Construction and Building Materials 186 (2018) 969–977

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Effect of fiber type on the behavior of cementitious composite beam-column joints under reversed cyclic loading

Mohamed K. Ismail, Basem H. Abdelaleem *, Assem A.A. Hassan

Faculty of Engineering and Applied Science, Memorial University of Newfoundland, St. John's, NL A1B 3X5, Canada

HIGHLIGHTS

- ECC beam-column joints under reversed cyclic loading were investigated.
- Different types of polymeric and steel fibers were tested.
- Hysteresis behavior, ductility, energy dissipation, and cracking were evaluated.
- ECC beam-column joints showed improved ductility compared to NC joint.
- Joints with steel fibers showed the best behavior under cyclic loading.

ARTICLE INFO

Article history:
Received 12 April 2018
Received in revised form 1 August 2018
Accepted 6 August 2018

Keywords:
Cement-based composites
Different types of fiber
Beam-column joint
Reversed cyclic loading

ABSTRACT

This paper investigates the effect of using different types of fiber on the behavior of engineered cementitious composite (ECC) beam-column joints under reversed cyclic loading. The tested ECC beam-column joints were cast with different types of fiber, including 8 mm and 12 mm polyvinyl alcohol fibers (PVA8 and PVA12), 13 mm polypropylene fibers (PP13), and 13 mm steel fibers (SF13). The investigation also tested a conventional normal concrete (NC) beam-column joint made with 10 mm coarse aggregate for comparison. The performance of the tested specimens was evaluated based on hysteresis behavior, ductility, energy dissipation capacity, and cracking behavior. The results indicated that compared to NC, ECC with either PVA or PP fibers can be a promising construction material to develop beam-column joints with improved ductile behavior under reversed cyclic loading. Using shorter PVA fibers (PVA8 vs. PVA12) appeared to have a stronger influence on improving the cyclic behavior of ECC joints. The highest improvements in terms of first crack load, ultimate load, ductility, and energy dissipation capacity were observed when SF13 was used. The results also indicated that the failure pattern of all ECC joints showed better cracking behavior and higher shear strength compared to the NC joint.

1. Introduction

Seismic activities have shown significant damages to the stability and structural integrity of reinforced concrete (RC) structures, resulting in catastrophic collapses. During earthquakes, the deformation capacity of structural components such as beams, columns, and joint zones is a key factor in determining the seismic performance and damage tolerance of RC structures. RC joints such as beam-column joints are one of the most critical regions in the moment-resisting RC-framed structures, which can suffer severe damages [1–4]. Researchers and designers have paid a great deal of attention to the structural design requirements of such joints in order to ensure better performance for RC structures and prevent sudden failures under major seismic events. Many approaches concerning reinforcement design and details have been recommended to enhance the ductility and energy absorption of RC beam-column joints [5,6]. However, using special construction materials characterized by high ductility and energy absorption in beam-column joints can be an additional easy and fast solution to further improve the seismic behavior of RC joints.

Significant research has been conducted on evaluating the use of steel fibers (SFs) in conventional normal concrete (NC) beam-column joints tested under reversed cyclic loading. As reported, the addition of SFs appeared to improve the ultimate capacity, ductility, and energy absorption capacity of beam-column joints [7,8]. SFs were also found to improve the shear capacity of joints, which helps reduce the requirements for transverse reinforcement and increases spacing of stirrups and hoops [9–12]. Furthermore, the

* Corresponding author.
E-mail addresses: mohamed.ismail@mun.ca (M.K. Ismail), b.abdelaleem@mun.ca (B.H. Abdelaleem), ahassan@mun.ca (A.A.A. Hassan).

https://doi.org/10.1016/j.conbuildmat.2018.08.024
0950-0618/

fibers' bridging mechanism allows arresting cracks, thus effectively delaying the growth of cracks and controlling the crack opening [13–15]. Despite the superior properties of SFs, using high volume of SFs in NC may result in high interference and blockage with coarse aggregate, which in turn leads to a reduction in the concrete workability [16].

Recently, many studies were carried out to develop new fiber-reinforced cementitious composites with excellent mechanical characteristics in terms of strength and strain properties. One of these composites is engineered cementitious composite (ECC), which is typically developed using cement, different supplementary cementing materials (SCMs), fine aggregate, and moderate-to-high volume of fibers. The absence of coarse aggregate in ECC facilitates using a high volume of fibers with minimized reduction in the mixture's workability. As reported by other studies, ECC can be developed with different types of fiber including carbon, steel, and polymeric fibers [17] with moderate volume fraction of 2%. However, most of the available studies in the literature were conducted on ECC made with polymeric fibers such as polyvinyl alcohol (PVA), polypropylene (PP), and polyethylene fibers. The results obtained from these studies indicated that under tensile loading ECCs are featured with strain hardening and multiple cracking behavior [18–21], achieving a tensile strength of 4 to 6 MPa, strain capacity of about 3% to 7%, and average crack width of about 60 μm [22–24]. In uniaxial compression tests, ECC also showed strength ranging from 30 to 80 MPa with a strain capacity of about 0.4% to 0.65% [25,26]. Other studies reported higher fatigue life, impact resistance, and energy absorption capacity of ECC compared to NC [27–29]. Such improved strain properties of ECCs can make this composite an optimum and innovative choice in the construction of beam-column joints with expected superior performance under seismic loading.

In this experimental investigation, four ECC beam-column joints were developed with different types of fibers for testing under reversed cyclic loading. The investigated fibers included 8 mm PVA (PVA8), 12 mm PVA (PVA12), 13 mm PP (PP13), and 13 mm SF (SF13). Additional NC beam-column joints developed with 10 mm coarse aggregate were cast for comparison. The performance of the tested beam-column joints under reversed cyclic loading was evaluated through first crack load, load-carrying capacity, cracking behavior, ductility, brittleness index, and energy dissipation capacity.

2. Research significance

Although there is sufficient research available in the literature dealing with the properties of ECC, there is a lack of information regarding the behavior of ECC beam-column joints under reversed cyclic loading, especially when different types of fibers are investigated. The results obtained from the present work have a unique significance because they show the influence of using various types/lengths of fibers on the cyclic behavior of beam-column joints, and how these contribute to the development of high-efficient ECC. Moreover, considering the cost and the availability of PVA (which is commonly used in standard ECC), using alternative fiber types with comparable performance can substantially help to produce more economic ECC. This study also compared the cyclic behavior of ECC to that of conventional NC developed with comparable strength. This comparison can help designers/engineers make appropriate decisions on using ECC in the construction industry.

3. Experimental program

3.1. Materials and mixture proportions

The mixture proportions of ECC and NC used in this study are shown in Table 1. Type GU Canadian Portland cement and FA were used as binder materials for all tested mixtures compliant with Type 1 ASTM C150 and ASTM C618 Type F, respectively. In ECC mixtures, silica sand with a maximum grain size of 0.4 mm and a specific gravity of 2.65 was used as fine aggregate. The developed ECC mixtures were reinforced with four different types of fibers as shown in Table 2. Fig. 1 and Table 3 present various characteristics of the fibers used. In NC, natural crushed stone with a maximum size of 10 mm and natural sand with a maximum size of 4.75 mm were used as coarse and fine aggregate, respectively, with a specific gravity of 2.6. A polycarboxylate-based high-range water-reducer admixture (HRWRA) compliant with ASTM C494 was added until the required workability for the developed mixtures was achieved.

3.2. Concrete mixtures, casting, and specimen details

Four ECC beam-column joints reinforced with four different types of fiber were cast in this investigation. The fibers included PVA8, PVA12, PP13, and SF13. The tested mixtures/specimens were designated by concrete type, fiber type, and length. For example, ECC-PVA12 refers to the ECC mixture/specimen cast with 12 mm PVA fibers. These mixtures were designed to evaluate the possibility of using different types of fibers in cement-based beam-column joints in order to achieve superior seismic resistance. An additional beam-column joint made with NC containing 10 mm coarse aggregate and no fibers was used for comparison. The NC mixture was developed with a strength class comparable to the investigated ECC, as all developed mixtures had a compressive strength ranging from 46 to 52 MPa.

The cast beam-column joints were designed to fail in flexure with a ductile behavior according to the Canadian standard (CSA-A23.3-04 [30]). Fig. 2 shows a schematic for typical dimensions and reinforcement details used in the cast joints. After 24 h from casting, the formworks were de-molded and then the curing process was started. For the first four days in curing, all beam-column joints were sprayed with water and covered with plastic sheets; air-curing was then applied until the date of testing (28 days).

Table 1
Mix proportions used in NC and ECC.

Type of mixture	C	SCMs type	SCMs/C	C.A./C	S/C	W/BC	Fiber (vol. %)
NC	1	MK + FA	1	2.26	3.22	0.4	–
ECC	1	FA	1.2	–	0.79	0.27	2

Note: C = cement; SCMs = supplementary cementing materials; FA = fly ash; MK = metakaolin; C.A. = coarse aggregate; S = Sand; W/B = water-to-binder (i.e. cement + SCMs).

Table 2
The properties of the tested ECC.

Mix #	Mixture designated	Fiber (vol. %)				Compressive strength (MPa)	Splitting tensile strength (MPa)
		PVA8	PVA12	PP13	SF13		
1	NC	–	–	–	–	50	3.7
2	ECC-PVA8	2	–	–	–	49	6.4
3	ECC-PVA12	–	2	–	–	48	5.4
4	ECC-PP13	–	–	2		46	6.0
5	ECC-SF13	–	–		2	52	7.8