Review paper

PASTE BACKFILL MATERIALS FOR UNDERGROUND MINING - SOME EXPERIENCES IN SERBIA – PART II

Milena Kostović¹

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Abstract: This review paper presents the backfill method and materials for paste backfill method which are used in the world practice of underground mining. The paper consists of two parts. The first part (Part I) provides a brief literature review concerning the presentation of the backfill method, mostly the paste backfill method, its application, advantages and disadvantages, and materials that can be used to form a paste. The second part (Part II) of the paper presents an overview of possible materials that could be used for the eventual application of this method in Serbia. Flotation tailings from lead-zinc mines and copper mines, fly ash from thermal power plants and metallurgical slag can be potentially used materials for this method. This paper presents the characterization of these materials from some localities in Serbia and results of some investigations in this area.

Keywords: backfill method, backfill materials, paste, underground mines, Serbia

1 INTRODUCTION

Paste backfill is defined as an mixture of fine solid particles (with binder) and water, containing between 72% and 82% solids by weight (<https://sites.google.com/site/mininginfosite/miner-s-toolbox/backfill/paste-backfill>)

It is important to know differences between paste backfill and other backfills, such as hydraulic fill and cemented hydraulic fill. Hydraulic fills are first applied in the 1960's. The aim was to provide material of adequate stability (due to shear strength) that drained sufficiently and disposed to underground. Binders (mainly cement) began to be added to provide additional strength and greater flexibility. Hydraulic fill and cemented hydraulic fill are transported in a turbulent flow regime which requires a significant quantity of water. After the placement some proportion of water must be released from the fill until the residual water content state is achieved. Paste fills evolved in the 1970's to overcome some of the difficulties of using hydraulic fills. Paste fills behaves as non-Newtonian plastic and transported in a laminar flow regime demonstrating plug flow behavior in pipelines without settlement of the particles in the pipe (Bloss et al. 2002).

¹ University of Belgrade - Faculty of Mining and Geology
Email: milena.kostovic@rgf.bg.ac.rs

It is a very important phase to testing the material that will be used to define the backfill method that precedes its practical application. First of all, it is important to determine the physical characteristics of the material to be used, as well as the characteristics of the formed mixtures in laboratory conditions. Some of these tests involve determining: porosity, density, dry bulk density, particle size distribution, chemical composition and mineralogical composition. Various microscopic methods (optical microscopy), than DTA, TGA, XRD and SEM methods can be used to determine the mineral composition. Zeta potential measurements and infrared spectroscopy techniques can be used for qualitative surface identification. Also, laboratory tests includes: strength testing, slump testing, flow table testing (Bloss et al. 2002).

As a general rule, a paste fill should contain a minimum of 15% (by weight) - 20 μm because. Pulp density is very important and must be strongly controlled. The viscosity depends from many factors and some of them are: pulp density, size class, mineralogy and grain shape. The concrete slump test has generally been used as a measure of the viscosity. Specific gravity and porosity of the material, as well as type of binder and its content are also important. Cement is usually added as binder in contents from 2-6% by weights (<https://sites.google.com/site/mininginfosite/miner-s-toolbox/backfill/paste-backfill>).

In the aim of the minimization of costs, it is gravitate to replace cement with some other materials, originated from mining and other industries, which are waste and, from this aspect, can be considered as secondary raw materials. These materials includes mostly fly ash from thermal power plants and metallurgical slag. The amount of added materials or binders should be as low as possible and the materials must be cheaper. The advantage of these materials are proven because of pozzolanic and hydraulic properties, as well as the reduction of costs.

In the second part (Part II) of this paper it will be shown the different materials (fly ashes from thermal power plants and heating plants, ferrous and nonferrous slag, cement and flotation tailings from lead-zinc and copper mines) that can be used to apply for the backfill method in Serbia. According to the available data, the particular characteristics of some of these materials (chemical, mechanical, physical, physico-chemical etc.) and results of available examinations in this area also will be shown.

2 MATERIALS FOR PASTE BACKFILL

According to Serbian standard (SRPS B.C1.011:2001) which is harmonized with European standard EN197-1:2000, cement is divided into 5 types, i.e. several types. In addition to pure Portland cement (CEM I), portland cement with the addition of slag, portland cement with the addition of artificial pozzolan (fly ash), portland cement with the addition of limestone and portland composite cement (CEM II), then metallurgical cement (CEM III), pozzolanic cement (CEM IV) and composite cement (CEM V) are differed as other types of cement. Fly ashes, as artificial pozzolans, and slags can be a

component of 6 types of cements, with various marks. For example, portland cement with addition of slag contains from 6% to 35% of slag and marked as PC 20S and PC 35S according to Serbian standard or CEM II/A-S and CEM II/ B-S according to European standard. The contents of fly ash varies from 6% to 35% in portland cement with the addition of artificial pozzolan (fly ash) which marked as PC 20V and PC 35V according to Serbian standard or CEM II/A-V and CEM II/ B-V according to European standard.

Slag is a waste originated from metallurgical processes of primary mineral raw materials. They are two types of slag: ferrous (steel and blast furnace Fe) and non-ferrous (Ag, Cu, Ni, Pb, Sn, Zn). The composition of ferrous slag is dominated by Ca and Si, Fe (in steel slag), Mg and Al (in Fe slag). Because of its characteristics, non-ferrous and ferrous slag may be reprocessed for secondary metal recovery. (Piatak N. et al, 2015). Examples of traditional applications of ferrous slag are the use as aggregates and cement component in the building sector or as fertilizer (<https://www.euroslag.com/>).

The metallurgical slag from the copper mine Bor is waste resulting from pyrometallurgical treatment of copper concentrates. More than 16×10^6 t of this waste has been deposited in the mines in Bor. Chemical analysis of slag in Bor showed the next composition: 0.65-0.84% Cu (with about 80% Cu_{sulph}), 0.2-0.55 g/t Au, 1.8-7.57 g/t Ag, more than 35% Fe, or 7-10% Fe₃O₄. Mineralogical analysis of slag showed the presence of fajalite (Fe₂SiO₄), magnetite (Fe₃O₄) and quartz (SiO₂), while copper minerals (mostly in the form of bornite, native copper, chalcopirite, chalcosine and covelin) with pyrite are presented in a content of about 10%. The density of slag is 3487 kg/m³. Bond's working indexes are 19.13 kWh/t (rod mill) and 31.96 kWh/t (ball mill) (Stanojlović et al., 2009). Chemical analysis of the slag from locality Bor also showed the next chemical components: Cu (0.68 %), Fe (25.69%), Fe₃O₄ (1.754%), CaO (17.26%), S (1.07%), SiO₂ (43.76%) and Al₂O₃ (3.89%) (Čadenović et al., 2011)

Flotation tailings in Serbia are waste originated from the mineral processing, i.e. from the process of flotation concentration, mostly from Cu, Pb and Zn sulphide ores. In general, flotation tailings in Serbia from lead- zinc and copper mines, in addition to the minimal presence of useful components, contains SiO₂ as main component, then Al₂O₃ and Fe₂O₃, as well as CaO, MgO, Na₂O, K₂O and TiO₂. The contents of these components vary and depend on the type of tailings, i.e. mines. The tailings density is from 2550-3300 kg/m³. The grain size distribution of our flotation tailings is favorable for the application of paste backfill method because the contents of size class -0.074 mm (by weight) is 57-66% (data for the mines Majdanpek, Veliki Krivelj, Bor and Rudnik) and the contents of the size class -0,020 mm is appropriate. Flotation tailings have the following chemical compositions: 66.1% SiO₂, 5.6% Al₂O₃, 9.4% Fe₂O₃ i 5.7% CaO (Rudnik mine), 63.2% SiO₂, 14.1% Al₂O₃, 3.8% Fe₂O₃ i 3.7% CaO (Majdanpek mine) and 60.8% SiO₂, 12.8% Al₂O₃, 5.8% Fe₂O₃ i 2.7% CaO (Veliki Krivelj mine) (Adamović M., et al., 1999).

Flotation tailings from copper mines in Bor are waste generated by flotation concentration of copper ore. Only in the old flotation tailings in Bor there is about 26×10^4 t of this waste. The basic minerals of copper according to the mineralogical analysis are: chalcopryrite, covelin, enargite, chalcosine, cuprite, bornite, azurite, then pyrite, as well as tailings minerals. The average copper content is 0.155-0.37%, the tailings density is $2650-3070 \text{ kg/m}^3$. The grain size distribution is different depending on the place of tailings disposal. The content (by weight) of size class -0.074 mm is from 25% (tailings dam) to 55% (central part of tailings dump), or 65% (peripheral part of tailings dump) (Stanojlović et al., 2009).

Durđevac Ignjatović et al. (2015) concluded that in the case of the Bor river mine the required uniaxial/unconfined compressive strength (UCS) of the fill should be at least 1.5 MPa. Also, Djurdjevac Ignjatović et al. (2016) established that mixture from flotation tailings (cycloned and uncycloned) with cement and water in various contents shows different physico-mechanical properties. Cycloned flotation tailings obtained as material in the plastic limit with the binding time after 10 hours. UCS of 1-1,5 MPa is fulfilled after 28 days for mixture with 7% of cement. Uncycloned flotation tailings is characterised as poor plastic material with the binding time also after 10 hours. UCS of 1-1,5 MPa is fulfilled after 28 days for mixture with 3% of cement. So, it can be concluded from these authors that the paste backfill, made with uncycloned tailings, has far better characteristics than the paste backfill with cyclone tailings.

Flotation tailings resulting from flotation concentration process of sulfide lead-zinc ores from Kopaonik mines with underground exploitation Belo Brdo, Žuta Prla and Crnac are located in two tailings (one old and the other active). In addition to Pb and Zn, flotation tailings contains Fe (14.5-27.2%), SiO_2 (19.58-31.55%), Al_2O_3 (2.74-9.2%) and MgO (1.27-4.0%). Volumetric mass is from $3.2-3.56 \text{ t/m}^3$ (Janković et al., 2009).

The chemical composition of blast furnace slag from the steel production plant in Smederevo in Serbia was the next: 23.82% SiO_2 , 13.02 Fe_2O_3 , 15.73 FeO , 7.70 Al_2O_3 , 26.5 CaO , 11.13 MgO , 0.08 TiO_2 , 21.2 Fe . Grain size was 0.470 mm (Jovanović B. M. et al., 2011). The converter slag is composed of the mineral phases: iron, calcium ferrite, larnite, rankinite, wustite, periclase, manganosite, Fe and Mn monticellite, Mn-cordierite, melilite and glass. The presence of the crystal phase is found to be in the range between 40 to 80 % (Radosavljević et al, 1996).

Fly ash is produced by coal-fired electric and steam generating plants. Fly ash consists of silt-sized particles which are generally spherical, typically ranging in size between 10-100 μm . Fly ash consists primarily of oxides of Si, Al, Fe and Ca and classified as Class C or Class F according to its chemical composition. Class C are originated from sub-bituminous coals and it referred as high calcium fly ash with more than 20% CaO . Class F are typically originated from bituminous and anthracite coals and it is referred as low calcium fly ash with less than 10% CaO (<https://www.fhwa.dot.gov/pavement/recycling/fach01.cfm>).

According to chemical composition, fly ashes produced in mostly thermal power plants in Serbia belong to group of siliceous fly ashes (Class C).

Fly ashes from TPP Nikola Tesla B and TPP Kostolac B have more than 45% chemically active SiO_2 (44.82-47.46% for TPP Kostolac B and 50.57-61.63% for TPP Nikola Tesla B). The contents of acid oxides ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) are over 75%. Contents of alkaline oxides are: 3.02-8.35% CaO and 3.74-8.7% MgO. These ashes have appropriate grain size distribution and characterized by high fineness. Fly ash from TPP Nikola Tesla B have greater fineness ($d_{50} = 0.025\text{-}0.135$ mm) than fly ash from TPP Kostolac B ($d_{50} = 0.075\text{-}0.20$ mm) (Kostović et al., 2008). Fly ash is low-cost secondary raw material and it can be a good supplement to a binder such as pozzolanic material and also for correction the grain size distribution of the backfill mixture. However, it is necessary to carefully consider the possibility of applying fly ash in relation to the cost of transport to the mine, which in this case is the only unfavorable circumstance.

3 CONCLUSION

Available literature data show that little attention has been paid to the paste backfill method in Serbia. Waste materials originated from various industrial processes have been tested mostly for use in the construction industry (such as fly ash or metallurgical slag) or for flotation concentrations of copper slag to obtain copper concentrate. Flotation tailings in Bor have been tested for the application of the backfill method and the first paste backfill plant is in the design phase and it is expected to be applied soon. Flotation tailings from lead-zinc mines, according to available data, were not tested for paste backfill. Different materials can be used for the backfill method according to the literature data. Flotation tailings, as well as other possible used waste materials, are specific and different from their characteristics. Flotation tailings from lead and zinc and copper mines in Serbia differ in relation to chemical, physical, physico-chemical and mechanical characteristics. Laboratory tests would refer to the characterization of the tested materials and the obtained mixtures, defining the composition and the most favorable ratios of materials in the mixture, as well as defining the characteristics of the obtained mixtures, which include rheological parameters and mechanical characteristics in order to obtain an appropriate paste backfill from a technological, economic and environmental aspect.

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SERBIAN STANDARD SRPS B. C1.011:2001- CEMENT

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