Engineering Structures 60 (2014) 148–154

Contents lists available at ScienceDirect

Engineering Structures

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

The influence of recycled concrete aggregates on the behavior of beam–column joints under cyclic loading

Viviana C. Letelier Gonzalez [a], Giacomo Moriconi [b,*]

[a] Department of "Ingeniería de Obras Civiles", Universidad de La Frontera, Temuco, Chile
[b] Department of "Scienze e Ingegneria della Materia, dell'Ambiente ed Urbanistica", Università Politecnica delle Marche, Ancona, Italy

ARTICLE INFO

Article history:
Received 18 May 2012
Revised 8 October 2013
Accepted 17 December 2013
Available online 24 January 2014

Keywords:
Recycled concrete aggregates
Beam–column joint
Cyclic loading

ABSTRACT

In this paper the behavior of three beam–column joints under cyclic loading was analyzed. The concrete joints, manufactured in a scale of 2/3 with respect to current size, were designed with reference to Eurocode 8, one made with ordinary concrete and the other two made with concrete containing 30% coarse recycled concrete aggregates as a partial replacement of the coarse natural aggregates, by taking into proper account the lower tensile strength and elastic modulus of the recycled aggregate concrete.

The experimental results allowed to observe a behavior under cyclic loading of the concrete made with 30% replacement of natural by recycled aggregates quite similar to ordinary concrete.

1. Introduction

Among the possible solutions favouring greater environmental sustainability in the construction industry, materials engineering is considering the use of recycled aggregates coming from building demolition to produce new concrete. This way can allow to reduce the consumption of non-renewable resources obtained by quarrying activities and, at the same time, reduce the rubble volume to be disposed of in landfill. Recent data in the literature [1–7] have shown that the use of relatively low amounts of recycled aggregate does not substantially affect the concrete properties. These results have currently allowed different Technical Norms for Building to authorize the use up to 30% of coarse recycled concrete aggregate for the production of structural concrete.

The main characteristic of the recycled concrete aggregate is mortar adhered to its surface, which is responsible for the mechanical behavior change of the recycled aggregate concrete with respect to ordinary natural aggregate concrete [8–10]. To date, several studies have analyzed the influence of quantity and quality of the mortar adhered to the surface of recycled concrete aggregates, concluding that increasing mortar amounts increase the differences in mechanical properties of recycled aggregate with respect to natural aggregate concrete [11,12]. This occurs independently of the strength class of the concrete giving origin to the recycled aggregates [8,13–18].

Several authors have also investigated the influence of recycling technologies, of different curing techniques [16] and of mixtures proportioning [6,7], with the aim to seek out procedures other than the ones used for ordinary concrete, able to improve the mechanical performance of recycled aggregate concrete. The results have shown, in some cases, compressive strengths equal to ordinary concrete ones. In this perspective, good results, with compressive strengths equal to those of ordinary concrete, have been achieved by utilizing silica fume and/or metakaolin as supplementary cementitious materials [19].

Several studies agree by asserting that, even at equal compressive strength, a lower tensile strength is anyway detected and a loss in the bond strength between concrete and reinforcing steel occurs [11,20,21], which are both important factors affecting the reinforced concrete behavior under cyclic loading.

On the other hand, studies analyzing elastic modulus changes conclude that these are in the range between 3% and 15% for aggregate replacements lower than 50% [2–22]. Xiao et al. [1] point out that usual correlations between compressive strength and static elastic modulus for ordinary concrete are not fitting for recycled aggregate concrete.

In this paper the behavior of beam–column joints designed according to Eurocode 8 is analyzed, taking into account that recommendations for ordinary concrete do not consider the characteristics of recycled aggregates. For this reason a new beam-column joint made of recycled aggregate concrete has been designed considering the lower tensile strength and elastic modulus of this kind of concrete and its behavior under cyclic loading has been analyzed and compared with the previous ones.

* Corresponding author. Tel.: +39 071 2204725; fax: +39 071 2204729.
E-mail address: g.moriconi@univpm.it (G. Moriconi).

0141-0296/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.engstruct.2013.12.024

2. Materials and methods

2.1. Materials

Two concrete mixtures have been prepared, one of which with natural (crushed limestone) aggregates only and the other one by replacing 30% coarse natural aggregate with coarse recycled concrete aggregate. The two mixtures had the same water–cement ratio equal to 0.53 and the same workability (fluid consistency, slump 160–210 mm). According to the concrete mixture proportions reported in Table 1, the cement dosage (cement type CEM II-A/L 42.5 R according to EN 197/1), the mixing water, the superplasticizer dosage (1.0% by weight of cement of a carboxylic acrylic ester polymer in the form of 30% aqueous solution), as well as the amounts of fine sand (0–4 mm graded sand, equal to 20% of the total aggregate amount), coarse sand (0–5 mm graded sand, equal to 20% of the total aggregate amount), and coarse gravel (11–22 mm graded crushed aggregate, equal to 30% of the total aggregate amount) have been kept constant. The two mixtures differed only for the fine gravel fraction (6–12 mm graded crushed aggregate), which in ordinary concrete was constituted by 525 kg/m^3 of natural gravel (density of 2580 kg/m^3 and 2.2% water absorption) whilst in recycled aggregate concrete by 500 kg/m^3 of recycled concrete (density of 2470 kg/m^3 and 7.0% water absorption). The particle size distribution of various aggregates used to prepare the concrete mixtures are reported in Fig. 1.

However, as reported in Table 1, two joints were manufactured with recycled aggregate concrete, type A and type B, whose concrete mixtures, in spite of the same proportions, are considered different, since they were prepared in different times and then with recycled concrete of unknown and likely different characteristics, even if provided by the same recycling plant. For this reason mechanical characterization was carried out for both concretes used to manufacture the two joints.

2.2. Specimens and testing methods

The analysis of the behavior under cyclic loading of concrete made with recycled concrete aggregates partly replacing natural aggregates has been carried out on two types of concrete beam–column joints (type A and type B), both scaled-down of 2/3 (Fig. 2), characterized by different geometry and steel reinforcement. The beam–column joint specimens were manufactured by a building contractor and cured in air at room temperature of about 20 °C for 28 days in order to simulate the real conditions at the building site.

Two type A joints have been manufactured, each one made of natural or recycled aggregate concrete, according to specifications in Eurocode 8. Adopted cross section of columns was 200 × 200 mm with height of 1950 mm, reinforced by 8ϕ12 longitudinal bars and ϕ6 stirrups each 100 mm thickened to 50 mm in the joint critical area. Beams cross section was 200 × 200 mm with 1650 mm span, reinforced by 3 + 3ϕ12 longitudinal bars and ϕ6 stirrups each 100 mm thickened to 50 mm in the joint critical area. Tests on type A joints have been carried out with a negligible axial load on the columns.

Only one type B joint has been manufactured with recycled aggregate concrete made by replacing 30% natural coarse aggregates with coarse recycled concrete. Adopted cross section of the column was 250 × 280 mm with height of 1950 mm, reinforced by 8ϕ12 longitudinal bars and ϕ6 stirrups each 100 mm thickened to 50 mm in the joint critical area. The beam cross section was 200 × 250 mm with 1650 mm span, reinforced by 3 + 3ϕ12 longitudinal bars and ϕ6 stirrups each 100 mm thickened to 50 mm in the joint critical area. In this case, during the test a constant axial load of 200 kN has been applied to the column.

The type B joint has been conservatively designed by limiting the principal tensile stress developed in the core of the beam–column joint to the value of the tensile strength of the used recycled aggregate concrete. Moreover, the factor γ_{Rd} (which should be not less than 1.2), accounting for overstrength due to steel strain-hardening according to Eurocode 8, has been adopted in the design of the joint type B in order to take into account the lower elastic modulus of concrete prepared by replacing 30% coarse natural aggregate with recycled concrete aggregate. Indeed, a lower elastic modulus causes higher strains in the joint concrete core, inducing in it higher stresses, the effect of which can be obviated by increasing the overstrength factor γ_{Rd} to 1.4.

Cyclic loading tests have been carried out by imposing displacements of 25, 50, 75, 100, 125 and 150 mm. In Fig. 3 the displacements application scheme is reported, in which the horizontal axis reproduces only a schematic representation of time.

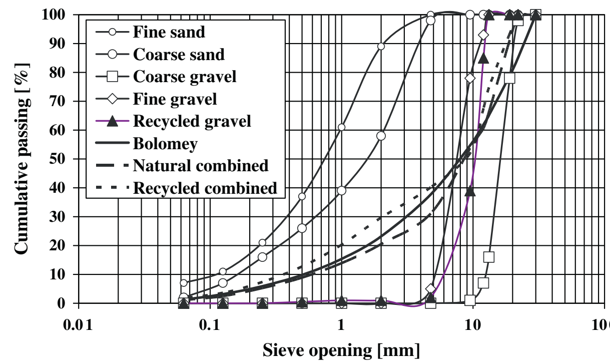

Fig. 1. Particle size distribution of aggregates used and of combined aggregates for natural and recycled aggregate concretes in comparison with the modified Bolomey distribution.

Fig. 2. Outline of the concrete beam–column joint under test.

Table 1
Concrete mixture proportions (kg/m^3).

Ingredient	Reference natural aggregate concrete	Recycled aggregate concrete type A joint	Recycled aggregate concrete type B joint
Cement	350	350	350
Water	185	185	185
Superplasticizer	3.5	3.5	3.5
Fine sand	345	345	345
Coarse sand	345	345	345
Fine gravel	525 (natural)	500 (recycled)	500 (recycled)
Coarse gravel	525	525	525