Asoc.prof.dr. Merima Sahinagic-Isovic
Dzemal Bijedic University of Mostar
Faculty of Civil Engineering
merima.sahinagic@unmo.ba

Asoc.prof.dr. Azra Spago
Dzemal Bijedic University of Mostar
Faculty of Civil Engineering
azra.spago@unmo.ba

LOCAL INDUSTRIAL BY-PRODUCTS FOR APPLICATION IN COMPOSITE MATERIALS

Concrete is the most used material in construction industry, and thus major consumer of natural resources through production of cement and aggregate. In recent years, numerous studies have been conducted in order to find replacement for cement and aggregate in composite materials, primarily concrete. In this paper, locally available industry waste materials are presented, that can be added in concrete, or act as a substitute for cement and/or aggregate. These waste materials are not used further in the industry and are treated as waste and as such deposited in landfills.

Keywords: fly ash, silica fume, red mud, slag

1. INTRODUCTION

Today, the demand for alternative materials that can substitute natural raw materials for obtaining cement composites is growing. Production of mortar and concrete, most widely used cement based materials (composites), has reached numerous records in recent years. Consumption of natural raw materials when producing these composites has increased significantly. Negative environmental impact is also evident by the loss of natural resources, but also the pollution of the environment by emissions CO_2 emissions during production. This production is directly responsible for approximately 8 percent of total CO_2 emissions into the atmosphere [1], with cement production dominating.

The cement industry is one of the largest pollutants environment. According to the IMARC Group, the total world cement production in 2010 was approximately 3.3 billion tons, and in 2017, production exceeded the amount of 5 billion tons, an annual increase of approximately 7% [2]. An interesting fact is that, according to some predictions, cement production in such quantities was expected in 2050.

One idea was to use industrial by-products as raw materials for cement production or cement replacement in composites. Mostly it is waste

materials that do not apply further in the industry. Justification of industrial applications by-products are found in their chemical composition and particle size [1]. In cement production materials like fly ash, silica dust and limestone are successfully applied. In this paper some materials locally available in Bosnia and Herzegovina suitable for application in cement or composite production will be presented.

2. MATERIALS

2.1 SILICA FUME

Silica fume (amorphous electro filter SiO_2 dust) is obtained as a secondary product in the production of ferosilicate and similar materials. The silica fume is an industrial mineral additive by origin, and according to its characteristics it is a pozzolan. Silica fume added to concrete is expected to improve hydration and produce CSH gel (calcium silicate hydrate). Silica fume is most active pozzolan with the highest pozzolanic activity. It consists mainly of SiO_2 with frequency ranges from 85 to 97%. The silica fume particle size ranges from 0.01 to 0.3 μm (10–300 nm) (Figure 1). After being added to the concrete, the silica fume is initially inert. Only when the Portland cement and water begin to react, i.e. the beginning of hydration, silica fume is activated. The chemical reaction creates two chemical compounds: calcium silicate hydrate (CSH) and calcium hydroxide (CH), which is still called free lime, serves only as a coating of concrete pores as a filer or drains out of concrete [3]. Pozzolanic reaction is taking place between the CH and silica fume, producing additional CSH in pores around hydrated cement. This process leads to the creation of a much denser mixtures of concrete, at the expense of undesirable voids in the concrete.

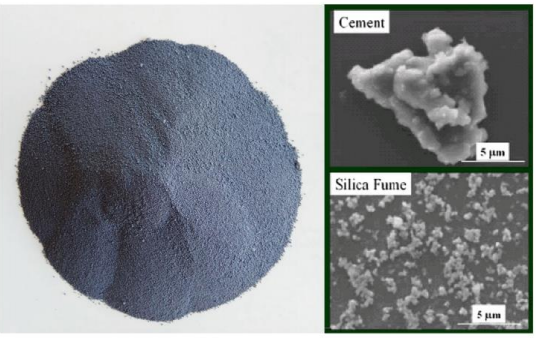

Figure 1. Silica fume in solid state (left) and comparation between cement and silica fume particle size (right)

With the proper use of silica fume not only the mechanical properties can be improved, but also the durability of concrete. Numerous studies have been carried out on use of silica fume as an additive for concrete, which confirm the improved properties of the concrete, primarily an increase in compressive strength and water resistance [4]. Also, small silica fume particles contribute to the fresh concrete behavior by improving the workability and increasing the cohesiveness and filling the inner structure because they are considerably smaller than the cement particles.

The company Timgrad from Jajce, Bosnia and Herzegovina, produces alloys which has as a byproduct microsilica. About 9,000-10,000 tonnes of microsilica are generated annually. Small part of this amount is used further, major rests in the landfills.

2.2 FLY ASH

Flying ashes is an industrial mineral additive, and according to the characteristics it belongs to pozzolan because it actively participates in the process of hydration of cement. It is obtained by combusting coal dust in coal-fired power plants and by separating the electrostatic filter equipment from waste gases. The chemical composition and characteristics of flying ash depend on a large number of factors, and hence its ability to use. SiO_2 is in the range of 20 – 60%, and CaO 1 – 12%. Actively used in the manufacture of some types of cement and can be used directly in the concrete mixture [5]. Particle size of fly ash is from 0.5 μm to 300 μm. In practice, it is known that fly ash improves the performance and quality of concrete. It has an impact on the improvement of plastic properties of concrete and workability, reduces the amount of water required, reduces segregation and bleeding and affects the reduction of the hydration heat. In addition, it increases the strength of concrete, reduces permeability, reduces corrosion of reinforcing steel, increases resistance, and reduces the alkaline-aggregate reaction [6]. Guidelines for the use of fly ash in construction have been included in the standards and can be found in EN 197-1, EN 450-1 and ASTM 618. It is actively used in the production of certain types of cement and can also be used directly in concrete mixtures.

TPP Kakanj in Bosnia and Herzegovina generates about 600,000 tonnes of fly ash annually from coal consumption, which is about 75% of the total amount of waste material. Kakanj Cement uses as a raw

material in cement production about 20-25% of annual production of fly ash or 120,000-150,000 tons. CEM II / B-W 42,5N cement is produced which has 21-35% fly ash. The remaining amount of fly ash is deposited in landfills.

2.3 SLAG

There are three types of slag: slag in the production of iron and steel, slag in the production of copper and slag in the production of zinc. The targeted application of slag in the concrete industry is as a partial replacement of aggregates in concrete and as a substitute for cement. In construction industry it can also be used: as an aggregate in road construction, for embankment construction - river banks, as a fill for laying pipelines, as a fill for drainage, etc. [5].

For every ton of raw iron produced, it is produced between 150 and 347 kg of slag. According to 2008 figures, 46.9 million tonnes of slag are produced annually in Europe, 87% of which is reused in construction, which is incredibly high percentage.

The effect of the slag in concrete depends on the percentage of replacement with cement and can go up to 50%. Slag in concrete improves workability and pumpability of concrete, increases strength, reduces hydration heat and permeability, increases durability and has a beneficial effect on sustainability factors. As a substitute for the aggregate, slag can be used up to 50% of total aggregate mass [6].

In the city of Zenica, Bosnia and Herzegovina, company Arcelormittal is producing iron and steel, and as residue slag is generated. In 2011, about 185,000 tonnes were generated, and in the following years about 239,000 tonnes per year of slag. Most of this is deposited in landfill, and only a small amount is used further in the industry.

2.4 RED MUD

Red mud is a byproduct of industrial aluminum production. Aluminum is commercially produced from bauxite in two steps. In the first stage, aluminum is obtained by Bayer's procedure, and in the second stage, aluminum is electrolysed to obtain metal for use. In this process, insoluble residue is created. That residue is known as red mud. It is estimated that at 1 t of produced aluminum, it creates 0.3 to 1.7 t of red mud [7]. Red mud consists mainly of iron oxide, quartz, sodium aluminosilicate, calcium carbonate, titanium dioxide and sodium hydroxide. Iron oxide is giving it recognizable red color (Figure 2). It has an average pH value of 10 to 12.5 and a particle size of less than 10 μm. Red mud can not be fully considered artificial pozzolana, because it does not meet all the requirements. However, its pozzolanic activity index is good. Main oxide in the chemical composition of the red mud is Fe_2O_3 12 – 56%, followed by Al_2O_3 6 – 12% and SiO_2 6 – 20% [6].

Figure 2. Dried red mud

The addition of red mud to concrete refers primarily to the partial substitution of this waste material with cement. Numerous studies have been done in this area and the general conclusion is that red mud can be used for these purposes, but only for non-load bearing concrete elements. A small percentage of cement substitution with red mud (up to 10%) even shows a certain increase in the compressive strength of concrete. However, with a percentage increase in the content of red mud in the mix, the physical and mechanical properties decline.

There are currently two red mud landfills in Bosnia and Herzegovina, in the village of Birač near Zvornik and near Mostar in Dobro Selo. It is estimated that about 10 million tonnes of red mud have been deposited in Dobro Selo.

Since 2017, an extensive exploration of the possibility of using red mud as a substitute for cement in mortar and concrete has begun at the Faculty of Civil Engineering of the "Džemal Bijedić" University in Mostar. Preliminary data have shown that it is possible to use this red mud in mortar and concrete mixtures. The results of physical and mechanical properties of mortars are satisfying for low percentage of red mud (10 and 15%). Testing of concrete is currently being implemented (Figure 3 and 4).

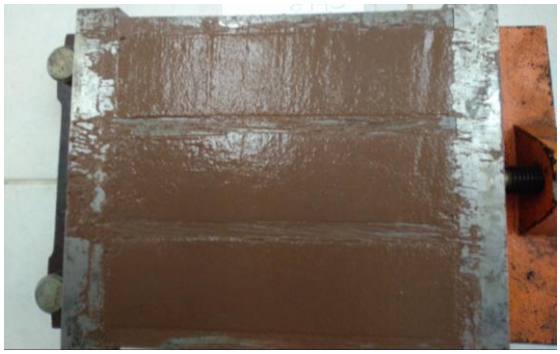

Figure 3. Mixture of mortar with high percentage of red mud (20%)

Figure 4. Mixture of concrete with high percentage of red mud (20%)

3. CONCLUSION

The aim of this paper is to present locally available industrial by-products, that are mostly waste materials, but with great potential to be used in composite materials as substitute for cement and/or aggregate. Materials presented are silica fume, fly ash, slag and red mud.

Bosnia and Herzegovina, which is among the inferior countries in industrial production in the world, still generates thousands of tons of these waste materials.

As shown, fly ash and silica fume have been used successfully in the concrete industry for many years, but there is room for improvement. Red mud and slag are materials that have great potential and are currently the target of researchers, and they are also expected to find their place in the construction industry, which would have multiple environmental benefits. It should be emphasized that these materials are just one fragment of a large number of alternative materials being tested for use in construction.

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