Development of Low-Carbon, High-Durability Concrete Using Bauxite Residue and Aluminium

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Abstract

The alumina industry is responsible for one of the world's largest industrial waste streams, namely Bauxite Residue (BR) with global levels estimated at around 3000 million tonnes at the end of 2010. The cement industry is the world's third largest emitter of carbon dioxide (CO_2), accounting for 5-8 % of the global anthropogenic emissions. The footprint of these two industries could be greatly reduced through the development of a low-carbon concrete where BR is one of the ingredients. This paper presents results from the initial study investigating the possibility of using BR from the Hydro Alunorte refinery as a cement constituent or direct cement replacement in mortar and concrete. It also presents initial results on the development of a reinforced concrete with high durability and low CO_2-footprint enabled through the replacement of steel reinforcement with aluminium reinforcement.

Keywords: Bauxite residue (BR), cement, carbon dioxide (CO_2) emission, Hydro Alunorte alumina refinery, aluminium reinforced concrete.

1. Introduction

The alumina industry is responsible for one of the world's largest industrial waste streams, namely Bauxite Residue (BR), with global levels estimated at around 3000 million tonnes at the end of 2010 and with an inventory growth of more than 120 million tonnes per annum. Throughout the entire history of alumina production there has been a desire to utilize the BR. Hundreds of patents have been issued and thousands of trials have been undertaken on various uses. In most cases the possible uses involve replacing another low-cost material so whilst the concept may be technically feasible, the cost and risks of using BR are not justified [1]. An example of this is the use of BR in cement and concrete. Despite the high number of patents filed for this application over the years the industrial use of BR in cement and concrete is limited because there has not been any incentive for the cement/concrete industry to change their cement recipes and to replace their traditional raw materials. However, this situation is about to change as will be explained below.

The cement industry is the world's third largest emitter of CO_2, accounting for 5-8 % of the global anthropogenic emissions, with 60 % coming from decomposition of limestone in the cement clinker production process and 40 % from fuel for calcination. There is an increasing pressure on the cement industry to reduce its CO_2-footprint. One of the most promising approaches to mitigate the CO_2-emission is to switch from Ordinary Portland Cement or regular cement over to "Portland composite cements" also termed blended cements. In blended cements CO_2 from limestone is greatly reduced by replacing cement clinker partially by supplementary cementitious materials (SCM). The industry is working with identifying the most suitable SCMs. Fly ash, slag and limestone are already being used today but it is necessary to add more SCMs to the list, among others due to the limited availability of fly ash and slag. Emerging alternatives are calcined clay and BR. The latter could be used "as is" or calcined.

Another way of reducing the CO_2-emission from the cement industry is to shift from regular cement to other classes of cement such as Calcium sulfoaluminate (CSA) cement. This cement class has low process-CO_2 as well as lower burning temperature than regular cement. A disadvantage of CSA cement is the need for bauxite as raw material which makes it more expensive than regular cement [2]. However, BR could potentially be used instead of bauxite and enable CSA cement to become an economically feasible option. Another disadvantage of CSA cement is that its initial low pH and low calcium hydroxide reserve makes it unsuitable for steel reinforced concrete because corrosion may be initiated by carbonation after relative short time. However, this challenge could possibly be solved by replacing steel reinforcement bars with aluminium reinforcement bars.

Steel is today the standard material for concrete reinforcement bars. The reason aluminium is not used is that it is not compatible with the high pH of regular cement. However, new low-CO_2 cement recipes (as outlined above) is likely to be more compatible with aluminium reinforcement bars than steel reinforcement bars. Furthermore, reinforcement bars in aluminium has a number of advantages as outlined in section 4.2.

The most common degradation mechanisms for steel reinforced concrete is chloride ingress and carbonation (i.e. neutralization by the CO_2 in the surrounding air) that can make the steel corrode and eventually make the concrete crack due to expanding rust. The concrete binder itself can handle both chloride intrusion and carbonation. Aluminum can also handle CO_2 and is stable towards chloride when alloyed with 5 % magnesium. However, aluminium cannot be used with regular cement/concrete because the high pH will etch aluminum and evolve hydrogen gas.

Norsk Hydro, Heidelberg Cement, Veidekke, SINTEF and NTNU have established a joint R&D project termed "Durable Aluminium Reinforced Environmentally friendly Concrete Construction (DARE2C)" in order to explore:

1. the possibility of using BR from the Hydro Alunorte alumina refinery in blended cement and in CSA cement.
2. the possibility of replacing steel reinforcement bars with aluminium reinforcement bars in concrete.

This article will present some initial test results from this project.

2. Bauxite Residue in Cement

In recent years several research groups have published promising results with respect to the use of BR as SCM for cement [3, 4]. The DARE2C project partly overlaps with these previous projects in order to produce data specifically for BR from Hydro Alunorte but also includes research beyond previous publications.

acceptable given the fact that BR would contribute positively with reduced CO_2-footprint and improved raw material security for the cement/concrete industry.

However, the profile of the strength curve may indicate that soluble sodium hydroxide is released to the pore fluid leading to reduced activity of water, and subsequently slowing down or even stopping hydration of cement. This may indicate that cement containing BR will suffer from reduced long-term properties if the BR content is too high. Previous publications found that maximum 7 % – 20 % BR "as is" might be used in blended cements [3]. For BR pre-treated with calcination it has been demonstrated that up to 30 % can be used [4].

It was found that the main advantage of the BR is that it acts as an accelerator, partly due to the pozzolanic reaction and partly due to a likely increase in pH when the sodalite phase is reacting. The accelerator effect was strongest when BR was combined with fly ash which is known to be accelerated by high pH. It is expected that the effect will be the same for slag and other SCMs known to be accelerated by high pH.

The initial results from the test of the effect of BR on alkali-aggregate reactions looks promising with no sign of deterioration at this early stage.

Finally, the results indicate that aluminum metal can be used for reinforcement of concrete if the regular cement (CEM I) is replaced with a sufficiently large fraction (> 50 %) of an active pozzolan consuming all calcium hydroxide from the cement hydration. Making concrete in which aluminum reinforcement is stable may enable "infinite" service life without maintenance.

The results presented in this article is the first step towards the long-term aspiration of developing low-carbon, high-durability concretes using BR and aluminium. The next steps include additional testing of BR as SCM in blended cements, testing of BR in CSA cement, as well as further testing of aluminium reinforcement concrete.

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7. References

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