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# INDUSTRIAL WASTES USED AS ADDITIVES IN BUILDING MATERIALS TO REDUCE ENVIRONMENTAL POLLUTION

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***Abstract***

*Environmental pollution is a major issue that we are dealing with at the moment. The reuse of industrial waste, which is used as raw materials in other industries such as the construction materials industry, is a beneficial way to reduce pollution. This is possible due to the physical, chemical, and mineralogical properties of industrial waste.*
*Examples of industrial waste that can be used for obtaining new building materials are: fly ash, furnace slag, silica fume, and so on. These wastes were analysed in this study using the following techniques: SEM, XRD, and EDAX. After characterization, the wastes were used as additives in cement-based materials. The following properties of the obtained materials were tested: compression strength, flexural strength, adhesion to the substrate, and shrinkage testing. Based on the results of the tests, the percentages used as waste addition were chosen.*

***Key words***: *cement-based materials, fly ash, furnace slag, silica fume.*

## INTRODUCTION

The world is attempting for a circular economy with low carbon emissions. Similarly, the construction industry wants to achieve this goal through alternative large-scale cement-related products, reducing the negative effects of cement production and creating a sustainable and environmentally friendly products (Juang & Kuo, 2023; Swaroop et al., 2013).
The most common building material is cement, whose manufacturing uses a lot of energy and raw materials and produces a lot of greenhouse emissions (Zhang et al., 2023).
Around the world, pozzolanic alternative materials are frequently used in construction as a partial replacement for ordinary Portland cement in mortars and concretes (Rafiza et al., 2022; Durastanti & Moretti, 2020). Fly ash, furnace slag, silica fume, and other industrial wastes are among those that can be used for replacing of regular Portland cement. Reusing these industrial wastes solves the problem of storing them in locations designated for that purpose, such as landfills, which reduces the level of pollution in the environment (He et al., 2019). The addition of waste material to concrete instead of cement helps to meet the growing demand for concrete while also improving the use of waste materials. Furthermore, it has been noted that the strength and durability of concrete are increased when waste materials are used as pozzolanic (Harja et al., 2022). This lessens the potential damage to the environment (Ahmad et al., 2021; Lee et al., 2016).
The industrial byproduct of burning coal in power plants and thermal power plants is coal fly ash, and practically every country in the world struggles with how to dispose of this material (Harja et al., 2023). However, it should be mentioned that fly ash has a lot of potential for use as a partial substitute for Portland cement because of its excellent pozzolanic activity, fine grain size, and physicochemical characteristics (Golewski & Szostak, 2022; Golewski, 2023; Fu et al., 2022; Wu et al., 2019; Wong et al., 2022).
Furnace slag is a common byproduct of the iron and steel industry and is frequently used as pozzolanic material due to the varying content of reactive silico-aluminate in it. This industrial waste is classified as a pozzolanic material due to its relatively stable chemical properties and high reactivity (Zhao et al., 2024).
Silica fume is a byproduct of the silicon and ferrosilicon alloy manufacturing process. Silica

fume is essential for increasing the strength of cementitious materials because it causes the formation of calcium silicate hydrate, which has a high strength (Mehta & Ashish, 2020; Vrabie et al., 2023; Cotofan et al., 2022). Silica fume increases the hydration level and compressive strength of hardened pastes, mortars and concretes. This increase in strength is due to the bonding of the hardened cement paste to the aggregate. The degree of crystal orientation, crystal size, and calcium hydroxide content at the interface are decreased by the addition of silica fume (Shoubar et al., 2020; Rahmouni et al., 2023).

This study developed a strategy for reusing industrial waste as a partial substitute for cement, reducing $CO_2$ emissions from cement production and addressing the issue of landfill disposal.

The physical, chemical, and mineralogical properties of the raw materials used have been described, as well as their significant impact on pollution reduction. The prepared materials were mechanically examined to determine the impact of using these wastes instead of cement. The following properties were evaluated: compression strength, flexural strength, adhesion to the substrate, and shrinkage grade of the materials produced.

## MATERIALS AND METHODS

In this study, industrial wastes were used as an additive to the mortar. Table 1 shows the compositions of the prepared mixtures. The cement/sand ratio was 1 to 2.5.

Table 1. Mix composition mortar samples

| Mix | Compound | Weight (kg) |
|---|---|---|
| Mix 0 | Portland Cement | 571 |
| | Sand 0 – 1 mm | 1427.5 |
| | Water | 257 |
| Mix 1 | Portland Cement | 571 |
| | Sand 0 – 1 mm | 1427.5 |
| | Fly ash | 57,1 |
| | Silica fume | 57,1 |
| | Water | 300 |
| Mix 2 | Portland Cement | 571 |
| | Sand 0 – 1 mm | 1427.5 |
| | Furnace Slag | 57.1 |
| | Silica fume | 57.1 |
| | Water | 295 |

Carpatcement Romania (Portland Cement) used in this study was type CEM II/A-LL 42.5 R. Bega Minerale Industriale from Romania supplied the sand used. The fly ash used in this study was obtained from Czech Republic. The furnace slag for this study was supplied by ArcelorMittal of Galaţi, Romania. The silica fume was supplied by Norchem, from the United States.

Industrial waste was analysed using SEM, XRD, and EDAX.

The compression and flexural strength tests were performed with 40 x 40 x 160 mm molds and the test machine compression/flexural 15/250kN. The adhesion to the substrate was tested using a PoliTest AT tensile adhesion tester. Shrinkage was measured using test machine length comparators.

## RESULTS AND DISCUSSIONS

### Characterization of fly ash

The SEM presented in Figure 1 shows that fly ash consists of spherical particles with a narrow granulometric spectrum.

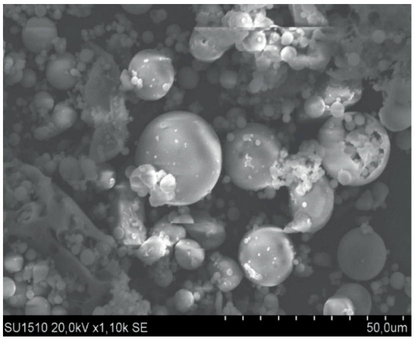


Figure 1. SEM analysis of fly ash

The analysed fly ash has a fine consistency, with particles of various spherical shape sizes, and an off-white colour, indicating a high concentration of CaO. SEM analysis reveals that the ash contains irregularly shaped particles, as well as spherical particles that aggregate into macrospheres. The various forms of silicon result in irregularly shaped particles. In the ash studied, the particles have a spherical shape, and the unburned carbon content is reduced.

Figure 2 depicts an EDAX analysis of fly ash. The ash contains Si, O, Al, Ca, Fe, K, Na, Mg, and Ti, that determined the physicochemical and technological properties. The elements are found in ash in oxide form.

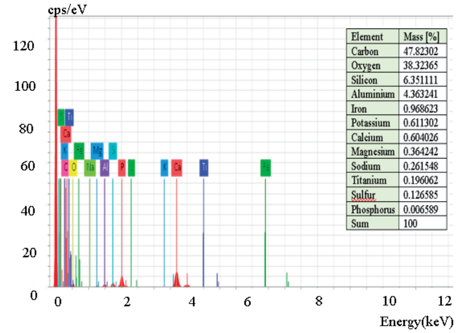


Figure 2. EDAX analysis of fly ash

The EDAX results show that the fly ash contains a high amount of calcium. However, the non-uniform composition of power plant waste and the use of surface EDAX readings at different points may influenced the results.
Figure 3 shows the XRD spectrum of the fly ash, which contains elements (crystalline phases) such as hematite (He), quartz (Q), mullite (M), and a glassy phase.

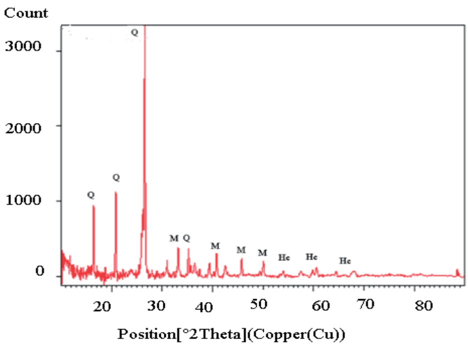


Figure 3. XRD analysis of fly ash

The elements present in the vitreous phase of the ash are estimated using XRD and EDAX analysis, revealing the presence of Si, Al, Ca and K. These elements were found in two main crystals: quartz and calcium-alumino silicates, each in a vitreous phase containing various amounts of K, Na, Ca, Mg and Fe.

**Characterization of furnace slag**

The data from Figure 4 show that the furnace slag is in the form of a fine powder with particles of various shapes, which are influence to mechanical grinding.
Furnace slag contains fine particles under 5 µm, accounting for a significant portion of its weight.
The presence of the coarse part indicates open circuit grinding.

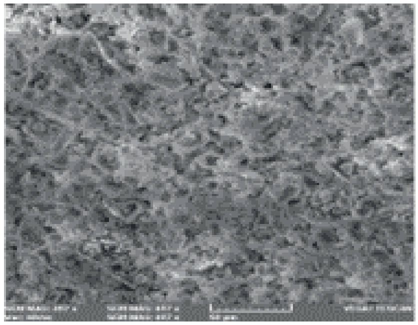

Figure 4. SEM analysis of furnace slag

The chemical elements present in the furnace slag were identified using elementary chemical analysis, with the results shown in Figure 5 and XRD Figure 6.

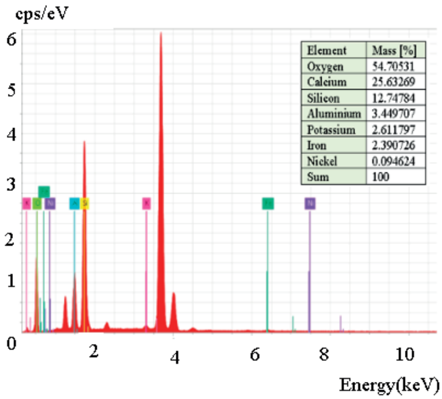


Figure 5. EDAX analysis of furnace slag

Furnace slag is composed of Ca, Si, O, Al, Mg, and Fe, with traces of K, Ti, and Ni found in one area. Chemical analysis reveals a high concentration of calcium oxide and magnesium oxide. In addition, the furnace slag analysed contains a high concentration of aluminium oxide. The XRD analysis shows the presence of alpha cristobalite phases, primarily as $Mg_3(Fe, Al, Si)_2(SiO_4)_3$. Furnace slag phases and amorphous content are in accord with literature.

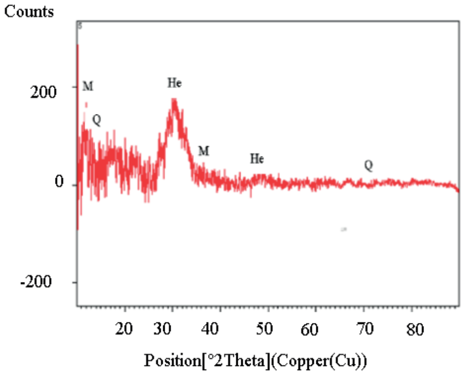


Figure 6. XRD analysis of furnace slag

Based on phase thermal equilibrium relations, the identified compounds form a melilite series that is specific to furnace slag. There are also small CaO and free MgO peaks (Figure 6).

**Characterization of silica fume**

Figure 7 shows a SEM image performed to emphasise the size and shape of the silica fume particles and Figure 8, the EDAX analysis.

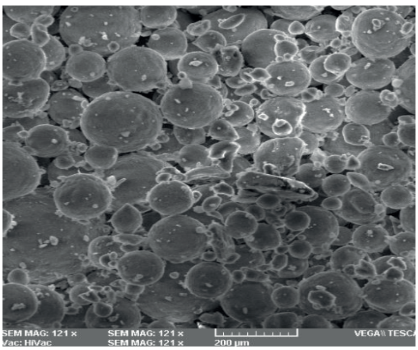


Figure 7. SEM analysis of silica fume

Silica fume is depicted as a grey powder with particles of various sizes and morphologies. Adjacent to these irregularly shaped microparticles are spherical microparticles, whose shape is determined by the temperature at which they are formed and cooled. Silica fume is primarily composed of silicon oxide, but can also contain silicon carbide (less than 3%), free carbon, and impurities from raw materials (Figure 8).

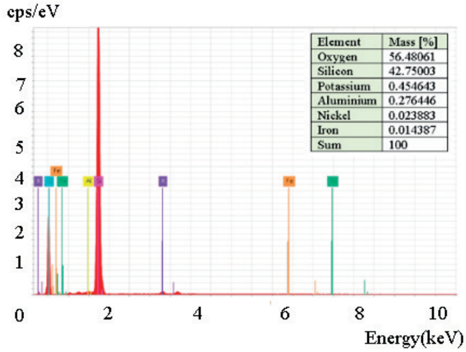


Figure 8. EDAX analysis of silica fume

Figure 9 depicts an XRD diagram of the chemical elements found in silica fume in crystalline form. The XRD analysis shows that quartz (Q) is the primary crystalline phase of silica fume, with minor amounts of muscovite (Ms), kaolinite (K), mullite (M), and other minerals.

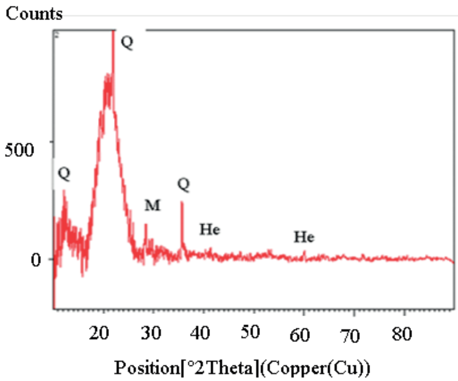


Figure 9. XRD analysis of silica fume

**Characterization of mortars**

- Compressive strength

Figure 10 shows that the mixture with the highest compressive strength contains silica fume and furnace slag as additives.

The reason for this is the chemical composition, which contains a high concentration of $SiO_2$ and CaO. Mechanical properties are influenced by the chemical composition of the components as well as the morphology and granulometry of the particles. Mixtures with high $SiO_2$ and CaO content exhibit higher compression values compared to the blank sample.

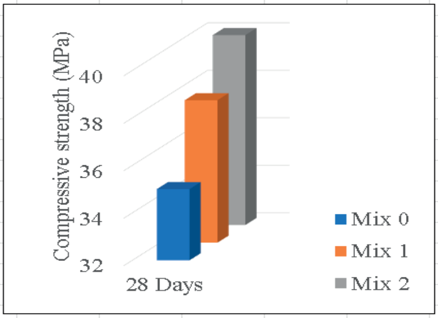


Figure 10. Compressive strength of mortar samples

Despite the fact that more water was required to ensure workability in this study, the prepared materials exhibited excellent properties. Using fly ash and silica fume resulted in lower values than Mix 2, but better than the blank sample (Mix 0). The values obtained ranged from 35 MPa (Mix 0), 38 MPa (Mix 1), and 40 MPa (Mix 2).

- Flexural strength of materials

The same phenomenon occurs with flexural strength as it does with compression strength.
Fly ash (Mix 1) and furnace slag (Mix 2) fill in the gaps in silica fume's properties. According to Figure 11, Mix 2 has the highest flexural value at 28 days (10.1 MPa), followed by Mix 1 (9.3 MPa), with the blank sample Mix 0 having the lowest value (8.5 MPa).

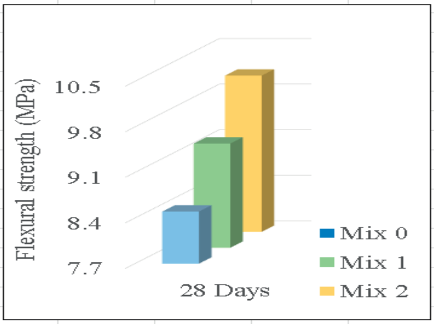


Figure 11. Flexural strength of mortar samples

- Adhesion on substrate of materials

The fineness of the particles, in addition to their chemical composition, is an important factor in adhesion to the substrate. Figure 12 shows that, as with the previously obtained mechanical characteristics, Mix 2 has the highest adhesion value. This is given that silica fume and furnace slag contain high levels of silicon oxide and calcium oxide. Adhesion values (Figure 12) range from 2.19 MPa (Mix 0), 2.25 MPa (Mix 1), and 2.32 MPa (Mix 2).

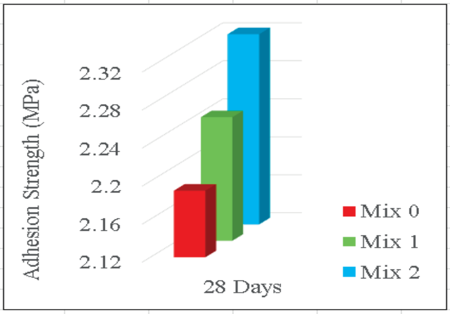


Figure 12. Adhesion strength of mortar samples

- Shrinkage of materials

The best recorded value for material shrinkage can be identified in the blank sample. The consumption of water is an important factor in this determination because it is released when the material matures, which causes the material to shrinkage. Percentages ranged from 0.4% to 0.49%, with a maximum of 0.5% (Figure 13).

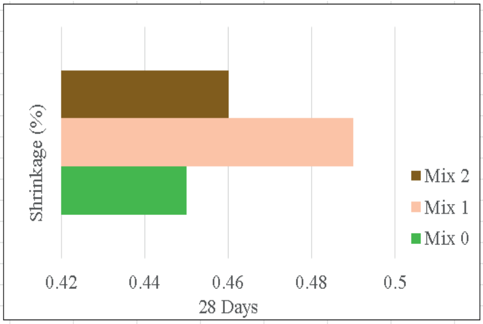


Figure 13. Shrinkage of mortar samples

## CONCLUSIONS

After the research conducted or observed, the following conclusions were reached.
During performing the analyses, it was found that the chemical, physical, and mineralogical compositions of used wastes such as fly ash, furnace slag, and silica fume are similar to those of cement, indicating that these industrial

wastes have a pozzolanic character and can be used in mortars. From this study, it was determined that they are effective when used as mortar additives.

The mechanical characterization of the obtained materials indicates that the use of industrial waste as additives, resulted in a compressive strength of up to 40 MPa and the flexural strength about 10.1 MPa. The good results were obtained for adhesion to the substrate, values as high as 2.23 MPa. Although the values are within the maximum permitted limit.

It was found that recycling industrial waste has benefits for lowering pollution levels as well as producing materials with superior qualities at comparatively low costs.

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