Fly-Ash/Borosilicate Glass Based Geopolymers: A Mechanical and Microstructural Investigation

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Abstract : Geopolymers are well-suited materials to abate CO2 emission coming from the Portland cement production, and then replace them, in the near future, in building and other applications. The cost of production of geopolymers may be seen the only weakness, but the use of wastes as raw materials could provide a valid solution to this problem, as demonstrated by the successful incorporation of fly-ash, a by-product of thermal power plants, and waste glasses. Recycled glass in waste-derived geopolymers was lately employed as a further silica source. In this work we present, for the first time, the introduction of recycled borosilicate glass (BSG). BSG is actually a waste glass, since it derives from dismantled pharmaceutical vials and cannot be reused in the manufacturing of the original articles. Owing to the specific chemical composition (BSG is an 'alumino-boro-silicate'), it was conceived to provide the key components of zeolitic networks, such as amorphous silica and alumina, as well as boria (B2O3), which may replace Al2O3 and contribute to the polycondensation process. The solid–state MAS NMR spectroscopy was used to assess the extent of boron oxide incorporation in the structure of geopolymers, and to define the degree of networking. FTIR spectroscopy was utilized to define the degree of polymerization and to detect boron bond vibration into the structure. Mechanical performance was tested by means of 3 point bending (flexural strength), chevron notch test (fracture toughness), compression test (compressive strength), micro-indentation test (Vicker's hardness). Spectroscopy (SEM and Confocal spectroscopy) was performed on the specimens conducted to failure. FTIR showed a characteristic absorption band attributed to the stretching modes of tetrahedral boron ions, whose tetrahedral configuration is compatible to the reaction product of geopolymerization. 27Al NMR and 29Si NMR spectra were instrumental in understanding the extent of the reaction. 11B NMR spectroscopies evidenced a change of the trigonal boron (BO3) inside the BSG in favor of a quasi-total tetrahedral boron configuration (BO4). Thanks to these results, it was inferred that boron is part of the geopolymeric structure, replacing the Si in the network, similarly to the aluminum, and therefore improving the quality of the microstructure, in favor of a more cross-linked network. As expected, the material gained as much as 25% in compressive strength (45 MPa) compared to the literature, whereas no improvements were detected in flexural strength (~ 5 MPa) and superficial hardness (~ 78 HV). The material also exhibited a low fracture toughness (0.35 MPa*m1/2), with a tangible brittleness. SEM micrographies corroborated this behavior, showing a ragged surface, along with several cracks, due to the high presence of porosity and impurities, acting as preferential points for crack initiation. The 3D pattern of the surface fracture, following the confocal spectroscopy, evidenced an irregular crack propagation, whose proclivity was mainly, but not always, to follow the porosity. Hence, the crack initiation and propagation are largely unpredictable.

Keywords : borosilicate glass, characterization, fly-ash, geopolymerization
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