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CIVIL ENGINEERING - SCIENCE & PRACTICE

GNP 2022 PROCEEDINGS

Kolašin, March 2022

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FACULTY OF CIVIL ENGINEERING

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THE FOREWORD

Traditionally, for the eighth time now, the International Conference "Civil Engineering – Science and Practice", GNP 2022 gathers us aiming at considering various topics and exchanging ideas of contemporary trends in civil engineering, once again in beautiful Kolašin.

The previous conference GNP 2020 had to be finished one day earlier than planned, due to the outbreak of COVID-19 pandemia. It has been followed by two-year period of slow investment activities, not only in the domain of civil engineering, and rapid ICT development. One of the aims of GNP 2022 is to contribute to the change of the current economic situation and, consequently, to the evolution of construction sector, through innovation, research, discussions and exchange of views.

GNP 2022 Proceedings collects 126 papers of 290 authors. Much higher number of conference participants, from 26 countries of Europe and beyond, give their precious contribution to GNP 2022, not only through writing, but also through other forms of active participation, such as paper reviewing and presentation, personal presence or online lecturing, significant support of sponsors and friends from Montenegro and abroad. We are grateful to all these colleagues and companies/institutions for enabling this GNP conference to be as it is.

Special thanks for all support and assistance in GNP 2022 realisation to the co-organiser – Engineers Chamber of Montenegro, Chamber of Civil Engineers.

We do hope discussions and presentations from GNP 2022 will be an additional incentive to advance the future of construction, in function of peace and progress of humanity.

Podgorica, March 2022 *GNP 2022 ORGANISING COMMITTEE*

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GNP 2022 – Kolašin, Montenegro, 8-12 March 2022

Marko Ćećez[1], Ivana Ćipranic[2], Merima Šahinagić–Isović[3], Radmila Marković [4], Zoran Stevanović[5]

THE POSSIBILITIES OF USING RED MUD IN BUILDING MATERIALS

Abstract

Red mud is a solid waste of industrial aluminum production Bayer process from bauxite ore. The Bayer process is the most widely used method, accounting for 95% of alumina production. Some norms classify red mud as toxic and dangerous material for the environment, due to its chemical composition. The chemical composition varies a lot depending on the origin and type of bauxite as well raw materials, methods of obtaining aluminum and methods of disposal. Its disposal represents a significant environmental problem. Furthermore, alumina production has significantly increased Worldwide. As its disposal is a problem, many studies have been developed in finding the utilization of red mud in some branch of industry. Different strategies for managing red mud have been developed in the past period. For instance, this solid waste may be transformed into useful products, such as adsorbents, or can be used for neutralization, of for revegetation. Also, it can be very useful in ceramic production etc. By exploitation of this solid waste material the aluminum industry would practically reduce waste to a minimum. Mass uses, such as building materials, can consume large volumes of red mud in an environmentally safe way. This paper presents the possibility of red mud use in civil engineering i.e. for building materials - concrete and cement. The possibilities of using red mud from landfill in Podgorica (Montenegro) in building materials are presented in this paper.

Keywords

Concrete, cement, red mud, industrial waste

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1. INTRODUCTION

In the process of industrial production of alumina, red mud is generated as waste, which consists mainly of bauxite ore components.

Depending on the quality of the raw material processed, 1–2.5 tons of red mud is generated per ton of alumina produced. The treatment and disposal of this residue is a major operation in an alumina plant [1]. Aluminum (Al) is mostly produced from bauxite ore, which contains up to 70% of Al_2O_3 (alumina). Before alumina is refined to aluminum metal, it is purified by hot alkaline extraction. As a waste by-product red mud is formed. Due to its high alkalinity and large quantities, it represents a severe disposal problem [2]. The global inventory of bauxite residue reached an estimated 2.7 billion tonnes in 2007 increasing at 120 million tonnes per annum [3], because of those leading countries in aluminum production face a serious landfill problem.

Aluminum is commercially produced from bauxite in two steps. In the first step, aluminum is obtained by the Bayer process, and in the second step, metal for use is obtained from aluminum by electrolysis. In the Bayer process, the broken bauxite is placed in sodium chloride solution and baked at a temperature of about 270°C. Under these conditions, most of the aluminum dissolves, leaving an insoluble residue called red mud. Further filtration removes red mud [1].

Red mud consists mainly of iron oxide, quartz, sodium aluminosilicates, calcium carbonate, titanium dioxide and sodium hydroxide, with an average pH of 10 - 12.5 and a particle size <10 μm [4]. Due to its alkalinity and chemical and mineralogical properties, red mud is classified as a toxic industrial waste [5], which needs to be treated before discharge [6]. Its impact on the environment and health includes [6]:

a) conventional disposal that occupies large areas of potentially productive land;

b) leachates generated during storage posing a potential risk to ground water;

c) adverse impact on soil physical properties, plant ecotoxicological impacts;

d) generation and transport of fine dust during dry seasons;

e) intake of fine particulate matter by animals and human;

f) adverse impacts on local tourism due to esthetic and stigma problems.

Depending on the bauxite and the method of production, the chemical composition of red mud varies in a fairly wide range. The approximate content of red mud given in Table 1 [1, 7]. The composition of red mud generated during bauxite refining varies according to the types of bauxite ores and different refining processes used [8].

Table 1. Chemical composition of red mud [1, 7]

Element	Content (%)
SiO_2	2 – 20
Al_2O_3	6 – 28
Fe_2O_3	12 – 56
TiO_2	2 – 28
Na_2O	1 – 10

There are different strategies of red mud management. Some strategies for treatment are [6]:

- use for building materials (bricks, cement, composite materials);
- metal recovery (Fe, Al, Ti, Ca, V, Sc);
- use for ceramic production (ceramic glazes);
- use for neutralization (neutralization for sewage, seawater and acid mine tailings);
- use as adsorbents (for waste water and gas treatment; anion adsorption, trace elements-heavy metals and metalloids, dye, organics, bacteria and virus);
- use for revegetation (after amended by different amendments, it can be used for revegetation)...

Bulk uses, such as building materials, can consume large amounts of red mud in an eco-environmental safe way. This paper present the possibility of red mud use in construction i.e. for building materials - concrete and cement. The red mud characeristics from landfill in Podgorica (Montenegro) are given. The possibilities of using that red mud in building materials are presented.

2. THE RED MUD BASINS IN PODGORICA

The Aluminum Plant in Podgorica (KAP) started producing aluminum in 1971. KAP is located in the south of Montenegro, about 10 km south of the capital Podgorica, and about 2 km from Podgorica Airport, between the Morača River and the main road connecting Podgorica to the coast. This area is part of the Zeta prairie, which is known as a fertile lowland with good climatic conditions for agriculture. The Morača River flows near the KAP site and flows into Skadar Lake, a large national park on the border with Albania. Next to KAP there is a red mud landfill, i.e. red mud basins, Figure 1.

Figure 1. The red mud basins in Podgorica (Google Earth)

In the industrial process itself in the Aluminum Plant, bauxite ore is crushed into pieces that enable the extraction of alumina by decomposition by the hot process with sodium hydroxide, the so-called "straining the red mud". The solid "red mud" is disposed of in large outdoor basins next to the factory. Due to the extraction conditions, the material is characterized by high base pH and high iron content (hence the red color).

During the primary and secondary production of aluminum, a large number of different waste fractions are generated, which are deposited in the immediate vicinity of the plant. The largest amount consists of alkaline red mud emulsion, which is deposited in two basins (basin A and basin B) with a total area of 450,000 m^2. The basin A area is 204,000 m^2 and the basin B area is 246,000 m^2. The total volume of basin A is about 2,200,000 m^3, and the total volume of basin B is about 2,500,000 m^3. Most of the landfill surface is covered with a liquid phase (liquid phase from washing pipelines and precipitation) which prevents the emission of dust during the dry period. Basins A and B are separated by a small dam, Figure 2. The bottom of basin A is sealed with plastic lining, while basin B has no basic sealing layer at all. No information is available on the current condition of the plastic liner. Both basins are partially covered by water. The thickness of the red mud deposit can be roughly estimated at 20 m in basin A and 15 m in basin B. It is assumed that the settled and dried red mud in both basins reaches an average thickness between 13 and 15 m.

Figure 2. The dam between basins A and B

2.1. RESULTS OF TESTING THE CHEMICAL COMPOSITION OF RED MUD

Table 2 shows the results of testing red mud from basin A and basin B. In the table are shown the contents of chemical elements in a solid sample of red mud. The test samples were taken from accessible locations in basins.

As can be seen from the table, the contents of chemical elements from basin A and basin B are differ.

Table 2. The results of red mud testing from basin A and basin B [9]

The chemical elements	Unit of measure	Value – Basin A	Value – Basin B
As	mg/kg	58	40
Ba	mg/kg	50	51
Be	mg/kg	3	3
Co	mg/kg	28	31
Cr	mg/kg	370	379
Cu	mg/kg	70	72
Li	mg/kg	100	94
Ni	mg/kg	114	112
Pb	mg/kg	358	412
Sr	mg/kg	142	140
V	mg/kg	106	114
Zn	mg/kg	316	286
Al	%	8.21	7.05
Fe	%	19.8	21.16
K	%	0.18	0.18
Mg	%	0.22	0.26
Mn	%	0.13	0.11
Ca	%	3.95	2.46
Na	%	3.23	2.84
Ti	%	2.51	2.71

Regarding results presented in table 2, main oxides can be calculated and are presented in the table 3.

Table 3. Main oxides of red mud from basin A and basin B [9]

Element	Content basin A (%)	Content basin B (%)
Al_2O_3	15.51	13.32
Fe_2O_3	28.31	30.25
TiO_2	4.19	4.52
Na_2O	4.35	3.83
K_2O	0.22	0.22
MgO	0.36	0.43

3. POSSIBILITIES OF USING RED MUD IN MORTARS AND CONCRETE

Particle size and chemical compositions are two main reasons for considering red mud as a material for applications in mortars and concrete [10]. Contribution of red mud in mortars and concrete can be considered from various aspects, such as addition as raw material in cement production [11], material for partial replacement of aggregate [12] and material for partial replacement of cement in mortars and concrete [13]. The simplest and most economical use of red mud is as partial replacement for cement, ie. as binder. Red mud can be added as treated or nontreated. Since chemical composition of red mud varies depending on bauxite ore and production process of alumina, thus detailed tests are needed in order to consider red mud as replacement for cement. High pH makes it compatible with cement matrix. According to ASTM C 618 (Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete) for material to be considered as artificial pozzolan the sum of silicon, aluminum and iron oxides should be at least 70%. Red mud generally does not meet this criterion, but it is close to the limit and can be considered for tests as partial replacement.

In literature review, it can be found that red mud addition as partial cement replacement in mortars and concrete is widely researched, and percentage of red mud addition is from 0% to 25%. The research includes fresh and hardened properties, as well as durability properties. Usually, adding more than 25% of red mud as cement replacement results in significant loss of fresh and hardened mortar and concrete properties [13].

For fresh mortar properties in previous research can be found that the workability of mortar is reduced proportionally by increase in red mud addition and it can be concluded that from this aspect amount of red mud should be limited. The mixtures with greater percentage of red mud are stiffer and have lower binding period. In most cases the results indicate an increased need for water to achieve desired workability [14]. Increase of red mud addition usually reflects in increase of density, but to a certain level. Above that level (in most cases more than 20%) particle packing is difficult and results in large inner pores, thus density decreases. The same tendency had been noticed for apparent porosity [15]. Addition of red mud in small percentage (up to 15%) leads to small increase in compressive strength or to retention of compressive strength as in comparative samples, which is also a good result [16]. Above that level compressive strength in most cases is decreasing.

Concrete fresh and hardened properties incorporating red mud as partial replacement for cement, behave in similar way as for mortars. Workability of the fresh concrete decreases with increase of red mud addition, and more than 20% of addition creates problems with proper molding, thus these samples often have reduced density. Red mud has significantly smaller particles than cement, and a large amount of water is used for wetting of that smaller particles. In that way, great amount of water is "spent" and is unavailable for achieving satisfied workability [13]. Compressive strength increases usually for small amount of red mud (up to 10%), and beyond that level strength is reduced [17]. In recent studies durability properties are in focus. The researchers shown that concrete containing red mud has lower chloride diffusivity with time lag increasing by increase of red mud addition [18]. The reduction in the interconnection between capillary pores in concrete with red mud and the presence of typical mineral phases such as sodium aluminosilicates, are responsible for reducing the flow of chloride ions and thus the diffusion coefficients [18]. Also, mixtures with red mud achieve lower heat of hydration and lower drying shrinkage. With lower chloride migration coefficient, which is linked to lower porosity in concrete with small amount of red mud, concrete durability is increased [19].

Red mud from KAP is interesting candidate to be considered as partial replacement for cement. In both basins. it has high pozzolanic oxide content, and low content of sodium and magnesium oxides. Both oxides are considered as harmful to be used in cement matrix, and their content should be under 5% [10]. The content of Na_2O is 4.35% for basin A and 3.83% for basin B, and MgO content is under 0.5% for both basins, which means red mud can be used as partial replacement for cement in mortars and concrete.

4. CONCLUSION

Solid waste from industrial aluminum production by Bayer process, known as "red mud" is investigated in this paper. Red mud consists mainly of iron, aluminum, silicon, sodium, calcium and titanium oxides. Properties of red mud are different in different landfills. This is due to different bauxite ores the alumina production process.

Nevertheless, red mud is interesting material for application in civil engineering from various aspects presented. In this paper focus is given on application as partial replacement material for cement in mortars and concrete. The material can not be fully considered as artificial pozzolan, but the chemical composition is very favorable as well as particle size. It is evident that properties of mortars and concrete with red mud addition vary widely depending on red mud origin. Fresh mortar and concrete properties are affected by red mud addition. In most cases the workability of the mixtures is reduced. For low red mud addition up to 15%, mortar and concrete hardened properties are satisfactory. Durability properties are reported to be slightly increased with red mud addition.

Based on the results of red mud testing from KAP basins, it is evident that this red mud can be considered for further research as material for partial replacement of cement in mortars and concrete.

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