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SUSTAINABLE COMPOSITE MATERIALS WITH INDUSTRIAL WASTE RED MUD – AN OVERVIEW

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ABSTRACT:
Red mud is a by-product in Bayer's process of alumina production. Favorable chemical composition and particle size justifies research for further utilization of this waste material. This work aims to present overview of research concerning utilization of red mud as partial replacement for cement in mortars and concrete. Although it can not be fully considered as artificial pozzolan, red mud is interesting candidate for researches worldwide. Since cement industry contributes greatly to environment pollution, partial replacement of raw material or cement itself would reduce its' impact. Technology for production of mortar and concrete with red mud addition would contribute to development of sustainable and eco-friendly materials.

Keywords: *sustainability, industrial waste, red mud, mortar, concrete*

1. INTRODUCTION

Over the past years, the search for new materials that can entirely or partially replace some basic natural building materials is expanding rapidly. In that case, most interesting materials are composite materials mortar and concrete. Since both materials are composed of at least three components, research focus is aggregate or binder.
Concrete is most used material in the world, besides water [1]. Its' production and production of components are negatively affecting environment. Consumption of natural materials in production of concretes' components is enormous. Cement industry is directly responsible for 8% of total CO_2 emission [1]. In 2019, production of cement was 5 billion t/year, which represents an increase of 7% per year in the last 10 years [2]. As cement production consumes natural resources and pollute environment, the idea of replacing cement in mortars and concrete is widespread in academia. That would generate sustainable eco-friendly materials.
One of the ideas is to use industrial waste materials that are no longer in utilization, for production of cement or directly in production of concrete or mortar [3]. This is justified from two aspects, particle size of waste materials and chemical composition [4]. Materials such as fly ash and silica fume are already in use as for production of cement and as additive to concrete and mortar. In recent years new materials are in focus and

among others red mud. Red mud is by-product of industrial production of alumina from bauxite ore as raw material. In this paper brief description of red mud will be presented, as well as overview of research in the field of concrete and mortar with the addition of red mud as replacement for cement.
It is important to note that in Bosnia and Herzegovina, amounts of red mud are not negligible. In total about 30 million tones are deposited in landfills Zvornik and Dobro Selo near Mostar. The possibilities of mortar and concrete production with red mud from Dobro Selo landfill as new technology is currently ongoing at Dzemal Bijedic University of Mostar, Faculty of Civil Engineering. Thus, experiences of similar research are of great importance and are presented in this paper.

2. RED MUD

Red mud is a by-product of industrial production of aluminum by the Bayer process from bauxite ore [5]. About 0,30 – 2,50 t of red mud per t of alumina produced is generated and deposited in some way, in most cases landfills or pools (Fig. 1). It is estimated that over 120 million t/y of red mud is produced in the world [6]. Red mud is considered as industrial waste. Its chemical composition includes iron, aluminum, sodium, calcium, and silicon oxides. Chemical composition is not fixed, but rather inconsistent, which depends on ore origin and production method. Average pH value is 10 – 12,5 and particle size <10μm [7]. Average values of basic oxides in red mud are listed in table 1.

Table 1. Average red mud chemical composition [7]

Component	Content [%]
SiO_2	2 - 20
Al_2O_3	6 - 28
Fe_2O_3	12 - 56
TiO_2	2 - 28
Na_2O	1 - 10

Fig.1. Examples of red mud deposition (redmud.org)

Red mud can not be fully considered as artificial pozzolan like for example silica fume, but its chemical composition is very promising and thus is interesting for research. Its

alkaline character is compatible with mortar and concrete ie. cement, thus it can be considered as additive for production of cement or for production of composites.
At first, red mud was considered as raw material for cement production, as a source of iron and aluminum. Main part of red mud Fe_2O_3 and Al_2O_3 would be used for production of C_3A and C_4AF cement minerals. Also, red mud was considered as replacement for slag as a source of Fe_2O_3 [8, 9, 10]. Production of special cements was also in focus, thus red mud was considered for production of cement based on calcium sulfoaluminate (CSA) [11] and production of mixed cement with alkaline activator, ie. in the direction of cement production without clinker (ASRC) [12]. In recent years, red mud is investigated as addition to mixture of mortars and concrete, which makes its consumption simple and effective.

3. MORTAR AND CONCRETE WITH ADDITION OF RED MUD

In this chapter overview of research conducted concerning red mud as an additive to mortar and concrete will be presented. Addition of red mud is in regard of cement replacement in some percentage, ei. red mud is considered as binder. Research are focused on properties of fresh and hardened mortar and concrete. Properties of fresh mortar and concrete are important in terms of installation process. Red mud is affecting workability of the mortar and concrete greatly. Within hardened properties, physical and mechanical properties are investigated, but also durability properties are presented.

3.1. Mortar

The study [13] considered the addition of red mud from Brazil as a partial replacement of cement in mortars in the amount of 0% to 30% by weight of cement. The workability of the mixture was affected by red mud addition. The mixtures with greater percentage of red mud are stiffer and have lower binding period. Hardened mortar showed increase in density up to 20% of red mud addition, and above that percentage density decreased due to poor workability. The same tendency had been noticed for apparent porosity. Addition of red mud in small percentage up to 15% led to increase in compressive strength. above that level compressive strength is decreasing. Increase in compressive strength is explained by the reaction of hydrated lime with alumina in red mud, which creates additional calcium aluminates CA that also hydrates. The authors concluded that maximum level of red mud should be no more than 15-20% to achieve satisfied workability and mechanical strengths.
In the research [14] red mud from Spain was added as partial replacement for cement in mortars up to 50%. The workability of the mortar is reduced proportionally by increase in red mud addition and it is concluded that from this aspect amount of red mud should be limited. The amount of water was kept constant for all mixtures, and with increase in red mud addition, which has significantly smaller particles than cement, water is used for wetting of smaller particles. In that way, great amount of water is "spent" and is unavailable for achieving satisfied workability. Results of compressive strength showed a small decrease with increase of red mud addition from 0% to 20%, but beyond that percentage compressive strength drops significantly.

Red mud from India was examined in research [15]. It was used as partial replacement for cement up to 50% by mass. As in previous research, compressive strength was increased for mixtures containing 20% of red mud, but with increase of red mud addition compressive strength was decreased. This result authors explain with improved hydration and structural properties of the mortar, as a result of the minimal pores of the mixture with 20% red mud. Authors also tested hardness, and mixture with 10% of red mud had the highest results. Fresh mortar properties were not tested.
In the research [16] authors used red mud from Ghana as partial replacement for cement in mortar. Red mud was added up to 25% by mass. In fresh mortar tests, the results indicate an increased need for water to achieve desired workability. Smaller particles of red mud are consuming more water than cement particles, thus more water is needed with increase of red mud. Density of mortar with 5% and 10% of red mud has increased compared to reference mixture. In terms of hardened mortar properties, splitting tensile strength was highest for mixture with 5% red mud addition. On the other hand, mixture with 5% red mud had similar result as reference mixture for compressive strength test. Other mixtures showed decrease of strengths.

3.2. Concrete

In the extensive research [17, 18] of Brazilian red mud, authors have investigated durability properties of concrete red mud as partial replacement for cement. Red mud was added up to 30% by mass. The research shown that concrete containing red mud had lower chloride diffusivity with time lag increasing by increase of red mud addition. 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. The life span of concrete with red mud has doubled compared to ordinary concrete. Besides that, the degree of reinforcement corrosion in concrete with red mud was significantly reduced with increasing percentage of red mud.
Neutralized red mud from India was used in research [19] as partial replacement for cement in concrete. research focus was compressive strength and it was tested for concrete age 7 and 28 days. It was noted that for red mud content up to 15% there is no significant compressive strength reduction. With greater increase of red mud compressive strength was reduced, for both 7 and 28 days of age.
Red mud from Bosnia and Herzegovina was used as partial replacement of cement (15% and 20%) for high performance concrete [4]. Besides red mud, concrete was prepared with addition of fly ash and quarry dust. Mixture containing red mud shown lower heat of hydration. Also drying shrinkage was lower compared to reference mixture, but autogenous shrinkage was higher. Red mud retained water during initial hydration and release it later during drying process. Mixture with cement, red mud, fly ash and quarry dust had lower chloride migration coefficient, which can be linked to lower porosity. Durability of concrete is thus increased. Compressive strength of mixtures with red mud was lower than reference, but authors consider it satisfactory.
Untreated red mud from India was investigated as partial replacement up to 20% for cement in concrete [20]. Compressive strengths for 28 and 56 days of age were tested, and results show that red mud addition influenced positively. Strength increased with

increase of red mud up to 10% and slowly decreased with further increase of mud content. Authors explained the phenomena with the presence of silica and free lime in concrete containing red mud which accelerates C-S-H gel formation. Also, concrete with red mud had better resistance to chloride ion penetration compared to control samples, which increases its durability.

4. CONCLUSION

It is evident that properties of mortars and concrete with red mud addition vary widely depending on red mud origin. Properties of red mud itself are different in different countries. This is because red mud is obtained from local bauxite ores and the alumina production process is not always the same.
Nevertheless, red mud is interesting material for application in civil engineering from various aspects presented. The material can not be fully considered as artificial pozzolan, but the chemical composition is very favorable as well as particle size.
Fresh mortar and concrete properties are affected by red mud addition. In most cases the workability of the mixtures is reduced, but that depends on red mud percentage. Most authors suggest increase of water content or addition of plasticizer to neutralize this phenomenon. Physical and mechanical properties of mortar and concrete with partial replaced cement with red mud also depend on red mud percentage. For low red mud addition up to 15%, mortar and concrete properties are satisfactory. Durability properties are slightly increased with red mud addition, which can be linked to particle size and reduced porosity.
With presented it can be concluded that production of mortar and concrete with partial replacement of cement with red mud is justified. The technology of red mud addition as raw binder is simple and effective, and can contribute not only to cheaper product but also to production of sustainable eco-friendly mortar and concrete.

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