Legacy slags - a solution to the future shortages of GGBFS in the UK?

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Keywords: Blast Furnace Slag, Cement, Legacy Wastes, Supply Chain Resilience

Ground granulated blast furnace slag (GGBFS) is an iron industry byproduct created by water quenching molten blast furnace slag (BFS), and then grinding the material into a fine glassy powder [1]. For decades, GGBFS has proven to be an effective supplementary cementitious material (SCM) in blended Portland cement-based systems [2]. GGBFS has also been used as a precursor for alkali-activated cements [3]. In the past few decades, the United Kingdom (UK) has been facing a GGBFS shortage due to a decrease in domestic iron production [4]. As a result, the UK relies on imported GGBFS to meet demand [5]. Yet the UK has over 190Mt of unused legacy slags, arising from the country's industrial history [6]. Utilizing these legacy slag stockpiles could provide a more sustainable option by reducing the dependency on imported GGBFS, and also increasing supply chain resilience.

We explored the feasibility of using these legacy UK GGBFS in cement production. First, an age bounded scope was determined for legacy slags, given the history of iron production and GGBFS use in the UK. Second, a comparative analysis was conducted between modern and legacy slags by evaluating whether legacy slags would be acceptable to modern standards and specifications. Lastly, the likely environmental effects that would result from the material's extraction were assessed to determine if any adverse impacts are likely to outweigh the potential benefits.

Despite the UK's industrial history of iron production, commercial use of GGBFS was not widespread until the 1950s [7]. Before this point, most BFS would likely have been air-cooled, a cooling method that does not give the material hydraulic properties. Throughout the late 20th century, the increase in demand for GGBFS as a SCM resulted in the Waste Protocols Project officially declaring BFS as a byproduct instead of a waste product in 2007. Given this historical context, the age bounded scope for UK legacy slags was therefore defined as slags produced between 1950s-2009.

Four slag data sets [8-11] from the defined age bounded scope were used to determine if legacy slags met the current requirements set by BS EN 15167-1&2:2006 [12] (Table 1).

Requirement [12]	Is the requirement met?
Mass of Glassy Slag > 68%	Yes
Basicity Factor; $K = \frac{CaO+MgO}{SiO_2} > 1$	Yes, however additional mass ratios that are not noted in the British Standard should be considered to properly evaluate slag quality.
Magnesium Oxide ≤ 18%	Yes
Sulphide ≤ 2% and Sulphate ≤ 2.5%	Very likely met for all data sets, given that the SO_3 present is less than 2.2% for all data sets.
Chloride ≤ 0.10%	Likely to be met given low amount of chloride typically present in GGBFS. GGBFS with higher levels of chloride can still be used in other cement types (i.e. CEM III).
Loss of Ignition ≤ 3.0%	Unlikely to be met.
Moisture Content ≤ 1.0%	Unlikely to be met.

Table 1. Comparative Analysis comparing the legacy slag data sets to constituent and chemical requirements for GGBFS in BS EN 15167-1&2:2006

While the inorganic constituents in these samples did meet the requirements, the exposure of legacy GGBFS to weathering and prehydration have affected loss of ignition and moisture content. This is likely to be a particular issue in slag extracted from near the bottom of GGBFS stockpiles, where H_2O and CO_2 concentrations are highest [13]. To mitigate this, pretreatment would need to occur through a secondary heating treatment process to remove this moisture and carbonate content. Studies on hydrated and partly hydrated recycled cement from concrete demolition waste may provide an insight on how this process may be applied to GGBFS [14].

The use of legacy GGBFS was then assessed from a sustainability perspective, considering both the pros and cons of extraction, and comparing this to the current solution of relying on imported slags. The greatest likely benefit associated with slag extraction is the potential to remove toxic heavy metals and other potent chemical compounds such as free lime from UK soils and waters that are present as a result of weathered slag [15]. The greatest challenge associated with the material's extraction is the inaccessibility of many slag deposits. Over 38% of slag deposits are found in urbanized or suburban areas, and may prove impossible to access [6]. In addition, a fifth of all slag deposits are found in coastal areas where many slag stockpiles are providing a form of environmental remediation [16]. A previous life cycle assessment (LCA) comparing UK legacy fly ash and imported fly ash for use as a SCM, was used as a comparative reference case for GGBFS [17]. For GGBFS in the UK, a priority should be to utilize the limited available stockpiles of legacy GGBFS, where feasible. Since demand will continue to be fulfilled partly with imports, procurement from neighboring countries (such as Netherlands and Germany) should be prioritized over sources from further afield, in order to reduce CO_2 emissions associated with transportation.

In conclusion, opportunities presented by the extraction and use of GGBFS could help meet the UK's increasing demand for low carbon cement. To provide definitive results on the material's viability for use in blended cements, it is recommended to carry out the exact testing procedures and specifications outlined in the British Standards on extracted legacy GGBFS samples**.** Since no studies have been conducted on increasing the reactivity of legacy GGBFS, further research is recommended to determine an adequate treatment process. Future work will include a hybrid LCA imported GGBFS, which will provide a benchmark against which legacy slags would have to compete.

Acknowledgment: The authors would like to express appreciation for the financial support of the EPSRC through EP/R001642/1, and a DTP PhD scholarship awarded to M. C. S. R. via the Energy Institute at The University of Sheffield.

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