

Valorisation of the fine fraction from EAF steel slag treatment through the application of carbonation-based processes

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Around 7 billion tonnes of alkaline residues are generated globally every year as by-products of different industrial activities (Renforth, 2019). Due to inadequate technical (e.g.: particle size, density or mechanical strength) and/or environmental properties (e.g.: alkaline pH and leaching of contaminants), these materials are generally downcycled or landfilled (Gomes et al., 2016).

Accelerated carbonation has been proposed as a treatment to access alternative and higher-value applications for the products obtained from alkaline industrial residues and therefore as a strategy to actually valorise them. By accelerated carbonation we refer to the reaction of Ca and Mg oxides-bearing phases with either pure or diluted CO₂ flows under controlled operating conditions. These reactions lead to the formation of Ca and/or Mg carbonates, therefore ensure the permanent storage of carbon dioxide in a solid form. As for the types of residues that have been tested by carbonation treatments, slag from steelmaking plants, as well as residues from waste to energy facilities and biomass combustion ashes, have shown the most promising results (Liu et al., 2021). Depending on the characteristics of the residues and on the reaction route selected, different types of products can be obtained. With indirect process routes, separating the dissolution of the reactive species from the carbonate precipitation phase, a fine relatively pure carbonate product (PCC) can be obtained; while employing the direct route, products such as aggregates or binding materials may be manufactured (Woodall et al., 2019; Liu et al., 2021). It is important to underline that assessing the chemical, technical and environmental properties of the obtained products is of paramount importance to determine their valorisation potential.

The study we propose to present at the Conference is being carried out within the activities of the ongoing Rome Technopole project, funded by the Italian National Recovery and Resilience Plan, aimed at promoting the creation of a virtuous system within the Lazio Region for universities, national research centres, institutions and business associations to cooperate to tackle some critical and heavily-debated issues such as that of decarbonisation and circular economy (Fondazione Rome Technopole).

The fine fraction (80%wt. below 0.06 mm in diameter) deriving from the treatment of Electric Arc Furnace steel slag was considered for this work; the sample, in fact, despite presenting adequate properties to be used as a filler, showed interesting characteristics to be employed in carbonation-based treatments considering both direct and especially indirect routes. For the direct route, we tested carbonation/granulation processes to obtain aggregates; the effects of carbonation with pre-granulation (GCp) and carbo-granulation (GCc) (simultaneous application of the two processes) were assessed and compared to those of sole granulation (G). After a 28-day curing phase, the aggregates were characterised according to their CO₂ uptake, environmental behaviour, granulometric curve and mechanical properties (ACV). The main findings are shown in Figure 1.

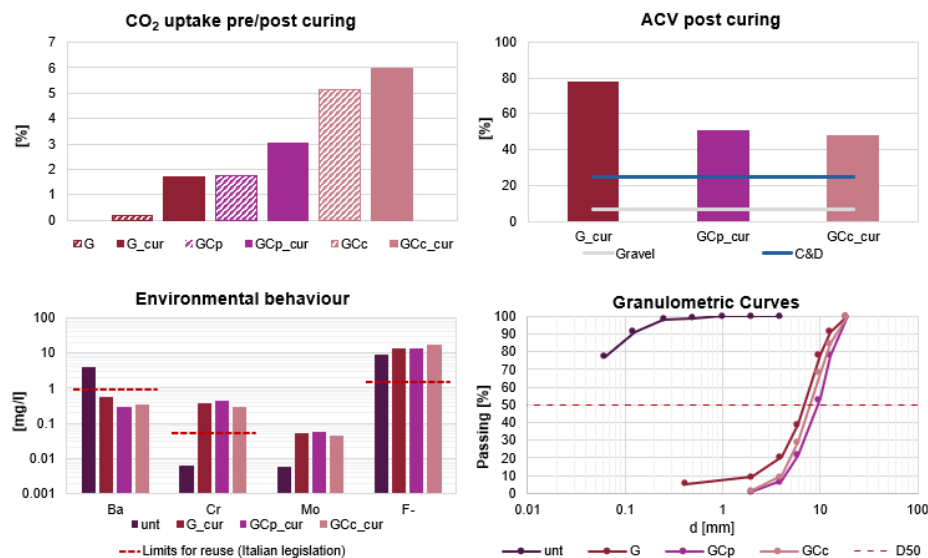


Figure 1. Results of the characterisation of the aggregates obtained from the direct carbonation tests.

An increase in the d_{50} of more than two orders of magnitude with respect to the initial dimension of the filler was observed for all the aggregates obtained from the implemented processes; the highest uptake (6%wt.) and the lowest ACV value (48%), hence the highest mechanical strength, were achieved when carbonation and granulation were performed simultaneously. Few critical aspects persist regarding the environmental behaviour of the products, especially considering the leaching of Cr and fluorides.

As for the indirect route, we performed pH-swing tests to precipitate PCC. First of all, the Ca extraction efficiency of several extracting agents (HCl, HNO_3 , citric acid and NH_4NO_3), selected on the basis of previous studies (e.g. Kim & Kim, 2018; Ho et al., 2022), was assessed considering different L/S ratios and molarities. Maximum extraction efficiencies ranging from 45% (for NH_4NO_3) to 80% (for strong acids) were obtained.

On the basis of the finding of this first phase, carbonation tests were later performed on the solutions obtained using the aforementioned reagents. Pure CO_2 was bubbled in the liquid considering different carbonation times; 5M NaOH was used for pH adjustment both before and during carbonation. XRD analyses on the precipitated products were also performed, showing the presence of either pure calcite or calcite and vaterite in the majority of the cases considered; the only exception was that of the PCC obtained when citric acid was used as extractant, in which sodium citrate dihydrate was also detected. As clearly shown in Figure 2, considering the carbonation phase, the worst performances in terms of carbonation efficiency, quality of the PCC and reagent consumption were associated to the use of citric acid. More innovative indirect routes are currently being experimented considering the utilisation of alternative reagents, namely amines, to combine the CO_2 capture (i.e. directly using carbon dioxide diluted streams) and mineralisation phases.

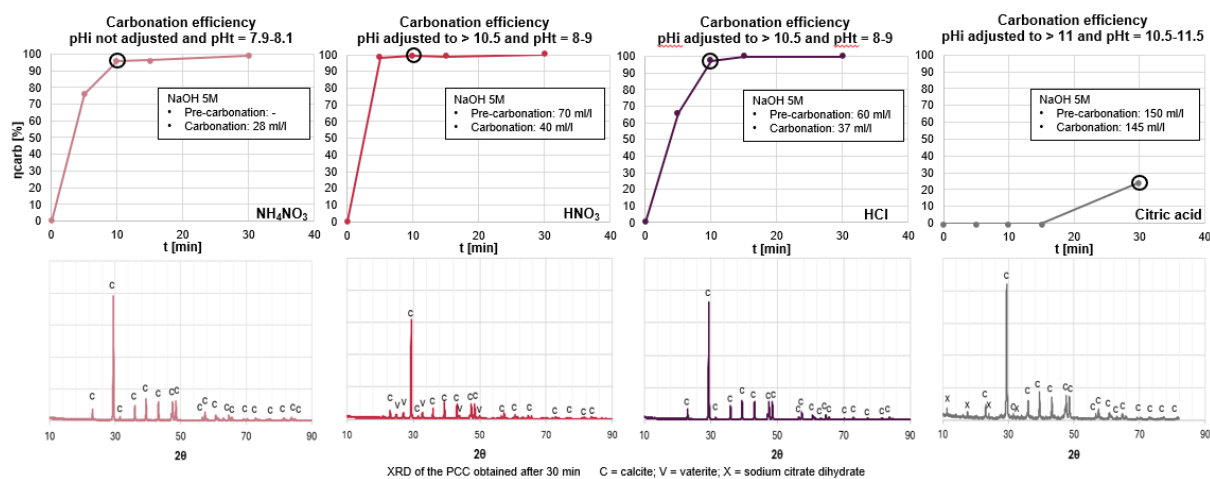


Figure 2. Results of the carbonation phase of the indirect process

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