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Low-velocity flexural impact response of fiber-reinforced aerated concrete

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ABSTRACT

Impact response of fiber-reinforced aerated concrete was investigated under a three-point bending configuration based on free-fall of an instrumented impact device. Two types of aerated concrete: plain autoclaved aerated concrete (AAC) and polymeric fiber-reinforced aerated concrete (FRAC) were tested. Comparisons were made in terms of stiffness, flexural strength, deformation capacity and energy absorption capacity. The effect of impact energy on the mechanical properties was investigated for various drop heights and different specimen sizes. It was observed that dynamic flexural strength under impact was more than 1.5 times higher than the static flexural strength. Both materials showed similar flexural load carrying capacity under impact, however, use of 0.5% volume fraction of polypropylene fibers resulted in more than three times higher flexural toughness. The performed instrumented impact test was found to be a good method for quantifying the impact resistance of cement-based materials such as aerated concrete masonry products.

1. Introduction

Structural elements and buildings may experience impact loads or deformation rates that are characterized by very high strain rates. Impact events due to hurricanes, seismic loads, wind gusts, moving objects, and ballistic projectiles could be of concern in the design of residential buildings. During such events, large amount of energy is transmitted to the structure in the form of dynamic loads. Certain impact events are characterized by low impact velocity and high projectile mass which can cause significant damages. Cement-based materials have low tensile strength and are inherently brittle by nature. Masonry blocks in particular are used in residential construction and have lower strength and ductility values compared to structural concrete. Fiber reinforcement aids in the improvement of ductility, tensile, impact and flexural performance of masonry and concrete buildings [1]. This enhances the structural resilience under impact loads.

In this study, the impact of plain autoclaved and fiber-reinforced aerated concrete was investigated under three-point bending using an instrumented drop weight system. The instrumentation included two load-cells to record the impact loading from hammer and also support reactions, a linear variable differential transformer (LVDT) to measure mid-span deflection of the specimen, and an accelerometer mounted to the specimen's tension zone (i.e. the bottom of the beam). Variables in the experiments included the type of the materials: AAC (autoclaved aerated concrete) and FRAC (fiber-reinforced aerated concrete), three different drop heights: 25 mm, 75 mm, 150 mm; and the cross-sectional area of the specimens. Time-history of the load, acceleration, deflection responses, and absorbed energy of the specimen were obtained and discussed in details.

1.1. Aerated concrete products

Aerated concrete (AC) is a lightweight, noncombustible, low cement-content material with excellent thermal characteristics. Aerated concrete is manufactured from a mixture of Portland cement, fly ash (or other sources of silica), water, and aluminum powder or paste [2]. The hydration of Portland cement with water releases calcium hydroxide which reacts with aluminum paste to release hydrogen gas, resulting in a highly porous structure. Approximately 80% of the volume of the hardened material is made up of pores with a general ratio of 2.5:1.0 air-pores to micro-pores [3]. Dry density of 400–800 kg/m^3 and compressive strength values of 2–6 MPa are common for aerated concrete products [4]. Thermal conductivity is reported to be 0.07–0.11 W/m °C that is several times lower than normal weight concrete [5].

The autoclave process in the production of AAC blocks accelerates the strength gain and reduces the shrinkage cracking. FRAC blocks on the other hand are cured at room temperature. Elimination of the autoclaving process lowers the energy costs for produc-

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tion; however, it reduces the strength and introduces heterogeneity in the material [16]. FRAC are internally reinforced with short polymeric fibers that increase the crack resistance and ductility of the blocks. FRAC can be considered as a ductile composite characterized by an elasto-plastic behavior [6]. Fig. 1 shows the images of FRAC pore-structure in two scales: macro-scale (obtained by digital scanning) and micro-scale (obtained by scanning electron microscopy). The discontinuous pore structure of aerated concrete material can be observed in these images.

Addition of short polypropylene fibers to aerated concrete improves the mechanical properties such as tensile and flexural strength and resistance to crack propagation [7]. Cellular solids such as aerated concrete exhibit a considerable amount of post-peak residual strength under compression after cracking as shown in Fig. 2a. Post-peak response under compression is predominantly characterized by sequential collapse of pores and cellular walls [8]. Under tensile/flexural loads, plain AAC is brittle while FRAC shows a ductile behavior, schematically illustrated in Fig. 2b. The ductility of FRAC is attributed to the effect of fibers that bridge the cracks and enable carrying residual load in the post-peak region under tension/flexure.

1.2. Impact tests on lightweight cement composites

High and low-velocity impact behavior of cement-based materials have been studied by several researchers using Charpy, Izod, drop-weight, split Hopkinson bar (SHB), explosive, and ballistic tests [1]. The instrumented tests measure resistance based on fracture energy, and damage accumulation. Bindiganavile and Banthia [9,10] and Manolis et al. [11] reported that flexural strength under impact is higher than quasi-static loading for polymeric fiber-reinforced concrete beams and slabs. Lok and Zhao [12] reported that at strain rates exceeding 50 s^{-1}, post-peak ductility of steel fiber-reinforced concrete (SFRC) is lost owing to the loss of bond between the concrete fragments and steel fibers. Wang et al. [13] identified two damage mechanisms of fiber fracture and fiber pull-out under impact loads. Zhu et al. [14] studied the impact behavior of alkali-resistant (AR) glass textile-reinforced cement composites. Maximum flexural stress and absorbed energy of beam specimen increased with the number of textile layers. Impact properties of polyethylene (PE) textile cement composites were investigated by Gencoglu et al. [15] and compared to AR glass textile. The PE textile composites showed higher load carrying capacity at large deflections and hence more ductile than AR glass textile composites.

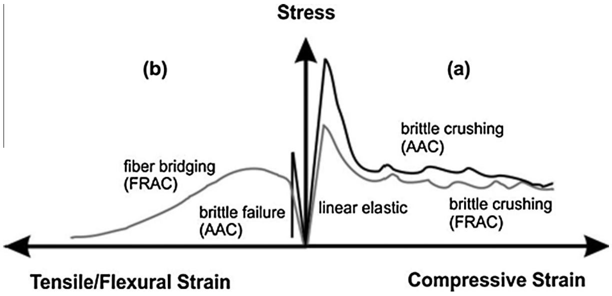

Fig. 2. Schematics of strain–stress response for AAC (black) and FRAC (gray).

2. Experimental program

2.1. Materials

AAC and FRAC materials were manufactured using an automatic batching system in the manufacturing plant as masonry blocks 200 mm × 250 mm × 600 mm in dimension. Mixture proportions used are listed in Table 1. The fresh slurry is poured into large steel molds (e.g. 8 m × 1.2 m × 0.6 m in dimensions). After initial curing is accomplished the block is cut using diamond wheel blades into masonry sized blocks. A comparison of the physical properties of AAC and FRAC materials determined by conducting static mechanical tests which includes density, compressive, flexural, tensile and thermal responses are presented in the author's previous work [16] and summarized in Table 2. As shown in the table, the average Young's Modulus and compressive strength of AAC is 7.5 GPa and 5.6 MPa which is much higher than 5.0 GPa and 3.2 MPa reported for FRAC, respectively. These profound differences in strength and modulus can be related to the autoclaving process in the production of AAC which results in better material homogeneity and increased strength. This process typically involves 8–14 h of high temperature (~180 °C) and high pressure (~800 kPa) curing. It should also be noted that more than 50% of cement is replaced with fly ash for FRAC material which can result in lower strength gain rate due to lower hydration reaction for fly ash. The polymeric fibers used in FRAC were monofilament polypropylene fibers with average length of 12 mm and aspect ratio of 250. Fig. 3 shows the test results for instrumented three-point static bending test for AAC and FRAC. Even though the maximum flexural stress is slightly higher in AAC, the deflection and toughness capacity in FRAC are much higher, due to the role of fiber in bridging of cracks.

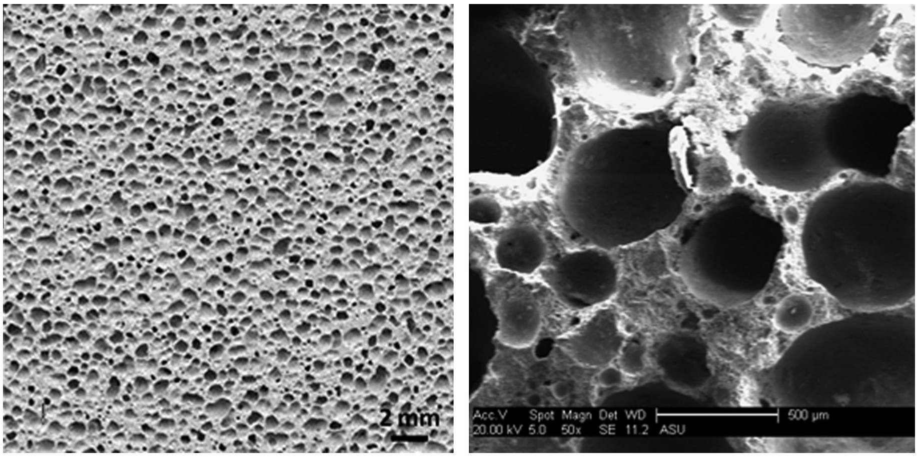

Fig. 1. Pore-structure of fiber-reinforced aerated concrete.