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Professional paper

APPLICATION OF POLYMER COMPOSITES FOR STABILIZATION OF DEGRADED ROCK MASS IN MINING

PRIMENA POLIMERNIH SMEŠA ZA STABILIZACIJU DEGRADIRANOG STENSKOG MASIVA U RUDARSTVU

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Abstract: In order to stabilize degraded rock mass, procedures of injecting polymer synthetic composites into wells or fissures around constructed underground chambers and facilities are being increasingly used today. Initially epoxy resins were used at underground coal exploitation, and then they were replaced by polyurethane resins (PUR) without foam, and only later by polyurethane resins (PUR) with foam effect. After that, quick-setting two-component synthetic resins characterized by much shorter time of binding were used. Few years ago, the usage of elastic silicat isocyanate resins (ESR) with higher elasticity began, and they found their use in rehabilitation of mine chambers requiring either mean or longer usage term.

Key words: degraded rock mass, polymer composites, strengthening and stabilization, mining and civil engineering

Apstrakt: Za stabilizaciju degradiranog stenskog masiva u rudarstvu danas se sve više koriste postupci injektiranja polimernih sintetičkih smeša u bušotine ili pukotine oko izrađenih podzemnih prostorija i objekata. U podzemnoj eksploataciji uglja najpre su počele da se koriste epoksidne smole, zatim su ih zamenile poliuretanske smole (PUR) bez pene, a kasnije poliuretanske smole (PUR) sa pena efektom. Nakon toga počele su da se primenjuju brzovezujuće dvokomponentne sintetičke smole koje karakteriše mnogo kraće vreme vezivanja. Pre nekoliko godina u upotrebu su ušle elastične silikatne izocijanitne smole (ESR smole) sa povećanom elastičnošću, koje su našle primenu za sanaciju rudarskih prostorija koje zahtevaju srednji ili duži rok korišćenja.

Ključne reči: degradirani stenski masiv, polimerne smeše, ojačanje i stabilizacija, rudarstvo i građevinarstvo

1. INTRODUCTION

New materials and technologies enable achievement of very significant improvements in many fields of civil engineering and mining, both when referring to

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faster, safer and more efficient construction and when referring to the maintenance and rehabilitation of building and mining structures.

This paper shows polymer synthetic materials being used for the improvement of load-bearing capacity and rehabilitation of incoherent terrains and rock masses, as well as for strengthening walls of mine chambers made within the degraded environment (cracked and rock mass divided by fissures). Polymer resins have found wide usage in rehabilitation and strengthening of the damaged building structures and for insulation of fissures in concrete constructions, rocks and embarkments made of stone. Certain types of resins are being used as insulating materials against water and gas penetration into the damaged and fissured constructions. Foamy types of resins have characteristics of thermal and sound insulation.

By injecting polymer composites into wells or into fissures and by strengthening them, the expansion of in-depth-deformations is prevented, and thereby the stability of the degraded rock material and constructed structures is provided.

2. POLYMER MATERIALS

The following materials have increasingly larger usage in engineering practice for stabilization and insulation of degraded rock mass: polymer resins, synthetic gels, polymer foams, polymer coatings and bio-polymers.

All of the above materials have certain common features. They are marked by:

- exceptional adhesive (bonding) features for all kinds of surfaces (metal and mineral);
- low viscosity, easy penetration into nkoherent environments beneath the level of ground water, all of which provides constant strength;
- high resistivity to corrosion (they are resistant to the chemical impact of sulphates, acids, alkaline solutions, microorganisms);
- they are ecologically harmless materials;
- they are marked by fast reaction time;
- easy and safe handling;
- high tensile strength;
- small mass;
- high thermal insulation.

The most frequently used polymer resins that have found wide application in the field of civil engineering and mining are: polyurethane resins, two-component silicate resins, epoxy resins and elastic silicate insulating resins.

2.1. Polyurethane resins

Polyurethane resins (PUR resins) have found their usage in improvement of mechanical characteristics of rocks, sandy-gravelly soil, coal, engineering structures, as well as for stopping gas and water leaks within mining, hydrotechnical structures, underground structures etc (Trifunović, 2011).

For those purposes, one-component or two-component polyurethane organic mineral resins are being used. Those materials take rock pressure well, they are elastic and they adapt to small movements of the rock mass. The presence of water does not affect the strength of the mixture. This mixture cements the degraded material by forming the compact mass. When using those mixtures, fissures in the rock mass are being filled in even in case of small pressures while injecting, they provide watertightness, resistance to the effects of organic acids, oils, lubricants and mechanical load (constant, impact). When using those resins, it is possible to control the stiffening rate (Ćulibrk, 2001; Code SIA, 2003; Nonveiller, 1989).

The usage of these resins is wide-ranging:

- stabilization of gravelly soil;
- reinforcement of fractured rocks (Figure 1);
- stabilization of mineral deposits as well as fissures within coal deposits before extraction (Figure 2) and during extraction (Figure 3);
- blocking of the ingress of ground water, sealing of rock mass (Figure 4);
- tamponade of exploratory bores;
- sealing of thermal springs;
- erection of impermeable curtains and barriers;
- protection of mechanically loaded floors, reservoirs, locations where complicated works are being executed and the like;
- filling of fissures made in concrete.

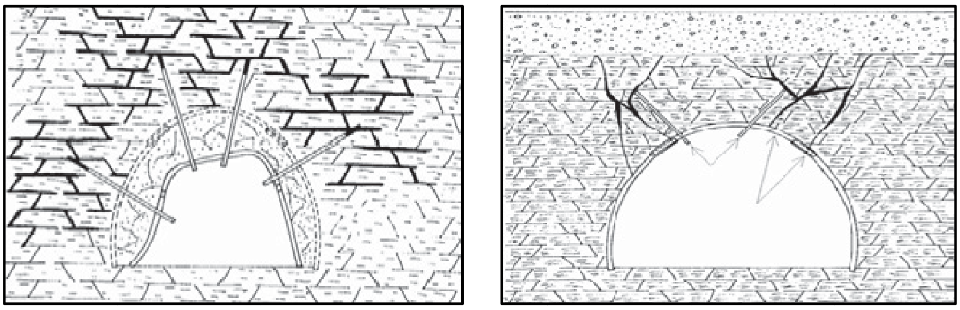

Figure 1 - Reinforcement of fractured rock mass

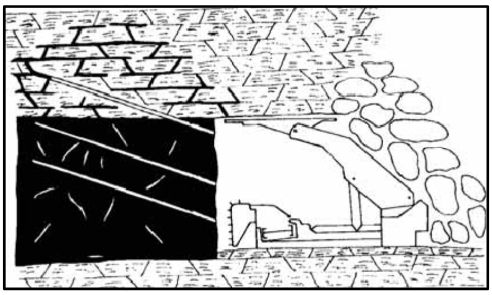

Figure 2 - Stabilization of mineral deposits before extraction of mineral row materials

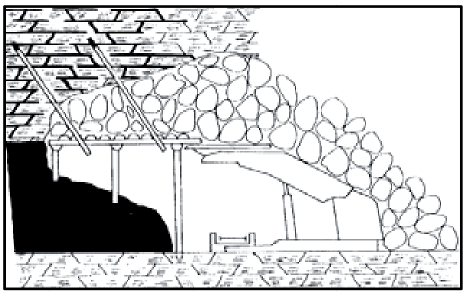

Figure 3 - Stabilization of mineral deposits during extraction of mineral row materials

Figure 4 - Injection into fissures in the vicinity of the barrier at the coal mine in Spain

The equipment and tools used for placing of these resins include pumps for two-component resins, whereby the process of mixing of those two components takes place in the mixing unit placed behind the pump itself in close vicinity of the bore opening. The pump sucks in the A component and the B component, and by means of a hose, under pressure, pushes them towards the bore, where two components are being mixed together in the mixing unit. Mixture, prepared in such a way, is being inserted under pressure into the rock mass by means of a packer and/or installed injecting anchors. The maximum injecting pressure is 200 bars. Resin penetrates the surrounding fissures and joints several meters deep, and consequently, the efficient reinforcement and sealing of the rock mass is provided.

Insertion of two-component artificial resins enables the efficient cementing of fissures within the degraded rock masses, which provides successful mining works when excavating mineral row materials under such conditions. There is also possibility to seal rock layers against ingress of water and gas. This material is distinguished by excellent insulating features and high qualities of adhesion to the surrounding material.

Relatively small viscosity of polyurethane resins enables ease mixing and injecting. Resins stiffen at room temperature with negligible linear shrinkage. After stiffening and maturing (after polymerization being completed) they manifest significant resistance to UV-radiation and they are not brittle.

Table 1 displays mechanical features of polyurethane resins of Smooth Cast® type, after polymerization being completed (www.smooth-on.com).

Table 1 - Mechanical features of polyurethane resins of Smooth Cast® type

Type	Processing time (at 23ºC) [min]	Tensile strength [MPa]	Module of elasticity at tension [MPa]	Elongation-to-break [%]	Bending strength [MPa]	Module of elasticity at bending [MPa]
Smooth-Cast 300Q	0.5	20.7	961.9	5	31.1	882.5
Smooth-Cast 300	3	20.7	961.9	5	31.1	882.5
Smooth-Cast 305	7	20.7	923.9	7.5	27.6	813.6
Smooth-Cast 310	15 - 20	20.7	923.9	7.5	27.6	813.6

- Mixing ratio: 1A : 1B volume mixing ratio; 100A : 90B mass ratio of mixing;
- Viscosity of the composite: 60 mPa·s;
- Density: 1.036 g/cm^3;
- Color: colorless, completely transparent;
- Its form is stable until reaching temperature: 60°C;
- All values were measured after 7d/RT (stiffening and maturing in the duration of 7 days at the room temperature of 23°C).

2.2. Two-component silicate resins

When constructing tunnels, stability problems of the structure are being resolved by injecting two-component silicate resins that display no foam effect. Those resins have proved to be a very efficient solution in cases when it was necessary to stabilize rock mass. Those two-component resins have excellent adhesion, and they can be injected into fissures with gap width larger than 0.15 mm (Figure 5).

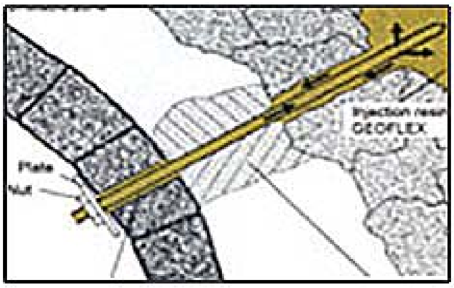

Figure 5 - Injection of two-component silicate resins behind tunnel lining

The advantage of the usage of silicate two-component resins without foam effect is in reaching 90% of final strength after only 15 minutes since injection thereof. The strength reached under pressure is approximately 5 MPa.

Due to its flexibility, those resins show no deformation when rock mass moves. Even if it was applied in thin layers it reaches bonding strength larger than 1 MPa in just a few minutes (Bolesta et al. 1997; Nonveiller, 1989).

If components are well mixed, the mixture is not going to absorb water. Hardened resin is resistant to acids, salty water and many organic solvents.

Table 2 - Physical characteristics of two-component silicate resins

Technical data	**Material data for components**		
	Unit	**A**	**B**
Density at 25ºC	kg/m^3	1480 ± 30	1140 ± 30
Flame Point	ºC	-	> 200
Viscosity at 25ºC	mPa·s	260 ± 60	140 ± 40
	Reaction at 25ºC		
Beginning of reaction	1′40″ ± 30″		
The end of the reaction	3′15″ ± 30″		
Shore factor	D 60		

Both components are being mixed in ratio 1 : 1 by using packer with built-in static mixer and they are to be pumped into the bores drilled through two-component pump. Physical characteristics of two-component silicate resins are shown in Table 2.

2.3. Epoxy resins

Epoxy resins are two-component organic resins. By mixing component A (epoxy resin) with component B (containing catalyst) a reaction occurs, which ends with hardening. The ratio between components varies at different manufacturers and resin types from 2 : 1 to 5 : 1. The catalyst component may contain yet another synthetic resin or some other additives determining specific features. By insertion, it is required to comply with the given weight or volumetric ratio as specified by the manufacturer. The change of volume may cause sudden hardening or may result in the fact that the resin never achieves such final features as expected. When two components are mixed, time needed for insertion of resin is some twenty minutes, also depending on the temperature of environment. If works cannot be done at room temperature, it is required to use specially adjusted resin for works at low and/or high temperatures. Temperature range is from +5°C to +35°C. After 24 hours, the compound may be loaded by forces, which it was specified for, i.e. it has 90% of its final strength. The rest of 10% it achieves in one week.

Different performances of epoxy resins, such as elasticity, stability at low or high temperatures, penetration into another (porous) materials, time and rate of bonding, possibility to work at lower or higher temperatures, can be controlled during the manufacture of epoxy resins, and during their application one may modify them by adding various fillers (most frequently mineral). Adhesiveness and cohesion are ideally balanced at epoxy resins. The disadvantage of epoxies is their sensitivity to ultraviolet rays, as well as relatively high price.

Epoxy resins are used at rehabilitation of leakages at horizontal breaks and continuations when concrete casting of blocks at the dam wall, at the downstream dam face within abutment blocks, at the control and injecting gallery etc.

2.4. Elastic silicate insulating resins - ESR resins

Few years ago, a new type of elastic silicate isocyanate resin (ESR resin) emerged on the market with increased elasticity (Cornely, 2003).

ESR resins are efficiently used when repairing water canals, for fastening of screws of anchors that can be used only few minutes after being built-in, for rehabilitation of premises requiring middle or long term of usage etc.

3. APPLICATION OF POLYMER RESINS IN MINING

There is growing share of underground chambers with large profiles and long excavation fields in underground coal mining. The efficiency of mining in those environments is displayed by undisturbed movement of the dredge and excavation of coal along excavation front having the length of 300 m and more. Any unstable place along this section can cause standstill in production. Therefore it is necessary to stabilize such critical zones, and especially tectonic zones that may occur at crossing points between excavation front and the road. Injecting into such zones is a proven method to resolve problems of disturbed stability.

As cement masses reach their strength too slowly, which is inadequate to maintain continued production, in the sixties of the last century in German coal industry the usage of quick-setting synthetic resins has begun. Initially were used epoxy resins. Shortly thereafter they were replaced by polyurethane resins (PUR) without foam and later by polyurethane resins (PUR) with foam effect.

Quick-setting synthetic resins are characterized by a lot shorter reaction-bonding time, satisfactory strength and elasticity, as well as small compressibility. Due to their brittleness, resins of this type cannot take larger loads irrespective of their advantageous mechanical properties.

In Russia, there was an attempt to use urea formaldehyde (so called carbamide) resin (UF), as cheaper and better replacement for PUR resins. However, those resins were not accepted mainly because UF resins are quite brittle after hardening. A similar resin type, phenol-formaldehyde (PF) resin without foam effect, has been recently introduced for usage in French and German coal industry as injection mortar (Vasilev, 1986).

Based on the experiences in underground coal mining, PUR resins are still not the optimal solution for rehabilitation of premises requiring middle or longer term of usage. High elasticity of PUR may, sometimes be disadvantage, especially for such cases, when those zones must be determined after insufficiently prepared locations. For this application, the more suitable solution is elastic silicate resin ESR (Čokorilo et al. 2002).

Table 3 displays physical and mechanical properties of different types of polymer resins, and Figure 6 displays their adhesive strength (Cornely, 2003).

Table 3 - Physical and mechanical properties of different types of polymer resins

Resin type	**Unit**	**PUR Bevedol S19-Bevedan**	**SIR Geodur OM**	**ESR Geoflex**	**PF Wilflex VP**
Viscosity of component A	mPa·s	310	250	280	220
Viscosity of component B	mPa·s	200	200	150	20
Viscosity of the composite	mPa·s	630	> 2000	> 5000	~ 100
Minimal width of fissure	mm	0.09	0.14	0.24	0.04
Adhesive strength after 0.5h	MPa	1.3	0.8	5.0	0.9
Strength after 7 dana	MPa	3.3	6.6	4.5	> 2.3
Critical time	min	25	1080	< 15	35
T_{max}	ºC	135	131	98	68
T_{max} with 2% of water	ºC	167	< 131	< 98	< 68

Large manufacturers worldwide produce one-component and two-component resins under various commercial names: Geodur OM, Carbo Stop 1C, Geoflex, Wilflex etc.

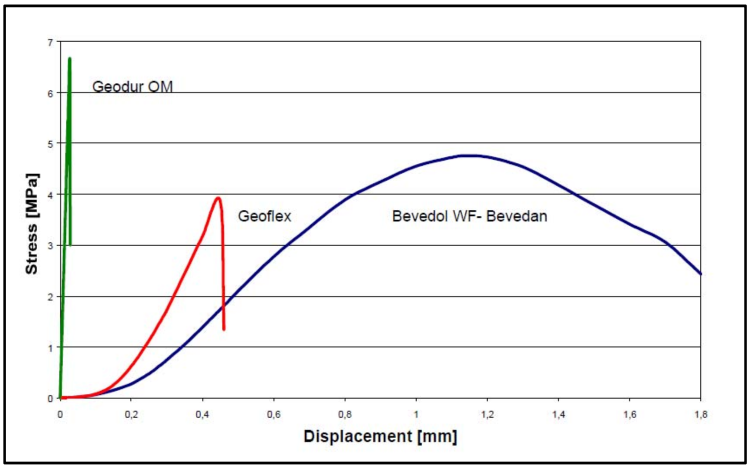

Figure 6 - Adhesive strength of various types of polymer resins

4. CONCLUSION

Modern materials based on polymer composites have growing application when resolving project tasks and rehabilitation works in the field of civil engineering and mining.

They are used for: stabilization of weak zones of rocks, soil and coal; stabilization of damp soil, reinforcement of rocks or walls; prevention of leakages around barriers and walls at underground structures; insulation of ingress of mineral waters; stabilization of zones where fissures are present; stopping of ingress of water. They are used as the material for underwater injecting, filling-in of fissures, holes etc.

Polymer composites are widely used for tamponage and chemical hardening of outlines of building structures or mining chambers, if they are to be applied in cracked and rock mass divided by fissures or in case of cohesionless sediments.

Polyurethane resins are used as very efficient means for stabilization of coal and accompanying sediments in underground coal mining. Their acceptance in building industry, especially in tunneling is still growing. The main advantages are: easy usage, quick reaction and facility to stabilize whole formations of rocks exposed to high pressures and movements.

The selection of polymer material is done individually for each specific case when constructing and by rehabilitation of underground mining and building structures, depending on the required stability and functionality of structures in a certain time period.

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