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Mechanically induced surface modification of diabase aggregate for high-performance concrete

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Abstract:

This study investigates the effect of pre-treatment of diabase sand in an aqueous medium on the mechanical properties of concrete. A submerged processing device equipped with two vertically arranged counter-rotating rotors was used to treat the mineral aggregate directly inside an open mixing vessel. Diabase sand from the Uzunbulak-II deposit with a particle size of 0.16–1.25 mm was used as the mineral component, while technical lignosulfonate was applied as a chemical additive. The treatment was performed for 30 min at a relative working-element velocity of 34.6 m/s and a rotor gap of 5 mm. Particle-size analysis showed that the content of particles smaller than 0.05 mm increased from 0.5% to 5%, while the main 0.16–0.63 mm fraction changed only slightly. Concrete produced using the treated aggregate achieved a 28-day compressive strength of 47.8 MPa, representing an 18.9% increase compared with the untreated control mixture. The obtained results indicate that pre-treatment of mineral aggregates in an aqueous medium can be considered a promising approach for improving the strength characteristics of concrete.

Keywords:

diabase sand, mineral aggregate, mechanical treatment, surface modification, aqueous medium, lignosulfonate, concrete, compressive strength, particle-size distribution, mechanical processing

1. Introduction

Concrete is one of the most widely used construction materials due to its high compressive strength, durability, availability of raw materials, and adaptability to different structural applications. The performance of concrete is determined not only by the properties of cement and water but also by the characteristics of mineral aggregates, which constitute the major volume fraction of the composite. Therefore, improving the interaction between aggregate particles and the cementitious matrix is an important approach for enhancing the mechanical performance and durability of concrete.

Mineral aggregates are generally considered relatively inert components of concrete; however, their surface characteristics have a significant influence on the formation of the interfacial transition zone between aggregate particles and cement paste. Surface roughness, particle morphology, specific surface area, and the presence of weak surface films can affect mechanical interlocking and adhesion within the cement matrix. Consequently, controlled modification of aggregate surfaces and particle-size characteristics can provide an opportunity to improve the structure and mechanical properties of cement-based composites.

Diabase and basalt aggregates are characterized by high hardness, strength, and resistance to environmental influences, which makes them suitable for use in concrete and other construction materials. At the same time, the relatively dense and mechanically stable structure of these mineral materials limits the possibility of modifying their surface characteristics using conventional mixing procedures. Intensive mechanical treatment can increase the specific surface area, alter particle morphology, remove weak surface layers, and generate additional active surfaces.

However, excessive grinding may result in unnecessary energy consumption and excessive formation of fine particles.

An alternative approach is the treatment of mineral aggregates directly in an aqueous suspension. In such a system, mechanical impact, shear deformation, particle–particle interaction, and hydrodynamic effects can occur simultaneously. The presence of a liquid medium facilitates the circulation of fine particles and provides favorable conditions for the interaction of freshly generated mineral surfaces with dissolved chemical additives. In particular, lignosulfonate-based additives can be adsorbed onto newly formed particle surfaces during mechanical processing, potentially affecting particle dispersion and their subsequent interaction with the cementitious matrix.

The efficiency of mechanical treatment depends strongly on the configuration and operating parameters of the processing system. Counter-rotating working elements can generate a localized zone of intense shear and impact within the suspension. Such a configuration provides relative movement between the working elements and promotes repeated interaction of mineral particles with the processing zone. When the treatment is performed directly inside an open mixing vessel, the need for a separate closed grinding chamber and forced material-transfer system can also be reduced.

The use of an immersed processing system is particularly relevant for concrete production because aggregate treatment can be integrated into the preparation of the concrete mixture. This approach may allow mineral particles to be processed together with water and a chemical additive before the introduction of cement and coarse aggregate. As a result, the treated suspension can be directly incorporated

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into the subsequent concrete mixing process without an additional drying or transportation stage.

Despite the potential advantages of intensive mechanical treatment of mineral aggregates, the relationship between treatment conditions, particle-size modification, and the resulting strength of concrete requires further experimental investigation. In particular, it is important to determine whether intensive treatment can improve the properties of the aggregate without causing excessive grinding of the original particle fraction.

Therefore, the objective of this study was to investigate the effect of in-situ mechanical treatment of diabase sand in an aqueous medium on its particle-size characteristics and on the compressive strength of concrete. The study focused on diabase sand with a particle size of 0.16–1.25 mm treated using a submerged counter-rotating rotor system in the presence of technical lignosulfonate. The influence of the treatment process was evaluated by comparing the particle-size distribution of untreated and treated sand and by determining the 7- and 28-day compressive strength of concrete prepared using the treated aggregate.

The results obtained in this study provide an experimental basis for evaluating the applicability of in-situ mechanical treatment of mineral aggregates as a technological approach for improving the mechanical performance of concrete while maintaining the main fraction of the original aggregate.

Literature Review. The mechanical performance of concrete is strongly influenced by the characteristics of its mineral aggregates and by the quality of the contact zone between aggregate particles and the cementitious matrix. Although aggregates are generally regarded as relatively inert components, their particle size distribution, morphology, surface roughness, and surface condition can substantially affect the packing structure and mechanical interaction within hardened concrete.

Mechanical treatment of mineral materials is widely considered an effective approach for modifying particle characteristics. During intensive mechanical processing, particles can undergo impact, shear, abrasion, and fracture, resulting in changes in particle-size distribution and surface morphology. The formation of newly exposed surfaces may improve mechanical interlocking between aggregate particles and cement paste. However, excessive grinding is undesirable because it increases energy consumption and may lead to an excessive amount of fine material.

Particular attention has been given to the treatment of mineral materials in liquid media. Compared with dry processing, treatment in an aqueous suspension provides continuous particle circulation and facilitates the removal and dispersion of fine particles. Simultaneous mechanical and hydrodynamic effects can promote the destruction of weak surface layers and modification of the external surface of mineral grains.

The use of chemical additives during mechanical treatment may further influence the dispersion process. Lignosulfonate-based additives are capable of interacting with mineral surfaces and can facilitate particle dispersion in aqueous systems. When mechanical treatment continuously generates fresh mineral surfaces, adsorption of the dissolved additive may occur simultaneously with surface renewal. This provides a potential mechanism for controlling particle agglomeration and improving the subsequent interaction between mineral particles and the cementitious matrix.

Another important factor is the hydrodynamic regime generated within the treatment zone. Counter-rotating working elements can produce a localized region characterized by high relative velocity, shear, and repeated particle movement. In comparison with a single rotating element, the counter-rotating configuration provides a greater relative velocity between opposing working elements at the same peripheral velocity. The resulting mechanical environment can intensify particle–particle and particle–working-element interactions.

The technological integration of aggregate treatment directly into a concrete mixer is also of practical interest. A submerged processing system eliminates the need for separate drying and grinding stages and allows the mineral suspension to be treated immediately before concrete production. Such an approach can potentially reduce material handling operations and simplify the technological process.

Previous approaches to mechanical activation of mineral materials have predominantly focused on intensive grinding and the production of highly dispersed powders. The present study considers a different technological objective: controlled modification of the surface and particle-size characteristics of a relatively coarse mineral aggregate while retaining a substantial portion of its initial fraction. This distinction is important because the objective is not complete grinding of the diabase but selective mechanical treatment that can improve its interaction with the cementitious matrix.

Based on these considerations, the present study evaluates the effect of aqueous mechanical pre-treatment of diabase sand on particle-size distribution and concrete compressive strength. The experimental approach combines mechanical processing, aqueous suspension treatment, and simultaneous addition of lignosulfonate.

2. Research methodology

Diabase sand obtained from the Uzunbulak-II deposit in the Jizzakh Region of the Republic of Uzbekistan was selected as the mineral aggregate. The initial particle-size range was 0.16–1.25 mm. According to the experimental description, the diabase had a Mohs hardness of approximately 6–7 and a density of 2.9–3.0 g/cm³.

Technical lignosulfonate (LST) was used as a chemical additive during aqueous treatment. In the experimental procedure, the additive dosage was 0.17% of the mass of the mineral aggregate.

For the concrete mixture, M400 cement, diabase crushed stone with a particle size of 5–20 mm, water, and the treated diabase sand were used. The concrete composition was maintained constant for the comparative tests.

Mechanical Pre-Treatment System

The mineral aggregate was treated using a submerged mechanical processing system equipped with two vertically oriented counter-rotating rotors. The working module consisted of two parallel vertical shafts positioned 90–190 mm apart. Disk-shaped rotors with diameters of 100–200 mm were mounted on the shafts.

In the basic experimental configuration, the rotor diameter was 110 mm, the shaft spacing was 100 mm, and the disks were vertically displaced by 55 mm. Each disk was equipped with six rod-shaped working elements having a length of 50 mm and a square cross-section of 10 × 10 mm.

The working elements of the upper rotor were directed downward, whereas those of the lower rotor were directed



upward. During operation, the working elements of one rotor passed through the spaces between the working elements of the opposite rotor without direct mechanical contact. The gap between the opposing elements was maintained at 5 mm.

The electric motor had a rated power of 3 kW and a rotational speed of 3000 rpm. The working module was immersed directly into the mineral suspension at a depth of approximately 25 cm. This configuration enabled treatment of the suspension directly inside the concrete mixer.

Preparation and Treatment of the Mineral Suspension

The suspension was prepared by sequentially introducing 45 kg of water, 60 kg of diabase sand, and 100 g of technical lignosulfonate into the mixing vessel. The initial water temperature was 18–20 °C. The resulting suspension had a total mass of approximately 105.1 kg, with a solid-to-total mass ratio of approximately 57%.

Before mechanical treatment, the components were preliminarily mixed for 2–3 min at a mixer rotation speed of approximately 20 rpm.

Particle-Size Analysis

The particle-size distribution of the diabase sand was determined before and after mechanical treatment. The initial aggregate consisted primarily of particles within the 0.16–1.25 mm range.

For comparative evaluation, the material was divided into four particle-size groups:

- 0.63–1.25 mm;
- 0.16–0.63 mm;
- 0.05–0.16 mm;
- <0.05 mm.

The changes in the proportion of these fractions were used to evaluate the degree of selective mechanical fragmentation.

Concrete Preparation and Strength Testing

After completion of the 30-min treatment, the working module was removed from the suspension. The treated diabase sand and the water contained in the suspension were subsequently used directly for concrete preparation.

The concrete mixture contained:

- M400 cement — 480 kg/m³;
- treated diabase sand — 720 kg/m³;
- diabase crushed stone, 5–20 mm — 1104 kg/m³;
- total mixing water — 180 L/m³.

The control mixture had the same basic proportion of cement, sand, coarse aggregate, and water but was prepared using untreated diabase sand.

The concrete specimens were tested for compressive strength at 7 and 28 days. The experimental procedure was based on the requirements specified in GOST 10180. The obtained strength values were compared with those of the control concrete.

The principal indicators used for evaluating the effectiveness of the treatment were the change in particle-

size distribution and the increase in compressive strength of concrete relative to the untreated control composition.

3. Results and Discussion

The mechanical pre-treatment of diabase sand in an aqueous medium resulted in a measurable change in its particle-size distribution. The initial material obtained from the Uzunbulak-II deposit was characterized by a particle-size range of 0.16–1.25 mm. After 30 min of treatment at a relative working-element velocity of 34.6 m/s and a rotor gap of 5 mm, an increase in the fine-particle fraction was observed.

The particle-size distribution before and after treatment is presented in Table 1.

Table 1
Particle-size distribution of diabase sand before and after aqueous mechanical treatment

Sample	0.63–1.25 mm	0.16–0.63 mm	0.05–0.16 mm	<0.05 mm
Control	46.0%	53.5%	–	0.5%
Treated	30.5%	49.5%	15.0%	5.0%

The results demonstrate that the proportion of particles smaller than 0.05 mm increased from 0.5% in the untreated material to 5.0% after treatment. At the same time, the main 0.16–0.63 mm fraction remained relatively stable, decreasing from 53.5% to 49.5%.

The proportion of the 0.63–1.25 mm fraction decreased from 46.0% to 30.5%, accompanied by the appearance of 0.05–0.16 mm particles at a proportion of 15%. This indicates that the treatment caused selective fragmentation of the larger particles rather than complete grinding of the original aggregate.

The observed changes are consistent with the intended operating principle of the processing system, in which mineral particles are subjected to repeated impact, shear, and abrasive interactions within the treatment zone. The formation of additional fine particles indicates that the mechanical treatment was sufficiently intensive to modify the particle-size distribution while retaining a considerable proportion of the original aggregate fractions.

Effect of Treated Diabase Sand on Concrete Strength

The treated diabase sand was subsequently used directly in concrete production. The concrete mixture was prepared using the same basic proportion of cement, sand, coarse aggregate, and water for both the experimental and control compositions.

The compressive strength results obtained at 7 and 28 days are summarized in Table 2.

Table 2

Compressive strength of concrete containing untreated and treated diabase sand

Group	Cement: Sand: Coarse aggregate	W/C	7-day strength, MPa	28-day strength, MPa	Increase relative to control
Control	1:1.5:2.3	0.40	28.4	40.2	–
Treated	1:1.5:2.3	0.40	36.2	47.8	+18.9%



The concrete containing the treated diabase sand demonstrated a 7-day compressive strength of 36.2 MPa compared with 28.4 MPa for the control mixture. This corresponds to an increase of approximately 27.5% at the early-age testing stage.

At 28 days, the compressive strength of the experimental concrete reached 47.8 MPa, whereas the control concrete achieved 40.2 MPa. Thus, the use of mechanically pre-treated diabase sand resulted in an increase of 7.6 MPa, corresponding to an improvement of 18.9% relative to the control composition.

The results also show that the treated concrete developed strength more rapidly during the early curing period. Its 7-day strength reached approximately 75.7% of its 28-day strength, while the corresponding value for the control concrete was approximately 70.6%.

Relationship between Particle-Size Modification and Concrete Strength

The increase in concrete strength was accompanied by changes in the particle-size distribution of the diabase sand. The treatment generated an additional fine fraction while preserving a substantial proportion of the original 0.16–0.63 mm fraction.

The formation of finer particles may improve the packing of the granular skeleton and reduce the size of voids between larger aggregate particles. In addition, mechanical treatment can modify the external surface of mineral particles, potentially improving mechanical interlocking with the cementitious matrix.

The experimental results therefore indicate a relationship between controlled modification of the aggregate and the resulting mechanical performance of concrete. However, the present experimental data do not allow the contribution of individual mechanisms—such as surface roughness, particle packing, shear effects, or chemical adsorption—to be quantified separately. These mechanisms should therefore be considered as possible contributing factors rather than independently verified causes.

Practical Effectiveness of the Treatment

One of the important features of the investigated approach is that the mineral aggregate was treated directly in the aqueous medium and subsequently used for concrete production without a separate drying stage. The treatment was performed for 30 min using a submerged counter-rotating rotor system.

The experimental configuration provided a relative working-element velocity of 34.6 m/s, a 5 mm inter-rotor gap, and a treatment duration of 30 min. Under these conditions, the fine fraction below 0.05 mm increased tenfold in relative terms, from 0.5% to 5.0%.

At the same time, the principal concrete performance indicator—the 28-day compressive strength—increased from 40.2 to 47.8 MPa. The combined particle-size and strength results demonstrate that controlled aqueous pre-treatment of diabase sand has the potential to improve the mechanical performance of concrete.

It should be emphasized that the reported experimental results are based on the specific processing conditions and concrete composition investigated in this study. Further experiments with different treatment durations, rotor velocities, gap sizes, additive dosages, and aggregate fractions are required to determine the optimal processing conditions and establish the reproducibility of the observed strength improvement.

Discussion

The obtained results demonstrate that aqueous mechanical pre-treatment can significantly modify the particle-size characteristics of diabase sand and positively affect the compressive strength of concrete. The increase in the fraction of particles smaller than 0.05 mm from 0.5% to 5.0% indicates that the treatment promotes selective fragmentation of the larger particles. At the same time, the main 0.16–0.63 mm fraction was largely preserved, suggesting that the process does not result in complete grinding of the aggregate.

The improvement in concrete strength can be associated with the combined effect of particle-size modification and changes in the surface condition of the mineral aggregate. The formation of additional fine particles may improve packing within the cementitious system, while mechanical treatment can enhance the physical interaction between the aggregate surface and cement paste. Under the investigated conditions, the 28-day compressive strength increased from 40.2 MPa for the control concrete to 47.8 MPa for concrete containing treated diabase sand, corresponding to an 18.9% improvement.

An important technological advantage of the investigated method is the possibility of treating the mineral aggregate directly in an aqueous suspension and subsequently using the treated suspension for concrete preparation. This eliminates the need for an additional drying stage and may simplify the overall production process. However, the contribution of individual mechanisms, including surface modification, particle packing, shear effects, and additive adsorption, requires further experimental verification.

4. Conclusion

The study demonstrated the effectiveness of aqueous mechanical pre-treatment of diabase sand for improving the mechanical performance of concrete. Under the investigated conditions, treatment at a relative working-element velocity of 34.6 m/s, a 5 mm rotor gap, and a duration of 30 min resulted in a substantial modification of the particle-size distribution.

The proportion of particles smaller than 0.05 mm increased from 0.5% to 5.0%, while a considerable part of the original aggregate structure was retained. The use of the treated diabase sand increased the 7-day compressive strength of concrete from 28.4 to 36.2 MPa and the 28-day strength from 40.2 to 47.8 MPa. The resulting 18.9% increase in 28-day compressive strength confirms the potential of the proposed pre-treatment approach.

The investigated technology can be considered a promising method for improving mineral aggregate performance directly within an aqueous medium. Further studies should focus on optimizing treatment duration, rotor velocity, inter-rotor gap, and chemical additive dosage, as well as on evaluating the durability and microstructural characteristics of the resulting concrete.

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