Construction and Building Materials 186 (2018) 400–422

Contents lists available at ScienceDirect

Construction and Building Materials

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

Experimental study on the flexural behaviour and ductility ratio of steel fibres coarse recycled aggregate concrete beams

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HIGHLIGHTS

- Effect of steel fibres and replacement recycled aggregate content on the flexural behaviour of reinforced concrete beams.
- Effect of transverse reinforcement spacing on the flexural behaviour of reinforced concrete beams.
- 9 concrete mixes containing steel fibres and recycled aggregate as replacement of natural aggregate.
- Experimental bending resistance compared with ACI, CSA and Eurocode 2 estimations.

ARTICLE INFO

Article history:
Received 1 May 2018
Received in revised form 16 July 2018
Accepted 18 July 2018

Keywords:
Recycled aggregate
Flexural behaviour
Reinforced concrete beams
Steel fibres

ABSTRACT

Environmental protection is a fundamental issue in today's world. In this research, the flexural behaviour and ductility ratio of reinforced concrete beams made with steel fibres and coarse recycled aggregate are studied. 27 reinforced concrete beams with a cross-section 150 mm wide, 200 mm high, and a length of 1500 mm, with various transverse reinforcement spacing, were manufactured and tested. Recycled aggregate from building demolition was used at 0%, 50% and 100% mass replacement of natural aggregate. Furthermore, steel fibres were added to improve the flexural behaviour of the beams at 0%, 1% and 2% (in terms of volume). A four-point bending test was performed. In these tests, the flexural capacity, maximum displacement at the mid-span of the specimens and ductility were measured. The effects of the steel fibres and the transverse reinforcement spacing on the flexural behaviour of recycled aggregate concrete beams were the main aims of this study. The results were also compared with ACI, CSA and Eurocode 2 requirements. It was found that the individual effects on the ductility ratio and maximum loading capacity depend on the other parameters (e.g. the steel fibers effect depends on the transverse reinforcement spacing and the effect of the recycled aggregates depends on both the steel fibres content and the transverse reinforcement spacing).

1. Introduction

Using wastes can help protect the environment. Recycled materials can be used to manufacture concrete elements. These materials can be replaced with cement, aggregate or be added to concrete mix as additions. Many researches have been done on using recycled materials instead of natural aggregate. In 2015, Arora and Singh [1] studied the flexural behaviour of a concrete beam manufactured with 100% coarse recycled aggregate under flexural fatigue failure. In this study, 100 mm × 100 mm × 500 mm

Abbreviations: SF, steel fibres; RA, recycled aggregate; TD, transverse reinforcement spacing; i, ductility ratio; $\Delta_{0.85}$, displacement at 85% of the maximum load; Δ_y, displacement at first yield; $M_{cr.ACI}$, cracking moment according to ACI; f_r, modulus of rupture of concrete; I_g, moment of inertia of the cross-section relative to the centroid axis, neglecting the reinforcement; y_t, distance from the centroid axis of the cross-section, neglecting the reinforcement, to the tensioned face; λ, modification factor; f'_c, compressive strength of the concrete beam; $M_{ult.ACI}$, ultimate moment in doubly-reinforced concrete beams according to ACI; b, span width; $d - d'$, distance between the centroids of the tension and compression reinforcement; A_s, area of the tension reinforcement; A'_s, area of the compression reinforcement; ρ, reinforcement ratio; d, effective depth; f_y, yield strength of steel; $M_{cr.CSA}$, cracking moment according to CSA; M_{fc}, factored resisting moment of the concrete and bottom steel; α_1, ratio between the average stress in the rectangular compression block and the specified concrete strength; β_1, ratio between the depth of the rectangular compression block and the depth of the neutral axis; $M_{cr.Euro}$, cracking moment according to Eurocode 2; f_{ctm}, mean tensile strength of concrete; I_u, second moment of the cross-section for uncracked condition; h, height of the cross-section; x_u, neutral axis depth for uncracked condition; f_{ck}, characteristic compressive concrete strength.

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https://doi.org/10.1016/j.conbuildmat.2018.07.132
0950-0618/

specimens were manufactured and tested. Four-point flexural loading was used. The results were compared with those of natural aggregate concrete beams. It was shown that using 100% recycled aggregate in concrete in place of natural aggregate resulted in poor fatigue performance. Choi and Yun [2] investigated long-term deflection and flexural behaviour of reinforced concrete beams with recycled aggregate. In this study, specimens were tested under long-term loading for 360 days. Specimens were manufactured using 100% natural aggregate, 100% recycled aggregate, and 50% natural aggregate plus 50% recycled aggregate. Furthermore, the experimental results were compared with ACI 318 analytical results and a formula was modified to calculate long-term flexural deflection. Similar crack patterns were observed regardless of the aggregate type, even though several cracks occurred in the beams made with recycled aggregate.

Azad [3] studied the flexural behaviour of reinforced concrete beams made with recycled waste materials. In this study, PET wastes were used as a recycled material. Compressive strength, maximum load capacity, load-deflection behaviour, stiffness and failure modes of the specimens were determined. The results showed that PET waste can be added to concrete up to 15%. Gao and Zhang [4] evaluated the flexural performance of steel fibre coarse recycled aggregate concrete. In this study, steel fibres added at 0%, 0.5%, 1%, 1.5% and 2% (in terms of volume). Furthermore, recycled coarse aggregate replaced natural aggregate at 0%, 30%, 50% and 100% (per volume). Flexural strength, toughness and deflection dramatically increased by increasing the steel fibres content. Based on previous researches, it is clear that adding steel fibres to recycled aggregate concrete beams is an effective way of improving their behaviour [5,6]. Also, previous studies confirmed the reinforcing effect of steel fibres on concrete [7,8], reducing crack propagation. Furthermore, steel fibres help preventing brittle fracture by increasing the tensile strength and toughness.

In another study, Seara-Paz et al. [9] studied the effect of coarse recycled aggregate on the flexural behaviour of reinforced concrete beams. Eight concrete specimens were manufactured by using four replacement ratios of recycled aggregate (0%, 20%, 50% and 100%) and two water/cement ratios 0.5 and 0.65. The specimens were subjected to four-point loading at 28 days. Bending moments, load-displacement curve, strains and curvatures were determined. The cracking behaviour showed differences between recycled aggregate and conventional concrete. So, it is possible that using steel fibres can improve the flexural behaviour of recycled aggregate concrete beams. Tošic et al. [10] compared the flexural behaviour of recycled aggregate reinforced concrete with Eurocode code's equations, based on 217 experimental specimens. They showed that Eurocode can estimate the flexural and shear strength of recycled aggregate concrete beams without transverse reinforcement. In another study, Tarek et al. [11] used brick as

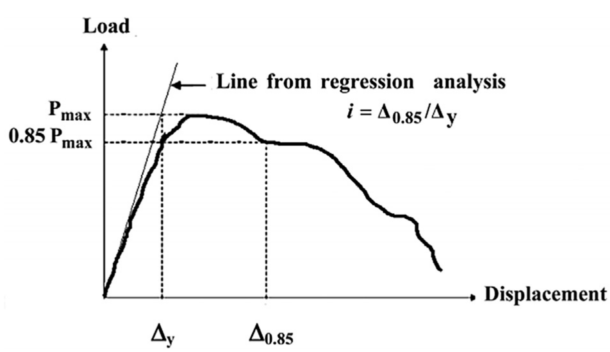

Fig. 1. Definition of the displacement-ductility ratio [20].

Fig. 2. Steel fibres.

Fig. 3. Recycled coarse aggregates.

Fig. 4. Natural coarse aggregates.

Table 1
Rebars test results.

Rebars diameter (mm)	Yield strength (MPa)	Ultimate strength (MPa)	Yield strain (%)	Ultimate strain (%)	Modulus of elasticity (GPa)
8	371	560	12.94	24.93	209.28
10	408	677	13.04	25.51	210.10
20	371	561	15.27	25.82	213.17