Technical Sciences
Academy of Romania
www.jesi.astr.ro

Journal of Engineering Sciences and Innovation
Volume 6, Issue 2 / 2021, pp. 203-212
http://doi.org/10.56958/jesi.2021.6.2.203

F. Petroleum and Mining Engineering

Received ***18 January 2021*** *Accepted* ***17 May 2021***
Received in revised from ***23 Apryl 2021***

Geotechnical research regarding the use of solid mineral tailings from the mining industry in construction, in the context of circular economy

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Abstract. The extractive activity and processing of useful mineral substances results in a significant amount of mining waste, in the form of mineral waste. According to European statistical institutions, mining and quarrying in Europe generates over 50% of total industrial waste. Most of this waste is stored in dumps and ponds. The processing of solid mineral tailings and the production of economically usable by-products is of major importance, both from an economic point of view and from the point of view of environmental management, having a major impact on the protection of the environment. The paper presents the results of research conducted for two areas, namely Deva and Abrud. The geotechnical conditions and the geomechanical characteristics of the tailings as well as of the concretes made from the sterile rocks from the two mining companies were detailed. Based on research, it was found that the mechanical strength of concrete cubes made of sterile material are superior to those made of quarry aggregates.

Keywords: mining industry, waste, dumps, ponds, environment, reuse.

1. Introduction

Romania is a country with significant quantities and varied types of mineral resources, such as gold, silver, magnesium, copper, iron and polymetallic ores. Quarrying and processing activity generate a vast amount of mining waste, in the form of solid mineral tailings. According to European statistical institutions, mining and quarrying in Europe generates over 50% of total industrial waste. Most of this waste is stored in dumps and ponds. There was a long period when the solid mineral tailings worldwide were seen as non-reusable waste. Today, research is carried out worldwide to determine the potential of reusing the solid mining tailings in various

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industrial fields. Mining waste stored in dumps and surface mining as well as tailings dumps affect hundreds of thousands of hectares of land that cannot be reused as before. [13] Processing solid mineral tailings and the production of economically viable by-products is highly important, both economically and from an environmental management point of view, having a major impact on the protection of the environment. [1, 3, 5]

Over time in Romania, 64 tailings ponds have been built as a result of mining activity, all of which cover almost 1350 hectares and store almost 350 million m^3 of solid mineral tailings. [7, 10]

The almost universal use of tailings ponds as the main method for storing solid tailings and treating polluted water in the mining industry comes undoubtedly from their multiple uses, as it is seen as a cheap storage and treatment solution for water and solid mineral tailings. Thinking about the security of tailings ponds fundamental aspects should be considered, such as: physical stability (to avoid dam breaks as a result of landslides, sinking, erosion and so on); chemical stability; toxic waste infiltration.

The problems and dangers associated with tailings ponds generated by mining activity also comprise: slope instability, acid water generation and the emission of toxic substances which could infiltrate over ground and underground water downstream, erosion and dust pollution, land degradation. [2, 3, 4]

At present Romania's mining production capacity has decreased considerably since 1990 and their use level varies between 60 to 90%, according to the type of useable mineral substances and the timeframe considered. [16]

2. The environmental impact of mining industry – circular economy

The useable mineral substances in an ore often make up very low percentages from the total rock mass quarried from a deposit. These percentages range from under ten for metalliferous ores to tens for non- metalliferous ores.

In the future extraction will take place from increasingly poor deposits. As the amount of extracted minerals increases so does the amount of waste resulted from their processing, on top of the amount of waste, sterile rocks resulted from underground mining, open pit mining but particularly from the deposits exploitation in quarries. The environmental impact through tailings ponds and processing them and dumps are: destruction and occupation of the land or pollution of water from surface or underground with dissolved chemical substances or with solid particle suspension carried by rain water from dams or infiltration; air pollution with gas resulted from storing minerals in ponds or from oxidizing or burning them; material or human life loss as a result of stability loss and so on. [6] It is a regenerative system in which any resource input, waste or energy loss is minimized through sustainable design which consider in circular economy. [12, 14]

Mining waste management is one of the most important issues Romania is currently dealing with in terms of environmental protection. Mining products (ores, coal, construction materials) are the basis of modern industry, but at the same time the mining industry has a strong impact on the environment at every stage of exploitation and processing, being necessary to consider it as a circular economy like in Fig. 1. [18].

Quarrying waste management includes managing any waste plant, including the post-closure stage as well as preventing major accidents involving the plant and reducing the environmental and public health impact. Case studies have been carried out for two metalliferous ore mining areas as part of the former public company MINVEST (Cuprumin and Deva Mine) in order to determine the reuse of tailing pond and dump waste for concrete and mortar production, in point of view of circular economy. [17]

Deva mine tailings pond cover an area of 1.6 hectares. Cuprumin dumps are: Valea Cuibarului (the volume of tailings generated from the quarry and stored there is 45.876.260 m^3 and covers an area of 67 hectares; the final available area is 82 hectares; the projected area of the dump is 149 hectares, enough to store 85.600.000 m^3), Geamana (the total projected area of the dump is 99 hectares of which approximately 26 hectares are currently used, with a total 6.317.174 m^3 of waste generated from the quarry). The available area is 73 hectares and the total projected storage capacity is 21.250.000 m^3 and Obarsia Muntari dump (total projected area of the dump is 46 hectares and so far, 5.300.000 m^3 of quarry waste has been stored, covering an area of 27 hectares). The total available area is 19 hectares. The total projected storage capacity is 10.500.000 m^3. The tailings generated from the copper ore floatation process quarried at Cuprumin is stored in Valea Sesei tailings ponds at Valea Stefancei 2 pond as a reserve. Valea Sesei pond is the main functioning pond. [7]

3. Case studies: Cuprumin and Deva Mine

Deva mining area is located 2.5 km away from Deva town, in Hunedoara county (currently rehabilitated).

The tailings generated from quarrying and processing the copper ore have been stored in tailings ponds and dumps: [17]

- Valea Herepeia tailings pond which started operating in 1981 and ceased activity in 1991. The tailings were generated by Deva copper ore plant and covered an area of 9 hectares;
- Valea Muresului tailings pond which started operating in 1959 and ceased activity in 1973 when it became a reserve. The tailings were generated by Deva copper ore plant and Deva mine and covered an area of 21,7 hectares, the volume of tailings stored was 4,3 million m^3 confirmed at the last review in 2004.

The tailings ponds have a total area S_{total} = 1,6 hectares.

- Deva pond from level ± 0m with an area S = 0,4 hectares,
- Caprioara tunnel pond with an area S = 0,7 hectares,
- 7th November gallery hill pond with an area S = 0,5 hectares.

A range of soil and waste samples from the tailings pond from the two mining areas were analysed and a particle size analysis was carried out for the materials in the

pond, granulometric curve of material, shown in Fig. 2. [1, 3] We also carried out a compression strength test for concrete cubes made using tailings with varied quantities of binder material (Table 1), in accordance with the standards SR EN 1926/2007, SR EN 206-1:2002, SR EN 12390-2/2005, SR EN 12390-1. [7, 8, 9]
We carried out research at Deva mine to determine the potential use of pond and dumps waste in the production of concrete and mortars by analyzing the pond material particle size and the compression strength of the concrete cubes from this area was established, Table 2. [7, 9]

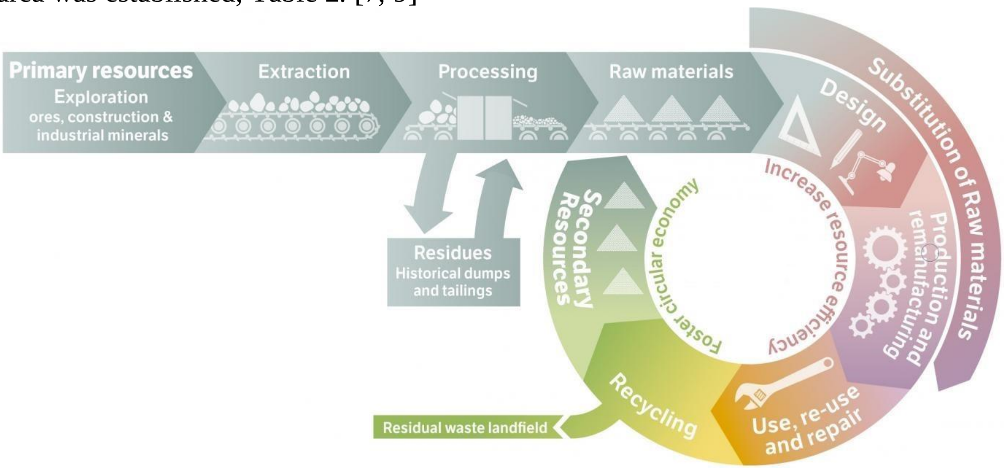

Fig. 1. The circular economy in mining

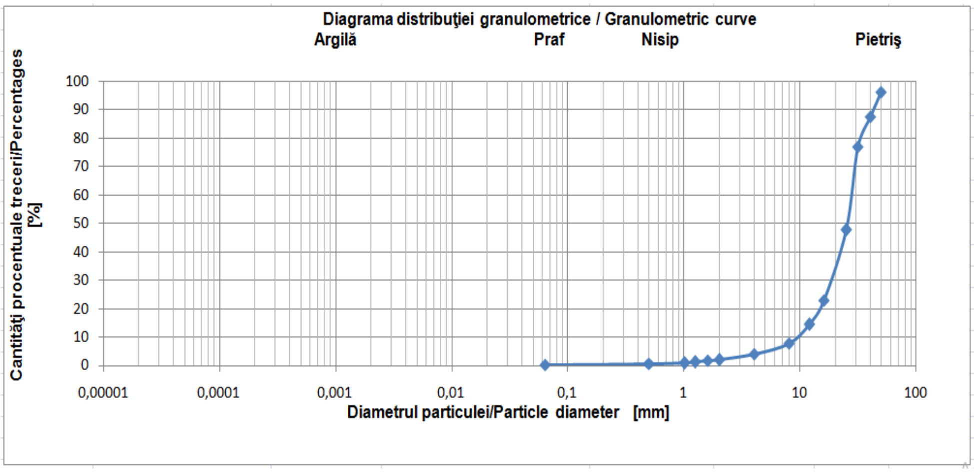

Fig. 2. Granulometric curve of tailings pond material.

Table 1. Compression strength

Sample	**Report of test**	**No. of test**	**Compression strength [MPa][N/mm²]**		**Class/ Concrete brand**
			On sample	**Average [N/mm²]**	
Tailings pond material	No. 106/ 12.09.2017	1	21.5	21.66	C16/20 B250
		2	20.5		
		3	23.0		
Aggregate	No. 107/ 12.09.2017	1	21.5	21.66	C16/20 B250
		2	20.5		
		3	23.0		
Tailings pond material	No. 108/ 12.09.2017	1	21.5	21.66	C16/20 B250
		2	20.5		
		3	23.0		
Tailings pond material	No. 109/ 12.09.2017	1	21.5	20.0	C16/20 B250
		2	19.5		
		3	20.0		
Aggregate	No. 110/ 12.09.2017	1	22.5	21.66	C16/20 B250
		2	20.5		
		3	22.0		
Aggregate	No. 111/ 12.09.2017	1	21.5	22.33	C16/20 B250
		2	22.5		
		3	23.0		
Material from dump	No. 112/ 12.09.2017	1	21.5	20.33	C16/20 B250
		2	19.5		
		3	20.0		
Material from dump	No. 113/ 12.09.2017	1	20.5	20.33	C16/20 B250
		2	20.3		
		3	20.1		
Material from dump	No. 114/ 12.09.2017	1	20.5	20.00	C16/20 B250
		2	19.5		
		3	20.0		
Material from dump	No. 115/ 12.09.2017	1	20.5	20.4	C16/20 B250
		2	20.5		
		3	20.2		
Material from dump	No. 116/ 12.09.2017	1	20.5	20.00	C16/20 B250
		2	19.5		
		3	20.0		
Aggregate	No. 117/ 12.09.2017	1	20.3	20.30	C16/20 B250
		2	20.5		
		3	20.1		

Table 2. Compression strength of the concrete cubes from Deva Mine

No. of sample	**Mixing ratio [%]**	**Binder dosage for 1mc [kg]**	**Maximum dry density [g/cm^3]**	**Optimum humidity [%]**	**Compression strength Rc [N/mm^2]**			
					3 days	**7 days**	**14 days**	**28 days**
P5	3	55	1.850	12.0	0.31	0.47	0.60	0.85
P6	3.5	64	1.920	17.2	0.84	1.24	1.55	1.83

From a particle size point of view the samples analysed are primarily made up of fine sands 90% and dusty sands with the following composition: sand (30 – 82) %, dust (29 – 42) %, clay (6 – 16) % with areas of sandy or clay dust around (5 – 10) %. Material properties have been studied as follows: volumetric weight varies between 1.55 t/ m^3 on the surface to 1.8 t/ m^3 in deeper layers; the porosity varies between 54,2% on the surface to (48 – 50)% in deeper layers; humidity ranges between (0,76 – 1) % on the surface dropping to (0,31 - 0,51)% in deeper layers where tailings are dry and crushed; the natural slope angle varies between 35º-37º when dry and 28º-29º when wet; humidity at saturation varies between (25,4 - 44,5)%. All these characteristics meet the criteria of a well consolidated and dry material, slightly wet on the surface and crushed in the deeper layers. [8]

Analysing the mining perimeters within Cuprumin company we established that the dumps are mainly made up of sedimentary and volcanic rocks comprised of Fundoaia and Poieni andesite impacted by hypogenic alteration and mineralization with various degrees and intensities. Tailings stored in dumps come from stripping deposits and is primarily made up of a mix of andesite, altered or disaggregated but also relatively fresh and compact, cretaceous sedimentary rocks with varied resistance properties as well as tailings with high clay content coming from surface areas and clay seams of cretaceous rocks.

We carried out studies within Geamana (Valea Sesei – Paraul Horburi) dumping perimeter and Valea Muntari dumping perimeter, Fig. 3. [7]

Based on geotechnical studies carried out for Geamana dump and Valea Steregoiului poor ore dump, the lithological succession comprises slope deluge (clay sands, sandy clays with rock fragments) varying in thickness from (0.8 – 8.20) m, which rest on the base rock made up of conglomerates, sandstones and sandstone clays thicker at the base of the deposit.

The quarry tailings – altered ore generated from stripping activity – subcategory 01.01 – waste from mineral mining, 01 01 01 – waste from metalliferous mineral mining, were stored in the following dumps [16]:

- Valea Cuibarului dump
- Geamana dump
- Obarsia Muntari dump.

Fig. 3. Geamana dumping perimeter and Valea Muntari.

Analysing the mining perimeters within Cuprumin company we established that the dumps are mainly made up of sedimentary and volcanic rocks comprised of Fundoaia and Poieni andesite impacted by hypogenic alteration and mineralization with various degrees and intensities. Tailings stored in ponds come from stripping deposits and is primarily made up of a mix of andesite, altered or disaggregated but also relatively fresh and compact, cretaceous sedimentary rocks with varied resistance properties as well as tailings with high clay content coming from surface areas and clay seams of cretaceous rocks.

The floatation tailings generated by the copper ore processing are stored in Valea Sesei and Valea Stefancei 2 (reserve tailings ponds that began functioning in 1995) tailings ponds, Fig. 4. [7]

Valea Sesei tailings ponds is the main functioning pond for storing tailings.

It is a valley pond created by damming Valea Sesei with an embankment dam with a filter on the upstream slope placed around 7.2 km away from the confluence of Valea Sesei and Aries river.

Valea Sesei has an area $S_{t\ projected}$ = 221 hectares.

Valea Stefancei I, has an area $S_{t\ projected}$ = 26 hectares, Valea Stefancei II has an area $S_{t\ projected}$ = 50 hectares.

The analysed tailings dump from Cuprumin are:

- Obarsia Muntari with an area $S_{t\ projected}$ = 46 hectares,
- Valea Cuibarului with an area St projected = 149 hectares,
- Geamana with an area St projected = 67 hectares.

Fig. 4 Taillings ponds from Valea Sesei

4. Using waste from dumps and ponds in concrete and mortar production

In order to highlight the potential to use the waste rocks from tailings ponds and dumps, Table 3 compares the monoaxial compression breakage strength of cubes sourced from ponds and dumps with those made with aggregates. [7]

Traditional building materials such as refractory materials, cement, concrete, paving blocks etc. are made from existing natural resources. The production methods have a greater or smaller impact on the environment due to the continuous exploitation of natural resources. Moreover, various toxic substances are released during the manufacturing process.

Various research has been carried out globally regarding the use of mining waste as addition to building materials. [11]

Of note are the following:

- Quarry waste – it is generated by aggregate crushing in crushing units. Quarry waste can be used as a substitute to sand used for building materials. Using quarry waste to substitute sand in building materials could help solve environmental issues caused by the depletion of natural resources like river sands and so on [15]. Quarry waste can be an alternative with low economic impact on production costs. This aspect is strongly influenced by the transport distance.

It has been determined that the mechanical resistance of the concrete cubes made with tailings is superior to those made with quarry aggregates. Mining waste can also be used as building materials for land infrastructure: roads and highways. Demand for building materials made from natural rocks has increased significantly in the last years. Traditional building materials such as refractory materials, cement, concrete and rock blocks are products from existing natural resources. The use of quarry waste could solve part of the environmental issues caused by natural resources exploitation and aggregates. [15]

Table 3. Compression breakage strength of cubes

Place	Data of report	Sample number	Compression breakage strength [MPa][N/mm^2]		Class/ Concrete brand
			On sample	Average [N/mm^2]	
Tailing ponds material	10.06.2017	1	19.5	20.33	C16/20 B250
		2	21.5		
		3	20.0		
Aggregate	10.06.2017	1	20.5	20.33	C16/20 B250
		2	19.5		
		3	21.0		
Material from dump	10.06.2015	1	20.5	21.67	C16/20 B250
		2	21.5		
		3	23.0		

Processing old tailings ponds material can lead to decommissioning environmentally a large area covered by these ponds and is an opportunity which shouldn't be overlooked [12, 13]. The use of mining waste could be an alternative with a strong economic impact on building material costs and a model for fitting into the circular economy model.

Mining waste, particularly rock waste, often has similar properties to rocks used as aggregates. This makes parts of tailings generated by the mining industry to be useable as quarry aggregate substitute. It is important to keep in mind that only sterile rocks with low levels of contaminated elements should be used. [15]

Case studies have been written regarding both the direct and the use following crushing and sorting of waste. Coal extraction generates large quantities of mining waste and many waste fractions could be used to produce aggregates. [11]

5. Conclusions

The research presented comes as an answer for the need to promote durable provision of prime material from European sources, indicated by the European Commission as being one of the three main pillars of mining politics in the EU. The research aims to support Europe's self-sustainability for mineral resources by using the mining waste stored as a significant source of valuable prime material.

Mining activity has a direct impact with negative effects both on the environment and on the well-being of the local community. Mining activities are carried out over long periods of time and have a long-term impact on large areas, accumulated over the entire exploitation period even after its completion.

Two areas have been identified for the case studies, Deva Mine and Cuprumin respectively. We have reviewed the geotechnical conditions and geomechanical characteristics of both the tailings and the concrete made with sterile rocks from the two mining companies in these areas.

It was determined that the mechanical resistance of the concrete cubes made with waste material is superior to those made with quarry aggregates. Recent investigations regarding the metalliferous ore reserves have confirmed that the ore has a significant potential to ensure a durable source of prime material from the European Union.

Currently there are global research programmes pursued to determine the potential to use mining tailings in a variety of fields and therefore restore the affected areas to the natural circuit.

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