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Physical and mechanical properties of light and heavyweight concretes reinforced with basalt fibre

Abstract. The purpose of this study was to investigate the effect of basalt fibres in concrete mixtures to improve their physical and mechanical properties. The study used Portland cement grade PC400 D0, granite crushed stone, perlite gravel fill, and sand coarse aggregate to create concrete mixtures of various densities. The findings of this study confirmed that the optimum dosage of basalt fibres plays a key role in achieving the best mechanical properties of concrete. Upon proper dosage of up to 3%, the fibres improve the structure of concrete, increasing its strength and crack resistance. However, when this level is exceeded up to 5%, agglomeration of fibres and lack of cement paste to bind the aggregates result in lower flexural strength of concrete. The study also revealed that the tensile strength and compressive strength of concrete varies with basalt fibre content. The tensile (flexural) strength showed an increasing trend with the addition of up to 3% fibres, with a maximum increase of 11.3% over the original sample. However,

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when the basalt fibre content was further increased, the strength started to decrease, emphasising the significance of maintaining the optimum dosage. Concrete shrinkage also varied with fibre content: as the basalt fibre content increased, shrinkage decreased due to the formation of an internal reinforcing structure that prevents the movement of concrete particles. In case of lightweight concrete, analogous trends were discovered: compressive strength and flexural strength increased up to a certain level of basalt fibre content, but then decreased when the optimum dosage was exceeded. The findings emphasise the significance of careful control of basalt fibre dosage in the design of concrete structures, as insufficient or excessive basalt fibre content can adversely affect the mechanical properties of concrete. Optimised use of basalt fibres can considerably improve the strength, crack resistance, and other characteristics of concrete, making it more stable and durable under various service conditions

Keywords: structure of building materials; fibre concrete; flexural strength; compression; extrusion; tensile breaking strength; tear strength

INTRODUCTION

With the ever-increasing need for innovative materials to build sustainable and durable structures, attention to innovative approaches to concrete reinforcement becomes inevitable. This is particularly important for improving material performance in the face of various construction requirements, including mechanical resistance, durability, and environmental friendliness. One of the key factors that motivates research in this area is the search for alternative materials that can improve the strength and stability of concrete without increasing its mass or degrading its environmental performance. Notably, conventional concrete reinforcement methods may have disadvantages, including insufficient resistance to various mechanical stresses, as well as other factors. In this context, the emergence of basalt fibre represents a promising solution because of its high strength, corrosion resistance, and chemical inertness. A detailed investigation of the properties of basalt fibre reinforced concretes may offer an improved understanding of the effect of this material on various characteristics of concrete structures. These studies will not only help to determine the optimum dosages of basalt fibre to achieve the desired mechanical properties of concrete but will also help to identify potential problems or limitations that may arise during the use of this material in construction. All this can significantly contribute to the development of more efficient and sustainable building materials, helping to improve the quality and durability of concrete structures.

Basalt fibre, due to its high strength as well as other properties, is a promising solution for reinforcing both light and heavyweight concretes. I. Tashpolotov and E. Mamatov (2022) investigated the chemical composition of basalt rocks in Kyrgyzstan and found that the addition of basalt fibre significantly increases the strength of concrete, and this is due to the improvement of the internal structure of the material and more uniform distribution of loads. A. Sagyndykov *et al*. (2023) focused on studying the effect of basalt fibre on the durability of concrete structures in different climatic conditions, showing that concrete with fibre addition shows better resistance to cyclic loads and aggressive media compared to conventional concrete. However, despite the findings, questions regarding the durability and performance of basalt fibres are still open and require further investigation to fully understand and effectively apply this material in the construction industry.

An essential feature of basalt fibre is also its ability to improve adhesion between cement paste and aggregate, creating additional bonding points and increasing the density of the material. Y. Zheng *et al*. (2022) found that the use of basalt fibre in concrete composition helps to considerably reduce shrinkage and increase compressive strength, which is particularly important for structures subjected to high loads. Y. Li *et al*. (2022) focused on the durability evaluation of basalt fibre concrete and showed that such concrete exhibits increased resistance to aggressive chemical media and moisture, which makes it more durable under extreme service conditions. At the same time, Z. Li *et al*. (2022) found that basalt fibre can reduce the permeability of concrete to water and gases, which further improves its performance, reducing the risk of reinforcement corrosion and increasing the service life of structures. Thus, this confirms the need for more detailed studies for the application of this material in the construction of diverse types of structures, including those operating in harsh environments.

It should also be considered that the use of basalt fibre in concrete can have an impact on its mechanical and performance characteristics. M. Khan *et al.* (2022) found that the addition of basalt fibre can substantially increase the strength of concrete, which confirms its effectiveness in improving the crack resistance of the material. H. Zhou *et al*. (2020) also showed that basalt fibre helps to improve the frost resistance of concrete, making the material more resistant to cyclic freezing and thawing, which is particularly important for regions with harsh climates. M. Elshazli *et al*. (2022) showed that the use of basalt fibre can reduce the overall weight of structures without sacrificing their strength and durability. However, to better understand all aspects of basalt fibre use in concrete, further research is needed to determine the optimum proportions and mixing methods, and to investigate the long-term effects and interactions of fibre with the various components of the concrete mix.

The purpose of this study was to investigate the effect of basalt fibre on the physical and mechanical properties of light and heavyweight concrete. For this, the respective objectives were set, which included determining the optimum dosage of basalt fibre to increase the flexural and tensile strength of concrete, as well as investigating the variation in compressive strength and shrinkage of concrete as a function of basalt fibre content.

MATERIALS AND METHODS

Portland cement of PC400 D0 grade manufactured at “Kant Cement Plant” (Kyrgyzstan) was used in this study. Its properties and characteristics are summarised in greater detail in Table 1.

Table 1. Characteristics of Portland cement PC400 D0

Characteristics	Indicator value
Compressive strength after 28 days, MPa	44.5
Initiation/completion of the setting process, min	300/420
Specific surface area, cm^2/g	2,850
Thickness of cement mortar, %	26

Source: developed by the authors of this study

Granite crushed stone of medium size fractions of 5-20 mm was also used in the study. The density of the material was 1,650 kg/m^3. The true density of this crushed stone was 2,700 kg/m^3. Crushed stone had a crushing capacity of – 12.5%, and the hollowness of the material was 39%. Perlite gravel fill was selected as the coarse lightweight aggregate. Its bulk density was 220 kg/m^3, but its true density was at 360 kg/m^3. The hollowness of the perlite gravel fill was up to 75%. Sand coarse aggregate was used as fine aggregate with a fraction size of 0.1-5 mm and a bulk density of 1,400-1,600 kg/m^3. The material also had a low content of organic impurities and particles. Basalt fibre in the role of dispersed reinforcement was used to reinforce the materials. The detailed characteristics of this fibre are summarised in Table 2.

Table 2. Characteristics of basalt fibre

Characteristics	Indicator value
Basalt fibre	
Tensile strength, MPa	2,800
Fibre thickness, m	$14 \cdot 10^{-6}$
Length of fibres, mm	10
Elasticity coefficient, GPa	75
Bulk density, kg/m^3	2,450

Source: developed by the authors of this study

The superplasticiser Sika ViscoCrete-20 HE (Switzerland) was used to control the mobility of concrete mortars. A hydraulic press UMM-5 (Russia) was used for compression tests. The NMP-2 instrument (Russia) was used to determine the deviations from the plane. To measure deviations from perpendicularity, the NP-3 instrument (Russia) was used in the study. Sartorius laboratory scales (Germany) were also used. The characteristics of the concrete mix composition used to create the heavyweight concrete are detailed in Table 3.

Table 3. Characteristics of concrete mix composition

Characteristics	Indicator value
Water-cement ratio	0.59
Cement, kg/m^3	369
Water, kg/m^3	199
Crushed stone, kg/m^3	1,151
Sand, kg/m^3	695
Concrete mix density (ρ), kg/m^3	2,470

Source: developed by the authors of this study

In creating lightweight concrete, 25% of the dense aggregate was replaced by porous material, keeping the cement consumption and sand to crushed stone ratio the same. The mobility of the concrete mix was controlled by adjusting the water flow rate. The concrete samples used in the study included different basalt fibre contents: A0 (no fibres), A1 (0.5%), A2 (1.5%), A3 (3%), and A4 (5%). To determine the compressive strength, the concrete samples were held in the tank for 24 hours and then placed in the testing machine. The load on the 250×250×250 mm cubes was increased at a rate of 289 kN per minute until failure. Strength was determined as the average of all samples. A hydraulic device was used to gradually increase the force at a variable rate from 0.05 to 0.15 mm per minute. The peak load (P) was calculated considering the instantaneous and residual strains of a 250×250×800 mm sample. The loading rate for the bending test was 3,745 kN per minute until the sample failed. Equation (1) is the fracture factor used to calculate the strength of a material:

$$f = PL/Bd^2, \quad (1)$$

where: L – the length of the sample; d – the depth of the sample; P – the load leading to failure; f – the flexural strength of the material.

To evaluate the flexural strength of concrete, tests were carried out on five samples of each type of mix, using universal equipment with a capacity of 350 kN and a load of 9 MPa per minute. The 200×450 mm samples contained 60 cylinders of basalt fibres in various proportions. The tensile breaking strength test was carried out at varying load rates from 0.5 to 1.5 MPa per minute until complete failure of the sample. To determine the tensile strength of concrete at splitting, the average value for three samples was taken according to the following equation (2):

$$f_p = 2P/\pi DL, \quad (2)$$

where: D – the sample diameter; f_p – the tensile strength of the material.

RESULTS

Figure 1 shows the results of the study demonstrating that an increase in the percentage of fibre volume leads to a decrease in concrete shrinkage.

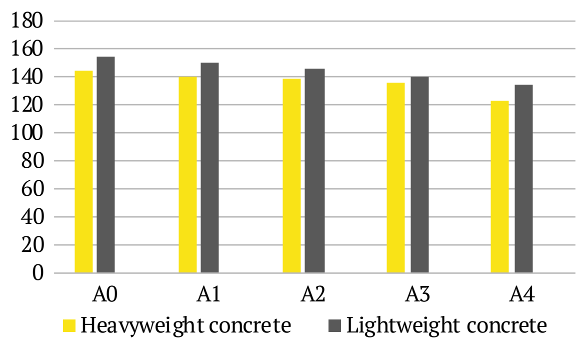

Figure 1. Results of subsidence tests on heavyweight and lightweight concrete, mm
Source: developed by the authors of this study

When adding chopped basalt fibres to concrete, a decrease in subsidence with increasing percentage of fibre content is observed and this trend is maintained throughout the experiment. For instance, for the A0 heavyweight concrete mix without chopped basalt fibres, the shrinkage value was 145 mm. In turn, for A1 concrete mix in which the basalt fibre content was 0.5%, the value of subsidence decreased to 141 mm and for the subsequent mixes, a further decrease in this value was observed to 139 mm, 136 mm, and 123 mm, respectively.

The effect of reducing concrete shrinkage by adding basalt fibres is based on a complex of physical processes occurring inside the concrete matrix. When basalt fibres are introduced into the mix, they form an internal structure resembling a reinforcing network that actively interacts with the concrete particles. This mechanism effectively restrains particle movement, preventing disintegration, and reducing water and binder seepage through the concrete matrix. As a result, the shrinkage of concrete is reduced, which is important to ensure quality structures and durability of the material (Pastsuk *et al.*, 2020; Tahwia *et al.*, 2023). Notably, the structure of basalt fibres allows water to be retained in the mixture at the micron level. This creates additional pathways for water within the concrete, which helps it to cure more efficiently and reduce shrinkage. Improving the workability of concrete is important for construction work because it facilitates the placing and shaping of structures and improves the quality and durability of the finished product.

The surface of basalt fibres also plays a key role in their interaction with the concrete matrix. Basalt fibres have microroughnesses and irregularities on their surface, which create additional contact points and improve adhesion to a binder material such as Portland cement. This mechanism promotes a more even distribution of fibres within the concrete matrix and creates a stronger structure. Increasing the amount of basalt fibres in the mix leads to an increase in the total interaction surface between the fibres and the material, which increases the number of interaction sites. This substantially strengthens the structure of concrete, making it more resistant to various impacts (Yu *et al.*, 2022). The increased contact area between the fibres and the concrete contributes to better handling of subsidence and enhancing its mechanical performance.

An essential aspect is also that microroughnesses and irregularities on the surface of basalt fibres contribute to the creation of additional mechanical interlocks with the concrete. This gives extra support and strengthens the bond between the fibres and the material, which ultimately increases its strength and stability. Thus, the surface characteristics of basalt fibres are crucial for the formation of a high-quality and durable concrete structure with high mechanical properties and resistance to various influences. Furthermore, the workability of concrete is significantly affected by parameters such as mixing ratio and moisture content. The correct proportion of water and binder material, ensured by an optimum mixing ratio, allows achieving an optimum consistency of the mixture, which is important for the ease of placement (Zhao *et al.*, 2020). Moisture content plays an important role in the proper performance of concrete, as insufficient or excessive moisture can lead to undesirable changes in concrete properties. Examination of the data presented in Figure 2 reveals the dynamics of changes in the compressive strength of heavyweight concrete when basalt fibre is used. When analysing the results of the study, it can be observed that when 0.5% basalt fibre is added, the compressive strength of the concrete stays almost unchanged compared to the control A0 concrete, showing a stable value of 74.5 MPa in the 28-day test. This result suggests that a small amount of basalt fibre does not substantially affect the compressive strength properties of concrete. However, with further increase in fibre concentration, some decrease in compressive strength of concrete is observed. For A1 concrete with fibre content at 0.5%, this reduction is 2.34% and for A2 concrete it is 3.01% compared to the control concrete. This indicates that an increase in basalt fibre content may adversely affect the compressive strength properties of concrete. Such changes may be related to the specific features of the interaction between basalt fibres and the concrete matrix, which may have a negative effect on the mechanical properties of the material. In turn, the results of the study using basalt fibre for lightweight concrete, are presented in Figure 3.

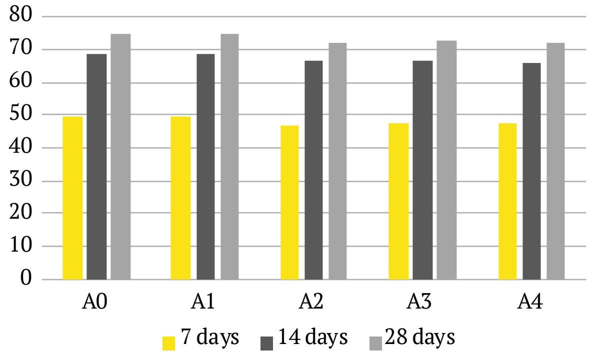

Figure 2. Results of research on compressive strength of heavyweight concretes, MPa
Source: developed by the authors of this study

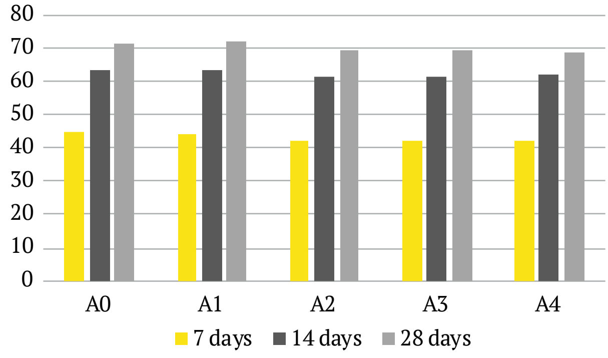

Figure 3. Results of the study on compressive strength of lightweight concretes, MPa
Source: developed by the authors of this study

Table 4. Average results of compressive strength tests

Sample No.	Solution name	Heavyweight concretes			Lightweight concretes		
		7 days	14 days	28 days	7 days	14 days	28 days
1	A0	49.8	66.4	73.4	44.3	60.3	69.7
2	A1	49.9	66.5	73.7	44.5	60.5	69.9
3	A2	47.5	64.8	71.2	42.3	58.9	68.2
4	A3	47.9	64.9	71.3	42.8	58.8	68.5
5	A4	47.6	64.3	70.8	42.5	58.2	68.1

Source: developed by the authors of this study

Notably, when lightweight concretes are considered, analogous trends in strength change with the addition of basalt fibre are observed. For instance, at a fibre concentration of 0.5%, the compressive strength of concrete can stay stable as in the case of heavyweight concrete, reaching values of about 71.5 MPa after 28 days of curing. However, when the fibre concentration is increased to 1.5% or more, a strength reduction analogous to that observed in heavyweight concrete may appear (Table 4).

These results may be conditioned by a series of factors, including the interaction features between the fibres and the concrete matrix (Zhang *et al.*, 2023). First of all, fibre concentration can play a key role in determining the strength properties of concrete. At low fibre concentrations, such as 0.5%, its effect on mechanical properties can remain negligible or even positive, as the fibres can strengthen the structure of the material without substantially affecting its mechanical properties. However, when the fibre concentration is further increased, for instance to 1.5%, 2.5%, or more, undesirable effects such as a reduction in the strength of the concrete may occur. Notably, an important aspect is the quality of basalt fibre and its dispersion in concrete. Uniform distribution of fibres in the matrix can contribute to better reinforcement of the material and increased strength. However, if the fibres are unevenly distributed or of poor quality, it may lead to the formation of weak areas in the concrete and consequently reduce its strength (Liu *et al.*, 2021).

The interaction of basalt fibres with cement paste and aggregate in concrete should also be considered. If the fibres are not sufficiently bonded to the matrix or insufficient binder is present to ensure proper adhesion, this can also reduce the strength properties of the material. Fibres, being unevenly distributed, can form clusters, which leads to local stress concentrations and development of microcracks. In turn, the lack of cement paste reduces the ability of the bonding components to effectively surround and retain aggregates, which deteriorates the overall cohesiveness and density of the concrete structure (Zajac *et al.*, 2020). These factors are particularly critical at high fibre concentrations where basalt fibres begin to compete for the limited amount of cement paste, reducing its availability to aggregates and weakening the final composite matrix. The results presented in Figures 4 and 5 provide a detailed analysis of the concrete tensile strength and related parameters.

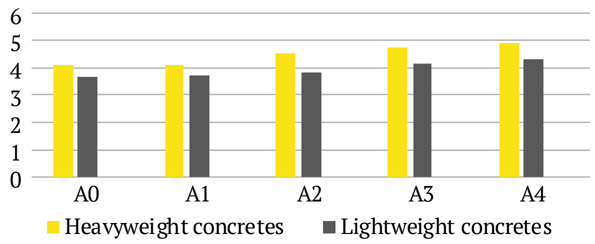

Figure 4. Tensile strength results of heavyweight and lightweight concretes, MPa
Source: developed by the authors of this study

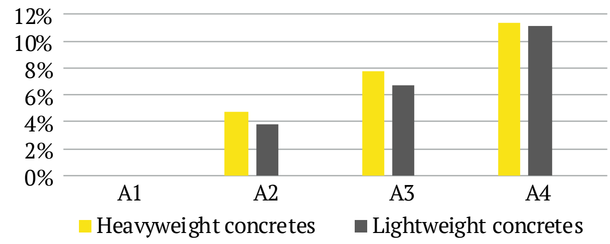

Figure 5. Dynamics of tensile strength increase of heavyweight and lightweight concrete, %
Source: developed by the authors of this study

When the mixture of heavyweight concrete without fibre addition was analysed, it was found that the breaking tensile strength was 4.1 MPa. This value stays constant when 0.5% basalt fibre is added. However, when 1.5% fibre was introduced, an increase in tensile strength of up to 4.7% was observed, which is higher than the control concrete. When the fibre content is further increased to 3%, the strength increases further, reaching an increase of 11.3%. The maximum strength is fixed at this fibre content. Increasing the proportion of basalt fibre in the concrete mixture leads to the manifestation of signs of cracking of the material, which contributes to the improvement of crack resistance of concrete. This effect can be attributed to several important processes occurring within the concrete matrix. First of all, basalt fibres distributed in the mix create an internal reinforcing network. This reinforcement prevents the propagation of micro-cracks that are caused by stresses. The fibres act as barriers, redirecting and dissipating stresses, which slows down crack development and reduces crack size (Li *et al.*, 2022a). The structure and properties of basalt fibres also contribute to a more even distribution of loads in the concrete matrix. The fibres have high tensile strength and modulus of elasticity, which allows them to effectively take up part of the load, thereby reducing stresses in the cement paste and aggregates. This even distribution of loads reduces the probability of weaknesses in the concrete and helps to improve its strength properties.

It is worth emphasising that basalt fibres play an important role in improving the adhesion between cement paste and aggregate in concrete mixes. These fibres, with their high strength and resistance to chemical attack, create additional bonding points in the concrete structure (Tamayo *et al.*, 2022). The microroughness and surface roughness of basalt fibres contribute to more effective mechanical interlocking with the cement paste, which provides better bonding of the mixture components. This improves the stress distribution within the concrete matrix, reducing the probability of micro-cracks forming and propagating under load. Additionally, basalt fibres have high surface activity, which facilitates the formation of chemical bonds between the fibres and the cement paste. These bonds strengthen the overall structure of concrete, making it denser and more resistant to various external influences. As a result, concrete mix with basalt fibre addition shows not only improved crack resistance, but also increased compressive and flexural strength. This is because the fibres effectively bind the cement matrix and aggregates, preventing them from separating under the influence of external forces.

An important aspect of using basalt fibres is their ability to be evenly distributed throughout the entire mass of the concrete mix. This ensures the creation of a homogeneous internal structure of concrete, which considerably improves its mechanical properties (Mohamed *et al.*, 2021). As a result, concrete with basalt fibres can withstand higher loads and shows a long service life without significant changes in its properties. This mix is particularly effective in applications where concrete is subjected to constant dynamic loads or extreme temperature conditions. Figures 6 and 7 show the results of the average flexural strength and the percentage increase in this strength compared to the original concrete after 28 days.

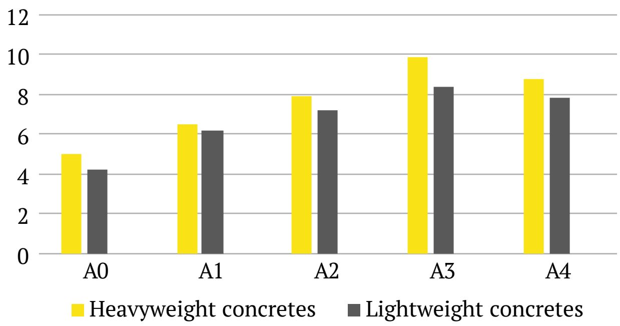

Figure 6. Average results of flexural strength tests of heavyweight and lightweight concrete, MPa
Source: developed by the authors of this study

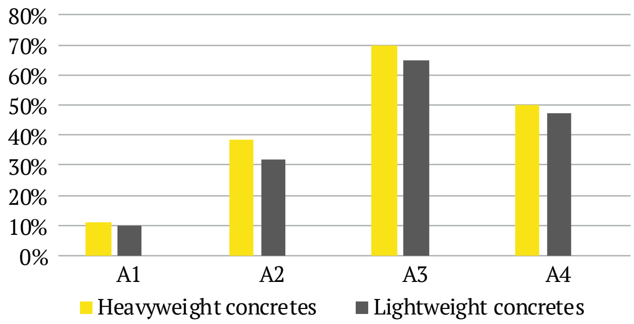

Figure 7. Dynamics of increase in average flexural strength of heavyweight and lightweight concretes
Source: developed by the authors of this study

Analysing the obtained results, it can be noted that the average flexural strength of the original concrete without fibre addition was 5.05 MPa. When 0.5% basalt fibres were added, the flexural strength increased by 11% for the A1 grade mix. This initial increase in strength is due to the fact that the basalt fibre begins to form an internal reinforcing structure that helps hold the concrete particles together, thereby preventing the development of micro-cracks and distributing loads more evenly. The fibres effectively limit crack growth and improve the overall strength of the material. A considerable improvement was observed when 1.5% fibres were added: the flexural strength increased by 38.5% compared to the original concrete. With this number of fibres, their reinforcing effect becomes more pronounced. They create multiple bonding points with the cement matrix, increasing its density and preventing the propagation of cracks. This results in a considerable increase in flexural strength, as the fibres effectively resist tensile forces and strengthen the concrete structure. When the fibre fraction was further increased to 3%, the average flexural strength reached 9.9 MPa, corresponding to an increase of 69.8%. This value was found to be the maximum for the A4 grade mix. With this fibre concentration, the fibres provide an even denser reinforcement, which considerably increases the mechanical resistance of the concrete. However, when 5% fibres were added, the flexural strength started to decrease. This is due to several factors that affect the interaction between fibres, cement paste and aggregates. First of all, the binding action of the fibres effectively limits crack growth only up to a certain limit, at which level the fibres create a sufficiently dense internal reinforcing structure that improves the ductility of the concrete and distributes loads more evenly. This helps to increase flexural strength as the fibres hold the concrete matrix together, preventing the propagation of micro-cracks and increasing the material's resistance to tensile forces.

Also importantly, when the fibre content is increased to 5% their effect on strength becomes negligible or even negative. This is due to agglomeration of the fibres as they begin to cluster or "bundle" together. These clusters of fibres create weak zones in the concrete matrix where strength is substantially lower. In these areas, the cement paste cannot effectively bond to the fibres and aggregates, resulting in a deterioration of the overall structural integrity of the concrete. Furthermore, the excessive number of fibres requires more cement paste to envelop and bind them. This reduces the amount of cement paste available to bind the aggregates, which impairs the overall cohesion and strength of the concrete. As a result, the bond between aggregates and cement paste is weakened, which negatively affects the mechanical properties of the material including flexural strength (Liu *et al*., 2020). In addition, with higher fibre concentrations there are difficulties in distributing them evenly in the mix. Improper distribution of fibres can lead to the formation of inhomogeneities in the structure of concrete, which also adversely affects its strength properties (Anas *et al*., 2022). The fibres begin to flocculate, further exacerbating the agglomeration problem. The obtained findings confirmed that the optimum dosage of basalt fibres plays a key role in achieving the best mechanical properties of concrete. At the correct dosage (up to 3%), the fibres improve the structure of concrete, increasing its strength and crack resistance. However, when this optimum level is exceeded (5%), agglomeration of fibres and lack of cement paste to bind the aggregates result in lower flexural strength of concrete. Consequently, the balance between the number of fibres and their uniform distribution in the concrete mix is a critical factor in ensuring high performance of the material.

Thus, the use of basalt fibres in concrete, both heavyweight and lightweight, requires careful control of their concentration to achieve optimum mechanical properties. Fibres can considerably improve the tensile strength, compressive strength, and crack resistance of concretes, but exceeding the optimum concentration leads to deterioration of these characteristics. This confirms that to obtain the best performing concrete, a balance must be struck between the amount of basalt fibres and their uniform distribution in the mix.

DISCUSSION

Building materials research plays a key role in the successful development of the construction industry. They can contribute to the improvement of existing materials and the development of new ones with improved performance characteristics. The importance of such studies is conditioned by the need to improve the durability, strength, and stability of building structures, which is especially relevant in the conditions of increasing loads and increasingly complex operating conditions. In addition, new developments and improvements in this area contribute to the economic efficiency of construction projects. Improvement of materials and technologies makes it possible to reduce the costs of construction and operation of buildings and structures. The introduction of new materials with improved characteristics also helps to reduce construction time and improve the quality of finished projects, ultimately resulting in resource savings and longer life cycles. Additionally, the various building materials must fulfil high requirements in terms of mechanical performance as well as environmental safety. In this regard, research aimed at reducing the negative environmental impact of construction processes is becoming increasingly important. The use of green and renewable resources such as natural fibres and waste materials reduces the carbon footprint of the construction industry and promotes sustainable construction.

In this study, it was found that when chopped basalt fibres were added to the concrete, there was a decrease in shrinkage with increasing percentage of fibres, which was a characteristic throughout the entire study. For the A0 heavyweight concrete mix, which did not contain chopped basalt fibres, the value of subsidence was 145 mm. In A1 concrete mix containing 0.5% basalt fibres, the shrinkage value decreased to 141 mm. Further increases in fibre content continued to reduce shrinkage: for A2 mix containing 1.5% fibres the shrinkage was 139 mm, for A3 mix with 3% fibres – 136 mm, and for A4 mix with 5% fibres – 123 mm. These results indicate a significant effect of basalt fibres on the rheological properties of concrete mixture. The reduction in shrinkage can be attributed to the formation of a denser and more cohesive internal structure in concrete due to the presence of fibres. Basalt fibres act as micro-reinforcing elements that prevent concrete particles from moving under their own weight and external loads. As a result, they help to improve the mixture's resistance to deformation. The observed decrease in shrinkage with increasing basalt fibre content has important practical implications for the construction industry. Lower shrinkage contributes to improved controllability and workability of the concrete mixture, which is particularly important when pouring and moulding structures. This allows for greater accuracy in the shape and size of the elements and reduces the probability of voids and defects in the finished product. B. Al-Kharabsheh *et al*. (2023) also found that the addition of basalt fibres substantially improves the mechanical properties of concrete including its resistance to cracking, especially at low fibre dosages. V. John and B. Dharmar (2021) showed that basalt fibres contribute to the durability of concrete structures by improving their resistance to freezing and thawing, as well as to the effects of aggressive chemical media. E. Al-Rousan *et al*. (2023) also showed a considerable reduction in shrinkage and cracking of concrete when basalt fibres were added, which helps to improve the overall structural integrity of the material. Nevertheless, the findings of the present study, in contrast to the cited studies, highlight the significance of proper dosing of basalt fibres to achieve optimum performance of the concrete mix. Increased crack resistance, improved structure and reduced shrinkage make concrete with basalt fibres a promising material for use in various construction applications where high mechanical and performance properties are required.

When analysing the results of the study, it is also important to note that the addition of 0.5% basalt fibre to the concrete had almost no effect on the compressive strength of the concrete compared to A0 concrete. The strength of the concrete at 28-day test stayed stable at 74.5 MPa. This result shows that a small amount of basalt fibre has no significant effect on the compressive strength properties of concrete. However, with further increase in fibre concentration, a tendency to decrease the compressive strength of concrete was observed. For instance, for A1 concrete with fibre content at 0.5%, the strength reduction was 2.34%, and for A2 concrete with 1.5-3.01% compared to A0 concrete. This indicates that negative effects on the mechanical properties of concrete may occur when the basalt fibre content is increased. This is probably caused by the specific features of interaction between basalt fibres and cement matrix, which can deteriorate the structure of the material and reduce its strength characteristics. Analogous trends are observed in lightweight concrete. When 0.5% fibre was added, the compressive strength of the concrete stayed stable, reaching values of about 71.5 MPa after 28 days of curing. However, when the fibre concentration was increased to 1.5% or more, the compressive strength of concrete started to decrease, which confirms the observations made for heavyweight concretes. These findings have important implications for the design and optimisation of concrete mixtures, especially when strength and crack resistance enhancement is required without considerably altering other mechanical properties. They point out that the amount of basalt fibre introduced into the mix needs to be carefully controlled to avoid adverse effects on the compressive strength of concrete. The findings also highlight that basalt fibre can be an effective material for improving the performance of both light and heavyweight concretes but requires optimisation of dosage to achieve maximum effect. H. Dilbas and Ö. Çakır (2020) also found that the addition of basalt fibres to concrete can improve its crack resistance and mechanical resistance, but a decrease in strength properties was observed when the optimum dosage was exceeded. C. Zhang *et al*. (2021) showed that various additives in concrete mix, including basalt fibres, contribute to the durability of concrete by improving its resistance to aggressive media and cyclic loading. Thus, the findings of this study, in conjunction with the above mentioned studies, highlight the significance of accurately determining and maintaining the optimum dosage of reinforcing fibres to achieve the best mechanical properties and durability of concrete, as well as the need for further research to better understand the interaction of such fibres with the concrete matrix.

A significant result of the study is also the finding that when the heavyweight concrete without fibre addition was analysed, the breaking tensile strength was 4.1 MPa. This value stayed unchanged when 0.5% basalt fibre was added, indicating that there was no significant effect of small amount of fibre on the tensile strength of concrete. However, when 1.5% basalt fibre was introduced, a marked increase in tensile strength up to 4.7 MPa was observed, which is significantly higher than that of the original A0 concrete. When the fibre content was further increased to 3%, the strength increased even further, reaching an increase of 11.3% over the original concrete. This result demonstrates that basalt fibre can considerably improve the tensile strength if the dosage is followed precisely. The maximum strength is recorded exactly at a fibre content of 3%, which emphasises the significance of accurate dosage selection to achieve the best results. The findings suggest that basalt fibre effectively improves the mechanical properties of concrete in tensile breaking, but only if the optimum dosage is maintained. Exceeding this level does not provide additional benefits and may even lead to reduced strength, as proved in other studies. This confirms the need to accurately determine and follow the optimum dosage of basalt fibre. This is a critical factor for improving the strength properties of concrete, which is important for its application in construction projects. L. Dvorkin *et al*. (2021)

showed that the addition of basalt fibre to concrete mixtures can considerably improve their strength characteristics at certain dosages, demonstrating that the optimum concentration of basalt fibre contributes to the strength of different types of concrete. Q. Liu *et al*. (2022) focused on the effect of carbon fibres and showed that their addition also improved the mechanical properties of concrete, but at slightly higher fibre concentrations. At the same time, when comparing the findings of the present study with those of the cited studies, it should be noted that in the former, the effect of different dosages of basalt fibre on the compressive strength of concrete was examined in greater detail. This allows drawing more comprehensive conclusions on the behaviour of concrete when the basalt fibre content is varied, highlighting the significance of precise adherence to the optimum dosage to achieve the best performance. Overall, the study complements and extends the existing data, confirming the effectiveness of reinforcing fibres in the form of basalt fibre and highlighting the need for further research to optimise its use in concrete mixtures.

One of the key findings of this study was to confirm that the addition of basalt fibres substantially affects the flexural strength properties of concrete mixtures. Starting with a small fibre content of 0.5%, a noticeable increase in flexural strength of 11% was observed for the A1 grade mix. This suggests the initial positive effect of the fibres, which form an internal reinforcing structure, inhibiting the development of micro-cracks and distributing the load evenly. Next, when 1.5% fibres were introduced, the increase in flexural strength was already 38.5%, indicating a more intensive reinforcement of their structure. The effective resistance of the fibres to tensile forces and the strengthening of the concrete results in a significant increase in its strength. On further increase in fibre content up to 3%, maximum increase in flexural strength was observed up to 69.8% for A4 grade mix. This result demonstrates that for a given fibre concentration, the optimum reinforcement of concrete is achieved to maximise its mechanical resistance. However, exceeding this dosage up to 5% begins to have a negative effect on the strength of concrete, which is probably due to the specific features of interaction of fibres with cement paste and aggregates. These results play an important role in the field of concrete structures design, especially in the context of finding effective methods to improve their mechanical properties. Understanding the effect of basalt fibre content on the flexural strength of concrete can enable the optimisation of concrete mixes to achieve maximum strength and durability of structures. L. Yang *et al*. (2021) also found that the addition of a large amount of fibre can lead to a decrease in the flexural strength of concrete, indicating insufficient binding to the concrete matrix. S. Biradar *et al*. (2020) also investigated analogous properties, but using materials with distinctive characteristics, highlighting the significance of considering the characteristics of each specific material when using it in concrete mixtures and noting the need for more research to optimise the conditions of use of such reinforcement additives. However, the findings of the present study, in contrast to the studies cited above, suggest the potential effectiveness of basalt fibre as a reinforcing admixture to improve the mechanical properties of concrete. These findings highlight the significance of research in optimising the composition of concrete mixtures considering a range of factors including the type and concentration of materials added.

Thus, the findings of all such studies may not only improve the general understanding of the effect of various reinforcing materials on concrete performance, but also emphasise the significance of further research in this area. Understanding these interrelationships will open new opportunities to develop more efficient and sustainable building materials, which contributes to infrastructure development, improved safety and durability of building structures, and reduced environmental impact. All these factors make such research necessary and relevant for the development of the construction industry and the sustainable development of society.

CONCLUSIONS

As a result of this study, it was confirmed that the optimum dosage of basalt fibres plays a key role in achieving the best mechanical properties of concrete. Upon proper dosage (up to 3%), the fibres improve the structure of concrete, increasing its strength and crack resistance. However, when this optimum level is exceeded (5%), agglomeration of fibres and lack of cement paste to bind the aggregates result in lower flexural strength of concrete.

The study also revealed that the tensile strength and compressive strength of concrete varies with basalt fibre content. The tensile strength showed an increasing trend with the addition of up to 3% fibres, with a maximum increase of 11.3% over the original concrete sample. However, with further increase in fibre content, the tensile strength started to decrease, indicating the significance of maintaining the optimum dosage. The compressive strength with up to 0.5% fibres stayed almost unchanged compared to the control concrete sample. However, when 1.5% fibres were added, the average compressive strength decreased by 2.34% and at 3% the average compressive strength decreased by 3.01% compared to the control concrete sample. The shrinkage of concrete also showed significant variations depending on the fibre content. As the basalt fibre content increased, the shrinkage decreased due to the formation of internal reinforcing structure that prevents the movement of concrete particles and shrinkage reduction. For the heavyweight concrete mix without fibres (A0) the shrinkage was 145 mm, while for the mix with 5% fibres (A4) it decreased to 123 mm. In the case of lightweight concretes, the results showed comparable trends. The compressive strength increased up to a certain level of fibre content but then decreased when the optimum dosage was exceeded. Tensile strength and flexural strength also improved with the addition of up to 3% fibres, confirming the effectiveness of basalt fibres in improving the mechanical properties of concrete.

It is worth remembering that while the study showed considerable positive results, it also revealed some limitations. For instance, the effect of basalt fibres on the durability of concrete under different climatic conditions and over a prolonged period is still understudied. Furthermore, the optimum fibre dosage may vary depending on the type of concrete and its application conditions. Further research in this area may include a more in-depth analysis of the effect of basalt fibres on other concrete characteristics, such as cyclic load resistance, and possible changes in the microstructure of the material, to better understand the long-term effects and performance of basalt fibres under different service conditions.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Фізико-механічні властивості легких і важких бетонів, армованих базальтовою фіброю

Анотація. Це дослідження було спрямоване на вивчення впливу базальтових фібр у бетонних сумішах для поліпшення їхніх фізико-механічних властивостей. Під час роботи використовували портландцемент марки ПЦ400 Д0, гранітний щебінь, перлітове гравійне наповнення і піщану крупку для створення бетонних сумішей різної щільності. Результати проведеної роботи підтвердили, що оптимальне дозування базальтових волокон відіграє ключову роль у досягненні найкращих механічних властивостей бетону. При правильному дозуванні до 3 %, волокна покращують структуру бетону, підвищуючи його міцність і тріщиностійкість. Однак при перевищенні цього рівня до 5 %, агломерація волокон і нестача цементної пасти для зв'язування заповнювачів призводять до зниження міцності бетону на вигин. Дослідження також виявило, що міцність на розрив і міцність на стиск бетону змінюються залежно від вмісту базальтових фібр. Міцність на розрив (вигин) показала тенденцію до збільшення при додаванні до 3 % волокон, з максимальним збільшенням на 11,3 % порівняно з вихідним зразком. Однак при подальшому збільшенні вмісту базальтових фібр, міцність почала знижуватися, підкреслюючи важливість дотримання оптимального дозування. Усадка бетону також змінювалася залежно від вмісту волокон: при збільшенні вмісту базальтових фібр усадка зменшувалася, що пов'язано з формуванням внутрішньої армувальної структури, яка перешкоджає переміщенню частинок бетону. У разі легких бетонів було виявлено аналогічні тенденції: міцність на стиск і міцність на вигин збільшувалися до певного рівня вмісту базальтових фібр, але потім знижувалися в разі перевищення оптимального дозування. Отримані результати підкреслюють важливість ретельного контролю дозування базальтових фібр під час проєктування бетонних конструкцій, оскільки недостатній або надлишковий вміст базальтових фібр може негативно вплинути на механічні властивості бетону. Оптимальне використання базальтових фібр може значно поліпшити міцність, тріщиностійкість та інші характеристики бетону, роблячи його більш стійким і довговічним у різних умовах експлуатації

Ключові слова: структура будівельних матеріалів; фібробетон; міцність на вигин; стиск; розривний розтяг; міцність на розрив; розривне розтягнення