Field Evaluation of a New Road Sub-Base Concept Including Bauxite Residue and Other Industrial By-Products

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Abstract

The refining of alumina produces significant amount of residue (BR, Bauxite Residue) which is similarly produced by other ferrous and non-ferrous metals industrial sectors. Alumina refining, iron and steel production can establish innovative industrial symbiosis models for the construction sector to valorise large volumes of residues and by-products. In the present study, results from a European pilot plant to produce and evaluate the performance of a new road sub-base concept using bauxite residue, coal fly ash and ground granulated blast furnace slag. The paper includes details and results of the project, the experimental work undertaken to determine the mechanical and environmental performance and the results achieved from the quality control and monitoring plan established. Mechanical results were compared with the Spanish and Irish regulations for hydraulically bound materials for roads. The results show that the key performance parameters have been achieved and that the new material developed is suitable for road sub-base construction. The proposed solution appears robust from a safety and environment point of view and the project showed no major construction process difficulties. In summary, the field evaluation has demonstrated the added value of using waste and by-products as alternative construction materials delivering a mechanical performance like soil cement pavement layer and a suitable circular economy strategy to reduce the environmental impact of alumina production and BR management.

Keywords: Bauxite residue, Road construction, Mechanical strength, Fly ash, GGBFS.

1. Introduction

Recycling of inorganic industrial waste and surplus materials have a decisive role in the development of the circular economy globally. This is because the solid waste stream represents billions of tons of material resources and a range of different types of materials (e.g. combustion ashes, slags and residue from metallurgic manufacturing, tailings from mining). The more secondary material resources we manage to keep in the circular economy, the more we can reduce the amount of natural resources used as primary resource resulting in less extractive waste stored at industrial sites.

Bauxite residue (BR) from alumina production is an alkaline by-product from the processing of bauxite through the well-known Bayer process. The alumina is extracted using sodium hydroxide under high temperature and pressure, where the so-called BR (insoluble part) is removed from the sodium aluminate solution. Typical range of residue to alumina production ratio is 0.75 to 2 tonnes of residue per tonne of alumina produced. Based on updated figures of the International Aluminium Institute [1], an estimate of almost 170 million tonnes of BR was generated in 2021. If we include BR storage in approximately 50 closed legacy sites, the total volume of BR may be around 3 billion tonnes of residue [2]. Hence, increasing the re-use of BR will contribute significantly to circular economy.

Ground granulated blast furnace slag (GGBFS) is a by-product from the iron and steel making industrial sector that has been dried and ground into fine powder. In Europe, almost 18 million tonnes of GGBFS is used in the cement and concrete industries. This is the most common use for GGBFS. It acts as a direct replacement for cement, and has many advantages including extending the life cycle of concrete, making concrete more durable, and reducing the carbon and energy footprint of concrete production. Blended cements (GGBFS and ordinary Portland cement) have a superior resistance to sulphates and an increased chloride binding capacity.

Pulverised coal fly ash (PFA) is a waste produced from the combustion of coal in the generation of electricity at power plants. It is most commonly used as a high-performance substitute for Portland cement or as clinker for Portland cement production. Cements blended with PFA have become common. Building material applications range from grouts and masonry products to cellular concrete and roofing tiles. Many concrete pavements contain PFA. Geotechnical applications include soil stabilization, road base, structural fill, embankments and mine reclamation.

Secondary materials for road construction offer wide range of possibilities for waste and by-products re-use. Materials required for road construction vary in particle sizes (surfacing, base course, sub-base, subgrades, embankments) and the civil engineering sector is huge in every country and there are always construction projects ongoing. Hence, the pilot road project makes it ideally to apply different types of alternative materials like recycled excavated soil, recycled aggregates, recycled glass [3, 4].

Several studies have been published on the use of BR with coal fly ash and calcium hydroxide to stabilise soil subgrade [5]. Mukiza et al [6] concluded in their review that BR was suitable as soil subgrade stabiliser for light traffic roads.

The use as road sub-base material needs addition of activators to boost up the geopolymer reactions. The effect of different activators (10 % addition) on BR have been ranked in the sequence of decreasing strength, calcium hydroxide, GGBFS, cement kiln dust and coal fly ash [6]. Not surprisingly, a strong correlation was established with the CaO content. Another study [7] using BR, coal fly ash and lime confirmed that this combination shows good geotechnical results, and that BR can be used as a geotechnical material with the appropriate method of stabilisation.

Leaching measured at single pH have been frequently reported including BR with flue gas desulfurization fly ash and cement [6], BR with rice husk ash [8], BR and fly ash in sulphuric acid and deionised water [9], BR and sintered BR [10]. However, only a few studies exist regarding equilibrium based leaching characterisation that cover the full pH range [11, 12]. Hence, a full pH dependent characterisation was conducted in RemovAL project [13]. Regarding full scale demonstration, only a few studies have been reported with road pilots with large use of BR in road pavement achieving high level of performance [14].

In the RemovAL research project funded by the European Union (www.RemovAL-project.com), large-scale use of geopolymer based BR as road sub-base (150 mm layer) was demonstrated. Firstly, laboratory studies were carried out to evaluate both the mechanical and environmental performance [13, 15], demonstrating that the use of BR combined with PFA, GGBFS and calcium hydroxide (hydrated lime) is suitable for roads construction and potentially a very good opportunity for the valorisation of BR. This study shows the results of the RemovAL sub-base layer pilot, a full-scale demonstration project using BR, PFA, GGBFS and hydrated lime, for the construction of a 150 mm sub-base pavement layer of a secondary road within the Bauxite Residue Deposit Area (BRDA) located at the Aughinish Alumina (Aughinish) refinery in Ireland.

6. References

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