Fly ash based Recycled Aggregate Concrete (FARAC): Studies at micro, macro and structural components level

Concrete construction is associated with adverse environmental impact owing to exploitation of limited natural resources (rock) as coarse aggregates and higher carbon dioxide footprint of the cement production process. To address these challenges, partial cement substituted (up to 30%) fly ash in 100% recycled aggregate concrete (designated as FARAC) may become a potential sustainable construction material. In this study, effect of 20% and 30% fly ash incorporated in recycled aggregate concrete (RAC) is comprehensively investigated for strength, safety, serviceability and sustainability. More specifically, the present study examined FARAC in terms of macro and microstructure properties, environmental impact assessment and performance of structural components.

Particle packing mix design method (PPM) adopted for FARAC is based on the philosophy of achieving maximum packing density through different sized particles, where smaller sizes pack in between the voids of larger ones. Concrete constituents are mixed by the triple mixing method to form a layer of fly ash slurry on the surface of recycled coarse aggregates. Equivalent 28 days compressive strength, flexural tensile strength and modulus of elasticity but lower split tensile strength are observed in FARAC as compared to natural aggregate concrete (NAC).

Microstructure properties of FARAC are studied through hydration reactions, morphology of hydration products along with area percentages determination of pores, CH and unhydrated cement or fly ash phases, micromechanical interface properties (modulus and hardness) and three-dimensional porosity. Lower degree of hydration in the interface as compared to bulk matrix, decreasing CH content in the presence of fly ash and higher carbonation component are reported in FARAC. Distribution of pore area percentage through analysis of scanning electron microscope images and modulus profile obtained by nanoindentation tests indicate thickness of interfacial transition zone in FARAC.

Life-cycle of FARAC and NAC are assessed through cradle-to-gate analysis of natural and recycled coarse aggregate production, cement and admixture manufacturing, extraction of fine aggregates and transportation associated with all of these raw materials. Fly ash is reused as a

part of the open-loop recycling and its contributions are considered using economic allocation. Comparative environmental impact of FARAC and NAC with and without fly ash designed in PPM and conventional Indian standard method indicate lower impact of 30% FARAC designed in PPM.

Behaviour of reinforced concrete beams, columns and flat slabs are investigated under flexure (and shear), compression and punching shear. Equivalent flexure, slight increase in peak load of column and reduction of failure shear are reported in FARAC. Span-to-effective depth provisions for RAC beams are suggested to satisfy target reliability of limit state of deflection. Reliability index is determined for limit state of shear and subsequently resistance factors are modified for RAC to achieve code-specified or NAC equivalent reliability. The present study helps in gaining confidence for the application of 100% RAC incorporating 30% cement substituted fly ash.

Keywords: fly ash, recycled aggregate, particle packing method, compressive strength, split tensile strength, hydration, pore area percentage, interface modulus, beam, column, flat slab, reliability index.