increased conductive pathways and lowered electrical resistance [47]. Due to the larger porosity gained due to a higher w/c ratio and fibers percentage, rising cavities through blending, and possible effects from the higher fiber volume, 0.45 and 0.50 percent. BF did not offer higher results for w/c = 0.45. Although there was no balling of the fibers, increased fiber volumes influence how the fibers are distributed, which reduces their effectiveness. According to research, BF increases water absorption and decreases electrical resistivity in cementitious materials, with the negative impact being more pronounced the greater the volume level of BF [34].

Figure 7. Resistivity of BF reinforced concrete [48].

6. Freezing and Thawing

The compressive capacity is intimately connected with its porosity, the smaller the perviousness, the denser the composition, the greater the compressive capacity and the critical pore size and pore size distribution are directly correlated with the permeability and durability of concrete.

Figure 8 implies that the initial porosity of the concrete will decrease with the addition of BF. It was discovered that the 0.02 percent BF group had the lowest original porosity, and the 0.03 percent BF group had a higher original porosity than the 0.02 percent BF and 0.02 percent BF groups. However, some studies claimed that promising results were achieved at 0.6% [49][50]. This was due to extreme fiber integration and significant amounts of disordered fiber clusters, which increased the likelihood of flaws. Each group's concrete started to become more porous as the single-side salt–freezing–drying–wetting cycle developed.

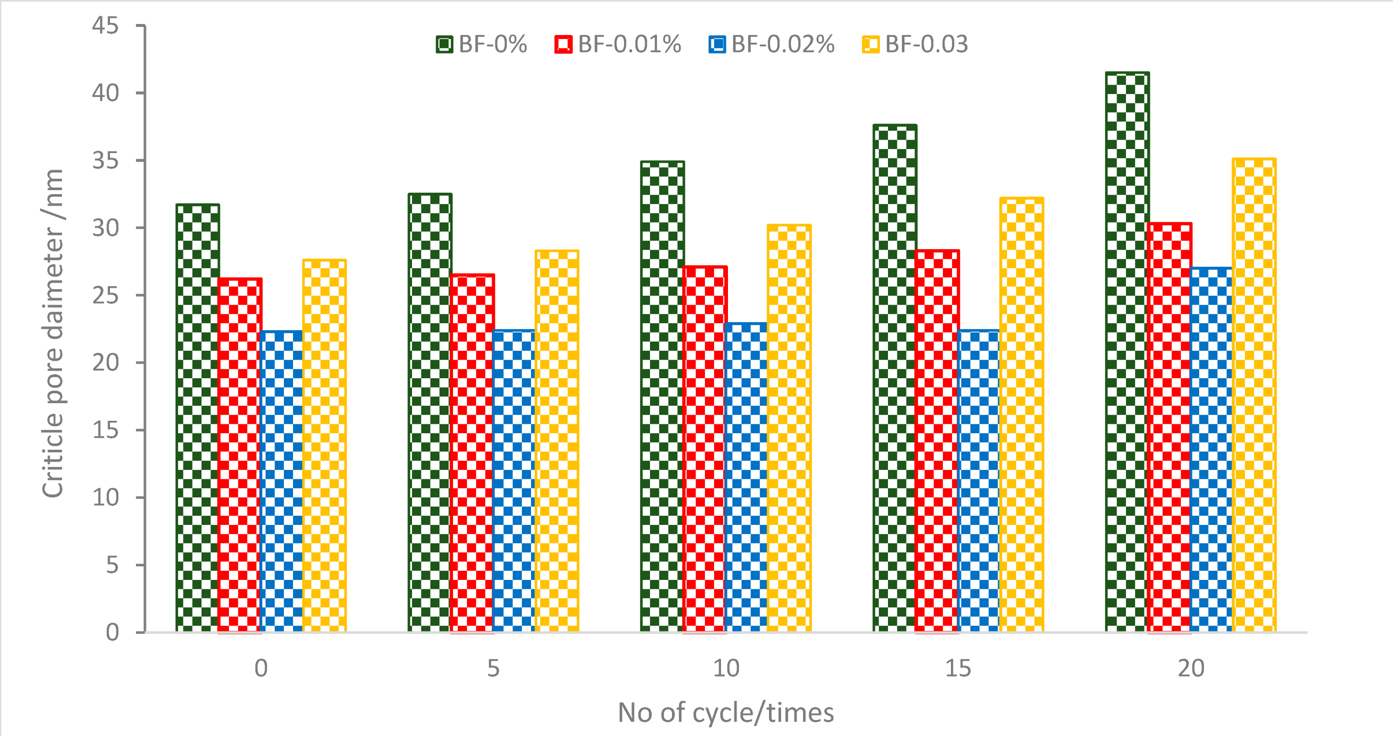


Figure 8. Porosity of BF reinforced concrete at different no. of cycle [73].

The expansion tension brought on by sulphate crystallization and the tensile stress brought on by freezing pressure and capillary osmotic pressure enhanced the perviousness [51]. After 20 cycles, the perviousness with additions of 0, 0.01, 0.02, and 0.03 percent of BF rose by 9.8, 4.1, 4.7, and 7.5%, respectively. As can be observed, the inclusion of BF prevents the single-side salt–freezing–drying–wetting cycle from increasing perviousness. The addition of BF enhances the compactness and increases the depth and content of concrete's resistance to sulphate ion destruction. BF resilience and crack resistance lessen the concentration of stress and the resulting damage. According to research, adding fiber to concrete may boost its resistance to freezing and thawing. Additionally, fibers may strengthen the matrix by halting the growth of cracks. Fibers may be added to boost the amount of unharmful openings, which can lower the extension pressure brought on by a freezing case and lower the amount of destruction from freezing–thawing [52].

7. Chloride Content

The total chloride concentration of concrete after the addition of BF is shown in **Figure 9**. The concrete containing 0.05 percent fibers has a greater total chloride ion concentration than normal concrete after curing for more than 3 days. At 14 to 90 days, concrete reinforced with 0.2% BF had a lower total chloride ion level than other specimens. The total chloride ion level decreased by 0.48 to 5.8 percent after 3 days after adding 0.05 and 0.20 percent of BF. The amount of total chloride ions in concrete with 0.05 percent BF rose by 2.7 percent after 90 days. However, by adding 0.1 percent to 0.2 percent of BF, the total chloride ion level was reduced by 0.45 percent to 5 percent.

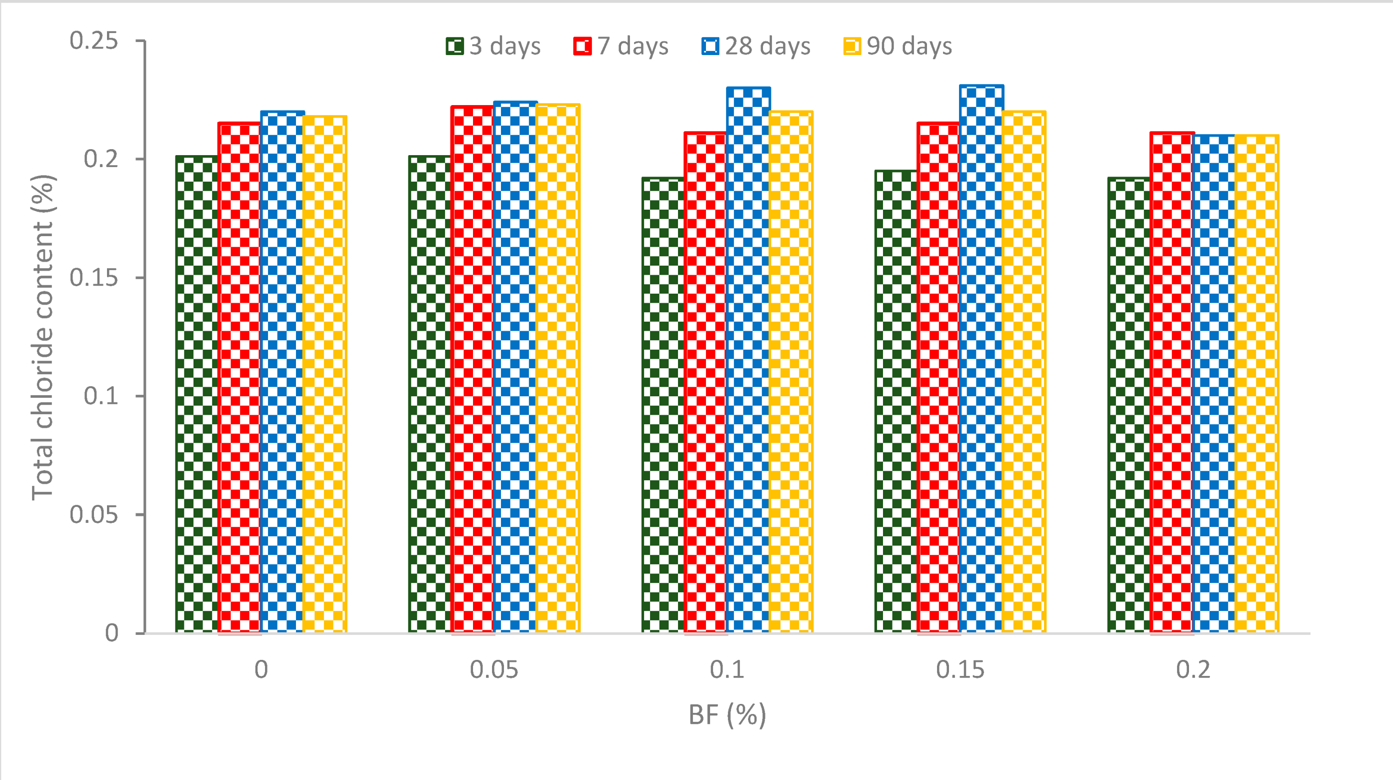


Figure 9. Total chloride content [38].

The pressure differential between the interior and exterior of the aggregate enables the prewetted water to be released when the moisture content of the concrete lowers due to continual hydration. Chloride ions from the inside of the aggregate with the water enter the concrete matrix as the internal curing process is accomplished. The internal curing action is most noticeable, the chloride ion concentration is maximum, and the pore structure is optimum in the 0.05 percent of BF-based concrete. A decreased total chloride ion concentration is the consequence of the internal curing action of concrete being less effective because of the greater BF content.

8. Ultra-Sonic Pulse Velocity

Figure 10 demonstrates that when the BF concentration increased, the pulse velocity decreased. The phenomenon may be attributed to several factors. The first is that BF-containing mixes have some capillaries that migrated into the hardened concrete as the hydration process progressed. It has long been known that the most significant influence on the impact of the transmission velocity of ultrasonic pulses comes from the capillaries in the concrete specimen. The fact that void concrete propagates pulses more quickly than solid matter does provide evidence that it slows the predicted velocity by increasing the pulse's capillary transit [53].

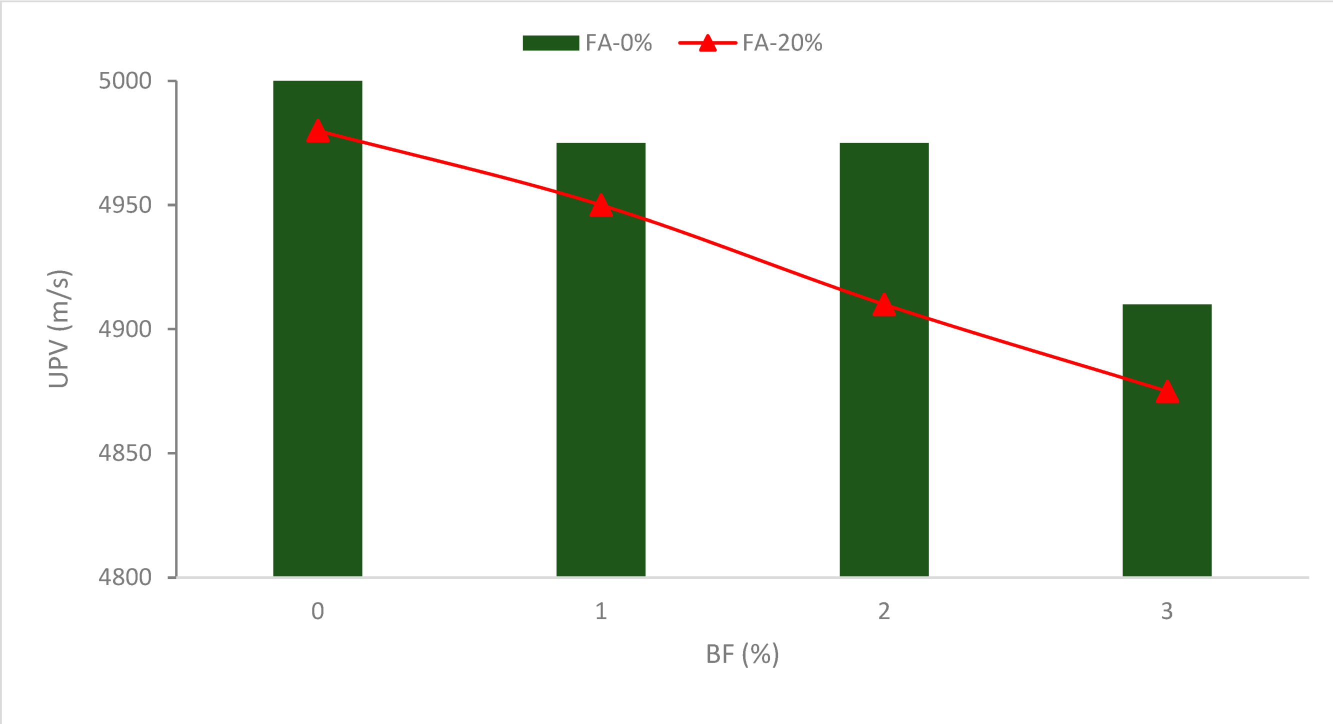


Figure 10. UPV of BF reinforced concrete [53].

9. Alkali Resistance

The challenge of excessive alkalinity from the adjacent material is a major problem when the fiber reinforced concrete components are buried in the concrete using the near-surface mounting technique. As concrete is alkaline, the alkali resistance of BF used in concrete is crucial. The research findings on BF's alkali resistance are contradictory. According to research, BF has strong alkali resistance at both low and high temperatures [54]. Similar research established that BF's alkali resistance is superior to its acid resistance [55].

The SEM images of the fibers after dipping at different mediums are shown in **Figure 11**, **Figure 12** and **Figure 13**. Under alkaline conditions, it was found that both BFs and GFs dramatically dropped volume. As the immersion duration lengthened, reaction products formed on the surfaces of these two fibers and disintegrated, reducing the sound portion or volume of the fibers. These reaction products were thought to be the result of the reaction among the alkali solution and the fibers' SiO_2 content. No such reaction product was seen in the CF, and the projected volume decrease after 28 days of immersion was less than 20%. The strength fluctuated in relation to the duration of immersion. Over 28 days, the capacity of the glass and BF decreased by more than 80%. After the CF had been submerged for 28 days, a strength drop of roughly 13 percent was recorded.

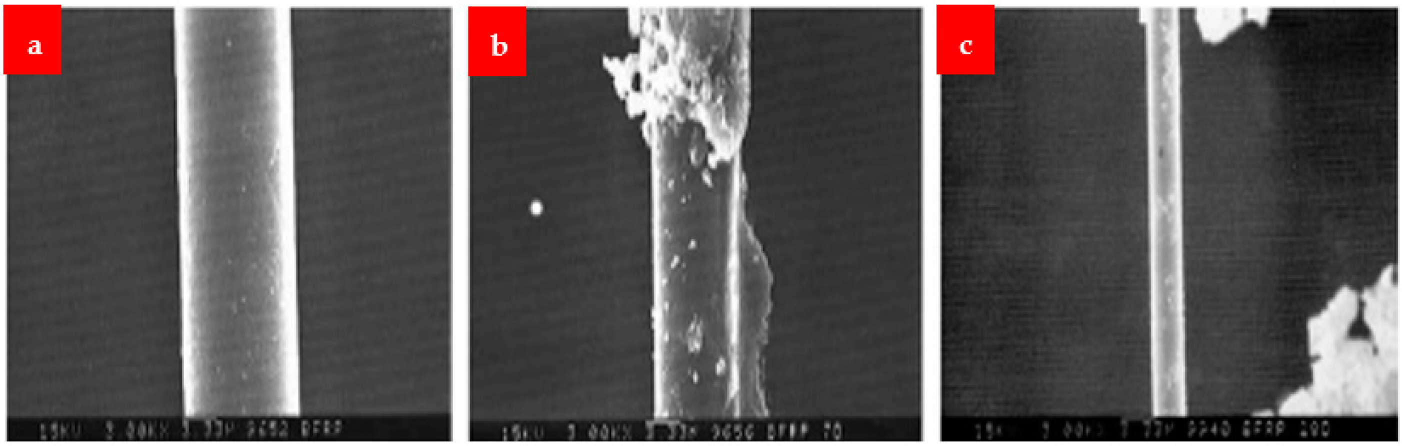


Figure 11. BF (**a**) normal, (**b**) 7 days under NaOH and (**c**) 28 days under NaOH [30].

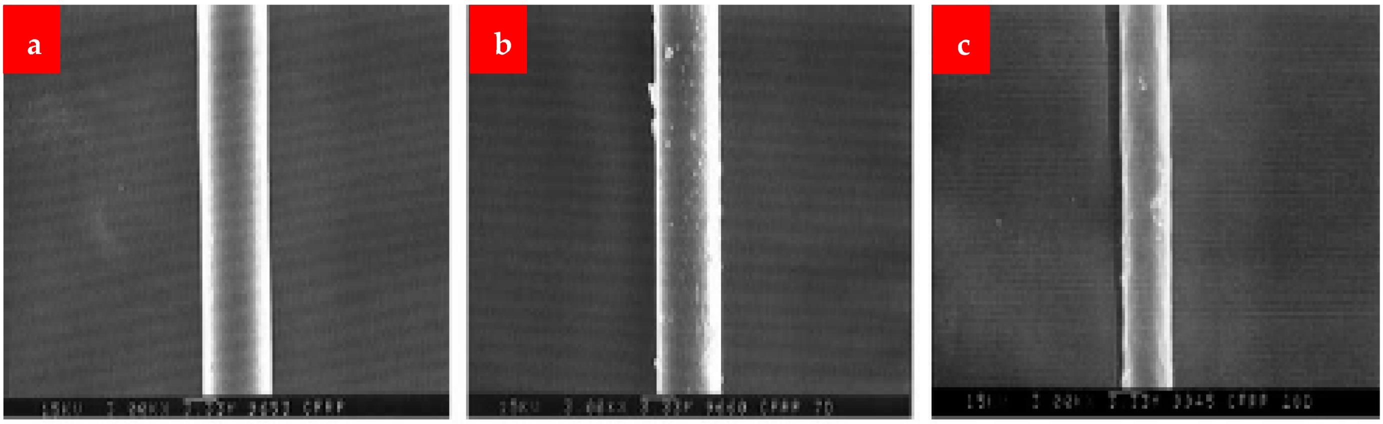


Figure 12. CF (**a**) normal, (**b**) 7 days under NaOH and (**c**) 28 days under NaOH [30].

Figure 13. GF (**a**) normal, (**b**) 7 days under NaOH and (**c**) 28 days under NaOH [30].

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