Sustainable heavy concrete additives: evaluating granite-based solutions for eco-efficient construction

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Abstract. This article presents the results of a study on the influence of one component of a newly developed modifying additive (specifically, granite dust) on the strength properties of concrete. The comprehensive study included standardized tests of beam samples for flexural and compressive strength. The research was conducted with varying concentrations of granite in the concrete mix: 1%, 2%, 3%, and 4%. The study results yielded curves illustrating changes in concrete strength relative to the concentration of granite added to the mix. The resulting curve of this relationship indicated that the optimal concentration of granite in concrete is 2%, at which the maximum sample strength was observed. With further increases in granite concentration, a decrease in strength was noted, both in compressive and flexural strength indicators.

1 Introduction

The modern world faces a pressing challenge in the disposal of industrial waste. Today, industrial waste has become a valuable raw material for creating new materials, including those used in construction. This article focuses on an innovative additive developed from a composite mix of industrial raw materials, showcasing promising opportunities for waste recycling and reducing environmental impact [1]. The additive comprises a unique composition of the following components: granite (Gr), soapstock (a by product of refined oil production, referred to as Sp), post-alcohol distillers' grains (a by product of alcohol production, referred to as PaB), as well as caustic soda (NaOH) as a stabilizer, and acrylic latex (a polymer component of the additive, referred to as Lx).

The proposed modifying additive is designed to enhance the physical and mechanical properties of pile foundations developed using a new technology. The foundation technology proposed in this project fundamentally differs from existing counterparts on the construction market, specifically from the classic square-section driven pile. The technological effect of increasing load-bearing capacity on the ground is achieved by incrementally rotating sections of the pile at various angles relative to the pile's axis of symmetry [2]. This effect is achieved through changes in the nature of the lateral contact between the pile and the soil, resulting in

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additional resistance areas. Consequently, the increased load-bearing capacity of the pile necessitates an increase in the material strength of the pile [3]. To improve the strength (and other) characteristics of the concrete, a comprehensive modified additive is proposed.

The granite dust included in the additive is generated in the process of granite crushing and coarse aggregate separation. It is a powder with particle sizes ranging from 0.05 to 0.07 mm [4]. The inclusion of granite in the additive aims to reduce the water absorption of the concrete (a generally accepted practice); however, its potential influence on the strength properties becomes a significant area of study, especially given the specific use of regional raw materials. Post-alcohol distillers' grains, a byproduct rich in organic substances, acts as a modifier in the proposed additive, affecting the plasticity and water-retaining ability of the concrete mix. The use of distillers' grains in the additive not only helps reduce waste volume but also enhances the additive's properties, such as increasing its adhesion to various materials [5]. The combination of neutralized soapstock and acrylic latex creates a hydrophobic material with increased frost resistance and reduced water absorption, capable of withstanding exposure to aggressive environments [6].

Currently, there exists a wide range of specialized additives to improve concrete quality. Some additives focus on targeted improvements, while others aim at comprehensive transformation. In any case, each additive offers distinct qualitative and quantitative improvement indicators, as well as cost considerations.

The modified additive developed in this project represents a unique technological solution and is classified as a new invention without existing counterparts in production.

The purpose of this study is to assess the impact of each component mentioned above. However, this article presents the results of only the first stage of the research, specifically, the influence of granite dust on the transformation processes of concrete, particularly its strength properties.

2 Methods

Determining the optimal composition of the modified additive involves sequential studies to assess the impact of each component on the qualitative properties of the cement-sand mixture:

Stage 1: Assessment of the influence of granite dust on the physical and mechanical properties of concrete with varying compositions;

Stage 2: Assessment of the influence of soapstock on the physical and mechanical properties of concrete with varying compositions;

Stage 3: Assessment of the influence of post-alcohol distillers' grains on the physical and mechanical properties of concrete with varying compositions;

Stage 4: Assessment of the influence of acrylic latex on the physical and mechanical properties of concrete with varying compositions.

After the studies to determine the optimal concentration of each component, the composition of the modified additive will be adjusted by mass. Table 1 presents the varying compositions of the mixtures used at each stage of the research.

Table 1. Variants of the studied mixture compositions.

Stage	**Component content by weight, g**							
	Sand	**Gr**	**Cement**	**Sp**	**NaOH**	**PaB**	**Water**	**Lx**
Reference	1500	0	500	-	-	-	200	-
Stage 1	1485	15	500	-	-	-	200	-
	1470	30	500	-	-	-	200	-
	1455	45	500	-	-	-	200	-
	1440	60	500	-	-	-	200	-

Continuation of Table 1.

Stage 2	1500	470	29.7	0.3	-	200	-
	1500	460	39.6	0.4	-	200	-
	1500	450	49.5	0.5	-	200	-
	1500	440	59.4	0.6	-	200	-
Stage 3	1500	500			4	196	-
	1500	500			8	192	-
	1500	500			12	188	-
	1500	500			18	182	-
Stage 4	1500	500			199.8		0.2
	1500	500			199.6		0.4
	1500	500			199.4		0.6
	1500	500			199.2		0.8

In the process of fabricating beam-shaped samples, polyfractional sand was initially used. However, for mineralogical composition analysis, the use of polyfractional sand is not entirely accurate. Due to the small size of the samples, polyfractional sand can lead to an uneven distribution of fractions from sample to sample. Consequently, screened sand with a fraction size of 0.63 mm (medium grain size) was used instead. Although the mixture is prepared by the mass of components (thus ensuring identical sand content by weight for each sample regardless of fraction sizes), using a fixed fraction size allows for consistent quantitative conditions during the hydration process (i.e., an identical number of sand grains in each sample per binding agent unit). Due to the small mixture sizes, analytical scales were employed for precise measurement.

The ratio of granite to sand is 1%, 2%, 3%, and 4% by mass. The ratio of soapstock with caustic soda to cement is 6%, 8%, 10%, and 12% by mass. The ratio of post-fermentation distillers' grains to water is 2%, 4%, 6%, and 8% by mass. The ratio of acrylic latex to soapstock and water is 0.1%, 0.2%, 0.3%, and 0.4% by mass.

The assessment of the compressive and flexural strength of the beam samples was carried out in accordance with GOST 310.4 (Figure 1). A comparative strength analysis of samples with varying compositions was conducted to determine the optimal composition of the modified additive and to evaluate its effectiveness. Comparing the strength properties of samples with and without additives allows for an assessment of the additive components' impact on concrete modification and transformation, particularly in terms of strength enhancement.

3 Test results

Figure 1 shows the average strength values of the reference sample beams under compression and flexion (Figure 1a – compression, Figure 1b – flexion). The diagrams display individual values for each sample (points) as well as their corresponding average values (line) at different concrete ages (7, 14, and 28 days).

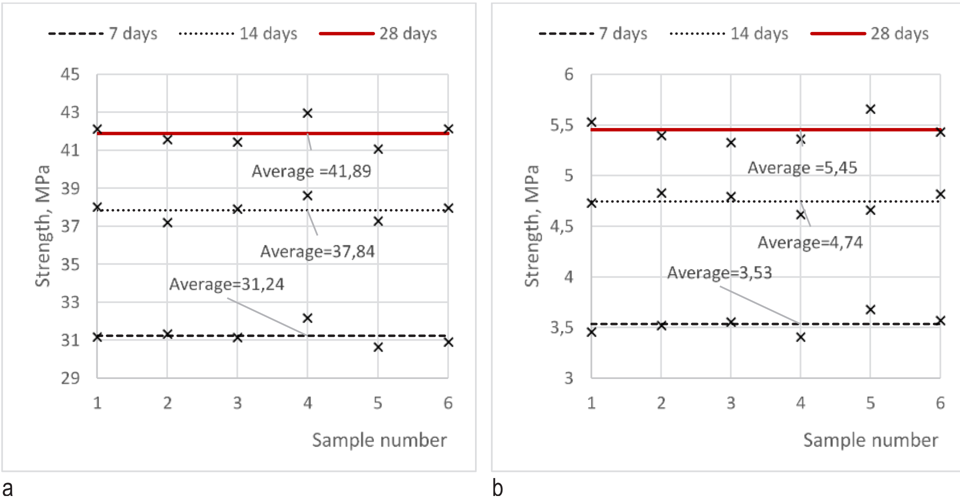

Fig. 1. Strength measurements of the reference sample.

According to the test results for the reference sample under compression, the variation in individual values at 7 days ranged from 30.65 to 32.19 MPa, with an average of 31.24 MPa. At 14 days, these values ranged from 37.21 to 38.62 MPa, with an average of 37.84 MPa. At 28 days, with 100% strength attainment, the compressive strength ranged from 41.09 to 42.14 MPa, averaging 41.89 MPa. At 7 days, the samples achieved approximately 75% of the maximum strength corresponding to 100% at 28 days. At 14 days, this value reached 90%. This data will be useful for assessing the additive's impact on the rate of concrete strength gain. Across all strength measurements at various ages, a strong correlation was observed between individual values, with variation coefficients of 1.7 for 7-day samples, 1.4 for 14-day samples, and 1.6 for 28-day samples. Consequently, a strength loss threshold of 1.6% was established as the statistical limit when assessing strength reduction in samples with different compositions from the reference sample.

In the flexural strength tests for the reference sample, the 7-day strength ranged from 3.41 to 3.68 MPa, with an average of 3.53 MPa. At 14 days, the strength ranged from 4.62 to 4.83 MPa, with an average of 4.74 MPa. At 100% strength attainment at 28 days, individual values ranged from 5.33 to 5.66 MPa, with an average of 5.45 MPa. At 7 days, the samples achieved about 65% of the maximum strength corresponding to 100% at 28 days, with this figure rising to 87% at 14 days. As in the compression tests, individual flexural strength values showed a strong correlation: the coefficient of variation did not exceed 2.7 at 7 days, 1.9 at 14 days, and 2.3 at 28 days. In this case, a deviation of 2.3% was adopted as the statistical indicator of strength changes in samples with compositions differing from the reference sample.

Figure 2 illustrates the same compressive and flexural strength values for samples containing 1% granite. Figure 2a shows the compression test results, while Figure 2b presents the flexural test results.

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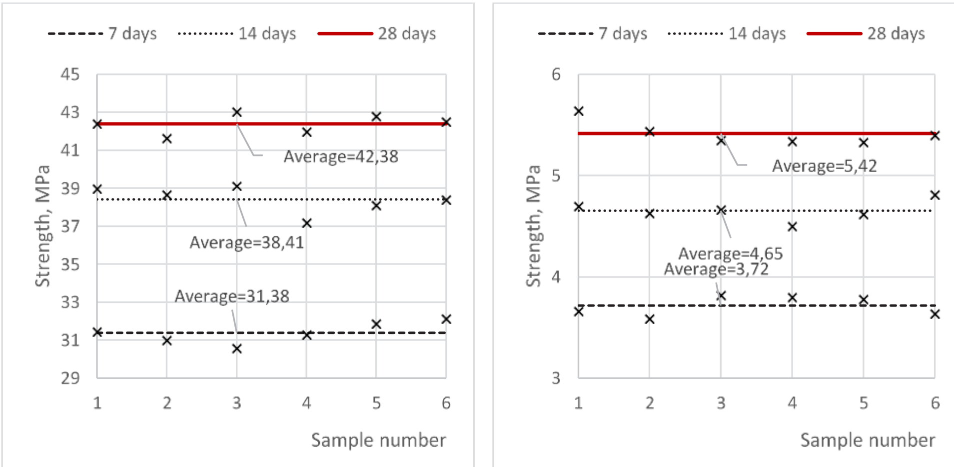

a b

Fig. 2. Strength measurements of the reference sample.

The individual compressive strength values at 7 days range from 30.98 to 32.14 MPa, with an average of 31.38 MPa. At 14 days, individual values range from 37.20 to 39.12 MPa, with an average of 38.41 MPa. At 28 days, the values range from 41.67 to 42.78 MPa, with an average of 42.38 MPa. Strength attainment at 7 days accounts for 74% of the 100% strength, while at 14 days, it reaches 90%, indicating no significant impact of the additive on the rate of strength gain. The obtained individual strength values are acceptable, with a coefficient of variation not exceeding 1.9 for samples at 7 and 14 days and 1.3 at 28 days. The relative deviation of the average strength of samples with the additive from the average of the reference sample is -1.2%, which is below the previously established strength reduction threshold of 1.6%. This suggests that the deviation in the average strength value falls within the confidence interval of individual values for the reference sample, indicating no actual changes in strength.

The individual flexural strength values at 7 days ranged from 3.64 to 3.82 MPa, with an average of 3.72 MPa. At 14 days, the range of values was from 4.50 to 4.81 MPa, with an average of 4.65 MPa. At 28 days, individual values ranged from 5.33 to 5.64 MPa, with an average of 5.42 MPa. The strength gain over time, relative to 100% strength, was 69% at 7 days and 86% at 14 days. The coefficients of variation in all cases did not exceed 2.2. The deviation of the average strength from the reference sample was 0.6%, which does not exceed the previously established error margin of 2.3%. Therefore, changes in strength relative to the reference sample can be attributed to statistical error.

Figure 3 shows the same compressive and flexural strength values for samples with 2% granite content. Figure 3a presents the compression test results, while Figure 3b shows the flexural test results.

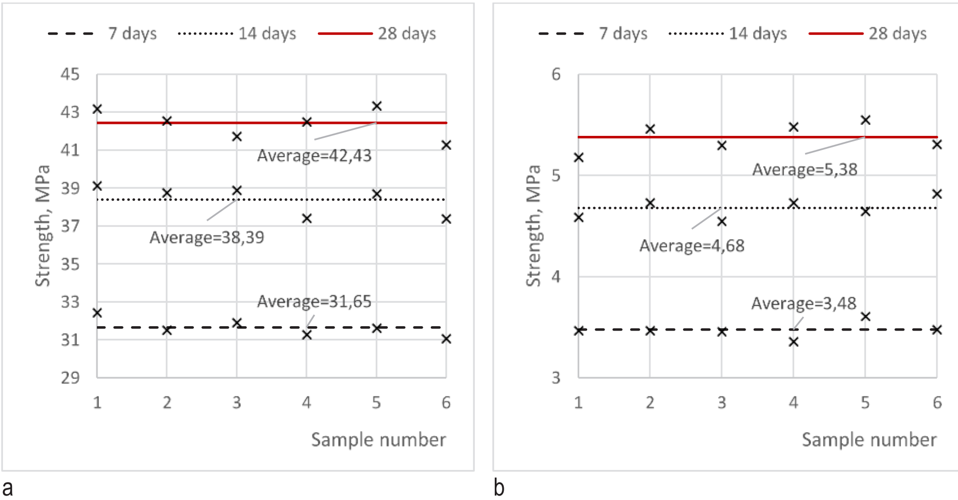

Fig. 3. Strength measurements of the reference sample.

According to the results, the individual compressive strength values for the samples at 7 days range from 31.08 to 32.44 MPa, with an average of 31.65 MPa. The range of individual values at 14 days varies from 37.40 to 39.15 MPa, with an average of 38.39 MPa. At 28 days, the individual compressive strength values range from 41.29 to 43.18 MPa, with an average of 42.43 MPa. Strength attainment at 7 days accounts for 75% of the total 100%, and at 14 days, it reaches 90%. Thus, we also observe no effect of the additive on the rate of strength gain. The individual values show a close dependency, with a coefficient of variation not exceeding 1.5 for 7-day samples, 1.9 for 14-day samples, and 1.8 for 28-day samples. The relative deviation of the average strength for samples with the additive from the reference sample's average strength is -1.3%, which is below the previously established 1.6% threshold for strength reduction. This indicates that the deviation in the average strength value lies within the confidence interval of the individual values of the reference sample, confirming that no actual change in strength occurs.

According to the Results the individual flexural strength values at 7 days range from 3.36 to 3.61 MPa, with an average of 3.48 MPa. At 14 days, these values vary from 4.65 to 4.82 MPa, with an average of 4.68 MPa. At 28 days, individual values range from 5.18 to 5.55 MPa, with an average of 5.38 MPa. The strength gain over time relative to 100% strength is 65% at 7 days and 87% at 14 days. In all cases, the coefficients of variation do not exceed 2.5. The deviation of the average strength value from the reference sample is 1.4%, which is within the previously defined error margin of 2.3%. Therefore, we observe no significant change in strength relative to the reference sample.

Figure 4 shows the same compressive and flexural strength values for samples with 3% granite content. Figure 4a presents the compression test results, while Figure 4b shows the flexural test results.

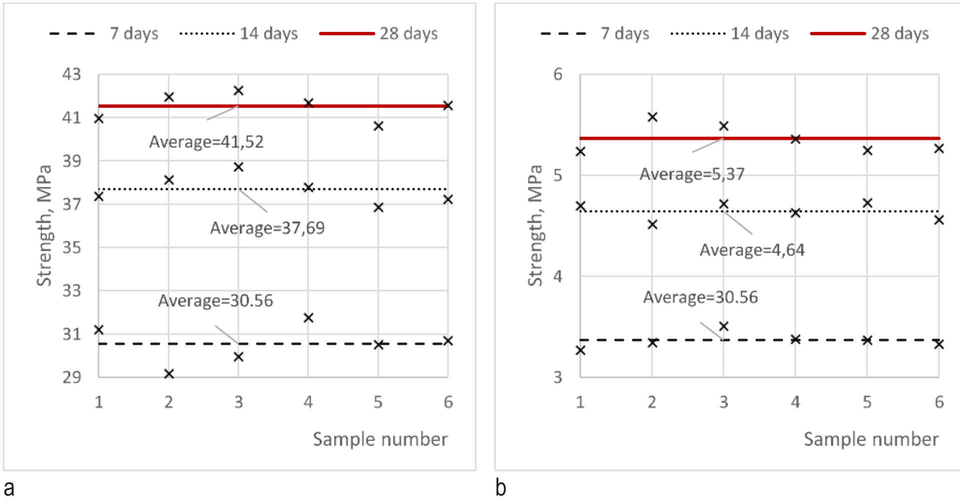

Fig. 4. Strength measurements of the reference sample.

The individual compressive strength values at 7 days range from 29.17 to 31.76 MPa, with an average of 30.56 MPa. At 14 days, these values range from 36.86 to 38.75 MPa, with an average of 37.69 MPa. At 28 days, values range from 40.63 to 42.26 MPa, with an average of 41.52 MPa. Strength attainment at 7 days represents 74% of the total 100% strength, and at 14 days, it reaches 90%. Thus, no effect of the additive on the rate of strength gain is observed. All individual values exhibit a close correlation, as shown by the coefficients of variation, which do not exceed 2.5 in all cases. The 100% strength decreases by 0.9% compared to the reference sample, which is within the statistical margin of individual values for the reference sample, indicating negligible strength loss. However, it should be noted that strength values at all ages are lower than those of the reference sample, showing a slight decreasing trend in concrete strength, with values ranging from 0.4% to 2.2% lower.

For flexural strength, individual values at 7 days range from 3.27 to 3.51 MPa, with an average of 3.37 MPa. At 14 days, values range from 4.52 to 4.73 MPa, with an average of 4.64 MPa. At 28 days, the range is 5.24 to 5.58 MPa, with an average of 5.37 MPa. Strength attainment at 7 days accounts for 63% of the nominal value, reaching 87% at 14 days, indicating no effect of the additive. The individual strength values are valid, with a coefficient of variation not exceeding 2.5 in all cases. The deviation of the average strength at 28 days is 1.6%, below the statistical threshold of 2.3%. Nevertheless, similar to the compressive strength results, a general downward trend in strength values is observed, with flexural strength values lower than those of the reference sample: 4.7% lower at 7 days and 2.1% lower at 14 days.

Figure 5 illustrates the same compressive and flexural strength values for samples containing 4% granite. Figure 5a presents the compression test results, while Figure 5b shows the flexural test results.

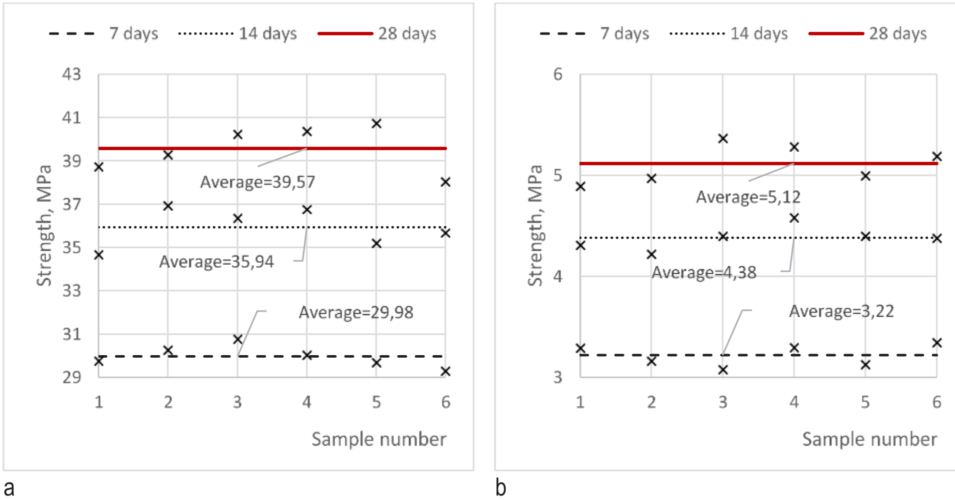

Fig. 5. Strength measurements of the reference sample.

At the maximum granite concentration, the individual compressive strength values at 7 days range from 29.31 to 30.79 MPa, with an average of 29.98 MPa. At 14 days, these values range from 35.21 to 36.93 MPa, with an average of 35.94 MPa. At 28 days, values range from 38.05 to 40.74 MPa, with an average of 39.57 MPa. The strength gain at 7 days represents 76% of the total 100% strength, and at 14 days, it reaches 90%. Thus, the additive shows no effect on the rate of strength gain. All individual values exhibit a strong correlation, with coefficients of variation not exceeding 2.6 in all cases. The 100% strength shows a reduction of 6.7%, indicating a significant decrease in strength compared to the reference sample. Similar reductions are observed at all ages, with compressive strength decreasing by 4.5% at 7 days and 6.5% at 14 days. This suggests a negative effect of the additive on compressive strength at high concentrations (over 4% by sand mass).

For flexural strength, individual values at 7 days range from 3.08 to 3.35 MPa, with an average of 3.22 MPa. At 14 days, values range from 4.22 to 4.58 MPa, with an average of 4.38 MPa. At 28 days, values range from 4.89 to 5.37 MPa, with an average of 5.12 MPa. The strength gain at 7 days is 63% of the nominal value, reaching 85% at 14 days, again indicating no effect of the additive on the rate of strength gain. While individual values for flexural strength remain closely correlated, the coefficients of variation increase to 3.5, compared to samples with lower granite content. The deviation in average strength at 28 days is 6.2%, exceeding the statistical error threshold of 2.3%. As with compressive strength, all flexural strength values at different ages are lower than those of the reference sample, with an 8.9% decrease at 7 days and a 7.7% decrease at 14 days. However, the percentage reduction in flexural strength is greater than the reduction in compressive strength.

Figure 6 displays comparative results for compressive strength in the beam samples. Figure 6a illustrates the strength gain curves for concrete samples with different granite concentrations, while Figure 6b provides a comparison of nominal strength values at 100% strength attainment (28 days) across various granite concentrations. Figure 7 presents analogous comparative diagrams for flexural strength.

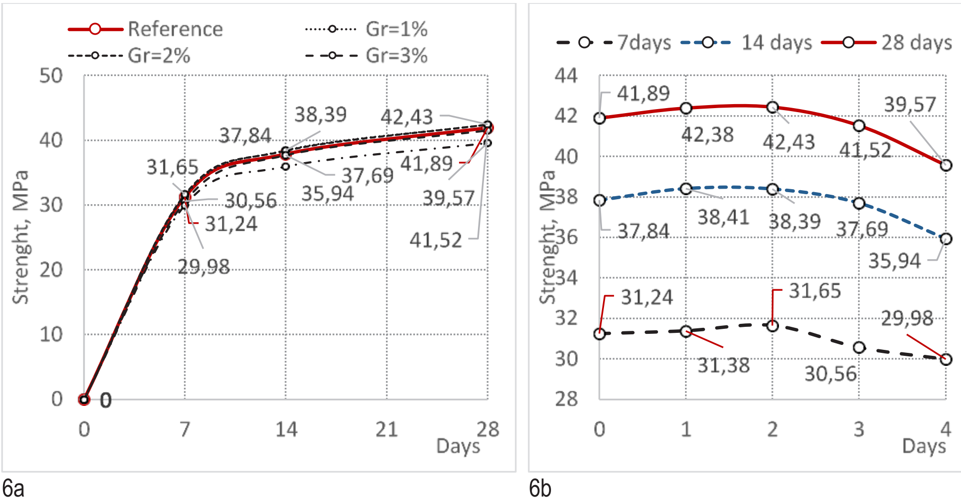

Fig. 6. Comparison of compressive strength.

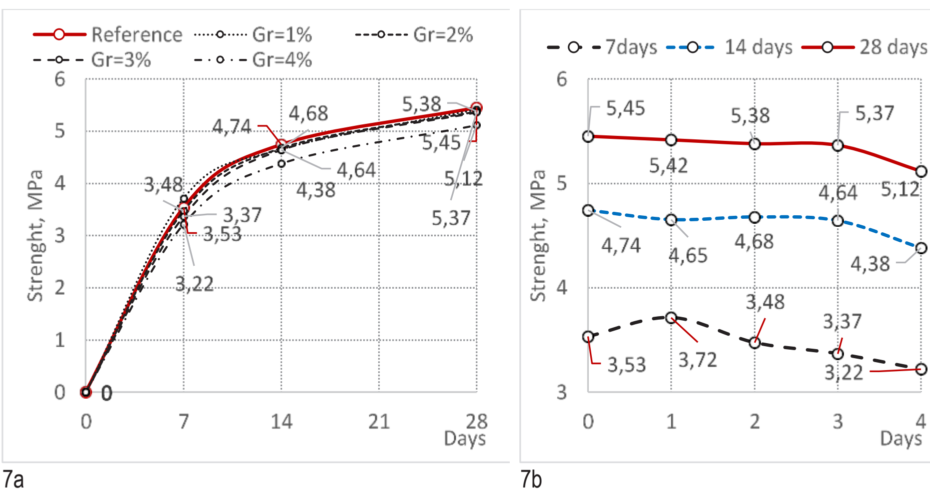

Fig. 7. Comparison of flexural strength.

According to the compressive strength comparison diagrams, the changes in sample strength at graphite contents of 1% and 2% fall within the statistical error range of the individual values for the reference sample, as follows: Gr=0% - 41.89 MPa, Gr=1% - 42.389 MPa, and Gr=2% - 42.43 MPa. The deviations are -1.2% and -1.3%, respectively, which do not exceed the statistical error of 1.6%. When the granite content is increased to 3%, a downward trend in strength is observed; however, the average value for Gr=3% - 41.52 MPa still falls within the statistical margin of error (0.9% < 1.6%). With a further increase in granite content to

4 Conclusion

Standard strength tests on beam samples for flexural and compressive strength were conducted. The tests were performed on samples with varying granite dust content (Gr): 1%, 2%, 3%, and 4% by the sand mass in the sand-cement mix.

According to the compressive strength test results, the maximum strength increase was observed in samples with Gr=2%, while the minimum strength was recorded for the reference sample. The flexural strength test results showed a similar trend, with an increase in strength at a 2% granite content.

The decrease in strength observed at higher granite concentrations (over 3%) may be due to an excess of fine particles in the concrete mix (the granite component of the modifying additive consists of powdery particles). A slight strength increase at a 2% granite concentration results from the densification of the concrete samples, as fine particles fill the micro-pore spaces of the concrete without compromising the structural strength formed by the cement binder.

Since the primary goal of adding granite was to reduce water absorption, the preservation of strength characteristics and even a slight increase in strength can be considered a positive outcome.

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