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WASTES USED FOR OBTAINING SUSTAINABLE BUILDING MATERIALS

BY

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Abstract. Advanced strategies have recently been investigated in order to decrease the environmental pollution, the danger of depleting raw material stocks, and increasing pollution following the release of significant volumes of CO_2, resulted by the manufacturing of ordinary cement. The total or partial substitution of cement with a variety of wastes or by-products, from other industrial sectors, is one method of utilizing its to create new building materials. The following wastes can be employed as raw materials in the formulation of advanced materials based on their qualities and chemical content: fly ash, silica fume, bottom ash, phosphogypsum, rice husk ash, red mud, slag, oil fuel ash, etc. For design the building materials with the requirement properties, wastes and by-products utilized as raw materials are activated with different reagents. In this paper wastes from burning processes and few industrial wastes are presented, with refer to most important properties for obtaining the proper building materials.

Keywords: wastes, fly ash, alkali activated materials, alkaline solution, slag, silica fume.

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1. Introduction

Due to extensive use of raw materials the fabrication of building materials uses the most natural resources. Portland cement has a large utilization in construction industry, but for it obtaining are necessary large amounts of raw materials and energy (Vasiliu *et al*., 2023). The greenhouse gas emissions and energy use, create serious environmental issues in cement production. Due to the prospect of running out of raw materials and the rising pollution brought on by the production of enormous amounts of cement, which emits large amounts of carbon dioxide into the atmosphere, alternative cementitious materials there are a solution to reduce environmental pollution. Using waste or by-products from other sectors as a source of raw materials to create new construction materials represent a useful technique. The chemical components of the wastes used as raw materials can be activated in the appropriate ways to produce products with the desired properties (Cotofan *et al.*, 2022; Harja *et al.*, 2022).

As a result of wastes capitalization, these not being placed in specially designed areas like landfills after being used, they also lessen the level of environmental pollution (Buema *et al.*, 2021; He *et al.*, 2019).

According to their properties and chemical content, the following wastes can be used as a starting point to make geopolymers: fly ash, bottom ash, phosphogypsum, slag, red mud, rice husk ash, palm oil fuel ash and silica fume.

Thermal power stations that burn coal produce the waste materials fly ash and bottom ash. 57 million tons of coal were utilized in Europe in 2021 (European statistic).

Annual production of phosphogypsum is thought to range from 110 to 280 tons worldwide (Jiang *et al.*, 2019). Global crude steel output was at 1808 million tons in 2018, which led to an estimated 181-271 million tons of annual steel slag production. Almost 133 million tons of alumina were produced annually in 2020, and more than 175 million tons of red mud were produced as a result. Around 200 kg of bark are produced for every ton of rice produced worldwide, or 649.7 million tons annually. When the bark is burned, around 40 kg of ash are created (Chandrasekhar *et al.*, 2003). When waste products from the palm oil industry are burned to create energy, power plants produce palm oil fuel ash (POFA) as a byproduct (Ranjbar *et al.*, 2014). Silica fume is produced as a byproduct during the production of silicon and ferrosilicon alloy (Mehta and Ashish, 2020).

2. Wastes result from burning processes

2.1. Fly ash

The most popular source of aluminosilicate for making geopolymeric materials is fly ash, which is obtained from electro filters after the burning of coal in power plants. With an estimated annual production of one billion tons, this trash poses major environmental issues if it is not properly kept and disposed (Wu *et al.*, 2019). The abundance of spherical structure, and large occurrence of highly reactive phases, the Class F fly ash is an excellent source of aluminosilicates (Bucur *et al.*, 2014; Harja *et al.*, 2008; Nematollahi *et al.*, 2015). In contrast, due to its quicker setting and availability (Chindaprasirt *et al.*, 2012; Duxson, 2009), fly ash with a high calcium content, also known as class C fly ash, is not as frequently utilized as an alkaline binder precursor.

To create aluminosilicate binders, fly ash can be activated with any kind of alkaline solution (Samarakoon *et al.*, 2019). The SEM study of the mostly spherical ash, which improves workability and allows for better flow in mixes, is shown in the Fig. 1a (Harja *et al.*, 2009). The strong peaks of quartz and mullite (an alumina silicate) in the fly ash, as shown in Fig. 1b, are indicators of crystalline phases, which can be seen using XRD examination (Cretescu *et al.*, 2018).

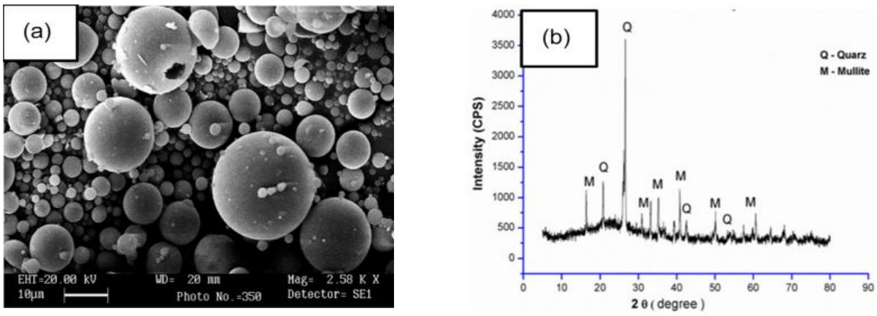


Fig. 1 − Fly ash SEM (a); XRD (b).

2.2. Bottom Ash

Bottom ash, is resulted by collecting at the bottom of a boiler, is different of fly ash, because it contains more unburned carbon and is composed of coarser, angular larger particles (Fidanchevski *et al.*, 2021). The Fig. 2 displays the SEM image of bottom ash, which has larger, coarser angular particles.

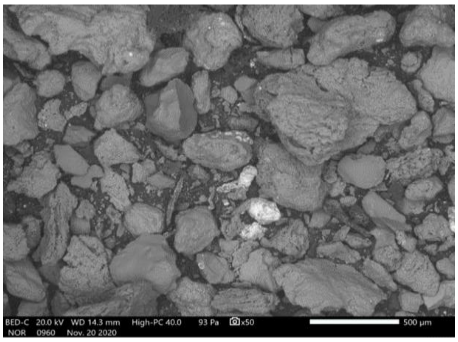


Fig. 2 − Bottom ash – SEM image.

The study has been conducted on geopolymers including bottom ash despite their lower qualities (Le Ping *et al.*, 2022). The behavior of bottom ash-based geopolymeric material with a reduced calcium concentration has been the subject of numerous research (Le Ping *et al.*, 2022; Xie *et al.*, 2015) that have been dried at room temperature. In this case a lower liquid-to-binder ratio or a larger fly ash-to-bottom ash mass ratio, increased the compressive strength of geopolymer concrete made with bottom ash (Singh *et al.*, 2022).

2.3. Rice husk ash

In agricultural production, rice husk is an unavoidable byproduct (Fu *et al.*, 2019; Thomas, 2018). Due to a lack of effective use models, substantial amounts of this commodity are wasted as agricultural waste or burned in the environment (Satayeva *et al.*, 2018). When contaminating the environment in this manner, it could lead to safety concerns. The necessity for the development and usage of this green and sustainable resources, making it imperative for use in building materials (Padhi *et al.*, 2018), in addition rice husk also has the potential to be recycled as cementitious material for mortar (He *et al.*, 2013; Hossain *et al*., 2021). Rice husk ash is a by-product of burning rice husk as a fuel source in boilers to create electricity (RHA). According to literature (Basri *et al.*, 2021), the usage of RHA in the creation of geopolymers offers the building industry a sustainable and eco-friendly solution. The sustainability and ecological path are debatable due to the caustic properties and high cost of the hydroxides and silicates employed in the activation process. The compressive strength of the geopolymer has value of 23 MPa for the RHA/AA ratio was between 0.7 and 0.8 and the NaOH concentration was between 12 and 14 M (Basri *et al.*, 2021).

3. Wastes result from industrial processes

3.1. Blast furnace slag

Granulated blast furnace slag is an industrial byproduct that is produced when molten steel is rapidly cooled with water. It has advantages for concrete and mortar because it is relatively inexpensive to obtain, chemically resistant, and has excellent thermal properties. This industrial waste's primary constituents include SiO_2, CaO, MgO, Al_2O_3, etc. (Marvila *et al.*, 2023). To increase the reactivity of these alkaline binders with a low calcium concentration, slag is combined with class F fly ash (El-Sayed *et al.*, 2011). However, as demonstrated in several research in the specialist literature, it can also be utilized by itself as a precursor in alkaline binder systems, which displayed superior mechanical and microstructural features (He *et al*., 2012; Li *et al*., 2023). Alkaline binders react more quickly to this byproduct's calcium, silica, and alumina content. In Fig. 3 is show of the morphology and mineralogical analysis of the granulated blast furnace slag.

According to the SEM images of the granulated blast furnace slag, as seen in Fig. 3a, the particles have an asymmetrical, angular shape and are spherical with a smooth surface. Also, it was noted that it exhibits square and diamond-shaped particles in various investigations in the literature (Ahmad *et al.*, 2022; Karim *et al*., 2013). Amorphous phase made primarily of glassy elements is shown in the XRD image of blast furnace slag.

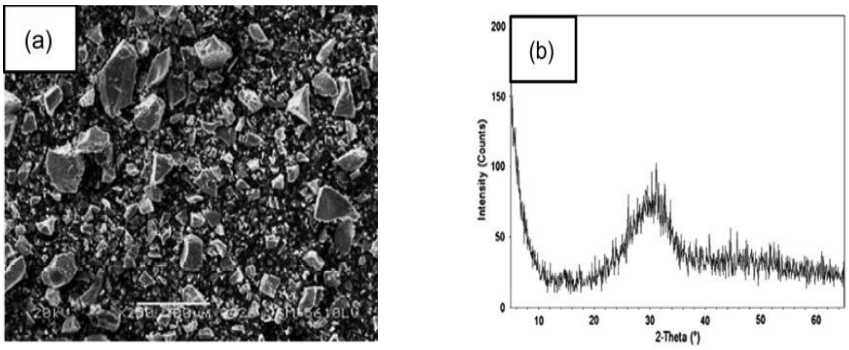
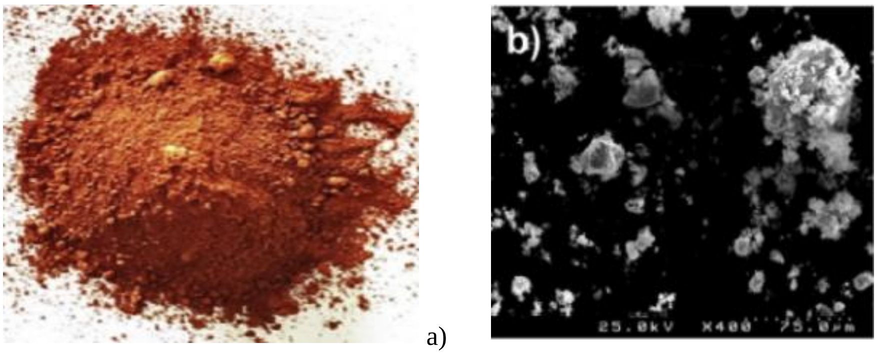


Fig. 3 − Blast furnace slag SEM (a); XRD (b).

3.2. Red mud

The by-product of the Bayer process used to transform bauxite ore into alumina is red mud (RM), sometimes named bauxite residue (Qaidi *et al.*, 2022). The Figs. 4 show this waste.



a) b)

Fig. 4 − Red mud sample (a); Red mud – micromorphology (b).

Sun *et al*. (2022) studied the mechanical and environmental properties of red mud geopolymers and found that at the 28-days compressive strength of these materials ranged from 35.2 MPa to 68.7 MPa, it was suggested that future works should examine the chemical composition, effects of pore structure, and activation methods over red mud geopolymers. These conclusions regarding mechanical properties of red mud geopolymers' are in accord with literature, the source material's properties, the alkali activator used, and the curing conditions influencing properties (He *et al*., 2012; Singh *et al*., 2018).

In the Bayer process the soluble component of bauxite is dissolved using sodium hydroxide at high temperatures and pressures. Undoubtedly, a small quantity of the sodium hydroxide employed in this operation is still present in the RM, which raises the pH level (Nie *et al.*, 2019). Using red mud lowers the cost of producing geopolymers by utilizing its high alkalinity to reduce the overall amount of alkaline activator (Yang *et al.*, 2019).

Studies show that geopolymer and red mud display increased strength and durability (Liu *et al.*, 2020).

3.3. Phosphogypsum

The industrial by-product of the wet-process phosphoric acid production from the reaction of phosphate ore and sulfuric acid is phosphogypsum (PG). Annually in China is produced over 80 million tonnes of phosphogypsum, followed by India with 11 million tonnes, the United States with 40 million tonnes, and South Africa with 35 million tonnes (Cao *et al.*, 2021; Mashifana *et al.*, 2018; Raut *et al*., 2022). Because it is readily available, phosphogypsum has been employed by other researchers for building and construction materials (Rashad, 2017; Wei and Deng, 2021). The phosphogypsum contains two main components CaO and SO_3 and small quantities of phosphates.

The product's morphology is shown in Fig. 5, which displays a dense crystalline structure and parallelepipeds with a crooked look (Vaiciukyniene *et al.*, 2020) as observed under a scanning electron microscope.

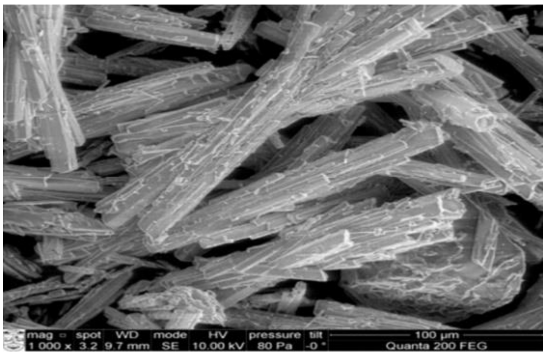


Fig. 5 − Phosphogypsum – morphology.

Phosphogypsum is a fine-grained (loamy or sandy loam), grey, wet material with a maximum grain size of 0.5 mm, and 50 - 75% of its particles are less than 0.075 mm (Saadaoui *et al.*, 2017). Typically, the moisture content ranges from 8% to 30% (Saadaoui *et al.*, 2017). Its density, strength, compressibility, and permeability depend on chemical composition, distribution size and how it is disposed (Wu *et al.*, 2022).

3.4. Silica Fume

An ultrafine powder called silica fume (SUF) is a by-product of the manufacturing of ferrosilicon alloy and elemental silicon in electric arc furnaces. When silicon oxide leaves the furnace, it oxidizes first before condensing into very small, spherical amorphous silica (SiO_2) particles, which are typically size between 30 and 300 nm. Particles of silica fume, Fig. 6, have a maximum diameter of 100 nm (Harja *et al.*, 2013). The by-active product's SiO_2 content varies depending on the kind of alloy produced (the higher the alloy's silicon content, the higher the silica content of the silica fume), from 85% in the manufacture of ferrosilicon to roughly 98% in the production of silicon metal (Ali *et al.*, 2022).

It is usually found as a fine gray powder, sometimes is capitalized into Portland cement or other building materials. Usually employed as a cementitious material addition, silica fume is also successfully applied to geopolymeric materials (Nasimuzzaman *et al.*, 2022).

Fig. 6 − Silica fume particles.

4. Conclusion

The wastes capitalization is widely approached in literature. The fly or bottom ash could be a valuable precursor for building materials due to low cost, large quantities and reduction of the environmental impact when its uncontrolled disposal. The types and sources of wastes, the specific obtaining conditions, the gathering solutions and the disposals conditions, influence chemical composition and technological properties of the wastes. The settings of alkaline attack and type of alkali influenced properties of resulted products. The dissolution of aluminum oxide and reaction with silica for generation of silica-rich products, which are advantageous to the mechanical strength, are influenced by the long attack time. On the other hand, the alkaline activators have a high impact, but and the SiO_2:Na_2O ratio over polymerization of inorganic precursors. Sodium hydroxide, sodium carbonate, potassium hydroxide, and sodium silicates, etc., are the most often used activators. The characteristics of the final products and the reaction kinetics are significantly influenced by temperature.

Each presented waste must be thoroughly investigated for finding the optimal conditions of alkaline attack and obtaining modified products with proper properties according the predicted practical applications.

The fact that these wastes are not dumped in specifically created regions, such as garbage depots, following their usage represents a significant benefit of using waste in the formulation of these construction materials.

Capitalization of waste has additional benefits due to its chemical and morphological behaviors, which offer the materials they are mixed into physical, chemical, and mechanical characteristics.

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DEȘEURI UTILIZATE PENTRU OBȚINEREA MATERIALELOR DE CONSTRUCȚII DURABILE

(Rezumat)

Recent au fost investigate strategii avansate pentru a reduce poluarea mediului, pericolul epuizării stocurilor de materii prime și creșterea poluării în urma eliberării unor volume semnificative de CO_2, rezultată din fabricarea cimentului obișnuit. Înlocuirea totală sau parțială a cimentului cu o varietate de deșeuri sau produse secundare, din alte sectoare industriale, este o metodă de utilizare a acestora pentru a crea noi materiale de

construcție. Următoarele deșeuri pot fi folosite ca materii prime în formularea materialelor avansate pe baza calităților și conținutului lor chimic: cenușă zburătoare, silice ultra fină, cenușă, fosfoghips, cenușă din deșeuri agricole, nămol roșu, zgură, cenușă de combustibil petrolier etc. Pentru proiectarea materialelor de construcție cu proprietăți impuse, deșeurile și subprodusele utilizate ca materii prime sunt activate cu diferiți reactivi. În această lucrare sunt prezentate deșeurile din procesele de ardere și câteva deșeuri industriale, cu referire la cele mai importante proprietăți pentru obținerea materialelor de construcție adecvate.