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Non-detonating chemical mixture for non-invasive methods of rock breaking

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Abstract: *Within the Innovation Project of the Ministry of Science and Technological Development of the Republic of Serbia, researchers of Blasting Center at the University of Belgrade - Faculty of Mining and Geology have developed several different non-detonating chemical mixtures for non-invasive methods of rock breaking. Laboratory and polygon tests gave the satisfactory results and knowledge enough to start the practical experiments in the field. The basis of this innovation is a theoretical assumption that certain chemical mixtures release a large quantity of gases during combustion. If these gases are found in the enclosed space a growing pressure on the walls of the chamber in which combustion takes place will be resulted. If this space is a borehole with good stemming, the rising pressure should be sufficient to break the rock material in which the borehole was drilled. Chemical mixtures developed through the research do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. Rock breaking occurs because of progressive increase in pressure. Non-detonating chemical mixtures can be applied in road and railroad construction, demolition works, secondary breaking, rock breaking for foundation, trenching and similar civil construction operations especially in urban areas as well as quarrying of dimension stones. In other words, for different methods of rock breaking where negative effects of blasting should be avoided.*
Keywords*: NON-DETONATING, CHEMICAL MIXTURE, ROCK BREAKING, BOREHOLE PRESSURE*

1. Introduction

Regarding the method of decomposition, except for black powder, which is classified as deflagrating explosive, all commercial explosives are decomposed by detonation. Deflagrating explosives have a relatively low decomposition rate because the activation energy is transferred from layer to layer by heat transfer. Detonation is the process of explosive decomposition, where the energy required to activate the explosive molecules is transferred from layer to layer by means of a shock wave, which moves through the explosive material at supersonic speed. During the detonation of explosives, there is a sudden release of energy, which is partly spent on breakage the rock mass, moving the broken rock, heating the immediate rock environment and on other useless effects of explosive energy such as seismic waves. The energy of seismic waves induced by blasting manifests itself in the form of ground vibration. Another negative effect of every blast are: air blast, toxic fumes, and flyrock. For this reason, it is necessary to strictly define safety zones to protect the immediate surroundings of the blast field from these negative effects when planning blasting especially in urban areas [1].

During the construction of buildings in urban areas, in some cases there is a need to remove large quantities of solid rock mass that cannot be excavated by machinery. For smaller quantities, the problem can be solved by hydraulic jackhammers mounted on the excavator. However, when larger volumes of rock mass are involved, the use of explosives is necessary.

In cases where there are facilities declared as cultural heritage, industrial and other objects that are very sensitive to ground vibration, blasting using commercial explosives may be prohibited. Despite this, the need to remove a certain solid rock mass still exists.

During building demolition in urban areas, certain parts of the structures, which are usually concrete or reinforced concrete, are blasted. In that case, the problem of negative effects of blasting is even more pronounced, so the procedure and calculation are even more complex [2].

The use of explosives is limited during the extraction of dimension stone blocks. Contour blasting methods using small-diameter explosive charges or a detonating cord are most often used to cut off primary blocks from the remaining rock mass. The parameters of contour blasting must be strictly defined so that the explosive energy would be used only for cutting the block and not for crushing the rock mass. The procedure is similar when the primary block is split into commercial blocks.

During production blasting in surface mines, depending on the quality of the blasting, the blasted rock mass may contain a smaller or larger percentage of oversized fragments of rock mass called boulders that must be subsequently crushed. A high percentage of boulders worsens the technical and economic indicators of surface mining, reduces the performance of loading and transport machinery, and increases the unit cost of the product.

The tendency in the world today is to find new solutions that can be applied to break solid rock masses, and which will be an adequate replacement for commercial explosives in sensitive areas. The reason for this is the problems related to blasting in urban areas, in road and railroad construction, demolition works, secondary breaking, rock breakage for foundation, trenching, stabilization of slopes and similar civil construction operations especially in urban areas as well as quarrying of dimension stones. In all the cases mentioned, there is a problem of removing solid rock mass or concrete structures in an efficient way, while protecting the environment. Except where prohibited or restricted, blasting remains the cheapest method of efficiently removing large volumes of solid rock mass. However, the problem of the negative effects of blasting remains.

The negative effects of blasting have influenced the researchers to work on improving new chemical mixtures that could be an adequate replacement for explosives. These are mainly different compositions that develop borehole pressure without the detonation process and which are placed in a previously drilled series of boreholes (in a case of the extraction of primary blocks of dimension stone, splitting the primary block of dimension stone into commercial blocks as well as cutting off a rock mass during slope stabilization as a substitute for contour blasting methods) or according to a pre-calculated pattern of bore holes (in a case of the building demolition, secondary breaking, rock breakage for foundation, trenching and similar civil construction operations especially in urban areas, etc.). When the stress overcomes the tensile strength of the rock, cracks appear along the predisposed direction and the rock is broken.

One of the mixtures that are used as a substitute for explosives for the generation of borehole pressure is expansive mortar. Expansive mortars do not detonate. Although there are several well-known manufacturers of expansive mortars, they are mostly chemical agents with similar characteristics. The expansive mortars are mixed with water in a certain ratio according to the recommendation of the manufacturer. When the mixture is obtained, it is poured into the boreholes. Expansive mortar in the boreholes expands, developing a pressure force in the range of 7-8 kN/cm^2, which is much more than the required force for splitting the rock mass. The speed of expansion directly depends on the temperature of the rock mass.

Expansive mortars have the following advantages: the rock mass splitting process takes place without detonation and explosions. Rock splitting is done without noise, dust, and toxic fumes. Expansive mixtures do not cause ground vibration, flyrock and excessive damage to the surrounding rock mass. They are clean ecological products and very acceptable from an environmental point of view. Storage and transport are not dangerous for the environment.

One of the well-known expansive mortars on the market is DEXPAN [3]. DEXPAN is used for controlled demolition of buildings, especially in urban areas, minor construction works, such as trenching and the extraction of blocks of dimension stone: granite, marble, limestone, and onyx. DEXPAN [3] is a mixture of powdery consistency which, expanding inside the boreholes, develops a pressure of 1241 bar, enabling the cutting the dimension stone blocks safely, without noise, vibration, and dust. Handling the DEXPAN mixture does not require special permits and certificates, as is the case with explosives, does not require the employment of a specially trained operator, as well as special regulations for safe storage, transport, and maintenance, because it is not categorized like explosive.

Cardox [4] non-detonating expansive system is another alternative to classic explosives. The Cardox system [4] has several different tubes for specific applications. The tubes are filled with liquid carbon dioxide (the same as a fire extinguisher). After activating the chemical heater with a small electrical charge, liquid carbon dioxide is converted into gas. This conversion expands the volume of CO_2 and increases the pressure inside the tube until it causes the disc at the end of the tube to burst. Then the release of CO_2 occurs - now 660 times greater than the original volume - through a special discharge nozzle, which creates a force, at pressures of up to 3000 bar. The whole process takes place in milliseconds. Since it does not detonate, the Cardox system is suitable for use in sensitive areas, for controlled demolition of reinforced concrete, tunneling, shafts, and underwater demolition. It does not create air blast, vibrations, dust, or harmful gases, so it is suitable for use in urban areas and in populated areas where blasting by conventional methods is prohibited. The Cardox system is also widely used for the exploitation of ore, as well as dimension stone blocks [5].

Within the Innovation Project of the Ministry of Science and Technological Development of the Republic of Serbia [6], researchers of Blasting Center at the University of Belgrade - Faculty of Mining and Geology have developed several different non-detonating chemical mixtures for non-invasive methods of rock breaking. Chemical mixtures do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. The gases increase the borehole pressure and cause stresses that should overcome the tensile strength of the rock and cause rock breaking. The laboratory and field tests were consistent with research of foreign Companies that dealing with this problem for several years.

2. The characteristics of developed non-detonating chemical mixtures

The basis of this innovation is a theoretical assumption that certain chemical mixtures release a large quantity of gases during combustion. If these gases are found in the enclosed space a growing pressure on the walls of the chamber in which combustion takes place will result. If this space is a borehole with good stemming, the rising pressure should be sufficient to break the rock material in which the borehole was drilled. Chemical mixtures developed through the research do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. Rock breaking occurs because of a progressive increase in pressure [2,6].

Developed non-detonating chemical mixtures are pyrotechnic compositions whose energy potential is lower than that of black powder. The process of developing the non-detonating chemical mixtures has started from the concept that new compositions should have the characteristics of „benumbed“ black powder in order to keep the rate of decomposition by deflagration even in the conditions of confined charging [2,6].

These generators of borehole pressure represent a wide range of mixtures made up of oxidants and fuels containing modifiers to adjust the speed of combustion and ignition temperatures. Compositions combust during the activation on the open with the speed of 2-5 cm/s, while in the closed space a significant acceleration of combustion is taking place, but still below the explosive one. Thereby it comes to a sudden jump in pressure, leading to an increase in combustion rate in such a way that there are at least two decomposition rates until the final decomposition of the mixture. All compositions have powdery consistency with the cartridge bulk density of 0.85 to 1.1 kg/dm^3. Commercial explosives detonate at a speed of 2000-6000 m/s, while the decomposition velocity of these mixtures should be set at 180 - 300 m/s. Combustion rate is lower than of black powder and conventional fuels [2,6].

Gas pressure grows exponentially during the several tens of milliseconds until they overcome the rock tensile strength, which is 10-20% of the compressive strength of rocks. Depending on the composition of the mixture it is possible to achieve borehole pressures at the initial speed of decomposition of 34, 68, 102 and 136 MPa when it comes to jump of combustion rate in the function of lnP, which gives a new pressure jump before the final decomposition of the mixture. Thus, mixture achieves at least two speeds in the combustion process. Gas pressure of powdered redox mixtures is aimed primarily at the bottom part of the borehole. Powdered redox compositions for this purpose after ignition burn at the subsonic speed, even at higher pressure up to 276 bar, while with the use of explosives a supersonic shock wave is created at normal atmospheric pressure.

2.1 The modifiers

In these compositions a decomposition rate and pressures of released gases in the borehole can be controlled to achieve stresses in rock mass slightly greater than the rock tensile strength. All this can be achieved by modifying the basic redox composition.

These modifiers are combustion catalysts such as metal oxides and organometallic compounds. Compounds that promote the reaction rate and the amount of released gases are also in use, because they also participate in the creation of gaseous products and thus increase the gas volume of mixtures. Besides these compounds, substances that contribute to the release of heat may also be used, although they do not release gaseous products alone. The released heat helps the reaction rate at which emission of gases occurs and affects the increase in pressure because with the heat the volume of released gases increases, too. For this purpose, various metal powders can be used such as: Al, Mg, FeSi, paying special attention to safety in the work [2,6].

2.2 Charging the cartridges with non-detonating chemical mixtures

The best effects are achieved by direct loading of boreholes with non-detonating chemical mixtures but it is often impossible in real conditions of application, so it is provided that the mixture is transported in form of cartridges. The cartridge should be made of flexible plastic material in order not to relieve until the reactive mixture is completely deflagrated after initiation. The possibility of deformation of 10 - 20% of cartridge is preferred before it bursts, and the diameter of the cartridge should be as close to the diameter of drilled hole.

Elasticity of the cartridge is achieved by choosing the material that can withstand plastic deformation, at least until the expansion of the cartridge on the borehole wall. In the case that the diameter of the cartridge is 30 to 33 mm, plastic cartridge in the radial direction should withstand the increase of the diameter on 35 to 38 mm before it expands.

During the research cartridges of high-density polyethylene, with the outer diameter of 25 mm, inner of 20 mm, wall thickness 2.5 mm and length 150 mm were used. Different types of mixtures were examined in terms of composition, powdered consistency, combustion time, the degree of coat deformation. For the initiation of the mixtures, various systems that were available were applied. At the same time, several redox compositions with increased density, using a natural binder for thickening the mixtures were also made and tested [2,6].

Stemming the bore holes was carried out with well compressed mixed clay - sandy material. It must be taken that stemming is not burden in the geometry but should be for a minimum of 50% higher than burden and the distance between bore holes. To determine the parameters of blasting the same amount of non-detonating chemical mixture per m^3 is recommended as in the case with conventional explosives 290-600 g/m^3. Stemming must be well done to withstand the pressure of released gases and direct them to the walls of the bore holes, where there is a breaking of the rock material due to tension stresses. In this case, the detonation does not occur as well as the formation of shock waves as in case during the use of commercial explosives.

***Fig.** 1 Charging the cartridges with non-detonating chemical mixture [2,6]*

***Fig. 2** Cartridges charged with non-detonating chemical mixture [2,6]*

2.3 Initiation of the non-detonating chemical mixtures

Initiation of non-detonating chemical mixtures was done with electrical fuse heads or NONEL shock tubes. Figure 3 shows preparing the initiation of cartridge with NONEL shock tube while Figure 4 shows preparing the initiation of cartridge with electrical fuse head.

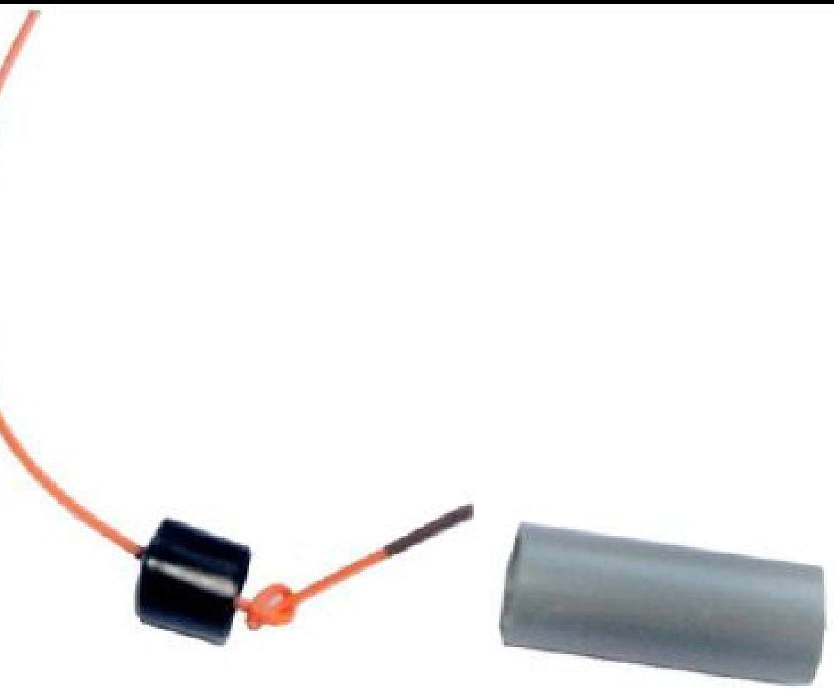

***Fig. 3** The initiation of cartridge with NONEL shock tube [2,6]*

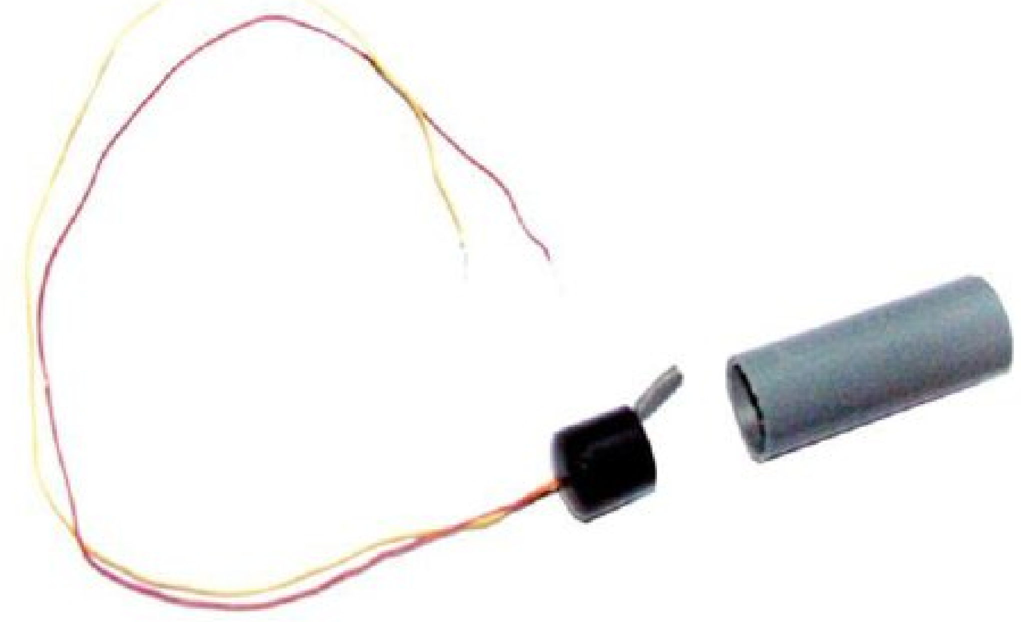

***Fig. 4** The initiation of cartridge with electrical fuse head [2,6]*

Non-detonating chemical mixture had different sensitivity to the initial impulse. Most sensitive are ignited with spark generated in standard NONEL shock tube (20 mg/m reactive mixture) while those less sensitive required a stronger initial impulse.

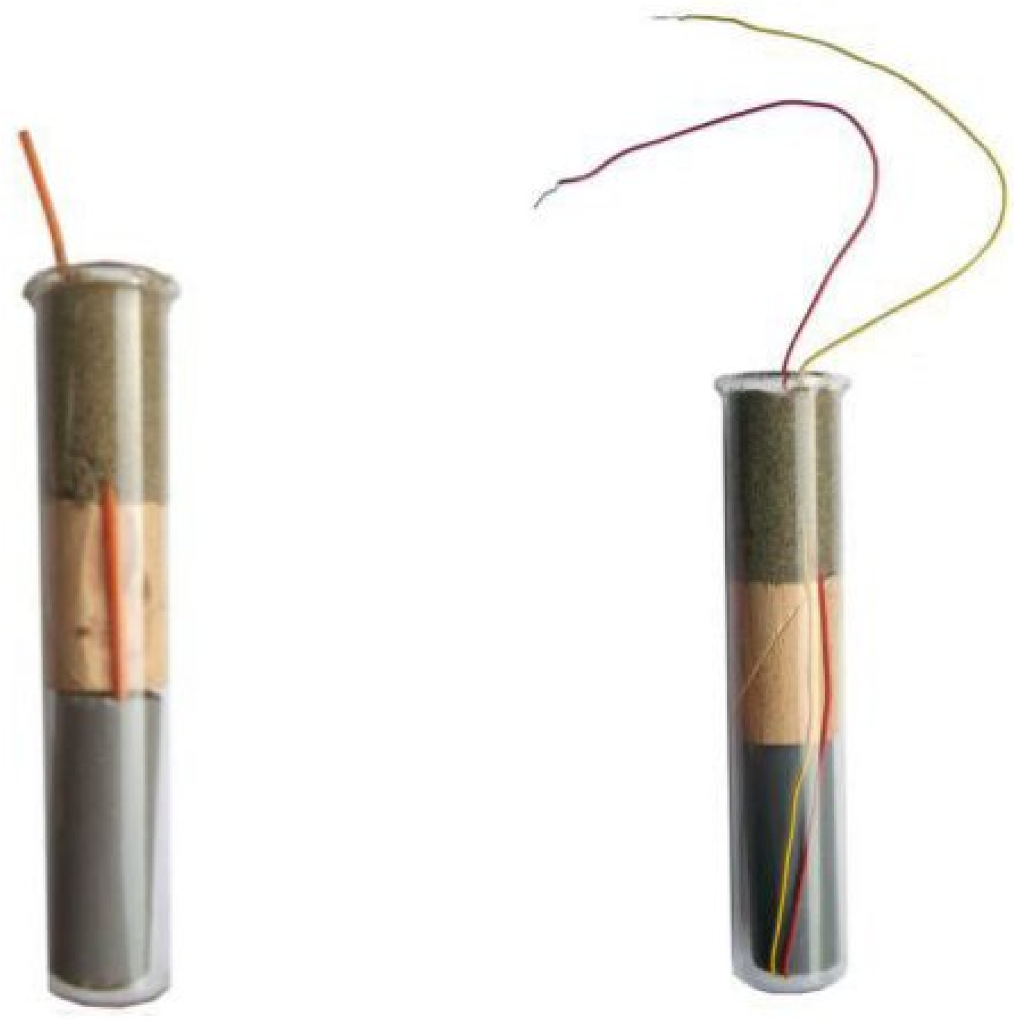

***Fig. 5** Initiation of charges of non-detonating chemical mixtures with NONEL shock tube (left) and electrical fuse head (right) [2,6]*

2.4 Polygon tests of non-detonating chemical mixture

Polygon tests of non-detonating chemical mixtures were carried out at the granite quarry. The tests consisted of cutting off a granite block using non-detonating chemical mixtures. A borehole with a diameter of 32 mm was drilled into the granite block, in which the cartridge with a diameter of 25 mm was placed. The cartridge was charged with a non-detonating chemical mixture. Initiation of the charge of non-detonating chemical mixture was done with an electrical fuse head [2,6].

The results of testing are satisfactory. As shown in Figure 6, cutting of the granite block was achieved by increasing the pressure of the gases produced by the combustion of non-detonating chemical mixture. The pressure of released gases in the borehole creates stresses in the rock mass slightly higher than the rock tensile strength, which is 10-20% of compressive strength and causes rock breaking without a shock wave.

After the fracture of rock mass, the stress decreases due to a sudden drop in the pressure of generated gases, thus avoiding excessive flyrock of rock pieces. As shown in Figure 6, after the fracture of rock mass, gaseous products of the combustion of non-detonating chemical mixture exit through the newly formed cracks, which causes the pressure of gases to decrease intensely, and the gas mixture begins to decompose by burning. The results of polygon tests of non-detonating chemical mixture are shown in Figure 6.

***Fig.** 6 The results of polygon test of non-detonating chemical mixture [2,6]*

3. Application of non-detonating chemical mixture

Non-detonating chemical mixture as borehole pressure generators, can be widely used as a replacement for commercial explosives when it is necessary to break the rock or concrete structures non-invasively, in sensitive and urban areas, such as:

- road and railroad construction,
- demolition works,
- secondary breaking,
- rock breakage for foundation,
- trenching,
- stabilization of slopes and similar civil construction operations especially in urban areas,
- quarrying of dimension stones block etc.

The main difference between the effects of explosives and non-detonating chemical mixtures is that in the case of non-detonating chemical mixture the energy is transferred to the rock mass by increasing the pressure of released gases without shock waves. In just a few milliseconds gas pressure exceeds the tension strength of rocks and splits or breaks the rock depending on the non-invasive method of rock braking. Stress waves rapidly decrease after rock breaking which is of great importance for the reduction of ground vibration, flyrock and possible damage of the surrounding rock mass.

Ground vibration is many times less than that caused by commercial explosives, and safety zone against flyrock does not exceed 30-35m. The air overpressure is 6-10 times lower than during blasting using explosives. An essential condition for successful application of non-detonating chemical mixture is that the cartridge must fit well with the wall of the borehole, because the smallest gap affects the reduction of the effect due to drop of the released gas pressure. Cartridge should have such a diameter that can be inserted into the bore hole without compression, and at the same time the gap between the cartridge and the borehole wall should be as small as possible.

4. Conclusion

After completion of laboratory and polygon testing, the basis for successful IN SITU implementation of non-detonating chemical mixture was created. The final adjustment of compositions remains, in terms of the optimization of charging and initiation pattern in specific types of rock regarding the type of non-invasive methods of rock breaking.

The best results are achieved if non-detonating chemical mixture is used in compact rock mass, because in bore holes with intensive system of joints, there are two reasons for the reduction of effect of non-detonating chemical mixture [2,6]:

1. expiration of products of decomposition through joints and thereby the inability of directing the released energy,

2. inability to create the optimal pressure and force necessary to break the rock because of conditions in which the reaction itself takes place.

For these reasons, the retention of the released gases in the cartridge is a necessary precondition for effective application of these mixtures until obtaining the optimum pressure.

Further research is moving towards finding adequate rates of decomposition of non-detonating chemical mixtures, achieving optimal bore hole pressures with the absence of detonation, controlling ground vibration, toxic fumes, flyrock, etc. A special problem is the precision of the initiation of non-detonating chemical mixtures, which is required, for example, when cutting the rock material.

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6. References

1. L. Kričak, *Seismic from blasting,* Blasting Center, Faculty of Mining and Geology, Belgrade, (2006).
2. Non-explosive generators of borehole pressure as a replacement of explosive charges, *technical solution – M85*, University of Belgrade Faculty of Mining and Geology, (2018).
3. DEXPAN, http://www.dexpan.com/dexpan-non-explosive-controlled-demolition-agent-silent-cracking-breaking.aspx
4. CARDOX, http://www.cardox.co.uk/how.htm
5. FORCEVECTORINC,https://www.forcevectorinc.com/cardox-vs-explosives-comparison.html
6. Innovation Project: *Non-explosive borehole pressure generators as a replacement for explosive charges*, Ministry of Science and Technological Development of the Republic of Serbia, (2009/2010).