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STUDIES OF NEW NONADHESIVE ANCHORING

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ABSTRACT

Purpose is to develop anchoring with nonadhesive high-strength roof bolting in terms of large pre-destructive deformations and its testing under laboratory conditions.

Methods. Laboratory studies of hydration hardening of self-extending mixtures, carried out with the use of digital microscope Bresser LCD 40-1600x, have determined the features of hydration of the modified mixtures. The developed mixture, testing by means of unevenly-component three-axial pressure (UCTAP), has determined its strength within post-hydration period, elasticity module, and deformation module. Bench tests concerning anchor fastening by means of self-expending mixtures as well as anchor glue Cement KL have helped perform comparative analysis of adhesive technique to hold anchors fixed and nonadhesive one. Underground on-site research to fasten anchors while Franciszek Karol chamber strengthening in the context of Wieliczka mine made it possible to determine dynamics of anchor loading.

Findings. It has been grounded experimentally that adding of Sika BV 3M ingredient to self-extending mixture results in up to 30% intensification of its strength limit on uniaxial compression. It has also been grounded experimentally that maximum effort to fasten anchor bolts by means of self-extending mixtures, excesses efforts for those bolts fastened with the help of resins more than twice. Analysis of operation mode of such anchors means that the action of anchor – fastener – rock system is close to that by modern energy absorbing bolts.

Originality. A new concept of anchor fixation at the expense of their fastening by means of self-extending mixtures throughout the hole length has been formulated. During the hardening process, 30 – 50 MPa pressure is developed making it possible to intensify maximum fastening effort being more than two times higher to compare with adhesive technique. Moreover, constant resistance is provided in the process of the anchor bolts displacement within a hole; the resistance is similar to that provided by adhesive technique.

Practical implications. The obtained results, having sufficient practical accuracy, can be used for the development of new anchoring in the context of large deformations of a stope boundary. If the parameters are substantiated theoretically and bench testing is passed, the proposed anchoring technique can be implemented in the stopes of coal mines, ore mines as well as nonmetallic ones. That favours the increase in load bearing capacity of the anchorage and rock support in terms of their elastic deformation.

Keywords: *anchor, anchor fixation, adhesion, rocks, stress*

1. INTRODUCTION

Anchors, being a technique to provide stability of stopes, are used worldwide in ore mines, nonmetallic mines, and coal mines (Windsor, 1997; Wen, 2010; Li, 2012; Wen, Jiang, Han, Yang, & Wang, 2016; Ghadimi, 2017; Pruška, 2017). Different mining and geological conditions of their use stipulated the development of a number of anchoring designs. In this context, anchors are considered as separate, independent support setting as well as components of more complex supporting systems (Kovalevska, Barabash, & Gusiev, 2016). However, despite the variety of design features, according to a technique of their fastening, anchors are divided into:

– anchors with local (point), mainly mechanical fastening;

– anchors with chemical fastening applied mainly throughout the length of the bolt (adhesive);

– anchors being fixed within a hole at the expense of friction forces).

Locally fastened anchors are fixed in a bottom part of a hole with the help of special-design latch mechanisms. Bearing capacity of such anchors is limited by the latch mechanism fixation effort. Modern anchors

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with the turned fastening are of rather high bearing capacity; thus, according to data of experiments by Korzeniowski (Korzeniowski, Skrzypkowski, & Zagórski, 2017), bearing capacity of such modified anchors as Phase II with deforming elements of latch mechanisms is 165 MPa. Basic disadvantage of such specific anchors is their complicated design and high labour intensity involved in their installation.

Anchors of group two are the most popular. Resins, polymers, or mineral mixtures are applied as fastening blends. According to studies by Stjern (Li, Stjern, & Myrvang, 2014), bearing capacity of chemically fastened anchors with 20 mm diameter is 210 kN if deformations are 40 mm. Bench studies by Li testify that in terms of relative deformations (i.e. 13 – 20%) such anchors break down due to local loading of the bolts (Li, 2012). Anchors of the group are applied by Ukrainian mines.

Anchors of group three make it possible to withstand large deformations in the context of constant resistance; however, their resistance is 3 – 4 times less than the resistance of adhesion bolts. Split Set, Swellex, and Omega are the three basic designs represented in the group. According to data by Stjern (Li, Stjern, & Myrvang, 2014), bearing capacity of Split Set anchors is almost 50 kN if deformations are more than 120 mm.

Energy absorbing anchors are the newest group. In actual fact, they combine advantages of the three abovementioned groups. Basic objective of their development is to design such an anchoring system providing high bearing capacity in terms of large deformations (He et al., 2014; Wen, Jiang, Han, Yang, & Wang, 2016).

It follows from the current studies of anchoring tendencies that large anchor deformations are impossible without frictional effect. Control over fastening friction effort at the expense of additional mechanical systems results in the increased complexity of anchoring design, in multioperational installation, and the increased anchoring costs.

Thus, the development of anchor system having high bearing capacity under large pre-destructive deformations and favouring the stability of boundary area rocks in the context of a simple design and quick installation is topical research and practice problem.

2. THE RESEARCH METHODS

The experiments were carried out as follows. Hydration hardening of non-explosive destructive mixtures (NEDM) was analyzed with the help of digital microscope Bresser LCD 40-1600x. Hydration process of the samples was observed in diffuse light. For the analysis, the prepared components were mixed according to stoichiometric calculation of B/T proportion (1) 1:3; then, they were coated thinly on a microscope slide. Digital video device recorded the process. Dimensions of the below illustrations are 63×84 μm.

$$CaO + H_2O = Ca(OH)_2 . \quad (1)$$

Mass of one CaO mole is 56 g/mole; mass of one H_2O mole is 18 g/mole. Their ratio is 56/18 ≈ 3.11.

Three different mixtures were analyzed: pure NEDM; saccharose-added NEDM; and NEDM with Sika BV 3M plasticizer. The results were analyzed with the help of visual comparison.

Stage two studied NEDM mixtures strength after they were hardened. To compare, pure NEDM with Sika BV 3M addition was taken. The experiments were carried out using NEDM plant. The samples were aged during 24 hours until their hardening under the conditions of the limited pressure within a working chamber of the plant. After that, horizontal press plates were unloaded, and the sample was tested by uniaxial compression while recording timing stress-deformation changes. The obtained results became source data for further analysis.

Studies of the proposed technique to fasten anchor bolts with the help of the self-extending mixture were carried out on a full scale under laboratory conditions. Boundary rocks were modeled using concrete which filled in steel pipes with 100 mm diameter. Height of the samples was 200 mm. At the age of 28 days, the concrete strength by uniaxial compression was 34 MPa. Holes were simulated by means of openings with 43 mm diameter.

Procedure of the experiments was as follows. Polysterene was placed within bottom part of the openings at the length of 50 mm. Then hardening mixture was added and anchor bolt was inserted. The bolt overhang the sample by 100 mm. When the mixture became hard, the polysterene was taken out and the samples were loaded on a press until the bolt put down by 50 mm.

The technique of anchor fixation by means of shrinking in to compare with pulling out is not very popular (Pytlik, 2013; Pytlik, 2016); however, it is also frequently used.

To determine the effect of armature surface profiling on the bearing capacity of anchor, when it is being fastened with the help of self-extending mixtures, research was carried out for bolts made of plain rolled metal with 37 mm diameter and armature steel with 38 mm external diameter. Internal diameter of a bolt made of armature steel is 34.6 mm; peak height is 1.7 mm at each side; and pitch between the peaks is 1.2 mm. To compare efforts of anchor fastening by means of self-extending mixtures with standard adhesion fastening, benchmark test series have been done; anchor glue Cement KL (Orica) has been used to fasten bolts made of armature steel.

Field studies concerning anchor fastening efforts were carried out while Franciszek Karol chamber strengthening under the conditions of Wieliczka mine (Poland). The experiments were carried out by means of standard technique of static bolt pulling out (Kılıc, Yasar, & Celik, 2002).

3. RESULTS AND DISCUSSION

The idea of anchoring, meeting the abovementioned requirements, is that anchors are fastened in holes not at the expense of adhesion but at the expense of lengthwise squeezing by means of mixtures self-extending while hardening. First of all, it concerns calcia-based NEDM. The matter is that in the process of hydration hardening they can experience their three-time increase in a free state; in terms of limited deformations, taking place with the anchor in a hole, expansion pressure may reach 30 – 50 MPa. Properties of such mixtures are studied thoroughly (Sakhno & Molodetsky, 2013); analysis of their characteristics within the task area is considered below.

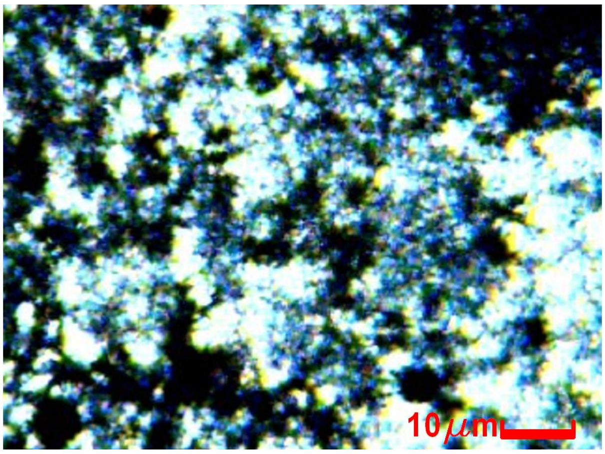
Use of the above-mentioned mixtures to fasten anchors results in the fact when self-extending mixture squeezes anchor bolt between hole walls despite quality of the walls, availability of dust and moisture. The mixture extension changes stress field in the neighbourhood of the hole with anchor; among other things, in radial directions. That improves corresponding components of stress field restricting both development and formation of any fissures and linear defects within the rock mass; moreover, available fissures, oriented normally to vectors of radial stresses, are also cemented which favours stope hardening.

Hardening self-extending mixtures are the basic innovative element of the concept. The mixtures must meet specific requirements: they should develop 30 – 40 MPa expansion pressure under the conditions of limited deformations; their shear strength should be close to strength of rocks of coal formations; they should withstand changes in temporary geomechanical stresses typical for stope roofs; and initial pressure of the mixture should be developed in no time. The modified mixtures were developed and studied under laboratory conditions.

Results of the analysis and comparison of the experiments results helped determine that NEDM hydration is of gradual nature. Stage one involves formation of films or, most probably, hydration shell around crystals (Fig. 1a). Thickness of the hydration shell is 1.3 to 1.5 μm. The stage is well observed on the typical refraction of the latter. Further hydration is characterized by formation of needle-like crystals within the contact boundary (Fig. 1b). Hydration shell ruins with time and the needles disappear; then, calcia starts to transform into hydroxide around output crystals; the process is observed as darkening with iteration of boundary of initial crystallization centres (Fig. 1c). The darkening areas are stipulated by the increased thickness and density of the mixture layer resul-ting from the increase in its volume and, consequently, poorer light transmission. Velocity slows down due to the impeded water penetration to active CaO. Dark zones interlock and the process decelerates down to its termination (Fig. 1d). At the final stage of the experiment, the mixture becomes of mesh-like structure: it is thinner in the central part and thicker along its boundary. The meshes are round; they imitate a boundary of the initial crystal.

Figure 2 represents typical stage of NEDM hydration mixture hardening with saccharose addition. Sharp acceleration of hydration is a characteristic feature of the process. Growth of crystals within the contact of hydrate shells cannot be documented visually.

(a)



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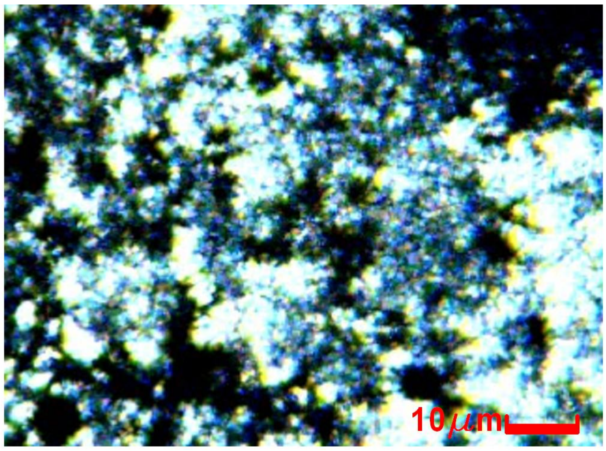

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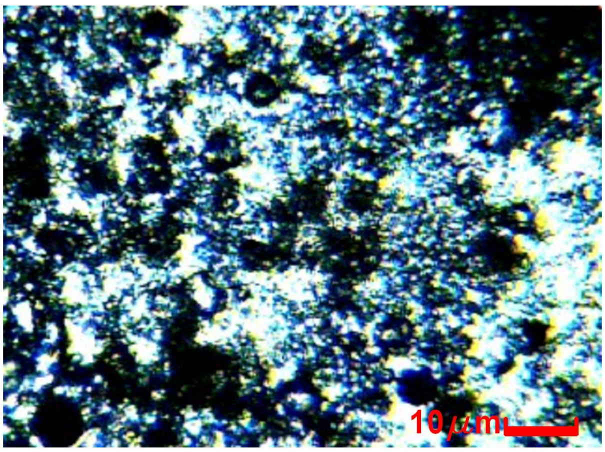


(d)

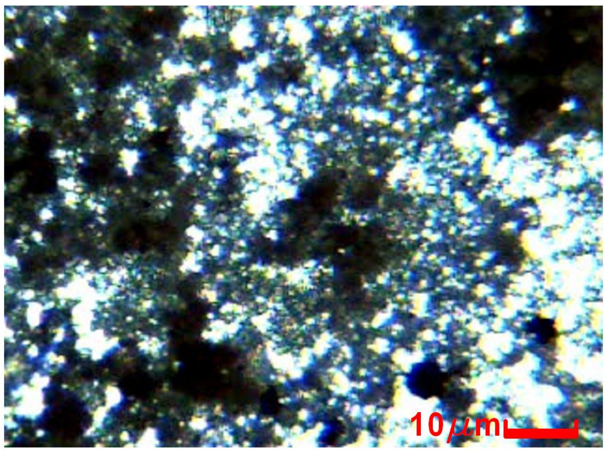


Figure 1. Hydration stages of NEDM: (a) formation of hydration shells; (b) origin of crystal formation; (c) decomposition of initial crystals with relics remained; (d) termination stage

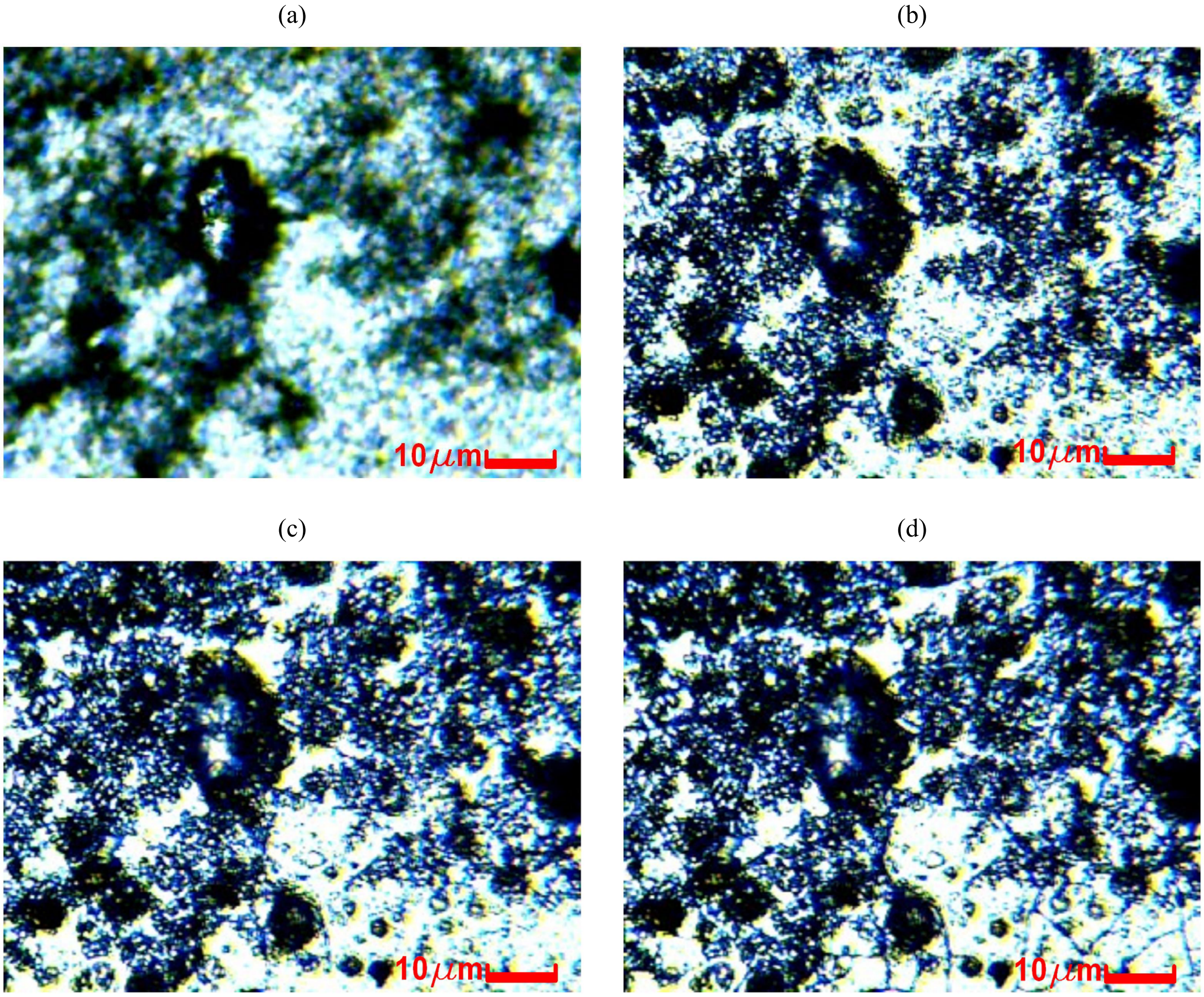


Figure 2. Stages of NEDM hydration with saccharose addition: (a) formation of hydrate shells; (b) hydroxide build around initial crystals with relics remained; (c) fissure growth beginning within the mixture; (d) termination stage

It confirms the fact that volumes of the mixture increase (Fig. 2b). Hydration shells are observed only during stage one of the hydration. Quick hardening and sharp stress increase results in the fact that the formed mineral matrix is decomposed by means of extension stress (Fig. 2c). The phenomenon develops; over the course of time it results in the sample decomposition due to fissure formation (Fig. 2d). Thus, acceleration of the reaction can be stated as the undoubtedly positive phenomenon at the beginning of the process; however, stress increase leaves behind mineral matrix formation resulting in the sample decompositions and its extreme brittleness.

Figure 3 demonstrates typical stages of hydration hardening of NEDM mixture added by Sika BV 3M plasticizer.

Availability of hydrate shells during the whole process is its characteristic feature (Fig. 3a – c). In this context, the hydration shells are thicker to compare with pure NEDM sample; it is 1.7 – 2.5 μm. Moreover, growth of calcium hydroxide crystals is of distinct nature; needles are seen clearly (Fig. 3c). Their length is 3 – 4 μm; thickness is less than 1.0 μm. It is impossible to conclude decisively whether they are monocrystals of crystalline concretions. However, it is quite obvious that the process of formation and growth of crystals is more intensive to compare with the mixture hardening process; that increases a component of pressure increase. Hence, NEDM added by Sika BV 3M plasticizer is more prospective to be used as the agent to fasten anchors within the holes by means of compression.

A process of a slide washing has shown that plasticizer-added slide is washed off harder than that where saccharose is added even after the slide is heat up which results in the increased hydration and calcium hydroxide layer separation.

Figure 4a demonstrates the results of self-extending mixture strength studies in the form of stress and deformation changes taking place in time. To analyze the results in more convenient manner, they are represented traditionally in the form of stresses-deformations dependences (Fig. 4b). The results have determined that NEDM elasticity modulus is 3.67 hPa within a stable zone of elastic deformations (5 – 23 MPa). During early stage of the tests a sampled was compressed and the modulus increased from 1.33 hPa. Plastic deformation started from relative deformations 0.088 in terms of 23.6 MPa pressure. Deformation modulus was 2.73 hPa. Compression strength limit was 24.6 MPa.

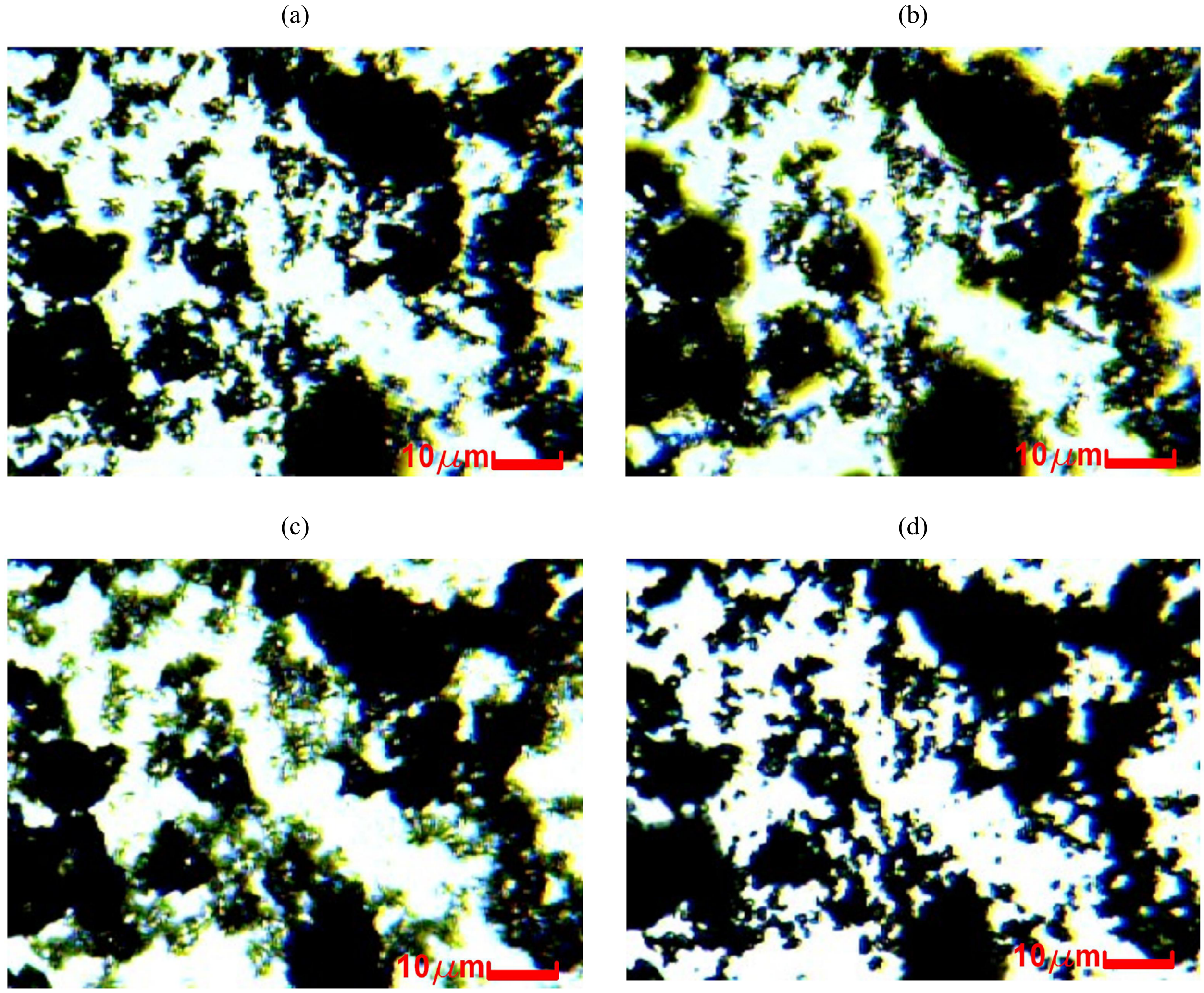


Figure 3. NEDM hydration stages if Sika BV 3M is added: (a) formation of hydration shells; (b) growth of hydration shells; (c) growth of crystals-needles; (d) termination stage

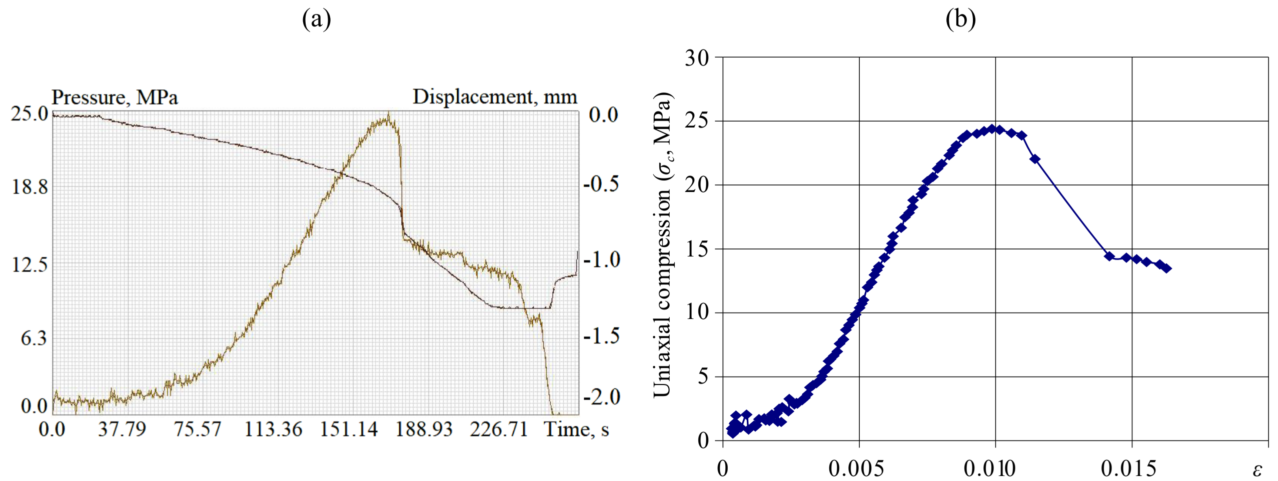


Figure 4. Graph of deformation change depending upon uniaxial compression of NEDM sample with Sika BV 3M in the context of CPF in time (a) and diagram of the sample deformation (b)

Since displacement strength limit, being critical while calculating efforts to be applied for anchor fastening, is the important parameter, it has been calculated with the use of a dependence proposed by L.I. Baron:

$$\tau_{shst.NEDM} = 0.5\sqrt{\sigma_c \cdot \sigma_t}\ ; \qquad (2)$$

$$\tau_{shst.NEDM} = 0.5\sqrt{24.62.46} = 3.88\ \text{MPa}. \qquad (3)$$

The obtained result means that in terms of NEDM, a value of displacement strength limit is close to values of argillaceous shales and sandy shales.

The experiments were repeated when content of Sika BV 3M plasticizer within the solution varied. That helped determine the dependence of Sika BV 3M addition per the hardened mixture strength limit on uniaxial compression. The results were used while developing nonexplosive self-extending mixture (Sakhno, Isayenkov, Lyashok, & Sakhno, 2017). Then, the nonexplosive self-extending mixture has been patented. The mixture contains calcium oxide, caustic ash, plasticizer, and sodium humate. Water solution of the modified Sika BV 3M magnesium lignosulfonates are applied as the plasticizer. Following ratio of components is used: caustic ash is 2.3 – 7.0%; sodium humate is 0.8 – 4.6; 20 – 40% is water solution of Sika BV 3M-30; and calcium oxide – others.

To produce nonexplosive self-extending mixture, NEDM powder is added by water solution of a plasticizer of the modified magnesium lignosulfonates Sika BV 3M-30. Concentration of the water solution to be added was 10, 20, 30, 40, and 50%. Table 1 explains results of the proposed mixture formulations tests.

Table 1. The results of the laboratory tests

Composition of the nonexplosive self-extending mixture, %						Compression strength, MPa, at the age of 24 hours
Calcium oxide	Na_2CO_3	Sodium humate	Sulfite-cellulose liquor	Water	Sika BV 3M	
63.10	30.7	2.30		27	3	27.2
63.10	33.0	2.30		24	6	28.4
63.10	36.0	2.30		21	9	30.7
63.10	17.4	2.30		18	12	33.0
63.10	26.2	2.30		15	15	36.0
66.93	30.7	2.30		21	9	17.4
65.40	33.9	2.30		21	9	26.2
54.10	35.8	2.30		30	9	30.7
60.80	19.1	2.30		21	9	33.9
59.20	24.6	2.30		21	9	35.8
65.02	30.7	0.38		21	9	19.1
64.63	34.2	0.77		21	9	24.6
63.10	34.8	2.30		21	9	30.7
60.80	4.6	4.60		21	9	34.2
59.70	4.6	5.70		21	9	34.8
Basis NEDM mixture						
61.1	4.6	2.3	2	30	0	24.1

Owing to the decrease in surface liquid tension within the boundary of separation of phases and the solution tighten after filling, addition of 20 – 40% water solution of the modified Sika BV 3M magnesium lignosulfonates (being condensation compounds of magnesium, sulphur, methoxyls, and hydroxyls) provides the control over hardening processes as well as increase in dimensions and the number new structural components in the process of recrystallization of calcia to hydroxide; together with other components it factors into the increased strength of the solution after its hardening. Moreover, at the expense of friction reduction between ground lime and other components, Sika BV 3M water solution provides the required mobility of the mixture favouring the decrease in water need.

Owing to free water fixation, sodium humate provides stabilization of water and velocity of hydration hardening reaction restricting uncontrolled temperature increase; moreover, it also restricts random mixture discharge from openings with 50 mm diameter under the conditions of underground stopes.

Caustic ash favours the crystallization frame exceeding the mixture strength both in the hardening process and after its termination.

Figure 5 illustrates preparation of the samples for laboratory bench experiments. Figure 6a, b demonstrates general view of the experiment; its results are represented in Figure 6c.

(a)

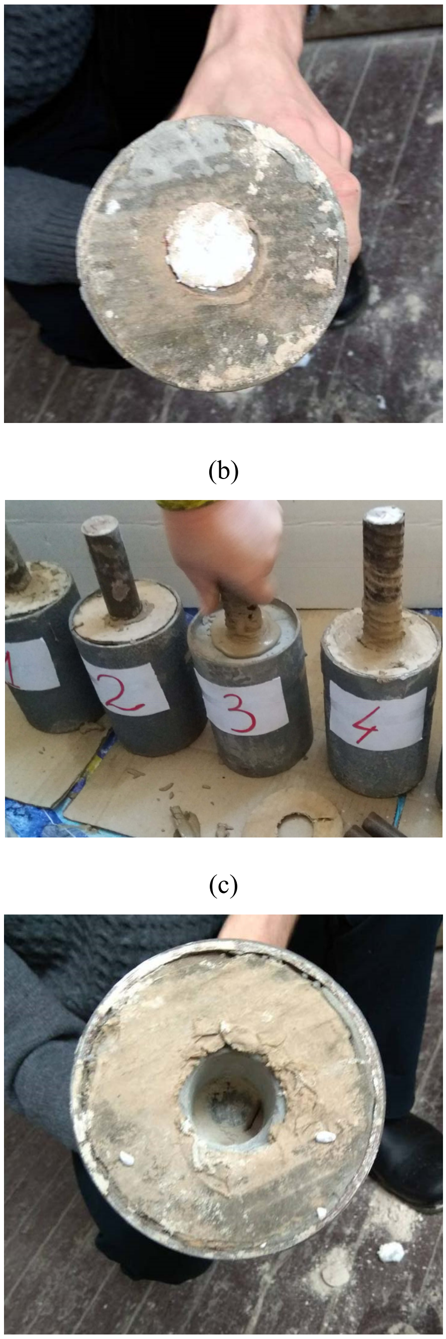
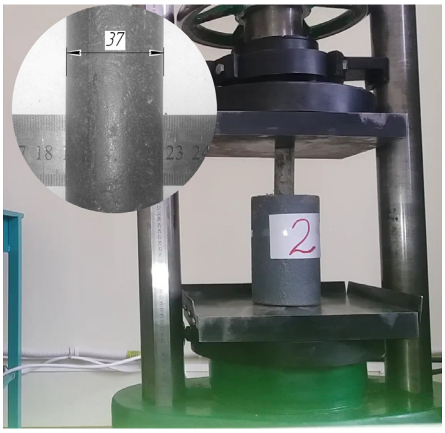


Figure 5. Preparation of the samples: (a) polysterene placing; (b) filling of NEDM hardening mixture; (c) taking out of polysterene

(a)



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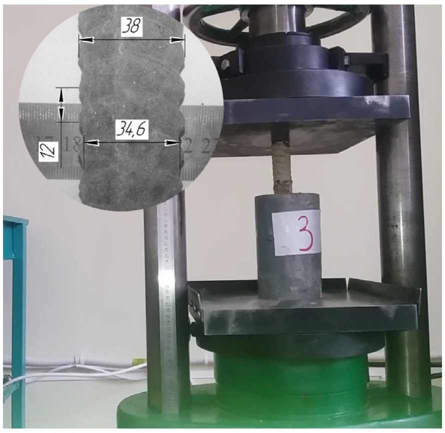

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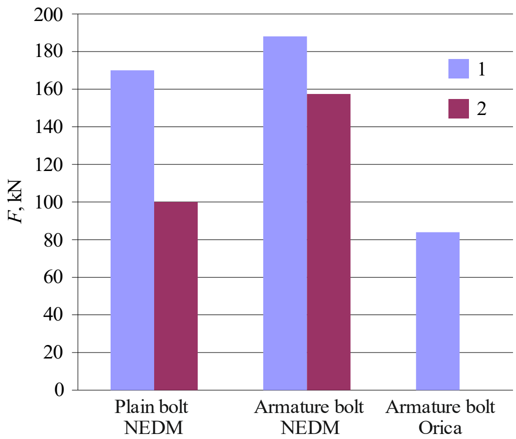

Figure 6. General view of the experiments with the use of bolts made of plain rolled product (a) and armature (b); results of the laboratory experiments (c): 1 – maximum fastening effort; 2 – efforts of the bolt motion

The results processing has helped determine that bearing capacity of the system (if its mode is hard) is: 170.7 kN for anchors with plain armature; 188.11 kN for NEDM-fastened reinforced steel; and 84 kN for that fastened by means of Cement KL mixture. It has also been determined that bolts with adhesive fastening have rigid deformation mechanism. Up to the peak bearing capacity, load is almost linear with minor bolt deformation (i.e. 4.0 – 4.6 mm); then, it decreases with slow growth of deformations. NEDM-fastened anchors had quite different deformation mechanism. After the anchors experienced their peak bearing capacity, they slid and moved then within a hole with approximately constant resistance. According to the results of the tests, in terms of yielding mode, average bearing capacity of the system was 100 kN for rolling plain anchor and 157.5 kN for reinforced steel anchor.

Thus, peak effort of self-extending mixture fastening is twice more to compare with effort by resin fastening. Comparison of testing results concerning plain rolling anchors and those made of reinforced steel gives ground for following conclusions. Bolt forming favours the increase in both maximum bearing capacity and efforts of anchor while displacing. In the context of the experiment, bolt forming effect on the maximum bearing capacity is 10%; the effect on displacement effort is 57%. It should be noted that when anchors are fastened with the help of adhesive mixtures, the forming effect on the bolt fastening is more significant. The phenomenon has been studied thoroughly by M. Ghadimi (Ghadimi, Shahriar, & Jalalifar, 2015; Ghadimi, 2017). Hence, bearing capacity of anchor under compression fastening depends less on bolt walls roughness than those with adhesive fastening.

The deformations and, loads obtained under laboratory conditions, were stipulated by geometry of physical model and its design. Actual fastening anchor length was 150 mm; peak deformations were 50 mm. In this context, bearing capacity is proportional to the working part of the anchor.

Figure 7a, b demonstrates results of field studies concerning anchor fastening with the help of Cement KL (Orica) mixtures while Franciszek Karol fastening by means of fast and slow modes of the bolts taking out. Slower loading scheme (Fig. 7b) is closer to the laboratory testing results.

Demands placed to the anchor fastening quality restrict their load at the level of 100 kN with no sliding. According to the above-mentioned results of the laboratory tests, anchor fastening with the help of self-extending mixtures guarantees such fastening efforts starting from 15 cm; if length is 1.0 m then ten-fold strength coefficient will be reached.

4. CONCLUSIONS

A new concept concerning anchor fastening within a hole has been formulated. The concept is based upon the anchor fastening at the expense of their compression throughout the length with the help of self-extending mixtures hardening. To compare with fastening by means of resins and other adhesive matters, fixation results from active friction effect rather than the expense of adhesion.

Thus, horizontal components of stress tensor increase in the hole adjacent area, effecting positively the stability of stopes. The results of studies concerning hydration hardening of non-explosive calcia-based mixtures carried out using microscopy techniques and bench tests using a plant of integrated gas preparation helped developed the modified mixture which properties are sufficient to fasten anchors at the expense of extending.

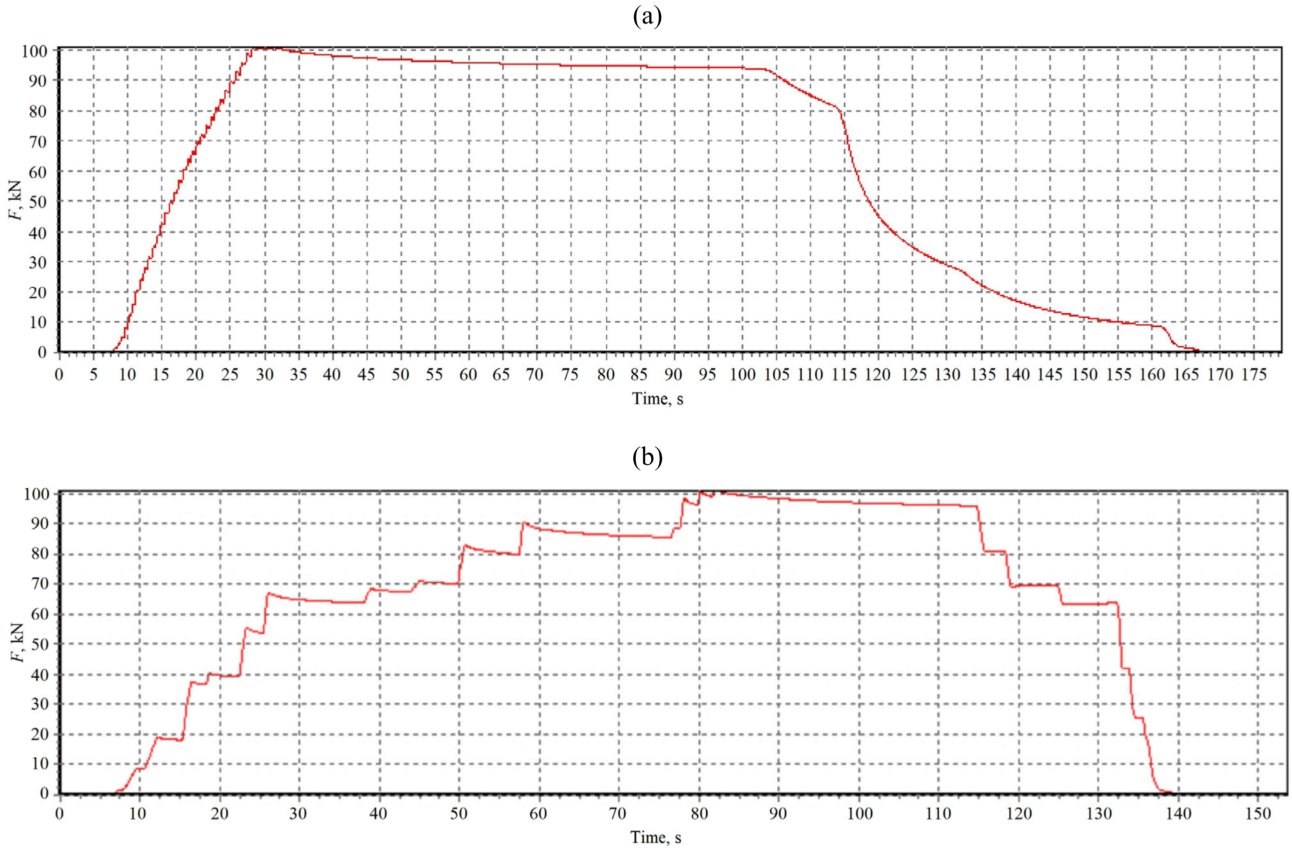

Figure 7. Testing results concerning quality of anchor fastening with the help of Cement KL (Orica) adhesive: (a) fast loading mode; (b) slow loading mode

Comparison laboratory tests made it possible to determine that the peak effort of anchor bolts fastened by means of self-extending mixtures more than twice exceeds efforts for anchor bolts fastened with the help of resins. Analysis of operation of such anchors confirms that mechanism of anchor-fastener-rock system is close to the current energy absorbing bolts.

In the near future, a problem of maintenance of development mine workings in the proper working order will be topical for the majority of mines engaged in deep coal mining. In this context, soil heaving prevention and its control remain one of the most urgent problems.

500 mm and higher soil heaving results from rock breaking; that signs on the development of a zone of non-elastic deformations deep in rock mass by a value determined by means of 1.10 – 1.06 opening coefficient while breaking. Floor rocks of a hole (no less than by 50% of the total breaking area) may be interpreted as discrete medium. In this context, 100 – 120 mm boundary layer becomes fine after 2 months the mine working was driven.

Thus, local rock strengthening is one of the most promising ways to restrict soil heaving. Strengthening with the fortified zone formation in the form of a right prism where its triangle vertex is directed to the mine working floor deserves particular attention.

According to the modeling results, such strengthening makes it possible to reduce rock compaction under the mine working by 20%; decrease soil heaving by 41.8%; and reduce volumes of rocks being deformed to the mine working cavity by 41.5%.

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ДОСЛІДЖЕННЯ НОВОГО, НЕАДГЕЗІЙНОГО, СПОСОБУ АНКЕРНОГО КРІПЛЕННЯ

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Мета. Розробка анкерної системи з неадгезійним закріпленням болтів, яка має високу несучу здатність при великих предруйнівних деформаціях та її тестування в лабораторних умовах.

Методика. Лабораторними дослідженнями гідратаційного твердіння сумішей, що саморозширюються, методом мікроскопії за допомогою цифрового мікроскопа Bresser LCD 40-1600x встановлено особливості протікання гідратації модифікованих сумішей. Тестуванням розробленої суміші на установці нерівно компонентного тривісного стиску (УНКТС) визначено її міцність у постгідратаційний період, модуль пружності, модуль деформації. Стендові дослідження зусилля закріплення анкерів сумішами, що саморозширюються, і анкерним клеєм Cement KL дозволили виконати порівняльний аналіз адгезійного та неадгезійного способів фіксації анкерів. Шахтні польові дослідження зусилля закріплення анкерів при укріпленні камери Franciszek Karol в умовах шахти “Величка” дозволили встановити динаміку навантаження анкерів.

Результати. Експериментально доведено, що введення домішки Sika BV 3M у склад суміші, що саморозширюється, при гідратації підвищує межу її міцності на одноосьовий стиск до 30%. Експериментально доведено, що максимальне зусилля закріплення анкерних болтів сумішами, що розширюються, перевищує зусилля для болтів, закріплених смолами, більше, ніж у два рази. Аналіз режиму роботи таких анкерів свідчить, що система “анкер – закріплювач – порода” має механізм роботи близький до сучасних енерго-абсорбуючих болтів.

Наукова новизна. Сформульована нова концепція фіксації анкерів за рахунок затиснення їх по всій довжині шпуру сумішами, що розширюються у процесі твердіння й створюють тиски 30 – 50 МПа, що дозволяє підвищити максимальне зусилля закріплення, порівняно з адгезійним способом, більше, ніж у 2 рази при забезпеченні постійного опору при переміщенні анкерних болтів у шпурі не менше, ніж адгезійним способом.

Практична значимість. Отримані результати, з достатньою для практичного застосування точністю, можуть використовуватися для розробки нових способів анкерного кріплення при великих деформаціях контуру виробки. Запропонований спосіб анкерного кріплення, за умови теоретичного обґрунтування параметрів та стендової перевірки, може бути реалізований в гірничих виробках вугільних, рудних і нерудних шахт. Це сприяє підвищенню несучої здатності кріплення та підтриманню порід при їх запружному деформуванні.

Ключові слова: *анкер, фіксація анкерів, адгезія, гірські породи, напруження*

ИССЛЕДОВАНИЯ НОВОГО, НЕАДГЕЗИОННОГО, СПОСОБА АНКЕРНОГО КРЕПЛЕНИЯ

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Цель. Разработка анкерной системы с неадгезионным закреплением болтов, которая имеет высокую несущую способность при больших предразрушающих деформациях и ее тестирование в лабораторных условиях.

Методика. Исследованиями гидратационного твердения саморасширяющихся смесей методом микроскопии установлены особенности протекания гидратации модифицированных смесей. Тестированием разработанной смеси на установке неравнокомпонентного трехосного сжатия определены ее прочность в постгидратационный период, модуль упругости, модуль деформации. Стендовые исследования усилия закрепления анкеров саморасширяющимися смесями и анкерным клеем Cement KL позволили выполнить сравнительный анализ адгезионного и неадгезионного способов фиксации анкеров.

Результаты. Экспериментально доказано, что введение добавки Sika BV 3M в состав саморасширяющейся при гидратации смеси повышает предел ее прочности на одноосное сжатие до 30%. Экспериментально доказано, что максимальное усилие закрепления анкерных болтов саморасширяющимися смесями превышает усилия для болтов, закрепленных смолами, больше, чем в два раза. Анализ режима работы таких анкеров свидетельствует, что система "анкер – закрепитель – порода" имеет механизм работы, близкий к современным энергоабсорбирующим болтам.

Научная новизна. Сформулирована новая концепция фиксации анкеров за счет зажатия их по всей длине шпура саморасширяющимися смесями, которые в процессе твердения создают давления 30 – 50 МПа, что позволяет повысить максимальное усилие закрепления, по сравнению с адгезионным способом, более, чем в 2 раза при обеспечении постоянного сопротивления при перемещении анкерных болтов в шпуре не менее, чем при адгезионном закреплении.

Практическая значимость. Полученные результаты, с достаточной для практического применения точностью, могут использоваться для разработки новых способов анкерного крепления при больших деформациях контура выработки. Предложенный способ анкерного крепления, при условии теоретического обоснования параметров и стендовой проверки, может быть реализован в горных выработках угольных, рудных и нерудных шахт. Это способствует повышению несущей способности крепи и поддержанию пород при их заупругом деформировании.

Ключевые слова: *анкер, фиксация анкеров, адгезия, горные породы, напряжения*

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