# Impact of Merging Basalt Fibers with Various Types of Concrete and the Factors Affecting Them: A Review

**Adil M. Jabbar**[(1)(*)] **Lubna S. Dankha**[(2)]

1- Department of Civil Engineering, College of Engineering, Wasit University, Wasit / Iraq
2- Civil Engineering Department, University of Technology, Baghdad / Iraq.
* Corresponding author, Email: adilmahdi@uowasit.edu.iq

# تأثير دمج الألياف البازلتية مع أنواع مختلفة من الخرسانة والعوامل المؤثرة عليها: دراسة مرجعية

م. د. عادل مهدي جبار[(1)] م. لبنى سالم دنخا [(2)]

1 – قسم الهندسة المدنية، كلية الهندسة، جامعة واسط، واسط \ العراق
2 – قسم الهندسة المدنية، الجامعة التكنولوجية، بغداد \ العراق

## Abstract

This paper reviews effecting of blending basalt fibers into concrete on mechanical properties, ductility, and toughness. Based on concrete components, the perfect basalt fiber percentage can differ and is influenced by factors like fiber length, w/c ratio, and age. The beneficial basalt fibers percentage is lower than that of steel fibers. Even with a low concentration of basalt fibers, concrete tensile and flexural strength can be improved more effectively than a higher amount of steel fibers. As the amount of basalt fiber increases, the mix workability decreases. Additionally, the flow ability may drop slightly as the length of the fibers increases. Adding basalt fiber to concrete can minimize drying shrinkage, size, and quantity of voids inside the concrete matrix. A content between (0.3 - 0.5) % is the best ratio to increase the compressive strength, while a higher percentage may reduce it. The tensile, flexural strength, stiffness, and toughness can improve by increasing the fiber content. However, higher content may cause the fibers to lose their forms due to flexibility. Generally, the higher the basalt fiber content, up to 1.5 %, the higher the tensile and flexural strength. Beyond 1.5 %, the increment may be lower. The presence of basalt fiber in beams delays the appearance of cracks and increases the beam's load capacity. The shorter the fiber length, the lower the content and the better the effect. The (6-24) mm is the best length to use in concrete that enhances mechanical properties. The increment in strength for a lower w/c ratio is higher than that for a higher one.

**Keywords: Basalt fiber reinforced concrete, Compressive strength, Tensile strength, Flexural strength, Ductility.**

## المستخلص

يستعرض هذا البحث تأثير مزج ألياف البازلت مع الخرسانة على الخواص الميكانيكية، الليونة، والمتانة. بناءً على المكونات الخرسانية، يمكن أن تختلف النسبة المثالية لألياف البازلت والتي تتأثر بعوامل مثل طول الألياف ونسبة الماء للإسمنت والعمر. تكون نسبة ألياف البازلت المفيدة أقل من نسبة ألياف الفولاذ. حتى مع وجود نسبة قليلة من ألياف البازلت، فإنها يمكن ان تحسن قوة الشد والانثناء للخرسانة بشكل أكثر فعالية من الكمية الأكبر من ألياف الفولاذ. مع زيادة كمية ألياف البازلت، تقل قابلية تشغيل الخليط. بالإضافة إلى ذلك، قد تنخفض قابلية التدفق قليلاً مع زيادة طول الألياف. يمكن أن تؤدي إضافة ألياف البازلت إلى الخرسانة إلى تقليل انكماش الجفاف وحجم وكمية الفراغات داخل نسيج الخرساني. تعتبر النسبة بين (0.3 – 0.5) % هي النسبة الأفضل لزيادة قوة الضغط، بينما النسبة الأعلى قد تقللها. ويمكن تحسين قوة الشد والانحناء والصلابة والمتانة عن طريق زيادة محتوى الألياف. ومع ذلك، قد يؤدي المحتوى العالي إلى فقدان الألياف لأشكالها بسبب مرونتها. بشكل عام، كلما زاد محتوى الألياف البازلتية، حتى 1.5 %، زادت قوة الشد والانثناء. وفيما يتجاوز 1.5 %، قد تكون الزيادة أقل. وجود الألياف البازلتية في العتبات يؤخر ظهور التشققات ويزيد من قدرة تحمل العتبات. كما انه كلما كان طول الألياف أقصر وقل المحتوى كان التأثير أفضل. يعتبر الطول (6–24) ملم هو الطول الأمثل للاستخدام في الخرسانة حيث يعزز الخواص الميكانيكية. الزيادة في مقاومة الخرسانة لنسبة الماء الى الاسمنت القليلة تكون أعلى من نسبة الماء للإسمنت الأعلى.


**الكلمات المفتاحية: الخرسانة المسلحة بألياف البازلت، مقاومة الانضغاط، مقاومة الشد، مقاومة الانحناء، الليونة**

## Introduction

Concrete is an incredibly versatile and reliable substance that is widely applied in different construction projects. Whether building a contemporary skyscraper, constructing a bridge or tunnel, or spreading a footing for a large steel and concrete structure, concrete is the mere choice for engineers and builders. Its strength, durability, and ease of usage make it an ideal selection for extended construction applications. Furthermore, with a wide range of different types and availability of compositions, it is easy to find the perfect concrete mix for any structure (Shaikh, 2013). Concrete is quite strong when it comes to being compressed. However, it is pretty weak when it comes to being in tension. That is because concrete has very little tensile strength, which means it cannot resist forces that try to pull it apart, and it is much more prone to cracking or breaking under tension. Therefore, it is commonly reinforced with steel bars or mesh to compensate for the weak tensile strength. On the other hand, concrete failure is also sudden, which is a dangerous failure. These defects boosted scientists and manufacturers to discover how to develop concrete tensile strength and fracture properties. The efforts led to the production of fiber-reinforced concrete (FRC). Incorporating fibers into a concrete matrix enhances the tensile characteristics to a considerable extent and compression to a lower degree. Also, they change the fracture from brittle to ductile (Hannawi, *et al.*, 2016), (Papakonstantinou, 2020).

Different kinds of fibers were utilized in concrete and afford multiple improvements. Therefore, some categories of fiber-reinforced concrete (FRC) that have various effects on self-regulating characteristics and application attributes were realized (Chiao, 1980). For illustration, counting steel fibers to concrete can boost tensile strength and toughness; however, steel fibers suffer from corrosion when they come in contact with moisture in concrete (Wang, *et al.*, 2019). Glass fiber can improve concrete toughness, but its resistance declines over time when they tough the alkali medium (Shaikh, 2013). Although carbon fibers give hardness and high strength when used in concrete, they are expensive (Alabduljabbar, *et al.*, 2020). Basalt fibers have proper chemical resilience, elevated tensile strength, corrosion resistance, and no environmental consequences (Spool, 2018), (Galen LLC Russia, 2009), (Jamshaid, 2017), (Xianggang, Yahong and Junna, 2020). Therefore, it is significant to inspect their influence on the mechanical characteristics of concrete. Furthermore, adding 45 kg of steel fiber to ordinary concrete of 30 MPa compressive strength can raise the flexural strength by 17%, whereas adding 3 kg of basalt fiber to the same concrete can increase the flexural strength by 29%, as illustrated in Figure 1.

Basalt is a fascinating type of rock created through the rapid cooling of magma or lava from volcanos (Ramadevi, Chithra, and Rajesh, 2017). It can be found in various regions around the world where volcanos are active, and its appearance can vary depending on the source, cooling rate of the rock, and exposure to weathering. It is impressive to think about such fiery substances to transform into something so different and unique (Branston, *et al.*, 2016).

Fine-quality fibers can be extracted from basalt rock through a method that involves heat treatment. This process is similar to glass fiber production but at a much higher temperature. Additionally, basalt rebar can be manufactured today. These basalt products have a thermal coefficient that is very similar to concrete (Branston, *et al.*, 2016).

Numerous investigations explored the influence of blending basalt fibers within concrete on its mechanical properties. Various proportions as volume fractions or cement content percentages, were incorporated into the concrete matrix to demonstrate their effect and decide the most suitable content. Each investigator decided the optimal proportion according to the added volume fraction during the experiments where they differed from one to another (Xianggang, *et al.*, 2018), (Xinzhong, *et al.*, 2017).

## Physical and Chemical Properties of Basalt Fibers

Basalt fibers are a new type of natural fibers that possess remarkable features. Their chemical composition is similar to that of glass fibers, but they have higher strength. That makes them an excellent candidate for utilization in concrete mixtures, as they can boost some mechanical properties. It consists of around 50% silicates to provide higher strength and better resistance to acid, alkali, and salt attacks (Chiao, 1980), (Deák and Czigány, 2009), (Li, *et al.*, 2018), (Hirde and Shelar, 2017), (Xinzhong, Chuanxi and Wei, 2016). The physical properties and chemical composition of basalt fiber are illustrated in Tables 1 and 2, respectively. These features make it a promising material for incorporating into concrete mixes to improve some mechanical properties. One of the forms in which basalt fiber is used is chopped fiber. Chopped basalt fiber is a micro-filament of 16-18 µm diameter and varying lengths (Branston *et al.*, 2016). According to experts, the specific gravity of basalt fiber is about 2.8, with a tensile strength ranging between 2800-4800 MPa. The modulus of elasticity ranges between 80-93 GPa, and it has a strain at failure of (0.0315) mm/mm (Branston, *et al.*, 2016). Basalt fiber density is approximately 2800 kg/m3. Its effects on concrete properties have been discussed in various research studies.

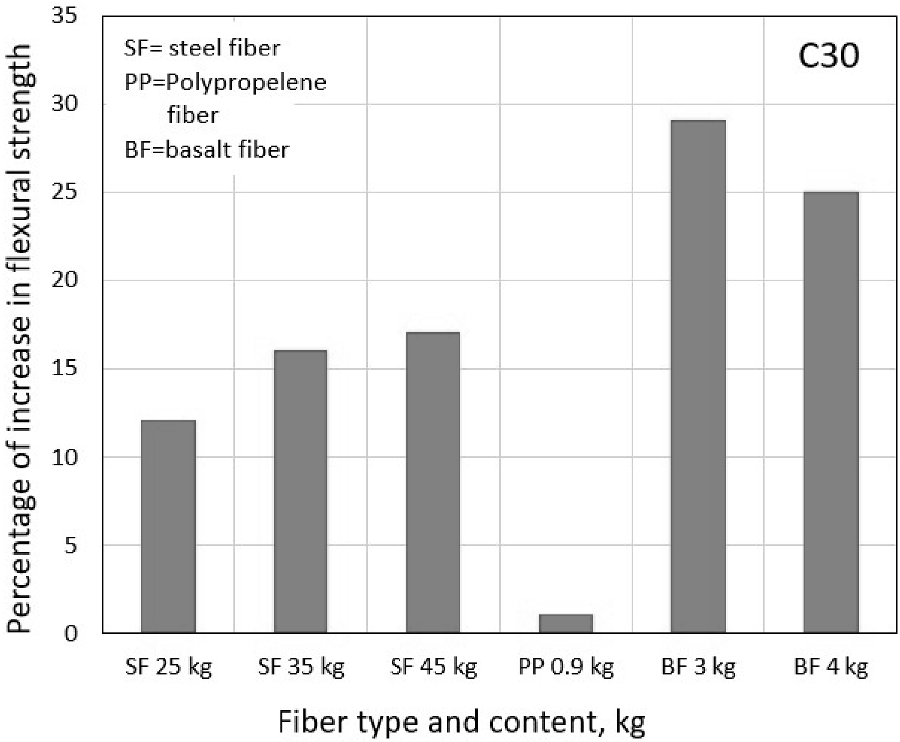


**Figure 1. A comparison between the effect of steel, polypropylene, and basalt fibers on 30 MPa concrete**

**Table 1. Physical Characteristics of Basalt Fibers (Chiao, 1980), (Spool, 2018), (Galen LLC Russia, 2009)**

| Property | Description |
|---|---|
| Appearance | Short filament |
| Color | Medium brown to olive |
| Specific gravity | 2.7 – 2.8 |
| Filament diameter, µm | 6 – 21 |
| Modulus of elasticity, GPa | 80-93 |
| Strain at break | 0.0315 – 0.032 |
| Moisture content,% | 0.4-12 |
| Tensile strength, MPa | 4800 – 2800 |

**Table 2. Chemical Components of Chopped Basalt Fibers (Elshekh, *et al.*, 2014)**

| Component | Percentage |
|---|---|
| $SiO_2$ | 51.65 |
| $AL_2O_3$ | 15.58 |
| $Fe_2O_3$ | 3.97 |
| FeO | 6.15 |
| CaO | 9.35 |
| MgO | 6.10 |
| $K_2O$ | 1.43 |
| $Na_2O$ | 2.05 |
| $TIO_2$ | 1.33 |
| Other oxides | 2.39 |
| Reactivity | Inert, it does not participate in chemical reactions |

## Type of Basalt Fibers Products

Basalt fibers can come in various forms and dimensions, depending on their planned usage. These fibers can be found in chopped form, as filaments, or even as minibars made from fine filaments glued together with epoxy-based resin. Their lengths range from 5 to 100 mm, giving them versatile applications. Also, they manufactured basalt rebar to use in reinforcing the concrete. Figure 2 shows the types of basalt fiber products.

El-Gelani, *et al.*, (2018) investigated the effect of two types of basalt fibers on normal-strength concrete properties. Chopped basalt fiber and pre-soaked in epoxy resin basalt fibers as minibars were added to the mix at a total weight of 1.8 kg/m3. The results showed the equal mixture of both types of fibers awarded the highest increment in 28-day compressive strength by 28 %, whereas adding chopped fiber alone raised compressive strength by only 5.6 %. For flexural strength, both minibar and chopped basalt fiber enhanced the strength by 17% over no fibrous concrete.

Branston, *et al.*, (2016) studied the influence of two types of manufactured basalt fibers. There were flat bundles and minibars. A flat bundle with two various lengths of chopped fibers, 36 mm, and 50 mm, was shaped as a flat bundle. The flat bundles of basalt fiber are about 0.6 mm wide and made of 16 µm diameter filaments. The minibar applied in the study was an epoxy-based resin reinforced with 17 µm diameter basalt filaments. The minibar was 43 mm long and about 0.65 mm in diameter. The minibars were more rigid than the flat bundles. The findings showed that adding basalt fibers raised the first-crack loading of concrete subjected to flexural force but had no significant effect when subjected to impact loading. For flexural loading, the first-crack strength increased with rising fiber content. The strength enhancement was higher upon using longer fibers, 50 mm, than that with a 36 mm flat bundle. A dosage of 12 kg/m3 of 50 mm flat bundle led to a first-crack strength approximately equal to that of concrete with steel fiber of 40 kg/m3. However, fiber content over 12 kg/m3 and 40 kg/m3 of flat bundles and minibars led to mixing issues due to fiber curling and caused difficulty in handling, pouring, and consolidating fresh concrete.

**Chopped basalt fiber** **Minibar basalt fiber** **Basalt fiber rebars**

**Figure 2. Types of Manufactured Basalt Fibers**

## Impact of Basalt Fibers on Ordinary Concrete

Adding basalt fiber to a concrete matrix can reduce drying shrinkage and the size and amount of voids in the concrete microstructure (Jabbar, Hamood, and Mohammed, 2021), (Lam and Hung, 2021). Also, it could enhance toughness and ductility (Jabbar, Mohammed, and Hamood, 2022), (Jabbar, Hamood, and Mohammed, 2021b). Incorporating chopped basalt fiber into the concrete mix can be beneficial when added at a volume range of 0.3-0.5 %. It can increase the strength of concrete, but when used above 0.5 %, it can be detrimental to the strength (Tumadhir and Borhan, 2013), (Dilbas and Çakır, 2020). However, some studies have found that adding 0.1 % is the optimum dose. It's significant to carefully evaluate the amount of chopped basalt fiber added to provide the most useful effects for concrete strength (Vajje and Krishna, 2013). Therefore, the optimal dosage of basalt fibers varies according to the concrete components. Nevertheless, the beneficial proportion of basalt fibers was smaller than that of steel fibers. It was stated that utilizing 12 kg/m3 of chopped basalt fibers can improve the concrete flexural strength at the identical rate of raising flexural strength by adding 40 kg/m3 of steel fibers (Galen and Russia, 2009).

El-Din, *et al.*, (2016) mentioned that incorporating 18 kg/m3 of basalt fiber into a concrete mix improved compressive strength by about 15 % above non-fibrous concrete. Dias and Thaumaturgo (2005) studied the effect of applying 0.5 % and 1% of basalt fiber on normal-strength concrete. The authors found that there was a 26.4 % and 3.9 % reduction in compressive strength upon incorporating 1 % and 0.5 % basalt fiber into the mix, respectively. However, 0.5% basalt fibers raised tensile strength by 8%, while 1.0% lowered it by 12 %. They concluded that using basalt fiber leads to decreasing compressive strength of concrete. They attributed that when the fiber content increased, the probability of balling these fibers together and leaving voids in the matrix was higher, which led to more porosity and reduced strength.

Abdulhadi (2014) studied the impact of chopped basalt fiber on conventional concrete of 36 MPa compressive strength. Five volume fractions were added to an identical concrete mix: 0.0 %, 0.3 %, 0.6 %, 0.9 %, and 1.2 %. The authors found that 0.3 % and 0.6 % raised splitting tensile strength by 2.7 % and 23.1 %, while 0.9 % and 1.2 % decreased it by 11.2 % and 19.7 %, respectively. On the other hand, the compressive strength was decreased for all volume fractions. Revade and Dharane (2015) studied the impact of basalt fibers at three proportions, as a percentage of the weight of cement, on the concrete properties. The results showed increasing compressive strength by 13 %, 12 %, and 10 %, upon adding the fibers at 1.0%, 1.5%, and 2.0 % into the concrete mix. However, the tensile strength was raised by 11 %, 17 %, and 21 % forthe same fibers' percentages. Galishnikova, *et al.*, (2019) surveyed the influence of chopped basalt fibers on the resistance of plastic deformation of lightweight concrete. The results showed that the concrete resistance to the deformation relies on the content of the fiber, its length, and its diameter. Increasing fiber content raised the concrete resistance to deformation. However, adding basalt fiber to the concrete mix can expand toughness and enhance the stiffness of the structural elements. Basalt fiber can readily disseminate in the concrete mixture without segregation, but the fibers often twist because of flexibility. However, the authors showed that the fiberpercentage affects the ductility.

Krassowska and Kosior (2019) investigated the impact of chopped basalt fiber proportion and steel stirrups on the reinforced concrete beams' behavior. Two weights of 50 mm fiber length were used: 2.5 kg/m$^3$ and 5 kg/m$^3$ incorporated into a concrete mix. The authors found that the addition of basalt fibers increased compressive strength by 4.76 % and 0.99 % and tensile strength by 10.06 % and 16.39 %, respectively. Also, fibrous beams were not quickly fractured. The defeat pattern of beams varied according to the stirrups amount and fiber quantity. Multiple oblique cracks with a shallower width were noticed in fiber-reinforced concrete beams. Beams free of fibers failed rapidly due to brittle cracking. Basalt fibers showed the tendency to transform the shear forces in compression after cracking to plain concrete. The beam section remained carrying the load after the initiation of the crack. When the loading reached the ultimate state in basalt fiber reinforced concrete beams, no sign of failure due to concrete crushing occurred. The presence of fibers permitted the growth of multiple diagonal cracks, and then one crack at least widened before shear failure. Ramesh and Eswari (2020) searched the impress of basalt fibers on the mechanical properties of normal concrete of 25 MPa compressive strength. Five volume fractions were adopted in the work: 0.0 %, 0.5 %, 1.0 %, 1.5 %, and 2.0 %. The slump decreased with increasing fiber content; therefore, a superplasticizer dosage was increased to modify the workability. The authors illustrated that a slight increase in compressive strength occurred up to 1.5 % of fiber, while 2.0 % of basalt fiber reduced compressive strength. They attributed the decrease in compressive strength at 2.0 % fiber content to the higher fiber volume fraction in the mix, which might have caused the fiber turning and accumulating to decrease the compressive strength. The splitting tensile strength improved for all fiber content. The 1.5 % basalt fiber content awarded higher increments in the tensile and flexural strengths. The increments were 22.58 % and 57 %, respectively.

According to the mentioned results, blending basalt fiber within a concrete matrix with a small percentage enhances the compressive strength more than the large volume fractions. On the other hand, the high content of basalt fibers improves tensile and flexural strength more than compressive strength, which may drop.

Al-Kharabsheh, *et al.*, (2022), in a comprehensive review, stated that the slump dropped when basalt fiber content increased; therefore, the authors proposed applying a superplasticizer to adjust workability. However, the strength of compression and tension was greatly enhanced, and failure patterns transferred from brittle to ductile upon blending basalt fiber with concrete matrix. Kirthika and Singh (2018) stated that 0.75 % highly increased strength in tension, while 0.5 % showed the highest compressive strength. Jia, *et al.*, (2021) claimed that 0.2 % basalt fiber provided the best tension strength from the three-volume fraction of 0.1 %, 0.2 %, and 0.3 %. Also, compressive strength was slightly improved upon adding the fibers up to 0.2 %. However, a 0.3 % basalt fiber volume fraction causes a decrease in the compressive strength.

Furthermore, some researchers claimed that basalt fibers have no significant impact on compressive strength. The investigators attributed that to lowering workability when basalt fibers are added to the mix due to the vast surface area of the filaments and proposed applying a plasticizer admixture to modify the concrete workability (Afroz, Patnaikuni and Venkatesan, 2017).

Jalasutram, *et al.*, (2016) studied the effect of adding chopped basalt fibers of 12.7 mm length at a volume fraction ranging between (0-2) % on the mechanical properties of ordinary concrete. The findings illustrated that the compressive strength slightly decreased upon adding basalt fibers compared to conventional concrete. However, the defeat pattern was altered from brittle to ductile in compression. The tensile strength was enhanced by about 15 % at a 2 % volume fraction of basalt fiber above the non-fibrous concrete. The highest increment occurred in flexural strength, which was 75 % at 2 % basalt fiber content. Furthermore, flexural toughness was improved by about three times of ordinary concrete.

Dilbas and Cakir (2020) suggested that the 0.25 % basalt fiber content provided the best increase in compressive strength, whereas 1.0 % volume fraction awarded the highest tensile strength. Hirde and Shelar (2017) stated that the ultimate improvement in compressive strength occurred at a 3 % volume fraction of basalt fiber. However, the 4 % provided the best increment in tensile strength, which arrived at 33.6 % above non-fibrous concrete. Iyer, *et al.*, (2015) stated that 18 kg/m3 of basalt fibers awarded the best improvement in compressive and flexural strengths.

## Impact of Basalt Fibers on High-strength and High-performance Concrete

Some researchers have explored the impact of basalt fibers on high-performance concrete (HPC), and it looks like they can enhance the strength of conventional concrete. Tamadhir and Borhan (2013) inspected the effect of adding a small volume fraction of chopped basalt fibers on high-strength concrete of about 60 MPa. The basalt fiber volume fractions adopted were (0

%, 0.1 %, 0.2 %, 0.3 %, and 0.5 %). The results indicated that there was a slight reduction in the compressive strength upon increasing basalt fiber over 0.3 %. The decrease was 12 % when adding 0.5 % basalt fibers. However, 0.3 % of fiber raised the compressive strength more than the other percentages. Also, 0.3 % enhanced tensile strength more than other percentages. The increment was about 13 % over the no-fibrous concrete.

Ayub, *et al*., (2014) investigated the influence of chopped basalt fibers on the compressive and tensile strength and elastic modulus of high-performance concrete. Three volume fractions of fiber were incorporated into three different mixtures. The first mixture included 1 %, 2 %, and 3 % basalt fiber with ordinary cement only. The second and third mixtures contained equal percentages of basalt fibers, besides 10% silica fume or 10 % metakaolin as a partial replacement for cement. Other constituents were the same in all mixtures. The results showed that 1 % and 2 % provide better compressive strength in all mixes, while 3 % caused a drop. For plain concrete, the 1 % and 2 % raised compressive strength by 2.3 % and 3.2 %, respectively. In the silica fume concrete, the 1 % and 2 % enhanced compressive strength by 0.54 % and 1.82 %, respectively. In metakaolin concrete, the 1 % and 2 % raised compressive strength by 1.58 % and 1.62 %, respectively. Therefore, adding silica fume or metakaolin to the concrete significantly increased the compressive strength. Adding 3 % basalt fiber raised tensile strength higher than 1 % and 2 %. However, the three proportions boosted the tensile strength. Further, adding metakaolin to concrete could raise compressive strength higher than silica fume, whereas vice versa arose for tensile strength.

## Impact of Basalt Fibers on Ultra-high Performance Concrete

Liu *et al*. (2019) found that adding micro basalt fibers into ultra-high performance concrete (UHPC) can significantly improve the strength. The study showed that increasing basalt fiber content from 0.15 % to 0.3 % could enhance flexure strength by about 22 % and compressive strength by 10 % adding a silica fume to the mix at 20 % of cement content. However, when adding the silica fume at 40 % of cement content, raising the fiber content from 0.15 % to 0.3% did not influence the flexural strength but decreased the compressive strength. The results also showed that the best compressive strength could be attained when the fine aggregate proportion equals the binder content, the silica fume/cement proportion is 0.3, and the basalt fiber content is 0.15 % at a w/cm of 0.18, leading to the highest compressive strength of 120 MPa (Liu, *et al*., 2019).

Jabbar, *et al*., (2021a) studied the influence of chopped basalt fibers incorporated into UHPC. The authors used three proportions; 0.5, 1.0, and 1.5 %. The results showed that 0.5 % and 1.0 % fiber proportion raised compressive strength by 44 % and 51 %, respectively, while 1.5 % increased the compressive strength lower than the two other percentages by 41 %.

It is noticed by Jabbar, *et al*., (2021) that blending basalt fibers with UHPC matrix minimized autogenous shrinkage and reduced the size and amount of voids. Furthermore, adding basalt fibers to the matrix could improve the toughness and ductility (Jabbar, Mohammed and Hamood, 2022). Also, the multiple basalt micro-fibers at every percentage and their distribution in all orientations contribute to delay crack initiation in the matrix and obstruct their propagation, which significantly enhances the strength (Jabbar, Hamood and Mohammed, 2021a; Jabbar, Mohammed and Hamood, 2022). Thus, basalt fibers work on the internal confining of concrete.

Generally, it seems that incorporating basalt fibers into various types of concrete can improve the strength in compression, tension, and flexure. Boosting the concrete strength can ultimately lead to higher bearing capacity for structural elements.

## Factors Affecting Concrete Strength Related to Basalt Fibers

### A. Fiber Length

The length of the fiber also has an impact on concrete strength (Elshafie and Whittleston, 2015). It was displayed that the best proportion of 12 mm long basalt fiber was 4 kg/m3, whereas 36 mm long was 8 kg/m3 to arrive at approximately equal 28-day compressive strength (Wang *et al.*, 2019). Therefore, the shorter the fiber length, the lower the content and the better the effect. Qin *et al.* (2018) discussed the impact of chopped basalt fibers on magnesium phosphate cement mixture. Four lengths of micro basalt fiber were tested: 6 mm, 12 mm, 20 mm, and 30 mm, and six volume fractions were adopted in their experimental works: 0.00 %, 0.25 %, 0.50 %, 0.75 %, 1.00 %, and 1.5 %. The findings clarified that adding the fibers to the mixture obviously dropped the mortar flow ability compared to the mortar without fibers. This influence may be interpreted as the filaments with large surface area required to adsorb a portion of cement paste water to wrap around. On the other hand, the flow ability of mortar was slightly dropped upon increasing the fiber length. For instance, the flow ability decreased from 80 % for the mixture with a fiber length of 6 mm to 70 % for the one with a 30 mm fiber length. Upon adding basalt fiber to the mortar, a slight decrease in bulk density occurred, which referred to increasing the voids due to the balling of the flexible fibers. The results indicated that raising the basalt fiber volume fraction increased tensile strength, and 1.25 % gave the most increment. The compression strength increased up to 1.0 % fiber content. However, over 1.0 %, the compression strength began to weaken.

Sun, *et al.*, (2019) investigated the effects of basalt fiber length and content on the mechanical properties of concrete. Two fiber lengths were adopted: 6 mm and 12 mm. Besides, six fiber volume fractions were incorporated into mixtures: 0.0 %, 0.1 %, 0.2 %, 0.3 %, 0.4 %, and 0.5 %. Test results showed that the BFRC with 6 mm length fiber and 0.3% percentage provided the highest compressive strength, followed by 0.4 % with the same length. For concrete with a fiber length of 12 mm, the content of 0.3 % fiber was awarded the best compressive strength of the group. However, 0.4 % and 0.5 % of 12 mm length caused a drop in the compressive strength. Generally, the 6 mm fiber length awarded higher strength than the counterpart with a 12 mm length having the same volume fraction of basalt fiber. Concrete with fibers of 12 mm long caused dropping tensile strength for all volume fractions used, whereas 0.3 % and 0.4 % provided the most increment in tensile strength for 6 mm length. The 0.5% fiber content of both 6 mm and 12 mm provided the highest flexural strength. It was suggested by most authors that the mechanical properties of different types of concrete were significantly enhanced upon adding basalt fibers of a length between 12 mm and 24 mm at a volume fraction between 0.1 % - 0.5 %.

## B. Water-to-cement Ratio of Concrete

Another factor can influence the enhancement of the concrete strength upon adding basalt fibers. That factor is the water-to-cement (w/c) ratio. According to Algin, *et al.*, (2020), who investigated the impact of basalt fibers on the workability and mechanical characteristics of two w/c ratios, the workability dropped when basalt fiber dosage increased. However, a slight enhancement appeared in compressive strength when the basalt fiber percentage rose from 0% to 0.8 %. At 0.8 % fiber content, the compressive strength increment was 16 % and 10 % for a w/c ratio of 0.59 and 0.47, respectively. Tensile strength was also raised by 34 % and 26 % for the same w/c ratios.

## C. The Age of Concrete

The age of BFRC affects concrete strength. Meyyappan and Carmished (2020) investigated the impact of basalt fiber on concrete strength at 7 and 28 days. The authors added 0.5 %, 1.0 %, 1.5 %, 2.0 %, 2.5 %, and 3.0 % basalt fiber to normal-strength concrete. Their results showed that compressive strength increased on the seventh day by 54 - 65 % compared to 28-day compressive strength for equal percentages of the fiber. At 1.0 % basalt fiber, the compressive strength increased to 11.45 %, whereas at 3.0 % basalt fiber, compressive strength declined by 33.87 %.

High, *et al.*, (2015) stated that 1.78 kg/m3 basalt fibers increased the strength of ordinary concrete in compression at 3 days by 5.5 %, at 7 days by 14 %, and at 28 days by 6.0 %.

## Conclusions

This paper introduces a review of the impact of the incorporation of basalt fibers into various types of concrete on the mechanical properties, toughness, and ductility. The following conclusions can be suggested:

1. A small content of basalt fibers can increase the concrete tensile and flexural strength better than a high amount of steel fibers. The optimum proportion of basalt fibers varies according to the concrete ingredients and depends on some factors, such as fiber length, w/c ratio, and the age of the concrete. However, the valuable percentage of basalt fibers is smaller than that of steel fibers. Basalt fiber also resists abrasion and chemicals, while steel fibers corrode over time when it is in contact with water.
2. Basalt fibers can be manufactured in various forms: chopped filaments, minibars, and flat bundles with lengths between (6-50) mm.
3. The concrete workability decreases with increasing basalt fiber content, and the flow-ability of the mixture is slightly dropped when fiber length increases. However, adding basalt fiber to concrete can minimize drying shrinkage, size, and quantity of voids inside the concrete matrix.
4. Adding a small proportion of basalt fiber to concrete mix, up to 0.5 %, can increase the compressive strength, provided that an appropriate mixing method is used that prevents fibers from balling into the internal structure of the concrete. However, a volume fraction between (0.3-0.5)% is considered the best

percentage to increase the compressive strength, while a higher percentage may cause a reduction of it. Additionally, the increase in compressive strength of only cement concrete is more than the concrete containing silica fume or metakaolin to replace a part of cement.

5. The tensile and flexural strength, ductility, and toughness improve with increasing the basalt fiber content. However, the higher content may cause the fibers to lose their forms due to their flexibility. Generally, the higher the content of basalt fiber, up to 1.5 %, the higher the tensile and flexural strength. Beyond 1.5 %, the increment of strength may be lower.
6. The presence of basalt fiber in reinforced concrete beams delays the appearance of cracks, increases the number of micro cracks, and increases the beam's ability to bear loads.
7. In UHPC, the ratio of silica fume to cement affects the proper proportion of basalt fiber to increase the strength. Basalt fiber acts by confining the concrete internally.
8. The shorter the fiber length, the lower the content and the better the effect. The (6-24) mm fiber length is suggested to be the best length to use in various types of concrete that enhance the mechanical properties.
9. The increment in compressive and tensile strength for a lower w/c ratio is higher than that for a higher w/c ratio. Also, the increment in compressive strength of BFRC at 7 days is higher than that at 28 days.

# References


1. Abdulhadi, M., (2014) 'A comparative Study of Basalt and Polypropylene Fibers Reinforced Concrete on Compressive and Tensile Behavior', *International Journal of Engineering Trends and Technology*, 9(6), pp. 295–300. doi: 10.14445/22315381/ijett-v9p258.
2. Afroz, M., Patnaikuni, I. and Venkatesan, S., (2017) 'Chemical Durability and Performance of Modified Basalt Fber in Concrete Medium', *Construction and Building Materials*, 154, pp. 191–203. doi: 10.1016/j.conbuildmat.2017.07.153.
3. Alabduljabbar, H., *et al*. (2020) 'Bond Behavior of Cleaned Corroded Lap Spliced Beams Repaired with Carbon Fiber Reinforced Polymer Sheets and Partial Depth Repairs', *Crystals*, 10(11), pp. 1–14. doi: 10.3390/cryst10111014.
4. ALGIN, Z., Mermerdas, K. and Khalid, L. W., (2020) 'Mechanical Performance of Basalt Fibre Reinforced Concretes', *Journal of the Institute of Science and Technology*, 10(2), pp. 1093–1106. doi: 10.21597/jist.626757.
5. Al-kharabsheh, B. N., *et al*., (2022) 'Basalt Fibers Reinforced Concrete: Strength and Failure Modes', *Materials*, 15(7350), pp. 1–24. doi: 10.3390/ma15207350.
6. Ayub, T., Shafiq, N. and Nuruddin, M. F., (2014) 'Effect of Chopped Basalt Fibers on the Mechanical Properties and Microstructure of High Performance Fiber Reinforced Concrete', *Advances in Materials Science and Engineering*, 2014. doi: 10.1155/2014/587686.
7. Branston, J., *et al*., (2016) 'Mechanical Behaviour of Basalt Fiber Reinforced Concrete', *Construction and Building Materials*, 124, pp. 878–886. doi: 10.1016/j.conbuildmat.2016.08.009.
8. Chiao, T. T., (1980) 'Fiber Composite Materials Technology Development.', pp. 428–434.
9. Deák, T. and Czigány, T., (2009) 'Chemical Composition and Mechanical Properties of Basalt and Glass Fibers: A Comparison', *Textile Research Journal*, 79(7), pp. 645–651. doi: 10.1177/0040517508095597.
10. Dias, D. P. and Thaumaturgo, C., (2005) 'Fracture Toughness of Geo-polymeric Concretes Reinforced with Basalt Fibers', *Cement and Concrete Composites*, 27(1), pp. 49–54. doi: 10.1016/j.cemconcomp.2004.02.044.
11. Dilbas, H. and Çakır, Ö., (2020) 'Influence of Basalt Fiber on Physical and Mechanical Properties of Treated Recycled Aggregate Concrete', *Construction and Building Materials*, 254, p. 119216. doi: 10.1016/j.conbuildmat.2020.119216.
12. El-Din, H. S., *et al*., (2016) 'Effect of Steel Fibers on Behavior of Ultra High Performance Concrete', in *First International Interactive Symposium on UHPC – 2016*, pp. 1–10. doi: 10.21838/uhpc.2016.11.
13. El-Gelani, A. M. *et al*. (2018) 'Effects of Basalt Fibers on Mechanical Properties of Concrete', *MATEC Web of Conferences*, 149, p. 01028. doi: 10.1051/matecconf/201814901028.

14. Elshafie, S. and Whittleston, G., (2015) 'a Review of the Effect of Basalt Fiber Lengths and Proportions on the Mechanical Properties of Concrete', *International Journal of Research in Engineering and Technology*, 04(01), pp. 458–465. doi: 10.15623/ijret.2015.0401069.

15. Elshekh, A. E. A., *et al.*, (2014) 'An Experimental Study on the Effectiveness of Chopped Basalt Fiber on the Fresh and Hardened Properties of High Strength Concrete', *Research Journal of Applied Sciences, Engineering and Technology*, 7(16), pp. 3304–3311. doi: 10.19026/rjaset.7.675.

16. Galen, L.L. and C. Russia, (2009) *Basalt Chopped Fiber*. Galen L.L. and C. Russia. Available at: www.galencomposite.ru.

17. Galishnikova, V. V., Chiadighikaobi, P. C. and Emiri, D. A., (2019) 'Comprehensive View on the Ductility of Basalt Fiber Reinforced Concrete fFcus on Lightweight Expanded Clay', *Structural Mechanics of Engineering Constructions and Buildings*, 15(5), pp. 360–366. doi: 10.22363/1815-5235-2019-15-5-360-366.

18. Hannawi, K. *et al.*, (2016) 'Effect of Different Types of Fibers on the Microstructure and the Mechanical Behavior of Ultra-High Performance Fiber-Reinforced Concretes', *Composites Part B: Engineering*, 86, pp. 214–220. doi: 10.1016/j.compositesb.2015.09.059.

19. High, C. *et al.* (2015) 'Use of basalt fibers for concrete structures', *Construction and Building Materials*, 96, pp. 37–46. doi: 10.1016/j.conbuildmat.2015.07.138.

20. Hirde, S. and Shelar, S., (2017) 'Effect of Basalt Fiber on Strength of Cement Concrete', *International Journal of Current Engineering and Technology*, 7(2), pp. 600–602.

21. Iyer, P., Kenno, S. Y. and Das, S. (2015) 'Mechanical Properties of Fiber-Reinforced Concrete Made with Basalt Filament Fibers', *Journal of Materials in Civil Engineering*, 27(11), pp. 1–8. doi: 10.1061/(asce)mt.1943-5533.0001272.

22. Jabbar, A. M., Hamood, M. J. and Mohammed, D. H., (2021a) 'The Effect of Using Basalt Fibers Compared to Steel Fibers on the Shear Behavior of Ultra-high Performance Concrete T-beam', *Case Studies in Construction Materials*, 15(September), pp. 1–24. doi: 10.1016/j.cscm.2021.e00702.

23. Jabbar, A. M., Hamood, M. J. and Mohammed, D. H., (2021b) 'The Effect of Using Basalt Fibers Compared to Steel Fibers On the Shear Behavior of Ultra-High Performance Concrete T-Beam', *Case Studies in Construction Materials*, 15(August), p. e00702. doi: 10.1016/j.cscm. 2021.e00702.

24. Jabbar, A. M., Mohammed, D. H. and Hamood, M. J., (2022) 'Using Fibers instead of Stirrups for Shear in Ultra-High Performance Concrete T-beams', *Australian Journal of Structural Engineering*, June 2022, pp. 1–14. doi: 10.1080/13287982.2022.2088654.

25. Jabbar, A., Hamood, M. and Mohammed, D., (2021) 'Mitigation of the Factors Affecting the Autogenous Shrinkage of Ultra-High Performance Concrete', *Engineering and Technology Journal*, 39(12), pp. 1860–1868. doi: 10.30684/etj.v39i12.2155.

26. Jalasutram, S., *et al.*, (2016) 'Experimental Investigation on Mechanical Properties of Basalt Fiber-reinforced Concrete', *Structural Concrete Journal of the fib*, 18(2), pp. 1–22. doi: 10.1002/suco.201500216.

27. Jamshaid, H., (2017) 'Basalt Fiber and its Applications', *Journal of Textile Engineering & Fashion Technology*, 1(6), pp. 254–255. doi: 10.15406/jteft.2017.01.00041.

28. Jia, M., *et al.*, (2021) 'A Comparative Study of the Mechanical Properties of Basalt Fiber and Basalt Grille Reinforced Concrete Composites and Theoretical Prediction', *Journal of Natural Fibers*, 00(00), pp. 1–18. doi: 10.1080/15440478.2021.1902451.

29. Kirthika, S. K. and Singh, S. K., (2018) 'Experimental Investigations on Basalt Fiber-Reinforced Concrete', *Journal of The Institution of Engineers (India): Series A*, 99(4), pp. 661–670. doi: 10.1007/s40030-018-0325-4.

30. Krassowska, J. and Kosior-Kazberuk, M., (2019) 'Failure Mode of Basalt Fiber Reinforced Concrete Beams', *IOP Conference Series: Materials Science and Engineering*, 471(5). doi: 10.1088/1757-899X/471/5/052043.

31. Lam, N. N. and Hung, L. Van, (2021) 'Mechanical and Shrinkage Behavior of Basalt Fiber Reinforced Ultra-High-Performance Concrete', *International Journal of Geomate*, 20(78), pp. 28–35. doi: 10.21660/2021.78.86151.

32. Li, Z., *et al.*, (2018) 'Properties and Applications of Basalt Fiber and Its Composites', *IOP Conference Series: Earth and Environmental Science*, 186(2). doi: 10.1088/1755-1315/186/2/012052.

33. Liu, H., *et al.*, (2019) 'Effect of Mix Proportion Parameters on Behaviors of Basalt Fiber RPC Based on Box-Behnken Model', *Applied Sciences (Switzerland)*, 9(10), pp. 1–14. doi: 10.3390/app9102031.

34. Meyyappan, P. L. and Jemimah Carmichael, M., (2020) 'Studies on Strength Properties of Basalt Fibre Reinforced Concrete', *Materials Today: Proceedings*, 43, pp. 2105–2108. doi: 10.1016/j.matpr.2020.11.890.

35. Papakonstantinou, C. G., (2020) 'Fiber Reinforced Polymer (FRP) Confined Circular Columns: Compressive Strength Assessment', *Journal of Engineering Science and Technology Review*, 13(6), pp. 1–13. doi: 10.25103/jestr.136.01.

36. Qin, J., *et al.*, (2018) 'Mechanical Properties of BasaltF Reinforced Magnesium Phosphate Cement Composites', *Construction and Building Materials*, 188, pp. 946–955. doi: 10.1016/j.conbuildmat.2018.08.044.

37. Ramadevi, K., Chithra, R. and Rajesh, B., (2017) 'Experimental Study on Strength Properties of Concrete with Different Aspect ratios of basalt fiber', *International Journal of Civil Engineering and Technology*, 8(9), pp. 629–637.
38. Ramesh, B. and Eswari, S., (2020) 'Mechanical Behavior of Basalt Fiber Reinforced Concrete: An Experimental Study', *Materials Today: Proceedings*, 43, pp. 2317–2322. doi: 10.1016/j.matpr.2021.01.071.
39. Revade, A. B. and S. S. Dharane, (2015) 'Study the Effects of Short Basalt Fibers on Mechanical Properties of Concrete', *Journal of Civil Engineering and Environmental Technology*, 13(3), pp. 1576–1580.
40. Shaikh, F. U. A., (2013) 'Review of Mechanical Properties of Short Fibre Reinforced Geo-polymer Composites', *Construction and Building Materials*, 43, pp. 37–49. doi: 10.1016/j.conbuildmat.2013.01.026.
41. Spool, B. F., (2018) 'Basalt Fiber Properties Source of Basalt Fiber New ! Comments', pp. 1–4.
42. Sun, X., *et al.*, (2019) 'Mechanical Properties Tests and Multiscale Numerical simulations for basalt fiber reinforced concrete', *Construction and Building Materials*, 202, pp. 58–72. doi: 10.1016/j.conbuildmat.2019.01.018.
43. Tumadhir, M. and Borhan, (2013) 'Thermal and Mechanical Properties of Basalt Fiber Reinforced Concrete', *International Journal of Civil and Environmental Engineering*, 7(4), pp. 334–337.
44. Vajje, S. and Krishna, N. R., (2013) 'Study On Addition Of The Natural Fibers Into Concrete', *International Journal of Scientific & Technology Research*, 2(11), pp. 213–218.
45. Wang, X. *et al.* (2019) 'The Effects of Fiber Length and Volume on Material Properties and Crack Resistance of Basalt Fiber Reinforced Concrete (BFRC)', *Advances in Materials Science and Engineering*. doi: 10.1155/2019/7520549.
46. Xianggang, Z., *et al.*, (2018) 'Experimental Study on Deformation Performance of Basalt Fiber-reinforced Recycled Aggregate Concrete', *Journal of Engineering Science and Technology Review*, 11(4), pp. 138–145. doi: 10.25103/jestr.114.18.
47. Xianggang, Z., Yahong, D. and Junna, Y., (2020) 'Mechanics Performances of Different Basalt-fiber-reinforced Recycled Aggregate Concretes Subjected to Compression Test', *Journal of Engineering Science and Technology Review*, 13(2), pp. 92–98. doi: 10.25103/jestr.132.13.
48. Xinzhong, W., *et al.*, (2017) 'Experimental Study on the Axial Compression of Short Basalt Fiber Reinforced Concrete Columns with Spiral Stirrups', *Journal of Engineering Science and Technology Review*, 10(1), pp. 55–60.
49. Xinzhong, W., Chuanxi, L. and Wei, Z., (2016) 'Experimental Study on the Ultimate Bearing Capacity of Long Basalt Fiber-reinforced Concrete (BFRC)-filled Steel Tube Columns Under Axial Compression', *Journal of Engineering Science and Technology Review*, 9(5), pp. 158–163. doi: 10.25103/jestr.095.25.