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WASTE GLASS AS AN ALTERNATIVE RAW MATERIAL IN THE CEMENT INDUSTRY

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SUMMARY

In the 21st century, the cement industry is facing a growing backlash from the public regarding the huge carbon dioxide emissions the cement industry produces. In order to mitigate carbon dioxide emissions, new alternative solutions regarding the cement production process must be introduced. One of those solutions is the use of waste glass as an alternative material in the cement production process. The results of scientific literature and papers that deal with this topic, as well as preliminary experimental research, give positive indications for the usage of waste glass for these purposes.

Key words: cement, carbon dioxide, alternative material, glass, green engineering

INTRODUCTION

The cement industry is one of the leading air pollutants and one of the causes of climate change. As a result of those effects, the average temperature has increased by 1.2°C, which has caused the melting of the ice caps and a rise in sea level. Cement is a widely used construction material, and its production has increased since the mid-19th century. In 2022, global cement production amounted to approximately 4.2 billion tons, a significant increase compared to 1.39 billion tons in 1995, and was produced in more than 90% of countries and territories, surpassing the 3.69–4.40 billion tons forecasted by the International Energy Agency (IEA) for 2050. So far, many professional and scientific works have been written and published in the field of the use of alternative raw materials in the cement industry. Waste glass can often be found in waste dumps and can be dangerous for the environment since glass is not biodegradable. Moreover, the lack of waste disposal space poses a challenge for many cities, especially in densely populated areas. A significant portion of landfills is occupied by glass waste. Therefore, it is necessary to reduce the amount of waste glass in landfills. One way to achieve this is through recycling or finding appropriate applications for waste glass in other sectors, such as industry. Waste glass, with its high silica content (SiO_2) that resembles the chemical composition of sand, enables us to conclude that glass could be a valuable substitute for this raw material. Many researchers have found that using glass as an alternative material requires significant changes to the traditional process of cement production.

As shown in Figure 1, the participation of the cement industry in the total carbon dioxide emissions is 7%

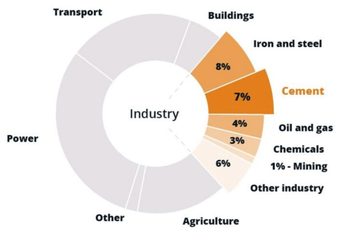

Figure 1. Share of global carbon dioxide emissions that come from the cement industry

The production of clinker, the main component of Portland cement, emits approximately 0.527 tons of carbon dioxide per ton of clinker, primarily due to the calcination process, which accounts for 50% of emissions in cement production. The remaining emissions come from carbon-based fuels and electricity consumption. These stages consume varying amounts of energy, with clinker burning responsible for the highest percentage of energy consumption (25%), followed by final grinding (40%), raw grinding (20%), and auxiliary grinding (15%).

Besides the enormous carbon dioxide emissions that the cement industry produces, cement production consumes a significant amount of energy.

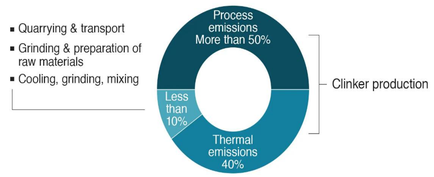

Figure 2. Carbon dioxide emissions produced by the cement industry from 1960 to 2022

From everything that we have stated before, we can conclude that the production of clinker is a major cause of massive carbon dioxide emissions. Thus, by finding a way to replace a small portion of clinker with an alternative material that does not have a negative impact on the environment and has similar chemical characteristics to other primary raw materials used in cement production, we can reduce carbon dioxide emissions. As a matter of fact, we can achieve lower carbon dioxide emissions without affecting the quality of the clinker, and therefore the cement. Using glass as an alternative material in the cement industry promises less energy consumption in the cement production process, as the energy required for reusing recycled materials is lower than for primary materials.

Disposing of glass in landfills is not an environmentally sustainable solution due to its non-biodegradable nature. Consequently, waste glass presents a major challenge for solid waste management systems worldwide, as it has a low recycling rate, landfill space is limited, and finding new landfill sites is increasingly difficult. The cement industry provides a practical and effective solution to this issue. Since glass has a chemical composition and physical properties similar to those of sand and cement, it can be utilized in cement and concrete production. This not only helps preserve natural resources but also reduces energy consumption, lowers costs, and decreases carbon dioxide and other greenhouse gas emissions.

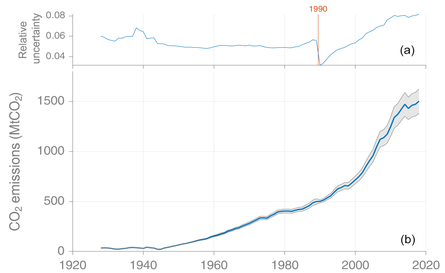

Figure 3. Carbon dioxide emissions produced by the cement industry from 1960 to 2022

RESEARCH AND MATERIALS

The laboratory analysis of the glass used in the industrial trial is given in Table 1 [1], and the laboratory analysis of clinker obtained from three various mixtures in the industrial trial is given in Table 2 [2].

Components	Unit (%)
SiO_2	66.12
Na_2O	15.24
CaO	13.36
Al_2O_3	1.97
Fe_2O_3	0.55
Moisture	0.4

Table 1. Chemical composition of alternative raw material waste glass

Components	Raw material mix 1 (%)	Raw material mix 2 (%)	Raw material mix 4 (%)
CaO	68.47	68.42	68.19
SiO_2	21.99	22.01	21.88
Al_2O_3	5.17	5.18	5.24
Fe_2O_3	3.34	3.33	3.30
Na_2O	0.18	0.23	0.43
K_2O	0.35	0.35	0.31
SO_3	0.54	0.55	0.54
Alite	72.01	71.60	71.63
Belite	8.74	9.10	8.72
Ferrite	10.17	10.13	10.03
Aluminate	8.04	8.09	8.19

Table 2. Chemical composition of the clinker

RESULTS

As shown in Figure 4, moisture 2, which contains limestone, slag, and waste glass, causes less carbon dioxide emissions [1]. The comparison of samples in Hot Meal is given in Figure 5 [2].

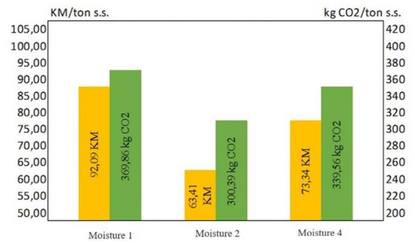

Figure 4. Raw material mixture costs and carbon dioxide emissions per ton of raw material mixture used

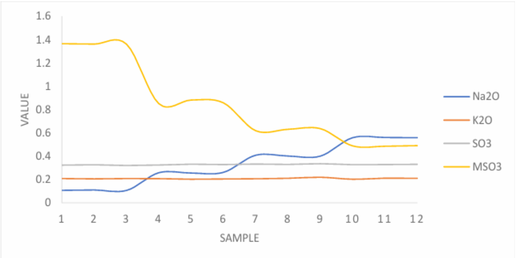

Figure 5. Comparison of Samples in Hot Meal

CONCLUSION:

- Replacing a portion of the clinker with waste glass significantly helps reduce waste in landfills, solving the problem of disposing of non-biodegradable glass. This contributes to a more sustainable waste management system.
- By substituting one portion of clinker with glass, we are saving on natural resources like clay, sand, and limestone, which then could be used for other purposes.
- The total energy required for the production of cement will be reduced, which may ultimately result in more affordable cement.
- With the usage of waste glass as an alternative material in production in the cement industry, carbon dioxide emissions and their negative impact on the environment are mitigated
- Using glass in cement requires careful processing (grinding to fine powder). It is necessary to determine the exact amount of waste glass that could be added to the raw material mixture, which would not interfere with the chemical compositions and other clinker properties
- The development of software tools significantly shortens the time of finding the optimal solution, that is, choosing the optimal raw material mixture [1].

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