UDC 622.245.422.4
DOI: 10.15587/1729-4061.2023.288551

IDENTIFYING THE INFLUENCE OF BASALT FIBER REINFORCEMENT ON THE DEFORMATION AND STRENGTH CHARACTERISTICS OF CEMENT STONE

Arman Kabdushev
PhD*
Dinara Delikesheva
Corresponding author
PhD***
E-mail: d.delikesheva@satbayev.university
Darkhan Korgasbekov
PhD***
Bauyrzhan Manapbayev
PhD*
Marzhan Kalmakhanova
PhD
Department of Chemistry and Chemical Technology**
*Department of Oil and Gas and Mining**
**M.Kh. Dulaty Taraz Regional University
Suleymenov str., 7, Taraz, Republic of Kazakhstan, 080012
***Department of Petroleum Engineering
Satbayev University
Satpaev str., 22a, Almaty, Republic of Kazakhstan, 050013

The object of the research is the quality of cementing oil and gas wells with increasing the strength and deformation capacity of cement stone using basalt fibers.

Cement slurry used in cementing oil and gas wells faces the problem of failure under the influence of hydraulic fracturing and perforation procedures. This failure leads to the formation of cracks and may require remedial cementing, which increases operating costs and complicates the process of oil and gas production. Moreover, this problem can lead to premature well water breakthrough and cause serious damage such as oil and gas shows and blowouts, which poses a threat to the environment and safety. To solve the problem of the destruction of cement stone under external influences, the study proposed the approach of reinforcing with basalt fiber.

During the study, a cementing material based on Portland cement, reinforced with various concentrations of basalt fibers (0.1 %, 0.5 %, 1 % and 2 %), was developed and tested. Cement strength tests at 2, 7, and 14 days, along with deformation monitoring under load, were performed.

The addition of basalt fibers to cement stone significantly improved its strength characteristics. The most successful results were achieved with the addition of 0.5 % basalt fibers, resulting in an 11 % increase in compressive and flexural strength. Basalt fibers complement the structure of cement stone, increasing its ability to deform.

One of the key features of the obtained results is the possibility of improving the strength of the cement stone without losing its fluidity as a cement slurry.

The results obtained are applicable in the development and production of cement materials based on basalt fibers. This will improve the quality of well cementing and reduce the risks of complications

Keywords: oil well cement, cement composite materials, basalt fiber, strength, deformation characteristics

Received date 04.08.2023
Accepted date 16.10.2023
Published date 30.10.2023

How to Cite: *Kabdushev, A., Delikesheva, D., Korgasbekov, D., Manapbayev, B., Kalmakhanova, M. (2023). Identifying the influence of basalt fiber reinforcement on the deformation and strength characteristics of cement stone. Eastern-European Journal of Enterprise Technologies, 5 (6 (125)), 58–65. doi: https://doi.org/10.15587/1729-4061.2023.288551*

1. Introduction

The increased emphasis on ensuring reliable well cementing, especially its quality, can be attributed to the fact that this stage is the concluding step in well design. Any mishaps or shortcomings during these tasks can undermine all the positive outcomes achieved in earlier phases of the work.

Insufficient cementing quality often becomes the primary cause of oil and gas influxes, gas seepage, and uncontrolled emissions, all of which can result in significant harm. Additionally, subpar cementing leads to an inaccurate estimation of oil and gas reserves in productive formations, contributes to crossflows into lower-pressure strata, and causes water breakthroughs into productive zones. Successfully addressing the task of isolating productive formations plays a crucial role in ensuring the long-term, trouble-free operation of facilities, thereby reducing unforeseen expenses for well maintenance.

Regrettably, experience shows that the most vulnerable part, namely the cementitious material, is the weak link that is easily compromised by external factors. These factors include aggressive environments, pressure differentials, and dynamic loads transmitted to the cementitious material through the casing during various operational procedures, such as hydraulic fracturing and perforation [1–3].

Modern cementitious materials based on Portland cement exhibit insufficient impact resistance and perform poorly under shock loads, as well as having low tensile strength.

Many researchers believe that problems related to premature water breakthroughs in wells are directly linked to the limited deformability of the cementitious material. To enhance the strength properties of the cementitious material, a reinforcement method is employed, involving the addition of fibrous fillers to the cement [4]. This process operates on the principle of a “composer;”, where a portion of the tensile load acting on the cementitious material is transferred to a “reinforcing” layer formed by the added fibers. Various types of fibers, such as asbestos, polyamide, basalt, and others, are effectively used to achieve this goal [5–7].

In recent years, it has been found that basalt fibers in cement exhibit higher strength characteristics and economic efficiency compared to other fibers [5]. Basalt fiber is widely used in the construction industry for reinforcing concrete. Basalt fiber possesses high resistance to aggressive environments, thermal insulation properties, resistance to very low temperatures, high strength, elastic modulus, and is readily available in the market at relatively low cost [5, 7–9]. The fibers are produced from molten volcanic rocks, then passed through special forms to create fibers. Subsequently, the fibers are ground, and a binder is added to create a three-dimensional structure. The advantages of basalt fiber include its light weight, corrosion resistance, high adhesion, and compatibility with the cement matrix [5].

By analyzing the influence of basalt fiber on the mechanical and deformation properties of cementitious materials and developing new formulations, researchers can assess the potential benefits of using such materials in well drilling. These findings drive the development of more flexible cement sheaths that can better withstand issues such as fluid movement, pressure fluctuations, and temperature changes. This, in turn, reinforces the integrity of the wellbore and reduces the risks associated with unwanted fluid migration. Consequently, the study of basalt fiber's impact on the strength and deformation properties of cementitious materials, with the aim of enhancing the reliability of cement sheaths in well drilling, is of great relevance.

2. Literature review and problem statement

The paper [10] presents the results of a study on the impact of adding basalt fiber to various compositions of high-strength concrete. Three mixtures were used in the experiments: one with 100 % cement and two with the replacement of 10 % cement with microsilica and metakaolin, respectively. The results obtained indicate that the addition of basalt fibers in combination with mineral additives increases the compressive strength of concrete. The strains corresponding to maximum compressive and tensile strengths are also improved at all fiber volumes. However, it should be noted that the effect of adding fibers on the elastic modulus of concrete is negligible.

The work [11] focuses on studying the impact characteristics of concrete reinforced with different volume fractions of basalt fiber and its behavior at different strain rates. It is noted that the damage of concrete increases with an increase in the rate of deformation under shock loading. The addition of basalt fibers helps to reduce the brittleness of concrete and increase its impact strength. However, it should be noted that the results of the study emphasize the significant effect of strain rate, and the dynamic compressive strength increases almost linearly with increasing strain rate. It is necessary to consider the limitations associated with the use of a particular research method and the characteristics of the conditions used.

The study [12] examines the influence of adding different proportions of basalt fiber to concrete to enhance its impact viscosity and prevent cracking. Tests were conducted on concrete samples with varying contents of basalt fiber for compression, tension, and flexure. The test results, failure modes, and mechanical properties were compared and analyzed to establish the relationship between the content of basalt fiber and the mechanical properties. The obtained data show that basalt fiber significantly improves the strength and crack resistance of concrete. The effect of basalt fiber on compressive strength is less pronounced compared to tensile and flexural strength. The greatest improvement is observed at a basalt fiber content of 0.3 % and 0.4 %.

The work [13] aims to investigate the influence of basalt fiber content on the mechanical properties of uniaxial compression and damage characteristics of concrete. The results showed that introducing an appropriate amount of basalt fiber enhances the compressive strength of concrete, reduces damage characteristics, slows down cracking, and transforms long cracks into micro-cracks.

The paper [14] presented a comprehensive examining of the deformation of basalt fiber-reinforced cement stone using a method for studying the dynamic shear characteristics of cement stone at various concentrations from 0.1 % to 0.3 % and at various fiber lengths, followed by scanning on an electron scanning microscope. The experiments carried out showed the effectiveness of using a fiber length of 6 mm at a concentration of 0.2 %. However, the presented studies were not compared with strength characteristics and the influence of the dynamic shear characteristics on other technological properties of cement was not shown.

In the study [15], tests were conducted on the tensile splitting of concrete specimens with varying loading rates and basalt fiber content, the influence of these variables on the dynamic splitting properties during tension and the damage characteristics of basalt fiber-reinforced concrete. The results showed that the inclusion of basalt fiber can increase the flexural strength of concrete and result in more ductile behavior with fewer cracks. Additionally, the fiber improves crack resistance and significantly enhances the behavior of beams under flexural loading.

In the paper [16], the characteristics of the behavior and energy dissipation of basalt fiber-reinforced concrete with different fiber content at different strain rates are investigated. The experiments were carried out using a split Hopkinson pressure bar. According to the results of the study, the fractal dimension of basalt-fiber-reinforced concrete increases in proportion to the strain rate, while the introduction of fiber restrains this growth. The process of dynamic concrete failure distinguishes four sections: initial compaction, plastic flow, energy storage after peak load, and subsequent damage. The density of dissipated energy increases linearly with increasing strain rate, and the energy dissipation rate has a quadratic dependence on the fractal dimension and strain rate.

Research findings indicate that the inclusion of basalt fibers in concrete does not significantly influence its compressive strength. Also, the strength properties under compression and bending are regulated for cement stone. However, some researchers believe it is necessary to introduce requirements for the elastic properties of cement stone and propose introducing indicators of cement stone properties necessary for evaluating its elastic properties, which are important during operations that subject it to impact loads [13, 14, 17, 18]. The examination conducted highlights that most studies have concentrated on assessing strength-related properties, while a comprehensive understanding of its deformation characteristics remains relatively limited. Consequently, it is advisable to explore the effects of basalt fiber on deformation characteristics and formulate a suitable cement slurry accordingly. This would not only expand our understanding of the material's behavior but also facilitate the development of cement slurries tailored to specific performance requirements, including deformation-related aspects.

Hence, it is advisable to conduct further research to explore how basalt fiber affects deformation characteristics and to formulate a suitable cement slurry accordingly.

3. The aim and objectives of the study

The aim of this study is to identify the effect of adding basalt fiber on the strength and deformation capacity of cement stone. This will increase the long-term integrity of cement used in oil well cement slurries.

To achieve the set aim, the following objectives have been identified:

– to study the effect of basalt fibers on the strength properties of cement stone;

– to study the deformation characteristics of cement stone under various types of loads: bending, compression and rupture.

4. Materials and methods

The object of the research is the quality of cementing oil and gas wells with increasing the strength and deformation capacity of cement stone using basalt fibers.

The operational concept behind fiber-reinforced cements, which incorporate fibers from diverse sources, relies on the observation that when the material is subjected to dynamic loads, a portion of the load is absorbed by the fibers integrated into the cement matrix. These cements exhibit a distinct mode of structural failure, with the gradual deterioration of the fibers that are tightly bonded to the cement substrate. This characteristic enables an enhancement in the overall strength of the cement under various types of loading conditions, while also increasing its resistance to impacts.

In this paper, we present the results of experiments in which we investigated the strength of cement stone at different fiber concentrations and at different stages of hardening. We also analyzed how the deformation capacity of the stone changes depending on the hardening time at different fiber concentrations.

When determining the strength and deformation capacity, a Portland cement I-50 class (applicable according to GOST 1581-2019) with a water-cement ratio of 0.5 was used, and the following mixtures were employed:

1. Base Portland cement.
2. Base Portland cement+basalt fiber (0.1 % by mass).
3. Base Portland cement+basalt fiber (0.5 % by mass).
4. Base Portland cement+basalt fiber (1 % by mass).
5. Base Portland cement+basalt fiber (2 % by mass).

The water-cement ratio was set at 0.5, which is explained by using Portland cement I-50 in our study, designed for shallow wells with low to moderate temperature conditions according to GOST 1581-2019. This is particularly relevant for wells that do not exceed a depth of 2,500 meters.

The main characteristics of basalt fiber are shown in Table 1.

Basalt rocks are based on various minerals, including basic plagioclase (labradorite), bytonite, augite, olivine, and a glassy phase. Each of these minerals has its own unique chemical composition and structure.

The basic plagioclase, represented as a labradorite, has the following chemical formula: $K_{0.1}Na_{0.54}Ca_{0.36}(Si,Al)_4O_8$. Bytovnite has the formula $K_{0.1}Na_{0.72}Ca_{0.18}(Si,Al)_4O_8$. Augite is represented by the formula $[Ca\ (Mg,Fe(II))(Al,Fe(III),Ti)\{(Si,Al)_2O_6\}]$. Olivine is denoted by the formula $[(Mg,Fe)_2\{SiO_4\}]$. In addition, basalt contains an incompletely crystallized glassy phase [19].

The chemical composition of basalt includes the main rock-forming oxides. SiO_2 is 43–58 % (wt.), Al_2O_3 is 11–20 %, CaO is 7–13 %, $FeO+Fe_2O_3$ is 8–16 %, and MgO is 4–12 %. In addition to these oxides, basalt also contains Na_2O, K_2O, and TiO_2, the content of the latter can reach up to 4 % [20].

The appearance of the fiber is shown in Fig. 1.

Fig. 1. Basalt fiber

Strength tests of the cement stone sample were carried out at the age of 2, 7 and 14 days. After preparation and extraction from water, the cement samples were tested on a Mitsis-200-3 instrument. The flexural and compressive strength tests were conducted following the guidelines outlined in GOST 28985-91. For these tests, molds conforming to the specifications of GOST 28985-91 were utilized to prepare cement beams with dimensions of 40×40×160. The test was conducted using basalt fiber with diameters of both 3 mm and 6 mm. The device is shown in Fig. 2.

This device, in addition to compressive and bending strength, made it possible to measure the deformation of cement stone. To facilitate this process, an enhancement was implemented by incorporating dial indicators with a scale division of 0.01 mm into the device's structure. Fig. 3 illustrates the dial indicator.

A schematic diagram of the deformation determination is shown in Fig. 4, which shows a sample of cement stone, the deformation of which is recorded by dial gauges.

To determine the deformation, it is necessary to compare the readings of the dial indicators before and after applying the load to the sample. The difference between the initial and final readings of the indicators was used to determine the degree of sample deformation.

Table 1

Physical Characteristics of Basalt Fiber

Minimum fiber diameter (μm)	Maximum fiber diameter (μm)	Average fiber diameter (μm)	Measured length of the fiber segment (mm)	Mass fraction of moisture, no more	Loose mass density, kg/m^3	Chemical resistance (weight loss after 3 hr boiling, g):			Operating temperature, °C
						in water	in sodium hydroxide	in hydrochloric acid	
20	400	200±20	6.12.18.24±1.0	0.3	70–80	1.6	2.75	2.2	from minus 270 to plus 750

Fig. 2. Mitsis-200-3 device

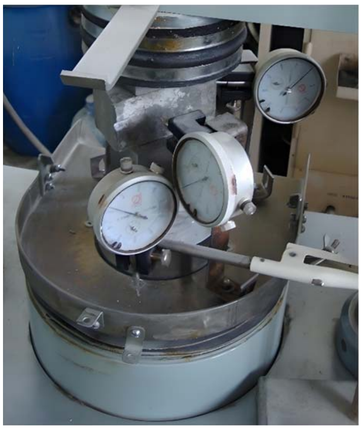

Fig. 3. Dial indicators

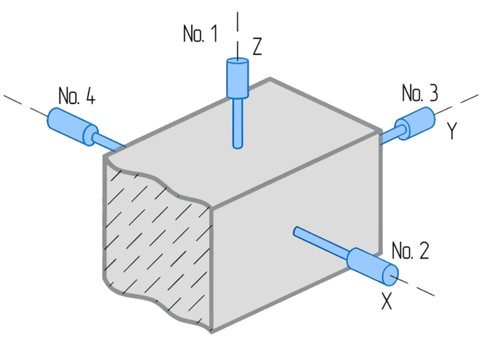

Fig. 4. Schematic diagram of testing a cement sample

The maximum load during loading tests is recorded on the digital control panel, and the device also allows you to record the results of research.

5. Results of experimental investigation of the strength characteristics and deformation capacity of cement stone reinforced with basalt fiber

5. 1. Investigation of the strength characteristics of cement stone for each concentration

The results of studies of strength characteristics for each concentration and 2, 7, 14 days of hardening are shown in Table 2.

Table 2 suggests that even though on the 2nd and 7th days there is no increase in tensile strength at any concentration of basalt fibers, already on the 14th day of hardening, the best result in terms of compressive strength and bending strength of cement stone is observed at a basalt fiber concentration of 0.5 %.

Table 2

Results of experiments to determine the strength of cement stone at different concentrations and different ages of hardening

Fiber percentage	Ultimate compressive strength, N/mm^2			Ultimate flexural strength, N/mm^2		
	2 days	7 days	14 days	2 days	7 days	14 days
Portland cement	24.50	39.79	37.47	6.04	5.67	6.68
Portland cement+0.1 %	23.59	29.94	38.36	4.32	5.83	5.79
Portland cement+0.5 %	23.66	26.95	41.58	5.31	5.17	7.43
Portland cement+1 %	23.67	30.72	38.18	4.94	6.01	4.71
Portland cement+2 %	23.43	33.34	27.84	5.65	5.41	5.69

As an example of the dependence of deformation on loading, we present the results of measuring a cement stone at the age of 2 days at various concentrations of basalt fiber.

5. 2. Investigation of the deformation capacity of reinforced cement stone under load

According to the results of the research, the dependencies of the load on the magnitude of deformation of the cement stone at the age of 2 days were obtained, the results are displayed in Fig. 5–9.

When using pure cement (Fig. 5), the deformation of the cement stone increases with increasing load. This can be seen from the strain values that increase as the load increases.

The strain values for each indicator are different. Longitudinal deformation (1st indicator) has lower values compared to transverse deformation (3rd indicator) and transverse deformation for the 2, 4th indicators.

With an increase in load, the strain values for all indicators increase, which indicates an increase in the overall deformation of the cement stone.

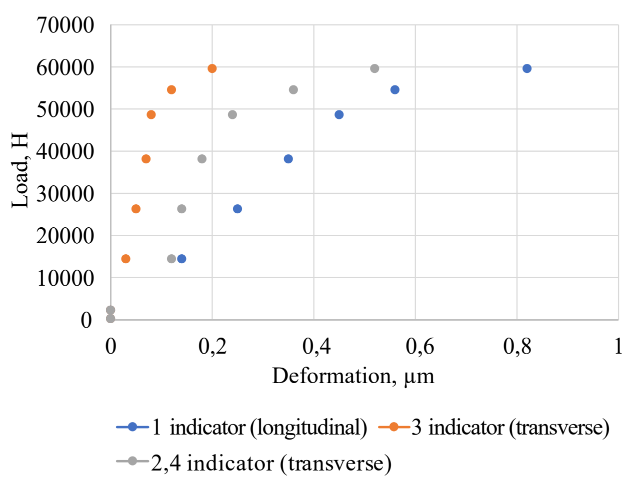

Fig. 5. Deformation of cement stone for each indicator, pure cement

When adding 0.1 % fibers to the cement stone (Fig. 6), a decrease in the deformation value is observed compared to pure cement under the same loads.

The addition of fibers results in a reduction in deformation in all indicators. The strain values for each indicator when fibers are added are less than for pure cement at the same loads.

The strain values for each indicator increase with increasing load, but with fibers they remain lower than with pure cement.

Longitudinal deformation (1st indicator) has lower values compared to transverse deformation (3rd indicator) and transverse deformation for the 2, 4th indicators, which indicates more effective resistance to deformation in the longitudinal direction.

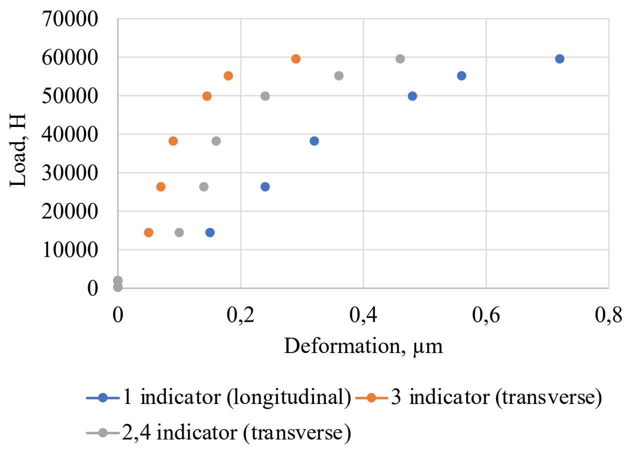

Fig. 6. Deformation of the cement stone for each indicator, 0.1 % fiber

By adding 0.5 % fibers to the cement stone (Fig. 7), the deformation is significantly reduced compared to pure cement and cement with 0.1 % fibers.

The strain values for each indicator when using 0.5 % fibers are the smallest compared to other concentrations, indicating a higher efficiency of adding more fibers.

Longitudinal strain (1st indicator) still has smaller values compared to transverse strain (3rd indicator) and transverse strain for the 2, 4th indicators.

As the load increases, the strain values increase but remain lower compared to pure cement and cement with 0.1 % fibers.

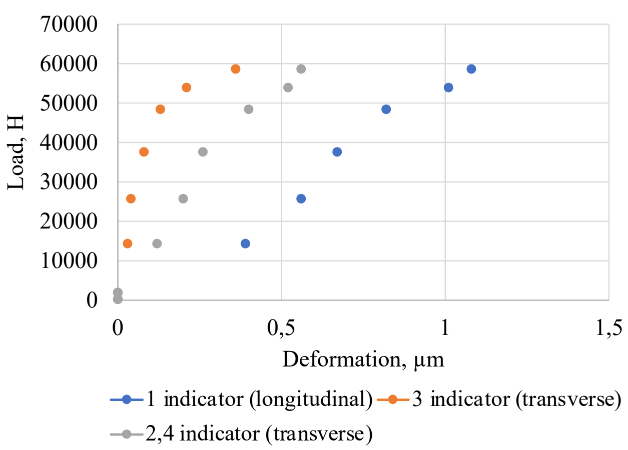

Fig. 7. Deformation of the cement stone for each indicator, 0.5 % fiber

From the graph (Fig. 8), with an increase in load, there is an increase in the values of deformation for all indicators. Longitudinal deformation (1st indicator) has the smallest values, while transverse deformation (3rd indicator and 2, 4th indicators) has more pronounced values. The use of 1 % fiber in the cement stone results in more noticeable transverse deformation compared to longitudinal deformation.

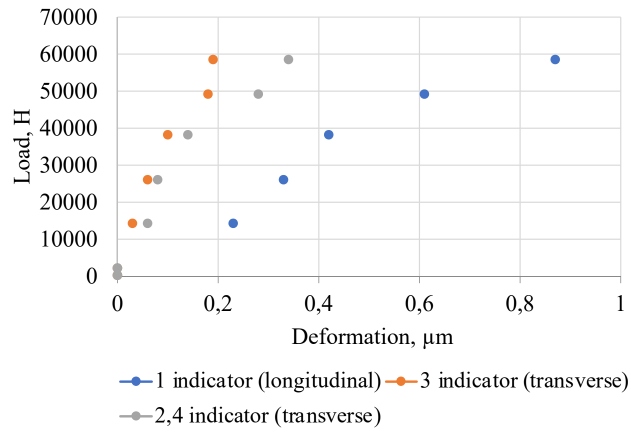

Fig. 8. Deformation of the cement stone for each indicator, 1 % fiber

It can be seen from the graph (Fig. 9) that with an increase in load, an increase in the values of deformation occurs for all indicators. Longitudinal deformation (1st indicator) has the smallest values, while transverse deformation (3rd indicator and 2, 4th indicators) has more pronounced values. The use of 2 % fiber in the cement stone results in more noticeable transverse deformation compared to longitudinal deformation.

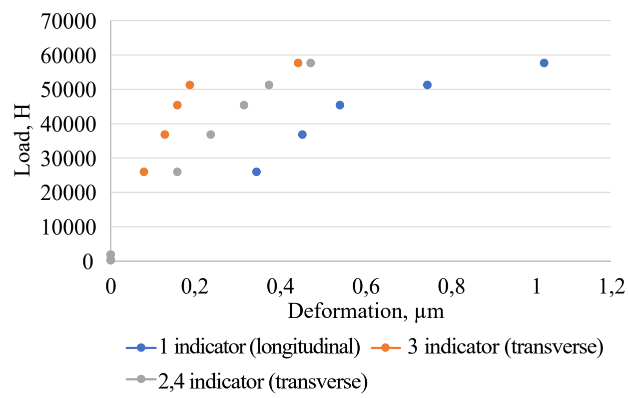

Fig. 9. Deformation of the cement stone for each indicator, 2 % fiber

With an increase in the concentration of fibers in the cement stone, an increase in the strain values is observed. The transverse deformation (3rd indicator and 2, 4th indicators) becomes more noticeable compared to the longitudinal deformation (1st indicator).

2 % fiber results in more pronounced strain values across all indicators compared to 0.5 % and 1 % fiber. Based on the presented data, it can be assumed that a fiber content of 0.5 % may be potentially optimal for achieving maximum strength of the cement stone. In this range, there is a signif-

icant increase in the strength of the material and a moderate increase in deformation.

The results of experiments to study the longitudinal and transverse deformation of the stone are shown in Fig. 10–12.

Longitudinal deformation of the cement stone: With increasing fiber concentration (from 0.1 % to 2 %), the longitudinal deformation of the cement stone decreases over time from the onset of hardening (2, 7 and 14 days). This indicates an improvement in the strength characteristics of the material with the addition of fibers. There is a decrease in deformation with increasing hardening time in all cases.

Transverse deformation according to the second and fourth indicators: With increasing fiber concentration (from 0.1 % to 2 %), the transverse deformation according to the second and fourth indicators has different dynamics depending on the hardening time. In some cases (e. g. 2 week-curing) there is a decrease in strain with increasing fiber concentration, while in other cases (e.g. 7-day curing) there is an increase in strain with increasing fiber concentration.

The third indicator transverse deformation: In the case of the third indicator transverse deformation, the effect of fiber concentration and hardening time is also observed. An increase in the fiber concentration can lead to both an increase and a decrease in transverse strain, depending on the hardening time.

The graph below (Fig. 10) shows that with increasing fiber concentration, the longitudinal deformation of the cement stone decreases. It is also noticeable that over time (hardening time), the deformation decreases regardless of the fiber concentration.

In the graph below (Fig. 11), with an increase in the fiber concentration, the transverse deformation of the cement stone according to the second and fourth indicators increases. It can also be seen that the strain decreases over time for all fiber concentrations.

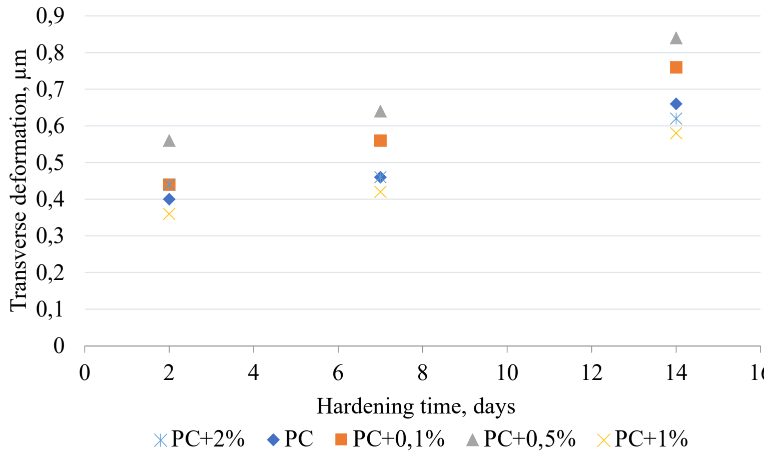

Fig. 11. Correlation of the transverse deformation according to the second and fourth indicators and hardening time of the stone at various concentrations

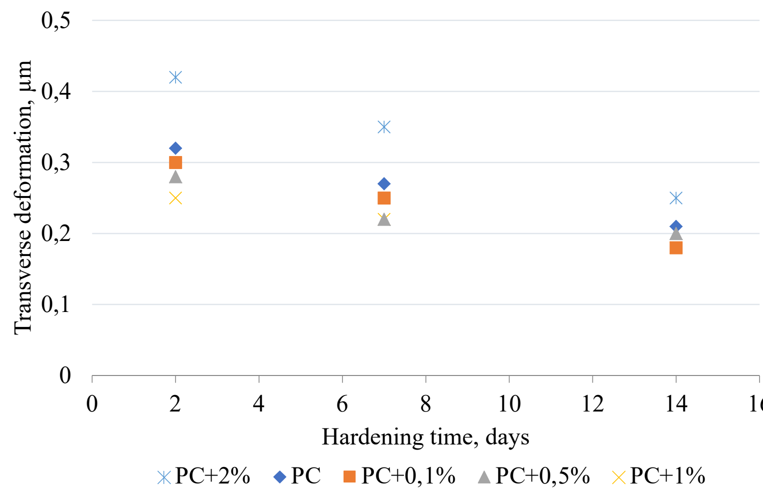

Fig. 12. Correlation of the transverse deformation according to the third indicator and hardening time of the stone at various concentrations

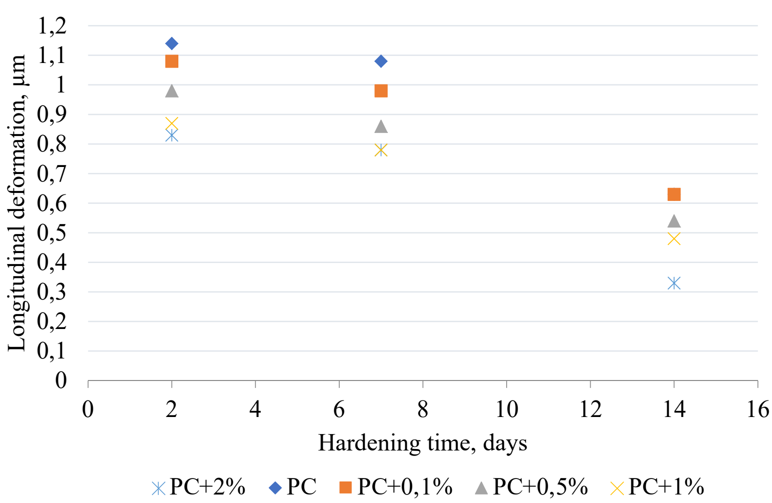

Fig. 10. Correlation of the longitudinal deformation and hardening time of the stone at various concentrations

There is a decrease in longitudinal strain with increasing fiber concentration. The optimum fiber content for minimum buckling may be in the range of 0.5 % to 2 %.

The effect of fiber concentration on transverse strain can be ambiguous and depends on the setting time and the specific indicator. In some cases, the optimum fiber content for minimum transverse strain may be around 0.1 %, while in other cases the optimum content may be higher, for example in the range of 0.5 % to 1 %.

6. Discussion of the experimental results of cement stone basalt fiber reinforcing

The obtained results can be attributed to several factors. The study clearly demonstrates the impact of varying concentrations of basalt fibers and different curing durations (2, 7, and

14 days) on the material's strength characteristics (as shown in Table 2). Notably, during the initial 2 and 7 days, there is no significant increase in tensile strength observed with the addition of basalt fibers across all concentrations. However, a noticeable enhancement in compressive and flexural strength becomes evident on the 14^{th} day when utilizing a 0.5 % concentration of basalt fiber.

Regarding deformation analysis under various loads, distinct trends emerge (as depicted in Fig. 5–9). Pure cement samples exhibit a correlation between increased loads and augmented deformations, as confirmed by rising deformation values. This trend varies across different parameters, where longitudinal deformation exhibits lower values compared to lateral and transverse deformations. The inclusion of 0.1 % basalt fibers in cement notably reduces deformations at the same loads as pure cement, with fiber admixture leading to reduced deformation values across all parameters, even lower than pure cement. While deformations increase under higher loads, they remain lower in the presence of fibers. Notably, longitudinal deformation displays greater stability than transverse deformation.

Furthermore, the introduction of 0.5 % basalt fiber substantially reduces deformations compared to both pure cement and the 0.1 % fiber concentration. At this concentration, minimal deformation values are evident, indicating the higher effectiveness of increased fiber concentration. Despite the persistent lower longitudinal deformation compared to transverse deformation, the application of higher loads still leads to greater deformation values than using pure cement and the 0.1 % fiber concentration.

A detailed examination of deformation with varying fiber concentrations reveals an interesting pattern. Deformation values increase with elevated fiber concentrations, particularly for transverse deformations. A high fiber concentration (2 %) results in more pronounced deformation than concentrations of 0.5 % and 1 %. From the data gathered, it can be deduced that the optimal fiber content for achieving maximum cement strength is 0.5 **%**, leading to significantly increased strength and moderate deformation enhancement.

The analysis of longitudinal and transverse deformation patterns (as depicted in Fig. 10–12) highlights intriguing tendencies. Longitudinal deformation diminishes with higher fiber concentrations, indicating improved material strength over time. The dynamics of transverse deformation are influenced by the duration of exposure, demonstrating both reduction and elevation of deformation under higher fiber concentrations, contingent on exposure periods. The impact of fiber concentration on transverse deformation proves intricate and variable, dependent on curing time and specific parameters. The optimal fiber content for minimizing transverse deformation can range from 0.1 % to 1 %.

This work provides a detailed characterization of load-strain behavior at various fiber concentrations, which may be crucial in developing optimal building solutions using these materials.

However, it's important to acknowledge the limitations of this study. The tests were conducted within a limited time frame (2, 7, and 14 days), which may not fully account for the long-term effects of basalt fibers on the material. Additionally, laboratory test conditions may not accurately replicate the influence of real construction factors such as environmental and chemical influences. Considering additional types of reinforcement and real building conditions can provide a more comprehensive understanding of material behavior.

For the further development of this study, real construction scenarios, various types of reinforcement, and the long-term behavior of the material should be taken into account. It is also essential to conduct more comprehensive analyses that consider the economic feasibility and practicalities of building practices. Addressing these limitations will yield more applicable and accurate results for the construction industry.

7. Conclusions

1. Failure of fiber-reinforced cement varies markedly from base cement behavior. Standard composition breakdown results in large chip formation due to brittle fragmentation. Reinforced cement failure reveals smaller local cracks and chips, indicating higher energy-intensive destruction. Reinforcement of concrete with fiber increases its strength characteristics, as well as plastic properties. In the study, with the help of reinforcement, it was possible to increase the compressive and bending strength by 11 %. This is since a randomly located fiber in the composition of the cement matrix perceives a part of the external load, not allowing it to fully affect the cement stone in the initial stages of loading. The most successful results were achieved with the addition of 0.5 % basalt fiber, at which the stone has the highest strength characteristics and does not lose its flow properties in the form of a cement mortar. The optimal concentration of the reinforcing material is 0.5 %, it is at this ratio that the strength and deformation characteristics can be increased while maintaining the flow properties of the cement slurry.

2. Deformation values exhibit an upward trend with increasing fiber concentrations, particularly in the case of transverse deformations. A high fiber concentration (2 %) notably yields more significant deformations compared to concentrations of 0.5 % and 1 %. The optimal fiber content for maximizing cement strength is 0.5 %, resulting in a substantial increase in strength with a moderate enhancement in deformation.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The paper was prepared within the framework of the project AP09058636 "Development of cement slurries with differential properties" within the framework of the ongoing competition for grant funding of fundamental and applied research of young scientists on scientific and (or) scientific and technical projects for 2021–2023 by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

Data availability

Data will be made available on reasonable request.

References

1. Zhu, H. Y., Deng, J. G., Zhao, J., Zhao, H., Liu, H. L., Wang, T. (2014). Cementing failure of the casing-cement-rock interfaces during hydraulic fracturing. Computers and Concrete, 14 (1), 91–107. doi: https://doi.org/10.12989/cac.2014.14.1.091
2. Fedorov, B., Ratov, B., Sharauova, A. (2017). Development of the model of petroleum well boreability with PDC bore bits for Uzen oilfield (the Republic of Kazakhstan). Eastern-European Journal of Enterprise Technologies, 3 (1 (87)), 16–22. doi: https://doi.org/10.15587/1729-4061.2017.99032
3. Yan, Y., Guan, Z., Yan, W., Wang, H. (2020). Analysis Method of Cement Sheath Damage Zone After Perforation. SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition. doi: https://doi.org/10.2118/196556-ms
4. Purnell, P., Short, N. R., Page, C. L., Majumdar, A. J. (2000). Microstructural observations in new matrix glass fibre reinforced cement. Cement and Concrete Research, 30 (11), 1747–1753. doi: https://doi.org/10.1016/s0008-8846(00)00407-5
5. Bheel, N. (2021). Basalt fibre-reinforced concrete: review of fresh and mechanical properties. Journal of Building Pathology and Rehabilitation, 6 (1). doi: https://doi.org/10.1007/s41024-021-00107-4
6. Paiva, L. C. M., Ferreira, I. M., Martinelli, A. E., Freitas, J. C. de O., Bezerra, U. T. (2019). Milled basalt fiber reinforced Portland slurries for oil well applications. Journal of Petroleum Science and Engineering, 175, 184–189. doi: https://doi.org/10.1016/j.petrol.2018.11.068
7. Zheng, Y., Zhang, Y., Zhuo, J., Zhang, Y., Wan, C. (2022). A review of the mechanical properties and durability of basalt fiber-reinforced concrete. Construction and Building Materials, 359, 129360. doi: https://doi.org/10.1016/j.conbuildmat.2022.129360
8. Wang, S., Chen, F., Xue, Q., Zhang, P. (2020). Splitting Tensile Strength of Cement Soil Reinforced with Basalt Fibers. Materials, 13 (14), 3110. doi: https://doi.org/10.3390/ma13143110
9. Afroz, M., Patnaikuni, I., Venkatesan, S. (2017). Chemical durability and performance of modified basalt fiber in concrete medium. Construction and Building Materials, 154, 191–203. doi: https://doi.org/10.1016/j.conbuildmat.2017.07.153
10. Ayub, T., Shafiq, N., Nuruddin, M. F. (2014). Mechanical Properties of High-performance Concrete Reinforced with Basalt Fibers. Procedia Engineering, 77, 131–139. doi: https://doi.org/10.1016/j.proeng.2014.07.029
11. Zhang, H., Wang, B., Xie, A., Qi, Y. (2017). Experimental study on dynamic mechanical properties and constitutive model of basalt fiber reinforced concrete. Construction and Building Materials, 152, 154–167. doi: https://doi.org/10.1016/j.conbuildmat.2017.06.177
12. Zhou, H., Jia, B., Huang, H., Mou, Y. (2020). Experimental Study on Basic Mechanical Properties of Basalt Fiber Reinforced Concrete. Materials, 13 (6), 1362. doi: https://doi.org/10.3390/ma13061362
13. Yang, L., Xie, H., Fang, S., Huang, C., Yang, A., Chao, Y. J. (2021). Experimental study on mechanical properties and damage mechanism of basalt fiber reinforced concrete under uniaxial compression. Structures, 31, 330–340. doi: https://doi.org/10.1016/j.istruc.2021.01.071
14. Xie, L., Sun, X., Yu, Z., Zhang, J., Li, G., Diao, M. (2023). Experimental Study and Mechanism Analysis of the Shear Dynamic Performance of Basalt Fiber–Reinforced Concrete. Journal of Materials in Civil Engineering, 35 (1). doi: https://doi.org/10.1061/(asce)mt.1943-5533.0004549
15. Zhang, H., Ji, S., Wang, L., Jin, C., Liu, X., Li, X. (2022). Study on dynamic splitting tensile damage characteristics of basalt fiber reinforced concrete based on AE and DSCM. Journal of Building Engineering, 57, 104905. doi: https://doi.org/10.1016/j.jobe.2022.104905
16. Zhou, Y., Zou, S., Wen, J., Zhang, Y. (2023). Study on the damage behavior and energy dissipation characteristics of basalt fiber concrete using SHPB device. Construction and Building Materials, 368, 130413. doi: https://doi.org/10.1016/j.conbuildmat.2023.130413
17. Kumbhar, P. V. (2014). An overview: basalt rock fibers-new construction material. Acta Engineering International, 2 (1), 11–18. Available at: https://www.researchgate.net/publication/302987042_An_overview_basalt_rock_fibres-new_construction_material
18. Agzamov, F. A., Belousov, A. O. (2018). Substantiation of the methodology for assessing dangerous stresses in the body of cement stone during technological operations in a well. Oil Province, 4, 225–239.
19. Gao, S. L., Mäder, E., Plonka, R. (2007). Nanostructured coatings of glass fibers: Improvement of alkali resistance and mechanical properties. Acta Materialia, 55 (3), 1043–1052. doi: https://doi.org/10.1016/j.actamat.2006.09.020
20. Barhum, R., Mechtcherine, V. (2012). Effect of short, dispersed glass and carbon fibres on the behaviour of textile-reinforced concrete under tensile loading. Engineering Fracture Mechanics, 92, 56–71. doi: https://doi.org/10.1016/j.engfracmech.2012.06.001