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Structural Behavior of Recycled Aggregate Concrete Beam-Column Connection in Presence of Micro Concrete at Joint Region

C. Marthong*, A.S. Sangma, S.A. Choudhury, R.N. Pyrbot, S.L. Tron, L. Mawroh, G.S. Bharti

Civil Engineering Department, National Institute of Technology Meghalaya, Shillong 793003, India

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ABSTRACT

This paper investigates the effect of addition of micro concrete on the behavior of RC exterior beam-column connections prepared with recycled coarse aggregate (RCA) under the reversed cyclic loading. The results on mechanical strength evaluation of concrete showed an optimum replacement of 30% of natural coarse aggregate (NCA) by RCA. To extend the application of RCA concrete to structural elements, four beam-column specimens with two each of 30% RCA and 100% RCA were cast and the joint region of one specimen of 30% RCA and 100% RCA were cast with a micro concrete. A reference specimen was also prepared using 100% NCA and then subjected to a similar cyclic load. It was observed that, RCA specimens resulted in a brittle mode of failure as compared to NCA specimen. However, the presence of a micro concrete improved the damage tolerance, load resisting capacity and hence the seismic parameters such as stiffness degradation, ductility and energy dissipation increased. Further, the addition of micro concrete in RCA specimens presented a lower damage indices and higher principal tensile stresses, which are comparable to the NCA specimen. Conclusively, strengthening of joint region using micro concrete is found to have a significant contribution in improving the seismic performance of RCA beam-column connections.

1. Introduction

Recycled coarse aggregate (RCA) has been used as a partial replacement of the natural coarse aggregate (NCA) for a number of years. Recycling of such waste is a beneficial from the viewpoint of environmental preservation and effective utilization of resources. Behera et al. [1] extensively reviewed and summarized the past achievement on using recycled aggregate (RA) for concrete productions. It was reported that the mechanical and durability performance of RCA concrete are generally inferior to conventional concrete. Numerous experimental investigations [1–5] showed that reduction in the mechanical strength is not much prominent, when RCA replacement is up to 30%. However, the behavior of RCA concrete towards mechanical action depends upon the level of RCA replacement, water cement ratio (w/c) and the moisture condition [6]. Thus, for confident utilization of RCA, its structural behavior ought to be investigated. Some past studies concerning the behavior of beams [7], columns [8] and beam-column joints [9–11], RC frame structure [12] manufactured from RCA were reported. Most of their findings on their structural behavior are positive. However, due to the brittle nature of RCA the load carrying capacity of most of the RCA specimens gets reduced. This perhaps the reasons that RCA was not prominently use in structural elements.

The behavior of RC beam-column connection plays an important role in the response of a framed structure. It strongly influences the seismic behavior and energy dissipation capacities of the moment resisting frames. Thus, in order to achieve better seismic performances, building codes e.g. [13,14] recommended the minimum amount of longitudinal and transverse reinforcement, and [15] on the use of closely spaced hoops as transverse reinforcement. However, due to these congested joint regions practical difficulties faced during construction and may lead to a honey combing in concrete [16]. In contrast, reducing the hoops spacing of a transverse reinforcement also may lead to improper bonding between the reinforcing bars and the concrete and thus achieving a proper concrete confinement level within the joint regions may not be possible. To overcome these issues, considerable researches [17–20] on beam-column joints have been conducted using steel fibers reinforced concrete (SFRC) in the joint region. Test results revealed that SFRC enhances flexural capacity, shear strength, ductility and energy dissipation capacity. However, steel SFRC mixtures encounter difficulties when fiber content is increased, such as lack of workability, homogeneity and balling phenomenon in fresh SFRC.

While a significant amount of research has been done on improving the seismic performance of RC beam-column joints using SFRC, a limited research has focused on utilizing special materials like High

* Corresponding author.
E-mail address: commarthong@nitm.ac.in (C. Marthong).

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Performance Fiber Reinforced Cementitious Composites (HPFRCC) or Engineered Cementitious Composites (ECC) [21,22] and Slurry Infiltrated Fibrous Concrete (SIFCON) [23] and micro concrete [24] to improve the seismic behaviors of the beam-column joints/connections. Micro concrete is another type of high strength concrete, which is based on Portland cements, graded aggregates, fillers and additives which impart controlled expansion characteristic in plastic state. The polymer modified micro concrete is supplied as a ready to use dry powders that requires only addition of clean water at site to produce a free-flowing non-shrink repair micro concrete. It has been successfully used in repairing and strengthening of RC element like beam, column, beam-column connections etc., where access is restricted and compaction is not possible.

Due to the inferior quality of RCA used for concrete production, the seismic performance of RCA beam-column connections may be lower than those of conventional concrete. Like SFRC, HPFRCC and SIFCON, the micro concrete which has 28 days compressive strength of 55 MPa and with various advantages like improving the early compressive, tensile and flexural strength as well as in reducing the brittle nature of specimen it can be used to enhance the seismic capacity of the RCA specimens. Therefore, the main objectives of this study is to investigate the structural behavior of beam-column connections prepared with RCA concrete and enhancement by incorporating a micro concrete within the joint region and partly in both column and beams, which is the D-region as defined by ACI 318-08 [14].

2. Experimental program

The testing program consisted of two parts:

1. To evaluate the mechanical properties of RCA concrete and to determine the optimum replacement ratio of NCA by RCA.
2. To improve the seismic resistance of RCA beam-column connection using a high strength micro concrete at the joint region.

2.1. Materials

Ordinary Portland Cement (OPC) of 43 grades conforming to IS: 8112 [25] was considered. The maximum size of NCA's was 16 mm. River sand was used as fine aggregate (FA) (0–4.75 mm size). The RCA's (5–16 mm size) are obtained from the demolished reinforced cement concrete (RCC) roof slab of 20 years old. The large pieces of the roof slab are transported to the laboratory and broken into pieces of aggregates smaller than 20 mm in size and sieved through a 16 mm sieve. The aggregates greater than 16 mm in size are further broken to a maximum size of 16 mm. All aggregates used in this study have been tested as per relevant codes [26,27] and the physical properties are presented in Table 1 and the particle size gradation is shown in Fig. 1. The high strength concrete used is a polymer modified concrete (powder) which is based on Portland cements, graded aggregates, fillers and additives which impart controlled expansion characteristic in plastic state. It is commercially supplied as a ready to use dry powders that requires only addition of clean water at site to produce a free-flowing non-shrink repair micro concrete. It is suitable for various structural strengthening measures such as encasement build-ups, jacketing, etc. where access is restricted and vibration of the placed material is difficult or impossible. The micro concrete was modified by the addition of 5 mm to 12 mm aggregates as per manufacturer instructions. The properties of micro concrete obtained from the data sheet supplied by the manufacturer are presented in Table 2.

Table 1
Physical properties of NCA and RCA.

Mix	Apparent density (kg/m^3)	Bulk density (kg/m^3)	Grading (mm)	Elongated particle content (%)	Water absorption (%)	Crush index (%)
NCA	2830	1560	5–16	5	0.97	5.81
RCA	1600	1130	5–16	10	5.30	12.73

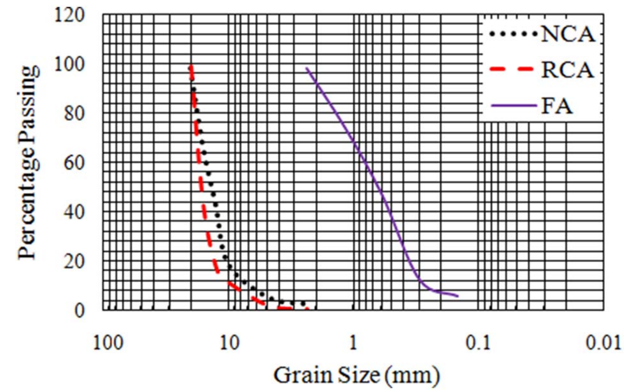

Fig. 1. Particle size gradation.

Table 2
Properties of micro concrete.

Powder:coarse aggregate (by weight)	1:0.75			
Water:powder (by weight)	0.16			
Compressive strength (MPa)	1 Day	3 Days	7 Days	28 Days
	15	35	45	55
Workability	Flowable			

2.2. Concrete mixture proportions

Table 3 presented the specimens and test parameters for characterizing the mechanical properties of concrete. Five concrete mixes were considered e.g. M-0 and M-100 were prepared using 100% of NCA and 100% RCA, while, 20% of NCA were replaced by RCA (by weight) for preparing M-20. Similarly, 30% and 50% of NCA were replaced by RCA for preparing mix M-30 and M-50 respectively. All concrete mixes were prepared with the same w/c of 0.5 and the same degree of workability (slump value of 60 mm) evaluated according to IS 1199 [28]. The concrete mixes were designed for a characteristic cube compressive strength of 25 MPa which resulted in a target mean cube compressive strength of 31.6 MPa as per IS 10262 [29]. The concrete mixes were produced with 372 kg/m^3 of cement, 733 kg/m^3 of fine aggregate and 1087 kg/m^3 of coarse aggregate for a w/c of 0.5. To achieve a better workability, 0.5% of superplasticizer by volume of water was used in the mixing of M-30 and M-50, while 0.85% for M-100. In each sample three specimens were cast. Concrete without RCA was used as a reference specimen (M-0). Specimens from the mould were removed after 24 h of casting and were kept in a water tank for 28 days curing before testing.

2.3. Selection of RC beam-column connections

A free body diagram of an isolated exterior beam-column connection in its deformed position is shown in Fig. 2. It comprises of half height of a column at top and bottom as well as half of a beam length, which corresponded to the points of contra-flexure in beam and column under lateral loads. In this figure, h_c is the storey height, l_b is half beam span corresponding to the length of the beam connected to the selected joint, N is the internal axial force of the column, P is the beam-tip load, V_{col} is the column shear force and Δ is the vertical beam-tip displacement. It may be noted that the symmetric boundary condition were maintained at both the ends of column for isolation of a single unit of beam-column connection. The dimensions of a typical full scale residential building with floor to floor height of 3.3 m and the beam