SUSTAINABILITY OF WASTE MATERIAL REUTILIZATION INTO NOVEL GLASS CERAMICS: A LIFE CYCLE ANALYSIS

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Abstract: This study is a systematic evaluation of the sustainability of recycling fly ash, from thermal power plants, into novel glass ceramics (GCs). This was facilitated by a life cycle analysis both, of the starting materials (fly ash, glass cullets, silica etc.) and final prototypes (bulk and porous GCs), thus providing a picture of true environmental impact these products exhibit over their entire life cycle. In conclusion it can be stated with confidence, that using waste materials as substitutes of conventional feed materials during the production of high added value products has a significant environmental potential, next to the obvious benefit of raw materials saving.

Keywords: Fly ash, Glass cullet, Waste recycling, Life Cycle Assessment.

1. Introduction

The industrial revolution of the 18th century led to an unprecedented industrialization of our planet that has drained natural resources at a high pace ever since. This exploitation and the resulting wastes materials that are in their majority directly landfilled [1] and on a lesser extend used as filler material in concrete [2] and clay products for construction purposes [3], contributed to an alarming ecological and environmental imbalance. The principles of sustainable manufacturing, with regard not only to the consumption of natural resources but also to the production of harmful emissions, dictate the use of waste materials in the fabrication of a variety of products, ranging from mass production to high added value ones. The sustainability of this approach is often evaluated through a method called life cycle assessment [4] the results of which, if extended to waste policy, may lead to an effective preservation of the environment for generations to come.

Over the past decade, the perception of fly ash as a polluting waste material has been completely changed into that of a potential material, capable of supplementing natural resources, in a variety of studies examining among others Metal Matrix Composites [5,6] and syntactic foams [7]. Fly ash and other waste materials (e.g. glass cullets) were recycled into novel bulk and porous glass ceramics which are widely considered as high added value products. Mechanical and physical testing revealed that these materials exhibit attractive properties that could be utilized in a series of applications e.g. construction, filters etc.

Next to extending the life cycle of end products, this approach could significantly reduce the energy required for their production, thus minimizing greenhouse gasses as well as amount of coal combustion products that must be disposed in landfills.

2. Methods

This investigation provides refined insight into the Life Cycle Analysis of porous and bulk glass ceramics produced by fly ash and other wastes in an effort to produce novel products through an environmentally friendly manner, according to figure 1.
The following parameters were considered during the life cycle assessment of both starting materials and end products:

• Primary energy intensity (PEI) in terms of energy consumed during manufacturing of product, accounting for both renewable and non-renewable sources of energy [8].
• Global warming potential (GWP) quantified by using global warming potentials for substances having the same effect as CO₂ in reflection of heat radiation [9].
• Ozone Depletion Potential (ODP), quantified by using potentials for substances having the same effect as Chlorofluorocarbons, which have an exceptionally high Ozone Depletion Potential [10].
• Photochemical Ozone Creation Potential (POCP), with ethene being chosen as the reference gas [10].
• Acidification Potential (AP), reflecting the tendency of a product or component to become acidified [8].
• Nutrification Potential (NP), defined as the potential to cause over-fertilisation of water and soil, which can result in increased growth of biomass [11].

3. Results

The results of the LCA was interpreted with emphasis on the environmental impact and health-hazardous parameters.

Two multi-criteria analyses were processed for this purpose. A Fuller triangle method was used to determine the weights of individual criteria for the first analysis, whereas in the second one a Saaty method was used [12].

Overall 6 environmental criteria were evaluated namely: PEI, GWP, ODP, POCP, AP, and NP; economic benefits concerning raw material cost were also considered next to health-hazardous parameters like reminder toxicants determined through toxicity leaching procedures.

Mechanical strength characteristics e.g. bending strength, were adopted from a previous study as product quality criteria [13]. The total environmental impact as calculated for each one of the primary assessed parameters is summarized in table 1.

The Life Cycle Analysis proved that fly ash in concentrations up to 40% could act as an effective replacement material for the production of bulk and porous glass ceramics. In addition to the low cost of fly ash as a starting material, these products exhibit notable strength characteristics at very low toxicity values. The reduction of residual toxins, apparent in fly ash, is another significant advantage of these type of recycling procedures.
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Even though it is difficult to evaluate the importance of this on human health, it is widely accepted that landfilling of fly ash has negative environmental effects, as leaching of potentially toxic substances into soils and groundwater changes the elemental composition of vegetation growing close to the ashes, causing the accumulation of toxic elements in the food chain.

The main toxicants originating from coal ash that exhibit significant health impacts [14] are:

- Mercury, posing particular risk to children, infants and foetuses as it impacts the nervous system and damages the mental development.
- Chromium, as its ingestion may cause stomach and intestinal ulcers, anemia and cancer.
- Selenium, which is used in many bodily functions but can in excess result in neurological defects like impaired vision, paralysis and even death.
- Boron, the short term inhalation of which can lead to eye, nose and throat irritation. Longer periods of exposition may result in liver and kidney damage.
- Arsenic, which can lead to cardiovascular issues and carcinogenesis.
- Lead, exposure to which may cause brain swelling, kidney disease and even death.

In these terms the reduction of reminder toxicity in the produced glass ceramics, can only be considered as beneficial.

The reminder toxicity was determined through a toxicity a leaching procedure (TCLP), testing in accordance to which revealed no toxicants in the bulk GCs and some residual hazardous remains in the porous samples, with the overall toxicity being reduced by more than 87%. The results were compared with threshold values as defined by the United States Environmental Protection Agency (US EPA) and are summarized in table 2.

3. Discussion-Conclusions

Although the quality of fly ashes varies dramatically based to the coal source and the contents of major specified element oxides, there is a great potential to utilizing fly ash in the production of novel glass ceramics. There are international standards classifying the usability of fly ash as conventional admixtures to concrete, such as ASTM C 618-93 [15], the full recycling potential however exhibited by these materials has not yet been exploited.

This investigation underlines the vase environmental benefit that can be expected from recycling waste materials, like fly ash and glass cullets, into GCs once this is scaled up to mass production.

Acknowledgements

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program “Education and Lifelong Learning” of the National Strategic Reference Framework (NSRF) - Research Funding Program: ARCHIMEDES III. Investing in knowledge society through the European Social Fund. “Archimedes III: Funding of Research Groups in TEI of W. Macedonia” project acronym “GreenAsh”, project No. MIS 383583.
4. References