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THE IMPACT OF RESIDUAL MAGNETIZATION ON ACCELERATING GROUT MIXTURE COAGULATION PROCESSES AND THEIR PHYSICAL AND MECHANICAL PROPERTIES

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ВПЛИВ ЗАЛИШКОВОЇ НАМАГНІЧЕНОСТІ НА ПРИСКОРЕННЯ ПРОЦЕСІВ КОАГУЛЯЦІЇ ЦЕМЕНТНИХ РОЗЧИНІВ І ЇХ ФІЗИКО-МЕХАНІЧНІ ВЛАСТИВОСТІ

Purpose. Substantiating treatment parameters of grout mixtures in constant magnetic field applied while strengthening weak dispersed rocks by high-pressure jets of these mixtures resulted in increasing efficiency and effectiveness of works in progress.

Methodology. The methodological basis of solving this problem is a comprehensive approach including theoretical and experimental studies. Considered coagulation theory and constant magnetic field impact on ion and dispersed systems demonstrated the possibility of applying magnetic field to influence grout mixtures having low water and cement ratio. Afterwards, laboratory methods to determine physical and mechanical properties of grout mixtures and obtained cement rock were carried out. All experiments were repeatedly carried out from 3 to 5 times and experimental data were processed on PC by modern statistics methods. Coefficients of correlation and approximation validity were found for all dependences.

Findings. Performed experimental studies allowed determining such parameters of grout mixture treatment in a constant magnetic field that could greatly improve the following properties:

The point of starting and completing the cementation process and total time of strength generation (in optimal case the consolidation time is reduced by 12 % resulting in cutting work period required for rocks consolidation).

The uniaxial compression strength of the cement rock patterns under different methods and magnetic treatment parameters of initial mixtures is approximated by exponent and exponential function product and magnetic field induction value with approximation validity coefficient of 0.94. The dependence is extremum and has delineated maximum with magnetic field induction being $B = 0.36$ T.

Orginality. The residual magnetization impact of non-ferromagnetic material on coagulation process acceleration of grout mixtures having low water and cement ratio has been considered for the first time. In the course of studies the dependences of changing the period required for starting and completing the processes of setting and cementing as well as uniaxial compression strength of the obtained cement rock on the treatment parameters of these grout mixtures in the constant magnetic field (while changing magnetic field induction and fluid velocity in the working space of magnetic device) have been determined.

Practical value. Regularities of the impact of the constant magnetic field induction and fluid velocity in the working space of magnetic device on some physical and mechanical properties of grout mixtures and cement rock obtained after cementing have been established. Conducted experiments allowed identifying rational parameters to enhance these properties, which being applied to jet grout technology gives the possibility for its immense improvement. This enables to reduce cement consumption without sacrificing required fixation strength or raise fixation strength using the same amount of fixer.

Keywords: *high pressure jet flows, magnetic treatment, jet grouting technology, cement mixture*

Introduction. One of the main challenges of our time is intensive development and reconstruction of major cities. Unfortunately, most of them are characterized by complex hydrogeological conditions and terrain features and specific grouting techniques are required to perform various types of construction and hydraulic works. Jet grouting technology for consolidating rocks is considered to be the one meeting European standards of adaptability, efficiency and environmental friendliness. The main principle lies in the simultaneous destruction and mixing of dispersed rocks with high-pressure jets of grouting mixture, followed by the hardening of newly formed mortar and rock structures. In this case as the grouting quality is obvious to depend on the physical and mechanical properties of applied cement mixtures, its improvement is a very urgent task. Nowadays, magnetic treatment of liquid medium is commonly used in various industries and technological processes. This article discusses the use of magnetic treatment to intensify the processes of rock jet grouting. The problem of changing physical and mechanical properties of grout mixtures activated by magnetic field was investigated in this study.

Analysis of recent research and publications. The results of research carried out by a great number of prominent scientists served as the background for studying magnetic field impact on physical and chemical processes occurring while strengthening weak water-bearing rocks during mining works. At different periods the problem of magnetic field impact on water systems was studied by such scientists as V. I. Klassen, N. F. Bondarenko, E. Z. Gak, Y. B. Osipov et al. Jet grouting technology uses cement as the main component for grouting mixtures that can be referred to a wide class of aqueous systems due to their low water-cement ratio ($W/C = 1$). Applying magnetic water treatment for gauging in concrete manufacture is slow down because of a small effect and low effectiveness in comparison with other methods used for process improvement [1]. On the other hand, there is a great number of examples to prove the possibility of achieving significant effectiveness of the magnetic gauging water treatment in the production of concrete and other products based on other cementitious materials (hemihydrate gypsum, fly ash, slag, etc.) [2].

All of the aforesaid served as a foundation to carry out research dealing with intensifying the processes of dispersed rocks jet grouting with the help of magnetic treatment used for these hardening grouting mixtures based on cement content.

Unsolved aspects of the problem. Magnetic water treatment and hydrologic systems are of particular interest in terms of their application in the mining industry. Such features as significant quality growth of the concrete lining of mine workings resulted due to using magnetized water, decreasing dust formation during coal destruction processes, preventing from pipe wall scaling of mine drainage installations and local steam boilers, increasing grades of coal and ore beneficiation should be listed as promising.

However, such problem as magnetic treatment impact on cement mixtures with low (1/1) water-cement ratio has never been considered. In particular, such mixtures are used in rocks jet grouting. All of the aforesaid served as a foundation to carry out research dealing with intensifying the processes of dispersed rocks jet grouting with the help of magnetic treatment used for these hardening mixtures on cement basis.

Objectives of the article. It is proposed to improve the physical properties of cement mixture by the magnetic treatment followed by improving the quality of rocks jet grouting. It is required to identify conformities of changing such physical and mechanical properties as density, viscosity, starting and ending time points of cementing process, uniaxial compression strength, etc. with processing parameters in a magnetic field and determine rational parameters of magnetic treatment of cement mixtures based on obtained results.

Presentation of the main research. Grout mixtures with a low water-cement ratio can be referred to the type of dispersed lyophobic colloids as the cohesive energy within the dispersed phase is considerably higher than the interphase energy, and an entropy factor does not compensate this difference. The arrangement of the dispersed colloids between the particles and the medium of active phase division boundary having a certain value of the surface tension is considered to be the main feature. Dispersed system stability depends on the ion distribution around colloidal particles. Dispersed system stability (coagulation rate) depends on the sign and magnitude of the interaction total energy stipulated by the addition of ion-electric repulsion energy and attraction energy of van der Waals-London. Let's consider the process of particle coagulation of dispersed suspension.

Any of the interacting particles may be considered as a collector where coagulation occurs. Let the energy of particle interaction and the collector be $U(y)$, where $y = r - 2Re$ is the distance between the particle surface and the collector, R is a particle radius; r is the distance from the particle center to the collector. Then, proceed from the work of Deryagin B. V. a steady flow of particles to the collector can be represented in such a way

$$J = 4\pi \cdot r^2 \left(D_e \frac{dn}{dr} + \frac{n}{\mu_e} \frac{dU}{dr} \right), \quad (1)$$

where D_e is a coefficient of mutual diffusion of particles; n is a particle concentration, m^{-3}; μ_e is a hydrodynamic resistance to particle convergence being equal to the ratio of the resistance to the particle velocity, N · s; U is the interaction energy of the particle and the collector, J; r is the distance from the particle center to the collector, m.

Assuming that the values of D_e and μ_g are constant throughout the time of particle convergence and $\mu_g = \mu_S = 6\pi\eta R$ is Stokes formula where η is medium viscosity, the constraint definitely describing aerosol coagulation processes will be obtained. To describe coagulation processes in liquid medium having considerable viscosity, Einstein relation is required to apply

$$\mu_e D_e = kT = \theta,$$

where $\mu_e = \mu_e(r) = \mu_S \cdot \beta(r/R)$ is hydrodynamic resistance to the particle convergence for viscous fluid, N · s; $\beta(r/R)$ is a function that depends on the particle size and the distance between them; $\beta = 1$ when $r \gg R$ and $\beta \to \infty$ at $r \to 2R$.

Let's make the change of variables: $S = y/R$, $y = r - 2R$ and select a function $\beta(S)$ of the following form: $\beta(S) = 1 + 1/2S$.

Then, the solution of equation (1) must satisfy the following boundary conditions:

1) $n = n_0$ where $r \to \infty$;

2) $n = 0$ where $r \to 2R$.

Recon that $U(\infty) = 0$, we get

$$n(r) = \exp(-U(r)/\theta) \cdot \left[n_0 - \frac{J}{4\pi\theta} \int_r^{\infty} \frac{\mu_r(r)}{r^2} \exp(U(r)/\theta) dr \right].$$

From the second boundary condition we obtain

$$J = 8\pi D_0 n_0 R \Big/ \int_0^{\infty} \frac{\beta(S)}{(S+2)^2} \exp(U(S)/\theta) dS,$$

where $D_0 = \theta/6\pi\eta R$ is a diffusion coefficient of a solitary particle.

Flow amount can be written as

$$J = J_{Sm}/W,$$

where $J_{Sm} = 16\pi D_0 R n_0$ is the flow amount set by Smoluchowski excluding the hydrodynamic particle interaction, assuming that $\beta = 1$ and $U = 0$; W is a coagulation delay factor determined as follows

$$W = 2\int_0^{\infty} \frac{\beta(S)}{(S+2)^2} \exp(U(S)/\theta) dS. \quad (2)$$

The value W rises sharply with potential barrier growth between the particles and slumps with a decrease of the latter [3]. Asymptotic integral estimation done by the method of steepest descent (2) gives the following

$$W \approx 2\sqrt{\frac{2\pi\theta}{-U''(S_m)} \cdot \frac{\beta(S_m)}{(S_m+2)^2}} \cdot \exp(U(S_m)/\theta), \quad (3)$$

where the value of S_m corresponds to the maximum energy – $U(S_m) = U_{\max}$.

For aqueous colloidal mixtures according to Deryagin B. V. it looks as

$$\beta(S_m) = \frac{1}{2} S_m; \quad U''(S_m) \approx -\frac{A}{6S_m^3}, \quad (4)$$

where A is Hamaker constant.

Substituting (4) into (3) we get

$$W = \frac{1}{2}\sqrt{\frac{3\pi S_m \theta}{A}} \cdot \exp(U_{\max}/\theta).$$

A magnetic field disrupts the energy barrier between the particles, changes the maximum energy value of interaction between them and thus, accelerates the coagulation process. In addition, the magnetic field acts on the colloidal particles of ferromagnetic impurities. Grouting mixtures are referred to weak magnetic suspensions because of containing mainly non-magnetic materials with a small admixture of ferromagnetic substances. A permanent magnetic moment of substance atoms does not depend on the external magnetic field and has a magnitude order as ~ 10^{-23} J/Vb/m^2.

The ionic medium composition changes in the case of injecting iron admixtures into the liquid fluid and magnetic fields having a possible great effect on nearby water are formed around the magnetized ferromagnetic and paramagnetic particles. Colloidal charged micelles adsorb ions from the mixture and can serve as crystallization centers. Reactions are followed by forming a ferromagnetic product from non-ferromagnetic materials. (According to Bgatnagara' rule a magnetic field shifts a chemical reaction equilibrium towards the formation of substances with higher values of magnetic susceptibility). The energy of magnetic dipole particle interaction should be taken into account provided its commensurability with thermal motion energy.

Under conditions of the colloidal mixture charged particles are affected by two types of fields having impact on particle distribution: a proper particle field and domain boundary leakage field. A proper particle field fosters particle coagulation, wherein the particles in the aggregates are oriented to enclose a magnetic field. It means that an aggregate magnetic moment is less than the magnetic moments of the unit constituents. According to Kittel, the magnetic coagulation condition is as follows

$$\mu H > 3kT,$$

where μ is medium magnetic permeability; $\vec{H}$ is magnetic field strength A/m; k is Boltzmann constant, J/K; T is temperature, K.

The orientation of particle magnetic moments in suspensions under the magnetic field action as well as multidomain particle magnetization lead to full magnetization of paramagnetic dispersed system. Room temperature and weak external fields are favorable for the condition $P_m H \ll kT$ and then the medium magnetization is defined as

$$\vec{I} = \frac{P_m^2 n_0 \mu_0}{3kT} \vec{H},$$

where P_m is a permanent magnetic moment of substance atoms (molecules); J/Wb/m^2; k is Boltzmann constant, J/K; T is temperature, K; μ is medium permeability; $\vec{H}$

is magnetic field strength, A/m; n_0 is a particle number per unit volume, m^{-3}.

Volumetric energy density of a non-ferromagnetic magnetized medium is as follows

$$\omega = \mu_0 \frac{(\mu - 1) \cdot H^2}{2},$$

where μ is substance permeability; μ_0 is magnetic vacuum permeability, H/m.

Then, the magnetic field energy is as follows

$$W_m = \int_0^r \mu_0 \frac{(\mu - 1) \cdot H^2}{2} dV = \mu_0 \frac{(\mu - 1) \cdot H^2}{2} \cdot \frac{4}{3} \pi r^3,$$

where r is the average distance between two coagulating particles, m.

Thus, the energy of the magnetic field impact causes the maximum energy value of particle interaction to be changed, and the total system energy will be and, taking into account the magnetic field, a coagulation stability factor will be as follows

$$W = \frac{1}{2} \sqrt{\frac{3\pi S_m \theta}{A}} \cdot \exp((U_{\max} - W_m)/\theta).$$

As a result, the value of the steady particle flow to the collector is

$$J = J_0 \exp(W_m / 2\theta),$$

where J_0 is the flow rate without considering the magnetic field impact.

Thus, disperse particles are coagulated in the magnetic field to reach the size corresponding to the critical size of grown nucleation centers. Estimated acceleration of coagulation process is calculated based on average conditions and experimental data and looks like $J \approx \approx 1.05 \cdot J_0 - 1.17 \cdot J_0$. It is the magnetic field to accelerate coagulation processes on average by about 11 %. Residual magnetic treatment effect is explained by the fact that removing the magnetic field does not terminate the coagulation process.

Thus, the magnetic treatment of grouting mixtures should significantly alter physical and mechanical properties of obtained cement stone. Applying the magnetic field to activate cementing mixtures in the jet grouting technology of dispersed rocks will significantly improve the quality of their grouting. Applying the magnetic field to affect on fixing mixtures can control the processes of physical and chemical grouting of dispersed rocks.

Experimental studies of physical and mechanical properties of grout mixtures activated by the magnetic field were carried out to test the assumptions made beforehand. The research to determine the magnetic field impact on the properties of fixing mixtures was carried out at the experimental plant shown in Fig. 1. To create the magnetic field required for the experiments, the solenoid-type device forming a transverse magnetic field with a high degree of uniformity in the interpolar space having the size of $100 \times 30 \times 40$ mm^3 was applied [3].

Two ways of effecting electromagnetic fields on physical and mechanical properties of grout mixtures have been considered. They can be listed as the following:

1) electromagnetic water treatment for fixing mixture gauging;

2) magnetic treatment of grout slurry.

In future work prepared grout slurries will be referred to as type 1 and type 2 slurries, respectively.

While carrying out experimental work the following parameters have been changed:

a) magnetic field induction from 0 to 0.6T in increments of 0.06T by regulating current intensity in the unit from 0 to 2A in increments of 0.2A;

b) liquid medium velocity in the magnetic field by adjusting the pressure in the tank by a compressor from 0 to 5 atmospheres.

Slurries of types 1 and 2 as well as obtained cement stone were subjected to the following tests:

1. Determining consolidating time and hardening rate of the studied cementing slurries with Wick needle.

2. Measuring uniaxial compression strength of a cement stone of consolidated cementing slurries.

3. Investigating thin cement stone sections by electron microscope scanning.

All experiments were performed at least three times and average values were taken as valid. Liquid medium rate in a magnetic field was taken as a constant value

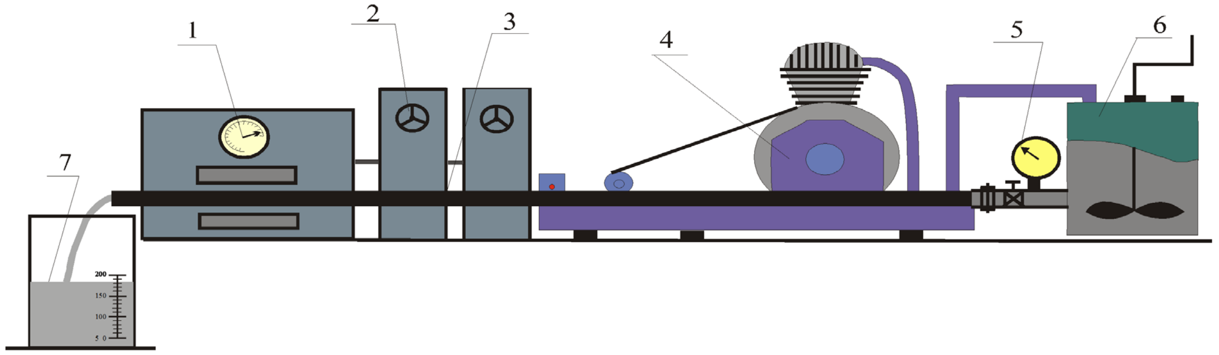


Fig. 1. General view of the experimental installation:

1 – a magnetic device; 2 – a laboratory transformer to regulate current intensity in a magnetic device; 3 – a plastic pipe; 4 – a compressor; 5 – a gauge; 6 – a fluid reservoir; 7 – a measuring tank within the framework of one experiment. An average fluid velocity in a magnetic field was determined by its consumption

$$u = Q/S \cdot t,$$

where Q is water flow, m^3; S is a tube sectional area, m^2; t is time, s.

The experiments were carried out with slurries based on the cement grade of M-400. To obtain the slurry the ratio of water to cement was taken as 1 : 1, while its density was ρ = 1,500 kg/m^3. Let us consider more deeply the results of the experimental studies.

The strength and structure of the cement stone are the final results of the cementation process. Cementation terms of grout mixture characterize the beginning and ending of transforming the slurry into a solid substance. Standard consistency of cement paste and cementation terms were determined by means of Wick device.

The dynamics of hardening all samples is well approximated by a function of the form

$$h = A \cdot \exp(-\lambda \cdot t),$$

where h is fall depth of Wick needle, mm; t is time starting from gauging moment, h; A, λ are approximation coefficients.

The dependence of grout mixture cementation dynamics on magnetic treatment parameters is shown in Fig. 2. Correlation coefficients between the values of the fall depth of Wick needle and the time elapsed after slurry gauging range from –0.97 to –0.99.

Resistance tests of the cement stone prepared from slurries of types 1 and 2 to uniaxial compression strength were performed on the 28th day after gauging. The obtained results showed that the dependence of the cement stone strength on the magnetic field induction has a signified extreme feature, and moreover, maximum values for any water flow velocity in the magnetic field are achieved when the magnetic field is B = 0.36 Tesla. The results of the research are shown in Fig. 3. As can be seen from Fig. 3 changing the magnetic induction field from to T results in increasing the values of the cement stone resistance to uniaxial compression, and for the case T they reach their maximum values for all considered water flow velocities in the magnetic field. Further increase of magnetic field induction up to 0.6T results in decreasing uniaxial compression strength values, although these values are still significantly higher (6–76 %) than the values of the samples not subjected to magnetic treatment.

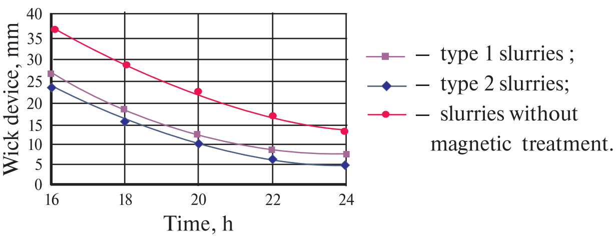


Fig. 2. The dependence of grout mixture cementation dynamics on magnetic treatment parameters

The study of physical and mechanical properties of the cement stone prepared from the grout slurries of type 2 indicated that dependence of uniaxial compression strength on the magnetic field is similar to the dependence for the samples obtained from the grout slurries of type 1. It means that despite an extreme character this dependence is a bit smoother. For greater clarity, the curves of dependence of uniaxial compression strength on the magnetic field induction for different velocities of cement slurry movement in the magnetic field are presented in Fig. 4.

As can be seen from Fig. 4 changing the magnetic induction field from 0 to 0.36T results in increasing the values of the cement stone resistance to uniaxial compression by 2.6–2.6 times, and for the case B = 0.36T they reach their maximum values for all considered water flow velocities in the magnetic field. Further increase of the magnetic field induction up to 0.6T results in decreasing uniaxial compression strength values.

The dependence of ultimate uniaxial compression strength value of the cement stone both for the samples obtained from the slurries of type 1 and type 2 on the magnetic field induction at the last change from 0 to 0.6T is well approximated by the expression

$$\sigma_c = \sigma_0 + k \cdot B^{2.5} \cdot \exp(-l \cdot B),$$

where B is magnetic induction, T; σ_0 is fracture pressure in the case of magnetic treatment failure, Pa; k, l is approximation coefficients.

Additionally, after having kept the control samples of the cement stone in a desiccator in a wet-air environment for one year, the uniaxial compressive strength was

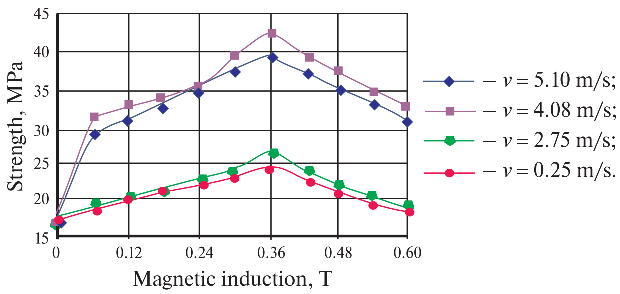


Fig. 3. The dependence of the resistance of cement stone samples obtained from the grout slurries of the type 1 to uniaxial compression on the magnetic field induction

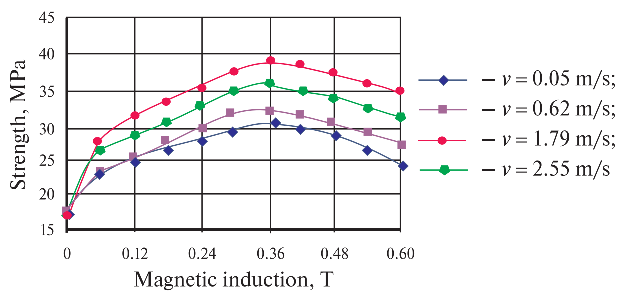


Fig. 4. The dependence of the resistance of cement stone samples obtained from the cement slurries of the type 2 to uniaxial compression on the magnetic field induction

tested. The strength for the slurries of types 1 and 2 was 46.59 and 44.07 MPa correspondingly, and the strength of untreated solutions was 22.04 MPa. The obtained increase of the cement stone strength remained the same in the course of the time.

The next stage of research was to investigate thin sections made from the cement stone obtained from the slurries of types 1 and 2.

Studies of the thin sections were carried out in reflected light at 600-fold magnification under an optical microscope. The analysis of the thin sections prepared from the cement stone of the slurries of type 1 showed the increase of grain number and the decrease of the cement mineral grain size (5.5 microns) compared with the sample not been subjected to magnetic treatment (20 microns). Accordingly, such changes as surface porosity decrease (from 30 to 8 %), packing density increase and improvement of grain cementation quality were observed. Besides, it was noted that the maximum strength corresponds to the minimum surface porosity and the minimum size of the grains of cement minerals. The analysis of the thin sections made from the cement stone of the slurries of type 2 demonstrated an increase of grain number and decrease of the grain size of cement minerals (up to 5.5 mm) compared with the samples not subjected to the magnetic treatment (20 microns). Accordingly, such changes as surface porosity reduction (from 26 to 6.5 %), packing density increase and improvement of grain cementation quality were observed. Moreover, as in the first case, it was noted that the maximum strength corresponds to the minimal surface porosity and minimum grain size of cement minerals. Microscopic studies have demonstrated that optimal values of velocity and magnetic field induction, i.e. the maximum values of uniaxial compression strength and density, as well as minimum values of the structural viscosity correspond to the minimum size of microcrystals of cement and pores. This can be explained by the fact that the magnetic treatment creates conditions for the occurrence of crystallization and structure formation processes in a denser mass of cementing material. Studies were carried out in reflected light at 600 times magnification and provided only a qualitative assessment of the samples. To get more accurate findings a further study using a scanning electron microscope was required.

The study of proposed samples was carried by using a focused-beam electron microscope with possibility to provide X-ray microanalysis with the help of REMMA 202-M. Fig. 5 demonstrates the pictures of the cement stone surface obtained from magnetized and non-magnetized slurries by increasing the order by 1300 times.

Picture analysis showed that the fracture topography of the cement stone obtained from the slurry not processed in a magnetic field is uneven. It has large and clean fracture; high porosity and cement particles are generally of an elongated shape. Studying the pictures of the cement stone prepared from the slurry of type 2 demonstrates that the fracture has the tendency to obtain a fine-cellular structure, particles have a rounded shape, the surface relief is much flattened and the mean grain size of the cement minerals is about 3.5–4 times less than the previous one (Fig. 6).

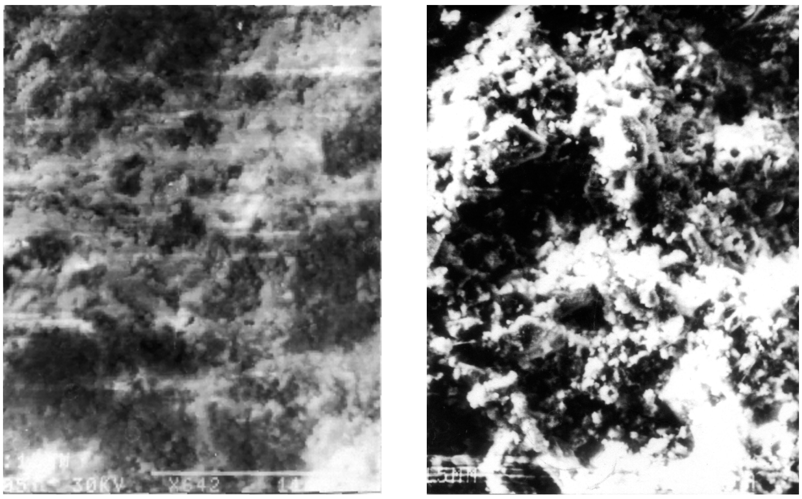
As can be seen from Fig. 6, magnetic treatment actually decreases the grain size by 3.5–4 times. Sample variance while analyzing a grain size for magnetized solution is 2.12, and for solution not subjected to the magnetic treatment it equals 23.24. A standard deviation was respectively 1.46 and 4.82.

Carried out research allowed making some general conclusions. It was found that the dependence of the uniaxial compression strength on the average surface porosity is linear, and the dependence of the uniaxial compression strength on medium-sized cement mineral grains is well approximated by the following formula

$$\sigma_c = C \cdot d^a,$$

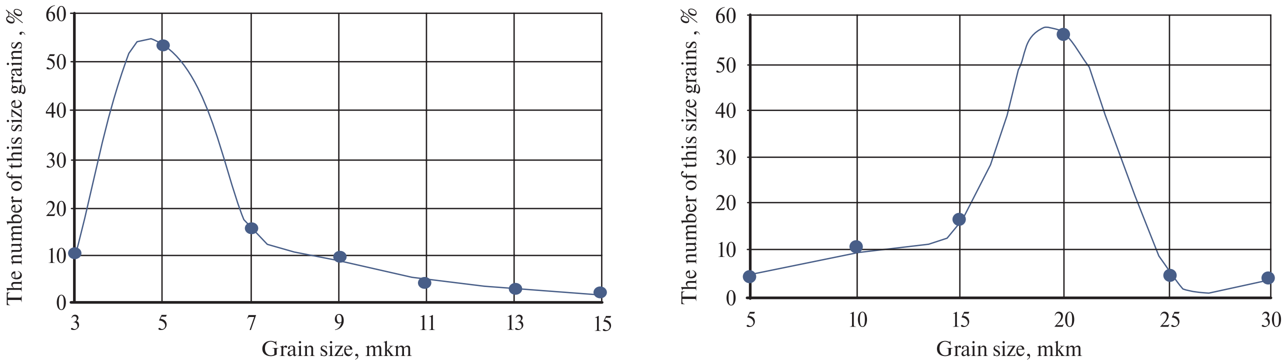
where d is the average grain size of cement minerals, microns; C, a are approximating coefficients.

Thus, based on the aforesaid we can draw the following **conclusions**:



a *b*

Fig. 5. Pictures of the cement stone surface obtained with a scanning electron microscope: a – obtained from magnetized ($B = 0.36T$, $v = 1.79$ m/s); b – obtained from a slurry not subjected to the magnetic treatment



a *b*

Fig. 6. Grain distribution in terms of their size in the cement stone samples:
a – obtained from two types of slurries; b – obtained from the slurry not processed in the magnetic field

1. The magnetic field affects the ions presented in the liquid medium, and increases the number of crystallization grains, resulting in a fine-grained, low-porosity structure with better filtration properties and strength. For the first time the analysis of the processes of magnetic field impact on the dispersion-colloidal systems allowed to consider a magnetic field effect on accelerating coagulation processes, and demonstrated that the magnetic field accelerates coagulation processes in average by 10 %.

2. Magnetic field treatment decreases the initial cementation time: for slurries of type 1 by 2–4 %, for slurries of type 2 by 6–10 %.

3. The time of final cementation is reduced and for slurries of type 1 is 32–33 hours, and for slurries of type 2 is 30–31 hours, thus is 3–6 and 9–12 % is lower, respectively, than for slurries not processed by the magnetic field.

4. Structural viscosity of cement slurries due to magnetic treatment is reduced by 5–16 % for slurries of type 1 and by 8–24 % for slurries of type 2.

5. The dependence of the uniaxial compression strength of the cement stone obtained from the slurries activated by the magnetic field on the magnetic field induction when the latter varies from 0 to 0.6*T* is extreme and can be approximated by the expression $\sigma_c = \sigma_0 + k \times \times B^{2.5} \cdot \exp(-l \cdot B)$.

6. The optimal value of magnetic field induction is specified where $B = 0.36T$. This value features the minimum setting and hardening time for types of slurries 1 and 2 as well as their viscosity, maximum strength and density of the obtained cement stone.

7. The optimal fluid processing velocity in the magnetic field is determined. Its value is 4.08 m/s for water and 1.79 m/s is for the grout slurry

8. By analyzing the pictures obtained with the help of a scanning electron microscope REMMA M-202, it was established that the magnetic treatment affects the shape and size of the cement mineral grains. The grains become more rounded, and their size is reduced by 3.5–4 times in average. The dependence of the uniaxial compression strength on the average grain size of the cement minerals follows a power law.

Based on the experimental results it can be concluded that while preparing cementing slurries direct magnetic treatment is more preferable than water treatment in the magnetic field, as it provides a greater strength to a fixed element and besides, is easier to perform from technological point of view. Therefore, for industrial use activating direct grout mixtures in the magnetic field is proposed. These experiments give the possibility to justify the parameters of intensification processes of rocks jet grouting under magnetic treatment of cementing slurries and improve the technology of working operations.

The effect of the cement slurries properties on the efficiency of rock consolidation can be assessed by modeling the stress-strain state of a fortified object. In particular, jet technologies are effective in strengthening natural slopes. Estimation of their stability is carried out by the finite element method, in which the properties of fixing materials can be taken into account [4, 5].

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Мета. Обґрунтування параметрів обробки в постійному магнітному полі цементних розчинів, які застосовуються при закріпленні слабких дисперсних порід високонапірними струменями цих розчинів, що забезпечує підвищення економічності й технологічності виконуваних робіт.

Методика. Методологічною основою вирішення поставленого завдання є комплексний підхід, що включає теоретичні та експериментальні дослідження. Розглянута теорія коагуляції та впливу на іонні й дисперсні системи постійного магнітного поля показала можливість застосування впливу магнітним полем на цементні розчини з невисоким водоцементним співвідношенням. Після чого були проведені лабораторні дослідження фізико-механічних параметрів як самих розчинів, так і отриманого з них цементного каменю. Усі експерименти повторювалися від 3 до 5 разів, результати оброблялися на ЕОМ сучасними статистичними засобами. Для всіх залежностей знаходилися коефіцієнти кореляції, апроксимуючі формули й коефіцієнти достовірності апроксимації.

Результати. Виконані експериментальні дослідження дозволили знайти такі режими обробки цементних розчинів у постійному магнітному полі, за яких максимально поліпшуються такі їх властивості:

1. Час початку й закінчення тужавлення та загальний час набору міцності (в оптимальному випадку час твердіння зменшується на 12 %, що дозволить скоротити терміни робіт із закріплення порід).

2. Міцність на одновісне стиснення зразків цементного каменю при різних способах і параметрах магнітної обробки вихідних розчинів апроксимується добутком експоненти й степеневої функції від величини індукції магнітного поля, з коефіцієнтом достовірності апроксимації 0,94. Залежність екстремальна та має виражений максимум при індукції магнітного поля $B = 0{,}36$ Тл.

Наукова новизна. Полягає в тому, що вперше враховано вплив залишкової намагніченості неферомагнітної речовини на прискорення процесів коагуляції цементних розчинів. У ході роботи встановлені залежності зміни часу схоплювання й твердіння, а також міцності на одновісне стиснення цементного каменю з них утвореного, від параметрів обробки цих розчинів у постійному магнітному полі (при зміні індукції магнітного поля та швидкості рідини в робочому просторі магнітного апарату).

Практична значимість. Полягає у встановленні закономірностей впливу індукції постійного магнітного поля та швидкості руху рідини в робочому просторі магнітного апарату на деякі фізико-механічні властивості цементних розчинів і цементного каменю, одержуваного з них після затвердіння. Проведені експериментальні дослідження дозволили виявити оптимальні параметри для поліпшення цих властивостей, що при застосуванні до струменевої технології дає можливість істотно її вдосконалити. Можливо зменшити витрату цементу при збереженні заданої міцності закріплення, або збільшити міцність закріплення, за такої ж кількості закріплюючого розчину.

Ключові слова: *індукція магнітного поля, магнітна обробка, струменева технологія закріплення, цементні розчини*

Цель. Обоснование параметров обработки в постоянном магнитном поле цементных растворов, применяемых при закреплении слабых дисперсных пород высоконапорными струями этих растворов, что обеспечивает повышение экономичности и технологичности выполняемых работ.

Методика. Методологической основой решения поставленной задачи является комплексный подход, включающий теоретические и экспериментальные исследования. Рассмотренная теория коагуляции и влияния на ионные и дисперсные системы постоянного магнитного поля показала возможность применения воздействия магнитным полем на цементные растворы с невысоким водоцементным соотношением. После чего были проведены лабораторные исследования физико-механических параметров как самих растворов, так и полученного из них цементного камня. Все эксперименты повторялись от 3 до 5 раз, результаты обрабатывались на ЭВМ современными статистическими средствами. Для всех зависимостей находились коэффициенты корреляции, аппроксимирующие формулы и коэффициенты достоверности аппроксимации.

Результаты. Выполненные экспериментальные исследования позволили найти такие режимы обработки цементных растворов в постоянном магнитном поле, при которых максимально улучшаются следующие их свойства:

1. Время начала и конца схватывания и общее время набора прочности (в оптимальном случае время твердения уменьшается на 12 %, что позволит сократить сроки работ по закреплению пород).

2. Прочность на одноосное сжатие образцов цементного камня при различных способах и параметрах магнитной обработки исходных растворов аппроксимируется произведением экспоненты и степенной функции от величины индукции магнитного поля, с коэффициентом достоверности аппроксимации 0,94. Зависимость экстремальна и имеет выраженный максимум при индукции магнитного поля $B = 0{,}36$ Тл.

Научная новизна. Состоит в том, что впервые учтено влияние остаточной намагниченности неферромагнитного вещества на ускорение процессов коагуляции цементных растворов. В ходе работы установлены зависимости изменения времени схватывания и твердения, а также прочности на одноосное сжатие цементного камня из них образованного, от параметров обработки этих растворов в постоянном магнитном поле (при изменении индукции магнитного поля и скорости жидкости в рабочем пространстве магнитного аппарата).

Практическая значимость. Заключается в установлении закономерностей влияния индукции постоянного магнитного поля и скорости движения жидкости в рабочем пространстве магнитного аппарата на некоторые физико-механические свойства цементных растворов и цементного камня, получаемого из них после твердения. Проведенные экспериментальные исследования позволили выявить оптимальные параметры для улучшения этих свойств, что применительно к струйной технологии дает возможность существенно ее усовершенствовать. Возможно уменьшить расход цемента при сохранении заданной прочности закрепления, или увеличить прочность закрепления при таком же количестве закрепляющего раствора.

Ключевые слова: *индукция магнитного поля, магнитная обработка, струйная технология закрепления, цементные растворы*

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EFFECT OF HARMONIC OSCILLATIONS ON A CRACK INITIATION IN THE ROCK MASS

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ВПЛИВ ГАРМОНІЙНИХ КОЛИВАНЬ НА СТРАГУВАННЯ ТРІЩИНИ В ПОРОДНОМУ МАСИВІ

Purpose. The purpose is to improve, develop and generalize the criterion of a crack initiation taking into account the simultaneous effect of the rock stress state and oscillatory processes. The influence of the oscillation amplitude-frequency characteristics on the critical crack length has to be studied as well.

Methodology. The methodological basis of the problem solution is a comprehensive approach that includes the mathematical analysis, numerical methods for solving transcendental equations, analysis of the results in the mathematical package Mathcad.

Findings. A crack initiation criterion has been developed considering both static stresses (tensile and compressive) and dynamic stress in an elastic wave spreading in the rock mass. The critical length of the initiated crack is determined depending on oscillation amplitude and frequency, static stress and rock crack resistance. The abrupt change in the critical crack length is defined as an indication of the dynamic rock failure. The values of oscillation frequency provoking a decrease in the critical crack length and dynamic rock failure are determined for different rocks.

Originality. New approach is used to describe the rock destruction considering the elastic oscillations in the rock mass. The criterion of a crack initiation has been generalized to consider the action of both tensile and compressive stress near by the crack and harmonic stress in an elastic wave. So, based on a common time-space failure criterion, we take into account the stress which is a sum of quasi-stationary and harmonic components. In this paper we focused on the critical crack length that provokes the crack initiation. The influence of oscillation amplitude and frequency on critical length altering has been estimated for different values of the crack resistance.

Practical value. The results obtained in the study of criterion crack initiation, can be used to improve the acoustic forecast of gas-dynamic phenomena by the amplitude-frequency characteristics of oscillations. For this purpose, we defined ranges of harmonic oscillation frequencies in some rocks (fine-grained sandstone, limestone, siltstone, coal) in which the initiating of "short" cracks occurs. And we got the real conditions (for coal), in which a slight change in the oscillation amplitude in the array of rocks leads to a jump in the length of the cracks.

Keywords: *crack initiation, the amplitude, crack resistance, critical crack length*

Introduction. Dynamic phenomena originating in mines, such as outburst and rockburst have been known for about 250 years. The problem of combating these phenomena in coal mines has been relevant in Ukraine for the past 85 years. The need to predict, prevent and avoid the negative effects provides the development of various methods focused on forecasting the outburst at certain stage of mining. One of the ways to deal with the gas-dynamic phenomena is the diagnosis of the rock stress-strain state and identification of the areas of potentially hazardous emissions of coal, rock and gas. The acoustic monitoring of a coal seam state as a source of a gas-dynamic phenomena is an effective diagnosis method. It includes the following basic stages: the seam probing by artificial acoustic signal, receiving a part of signal that passes through the stressed rock mass and subsequent analysis of the return signal. Based on this analysis the conclusion concerning the rock mass state can be