DEVELOPING LOW-CO$_2$, 3D-PRINTABLE CONCRETE WITH WASTE ASH AND RECYCLED AGGREGATES

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Abstract – The construction sector is responsible for over 35 % of the EU's total waste and greenhouse gas (GHG) emissions, as stated in the Circular Economy Action Plan. The European Green Deal highlights the need for energy-intensive industries, such as construction, to reduce emissions and become more sustainable. 3D concrete printing (3DCP) is an emerging technology that can lower material use and waste by optimizing models before printing. However, it currently relies on significant amounts of cement, which is a major source of CO$_2$ emissions. To address this issue, this study developed a low-CO$_2$, 3D-printable concrete by replacing cement with industrial waste ash as a binder and incorporating recycled waste aggregate (RWA). The ash used was high-calcium fly ash, whose binding properties were enhanced by combining with pozzolanic waste materials. The used RWA was sourced from construction and demolition waste (CDW) landfill and compared to conventional crushed aggregates (CCA) to evaluate performance differences. Granulometric analysis showed similar particle size distributions (PSD) between both aggregate types, ensuring comparable workability and water demand in both concrete mixtures. The RWA-based and CCAbased mixtures achieved 28-day compressive strength of 18.6 MPa and 20.6 MPa, respectively. Although the RWA-based concrete exhibited slightly lower strength, the difference was minimal, demonstrating its viability for use in 3DCP for sustainable, low-rise construction applications where a mechanical strength of around 10 MPa is sufficient. The main focus of this study was to assess the environmental potential of this new material. Results showed that the low-CO$_2$ mix reduces emissions by approximately 80–90 % compared to conventional 3D-printable concrete, with the majority of the reduction coming from the cement replacement. The use of recycled aggregates contributed to a smaller reduction.

Keywords – Additive manufacturing; construction and demolition waste; low-CO$_2$ concrete; low-strength concrete; recycled waste aggregate; waste ash