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Experimental and numerical investigation of reinforced concrete beams with variable material properties under impact loading

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HIGHLIGHTS

- Behaviors of RC beams manufactured concrete are experimentally investigated.
- Low strength, normal strength and ECC concrete containing PVA fibers are tested.
- Finite element analyses of the tested beams are also conducted.
- Material type affected the width of the observed cracks on the test specimens.
- FEA showed that the crack patterns on the test specimens are in good agreement.

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ABSTRACT

In this study, behaviors of reinforced concrete beams manufactured from several concrete types are experimentally and numerically investigated under dynamic impact loading. In the experimental part of the study, 12 beams manufactured using low strength concrete, normal strength concrete and engineered cementitious composites (ECC) containing polyvinyl alcohol (PVA) fibers are tested under dynamic impact loading. The dimensions of the manufactured reinforced concrete beams are also used as a variable to observe the effect of beam size on the behavior under dynamic impact loading. After the experimental study, finite element analyses of the tested beams are also conducted by using commonly used finite element software to observe the stress distribution under the impact loading. The results obtained from the experimental study illustrated that material type significantly affected the width of the observed cracks on the test specimens. Generally the smallest cracks formed on the test specimens manufactured using ECC and the largest cracks formed on the test specimens manufactured using low strength concrete. The results of the finite element study showed that the crack patterns on the test specimens are in good agreement with the stress distributions obtained from the impact loading simulations.

1. Introduction

Designing structures to resist low velocity impact loads is a popular issue due to the risks such associated with accidental or natural hazards (i.e., vehicle, ice, ship impacts, falling of heavy weights to structures; natural hazards such as strong winds, earthquakes and falling rocks in mountain areas). However, the behavior of reinforced concrete structures subjected to impact loading is not a fully described issue for civil engineers [20]. Consequently, many low velocity impact tests have been conducted to understand the response of reinforced concrete elements to impact loads. In this study a new series of experiments are conducted on reduced scale beams made of three materials: (i) low strength concrete, (ii) normal strength concrete and (iii) engineered cementitious composites (ECC). Low strength and normal strength concrete used in the experiments represent the conventional structural materials widely used all over the world. On the other hand, the innovative material ECC is used to consider the possible enhancement in the impact behavior of the tested beams.

The conventional concrete used in the experiments is a quasi brittle material, with a softened response after peak, which fails in a tensile mode under the effect of impact loads [6]. In the study of Maalej et al. [17], it is stated that the relation between the impact resistance and the tensile strength of concrete is more pronounced than the relation with the compressive strength of

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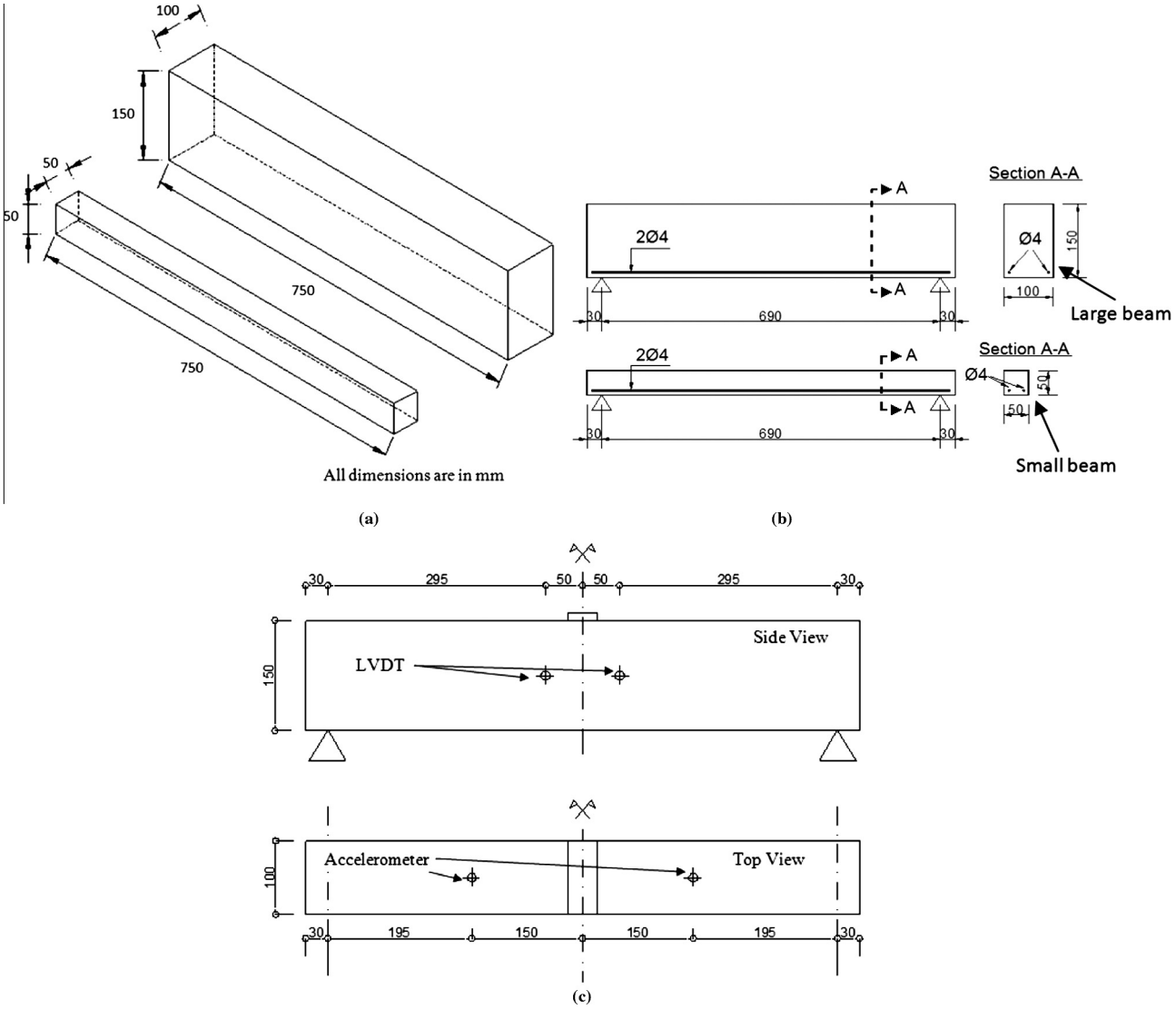

Fig. 1. (a) Dimensions of the tested specimens; (b) Reinforcement details of the tested specimens; (c) Locations of the measurement instrumentation. (All dimensions are in mm).

Table 1
Details of the material properties.

Component	Low strength concrete	Normal strength concrete	ECC
Units (kg/m³)			
Cement	270	380	383.3
Water	165	171	325.5
Fly Ash (Type F)	–	60	842.1
Fine aggregate (0–7 mm)	1168	940	–
Coarse aggregate (7–15 mm)	779	828	–
Super plasticizer	–	4.29	3
Sand (0–400 μm)	–	–	445.1
PVA	–	–	26

Table 2
Mechanical properties of PVA fibers.

Nominal strength (MPa)	1620.0
Apparent strength (MPa)	1092.0
Modulus of elasticity (GPa)	42.8
Elongation (%)	6.0

Table 3
Compressive strength of cylindrical specimens.

Concrete type	Specimen No.	Compressive strength (MPa)	Average compressive strength (MPa)
Normal strength concrete	1	41.9 (Excluded)	34.5
	2	36.8	
	3	31.7	
	4	35.1	
Low strength concrete	1	16.4	16.6
	2	16.9	
	3	16.8	
	4	16.1	
Engineered cementitious concrete	1	34	34.3
	2	33	
	3	35.2	
	4	34.8	

the concrete. The limit of the tensile strength of a brittle material may be defined by the formation of tensile cracks and subsequent separation of crack surfaces. In relation to that the impact resistance of concrete may be enhanced by delaying the formation