EFFECT OF STEEL FIBERS ADDITION ON COMPRESSIVE STRENGTH AND FLEXURAL BEHAVIOR OF RECYCLED AGGREGATE CONCRETE

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ABSTRACT: *The effect of steel fibers addition on the compressive strength and flexural behavior of Recycled Aggregate Concrete (RAC) is experimentally studied and results are presented and discussed in this paper. Demolished waste concrete of an industrial building with compressive cylinder strength of 21 MPa was used to produce recycled coarse aggregates for this study. For RAC mixes, the percentage replacement levels of Natural Aggregates (NA) with recycled coarse aggregates were kept as 0, 50 and 100 percent. All RAC mixes were reinforced with steel fibers at a constant dosage of 0.5% by volume of concrete. Prismatic and cylindrical specimens were prepared and tested under three point flexure and uniaxial compression, respectively at the age of 28 days. The results of this experimental study showed that with the replacement of NA with recycled aggregates, the compressive strength and flexural properties of concrete aredegraded; however, the addition of steel fibers not only restores the drop in the compressive strength and flexural properties but also enhanced them.*

Keywords: Concrete; Recycled Aggregates; Steel Fibers; Compressive Strength; Flexural Behavior;

1. INTRODUCTION

Use of Recycled Aggregate Concrete (RAC) in construction industry is important from environmental prospective. The recycling of the construction and demolition waste was promoted in 70's on account of saving natural resources and preservation of environment.

Many researchers from all over the world have investigated mechanical properties of RAC [1-2]. In general, the compressive strength and flexural behavior properties of RAC are found to be lower than Normal Concrete (NC), but yet feasible for applications in many Civil Engineering applications [3]. Many developed countries such as UK, Norway, Australia, New Zealand, Hong Kong and China etc. have accepted use of recycled aggregate concrete in limited structural applications [4-6].

According to ACI 555R, concrete prepared with coarse recycled concrete aggregates and natural fine aggregates exhibits compressive strength reduction from 5 to 25% as compared to normal concrete, for equivalent mix proportion. Furthermore, the elastic modulus has been found to decrease by 10 to 33% [2].

The results of research work conducted by J. Xiao et al. [7] showed that the mechanical properties of recycled aggregate concrete are decreased with increasing percentage replacement of NA with recycled concrete aggregates. Previous research studies on NC have shown that the addition of steel fibers improves flexural behavior, ductility in compression and cracking behavior in both flexure and compression [8-11].

In the present state of art knowledge on recycled aggregate concrete, very little information is available in relation to effect of steel fibers addition on mechanical properties of RAC. M. Heeralal et. al. [8] found marginal increase in compressive strength, whereas, a pronounced increase in flexural strength of about 15% upon addition of steel-fibers in RAC.

In order to study anticipated positive impact of hooked-ends steel fibers on degraded mechanical properties of RAC, uniaxial compression and flexure tests were performed on RAC (with and without addition of steel fibers). The percentage replacement levels of Natural Aggregates (NA) with recycled coarse aggregates were kept as 0, 50 and 100 percent. All RAC mixes were reinforced with steel fibers at a constant dosage of 0.5% by volume of concrete. Prismatic and cylindrical specimens were prepared and tested under three point flexural and uniaxial compression at the age of 28 days.

2. Experimental Program

The experimental study was conducted in two series. In series-I, three RAC mixes were prepared by varying percentage replacement of NA with Recycled Concrete Aggregates (RCA). The percentage replacement levels were kept as 0, 50 and 100 percent. Whereas, in series-II, only difference from series-I is the addition of steel fibers at a constant dosage of 40 kg/m^3 (V_f = 0.5%) to investigate possible enhancement of mechanical properties of RAC.

Cylindrical specimens having diameter 150mm and height 300 mm were prepared for determination of compressive strength and elastic modulus under uniaxial compression. Prismatic specimens having dimensions 100 × 100 × 500 mm were prepared to perform three point flexural load tests to determine modulus of rupture and load-deflection and Load-CMOD curves. For each composition of concrete, two cylindrical and two prismatic specimens were cast.

2.1 MATERIALS

The Ordinary Portland Cement (OPC) cement satisfying the requirements of ASTM C150 specifications [12] was used. Locally available crushed stones and pit sand were used as coarse aggregates and fine aggregates, respectively for preparation of all concrete mixes. Conventional drinking water available in laboratory was used as mixing water in all concrete mixes.

To produce recycled coarse aggregates demolished concrete of an industrial building having compressive strength of 21 MPa was used. Gradation curves of natural and recycled aggregates are shown in Figs. 1,2 respectively.

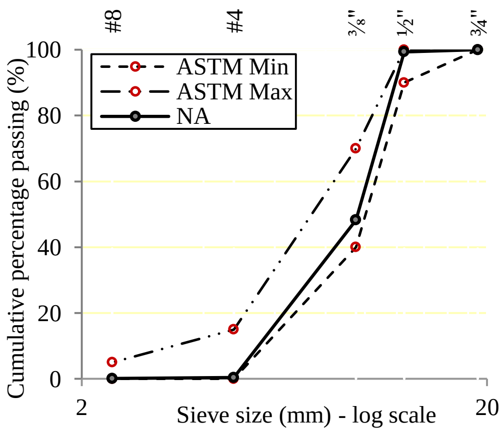

Fig.1: Gradation of Natural Aggregates

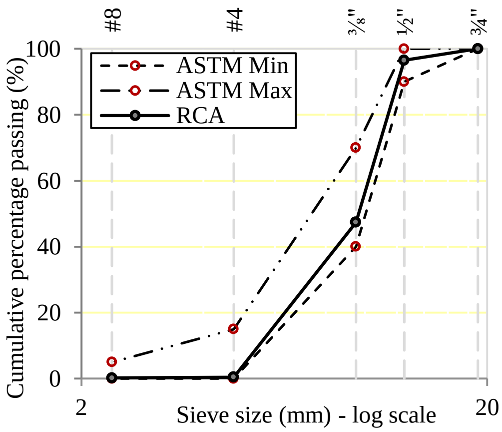

Fig.2: Gradation of Recycled Concrete Aggregates

Hooked ended steel fibers having diameter 0.53 mm, length 24.9 mm and tensile strength 795MPa as shown in Fig.3 were used in this study. It is important to mention that the aspect ratio of the fibers satisfies the requirements of ACI 544 [13] for the metallic fiber.

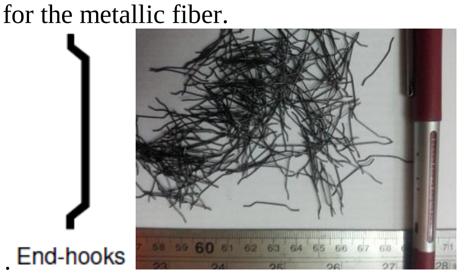

Fig.3: Hooked ended steel fibers

2.2 Mix Proportions

Both recycled and natural coarse aggregates were used in Saturated Surface Dry (SSD) condition in order to avoid negative effect of high water absorption of recycled aggregates.The W/C ratio was maintained as 0.55 for all concrete mixes. A total of 6 concrete mixes were prepared. Three mixes out of six were prepared as part of series-I and were designated as M0, M50 and M100, where M represents mix and 0 ,50 and 100 represent percentage replacement levels of natural aggregates with recycled aggregates. Mix proportions of these three concrete mixes are given in Table 1. In this study, M0 mix is taken as control or reference concrete.

Table 1: Mix proportions of concrete

Mix	Cement (kg/m^3)	Sand (kg/m^3)	Natural Aggregates (kg/m^3)	Recycled Concrete Aggregates (kg/m^3)	Water (kg/m^3)
M0	320	640	1280	0	176
M50	320	640	640	640	176
M100	320	640	0	1280	176

Concrete mixes ofseries-II were prepared by adding steel-fibers in corresponding concrete mixes of series-I and were designated as M0-SF, M50-SF and M100-SF. In **M0-SF**, “M” represents mix, “0” represent percentage replacement level of natural aggregates with recycled aggregates and “SF” stands for steel-fibers.

The target slump for all concrete mixes was set as 75 mm.During mixing it was observed that due to addition of steel-fibers and 100% replacement of natural aggregates with recycled aggregates the slump value is notably decreased. In order to maintain required slump value a super plasticizer was used at a dosage of 5ml/kg of cement.

2.3 Preparation of specimens

All mixing was conducted under laboratory conditions, conforming to current ASTM Standards. The sand, cement and coarse aggregates were placed in concrete mixer and dry-mixed for 2 minutes before addition of water. The wet-mixing was done for 3 minutes. Super-plasticizer was used for all mixes of Series-IIwith steel fibers. Half quantity of super-plasticizer was added with mixing water and remaining half quantity was added gradually during wet-mixing. Steel fibers were added at the end, and wet mixing was stopped after ensuring the proper distribution of the steel-fibers [14]. Slump test/compacting factor tests were conducted to determine the workability of each preparedconcrete mix. Casting of concrete into steel moulds for cylinders and prisms was carried out in three layers. Mechanical vibrating table was used to compact each layer. De-moulding was carried out on the next day of casting and specimens were immediately placed in the curing tank for 28 days at 20^{0}C.

2.4 Test Setup and Testing Methods

The compressive strength tests were conducted after 28 days curing of the specimens.

The compressive cylinder strength tests were carried out at a rate of loading of 2 mm / minute. Two LVDTs were attached with the specimen at a gauge length of 150 mm, in order to record displacements. A load cell capacity of 500 kN was used to record the load data. The setup for determination of compressive strength is shown in Fig. 3.

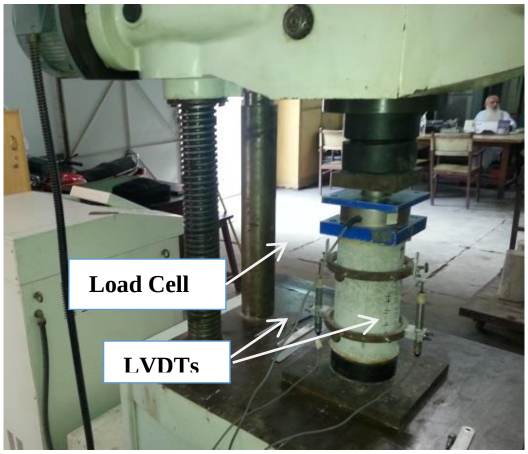

Fig. 3: Uniaxial compression test setup

The setup for determination of flexural behavior is shown in Fig. 4. Three point bending test was carried out at an imposed displacement rate of 0.5 mm/minute.

All prismatic specimens were notched with 17 mm notch depth at mid-span. The notched face was kept at bottom during flexural test. The Crack Mouth Opening Deflection (CMOD) was recorded by LVDT attached at bottom, as shown in Fig.4. Other LVDTs were used to record the mid-span deflection. Simply supported span between supports was maintained as 457 mm. The resistive force, "*P*" was recorded with a load cell of capacity 500 kN, as shown in Fig. 4.

Data acquisition system was used to digitally record the load and deflection data from load cell and LVDTs, respectively.

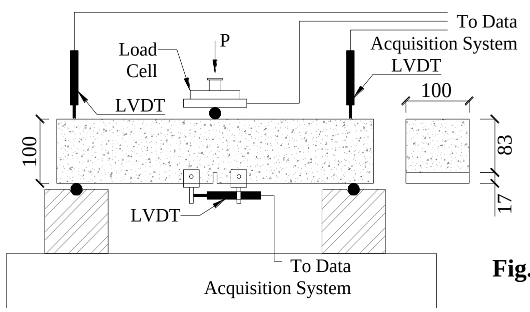

Fig. 4

Fig. 4: Three point flexural test setup

3. Test Results

3.1 Uniaxial Compression Tests

3.1.1 Compressive Strength (f_c')

Average compressive strength of specimens of series-I and series-II concrete mixes is shown in Fig. 5. Where, it can be observed that the compressive strength is decreased by increasing the percentage replacement of RCA in series-I. This is in accordance with different researchers [1,2,4,7,8]. For series-I the compressive strength was decreased by about 6% upon 50% replacement and 20% upon 100% replacement of NA with RCA.

The reduction in compressive strength of series-I mixes is mainly attributed to the cement mortar adhered to the RCA. Large pores and void mostly present around RCA, which weakens the adhesion between aggregate and old cement mortar.

Compressive strength test results of series-II show that the addition of steel fibers increased the compressive strength of M0, M50 and M100 by 11%, 4% and 26%, respectively. Increase in compressive strength of the fiber reinforced RAC specimen is mainly attributed to increased confinement due to steel fibers [14]. The failure patterns of specimens of series-II i.e., M0-SF, M50-SF and M100-SF are shown in Fig.6.

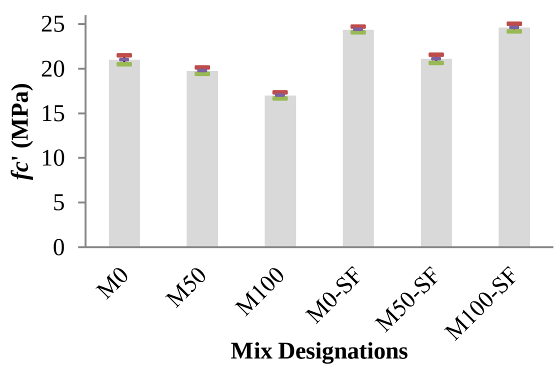

Fig. 5: Compressive strength results

Fig. 6. Uniaxial compression failure, immediate after testing (Undisturbed)

3.1.2 Modulus of Elasticity (MOE)

Modulus of elasticity, "*E*" of concrete was determined using Eq. 1 proposed by ASTM C469 [15],

$$E_c = \frac{\sigma_2 - \sigma_1}{\varepsilon_2 - 0.00005} \quad \text{(Eq. 1)}$$

Where,

σ_2 = Stress at 40% of the peak load

σ_1 = Stress at 0.00005 strain

$\mathcal{E}_2$ = Strain corresponding to σ_2

In this research, the reduction in MOE was found 11 % upon 50% replacement level of RCA and 38% upon 100% replacement of NCA with RCA. The test results for modulus of elasticity are shown in Fig. 7.

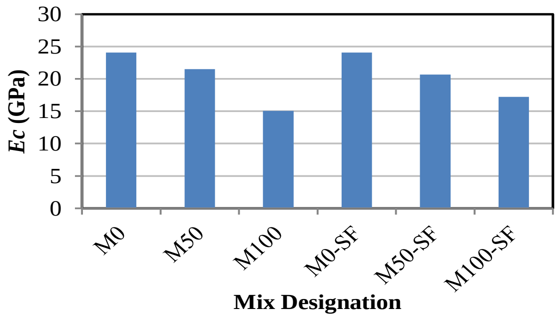

Fig.7: Modulus of elasticity of series-I and series-II

3.2Flexural Tests

3.2.1 Modulus of Rupture (MOR)

Modulus of rupture, "f_r" was determined from the elastic analysis based on the maximum load obtained during experiment [16,17]. The average values of MOR of concrete mixes in series-I and series-II are shown in Fig. 8. The results depict dependence of MOR on RCA replacement level and addition of steel-fibers. MOR reduces with increasing percentage replacement of RCA (0%, 50% and 100%). A 2.8% reduction was observed in case of 50% replacement (M50) and 13.9 % upon 100 % replacement level of RCA (M100). However, the positive influence of addition of steel fibers is pronounced and is increasing with increasing percentage replacement level of RCA (0%, 50% and 100%). In comparison to control mix with steel fibers (M0-SF), the MOR was found to increase by 2.6% and 9.6 % upon 50% and 100 % replacement levels, respectively.

MOR of M50 and M100 is increased by 12% and 35%, respectively by the addition of steel fibers at dosage of 40 kg/m^3.

Representative curves of Load P (kN) and Crack Mouth Opening Deflection (CMOD) for series-I are shown in Fig. 10. The initial ascending part of the curve shows similar pattern as exhibited by P-δ curve. However, duration between first crack and ultimate crack at peak load is more in case of M0 and reduces with increasing percentage replacement level of RCA (M50 and M100).

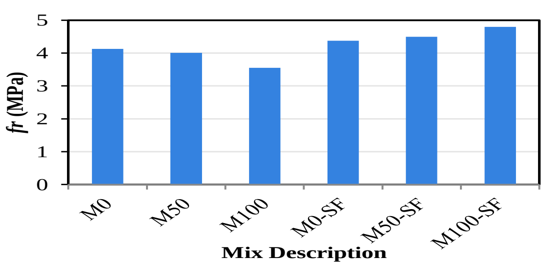

Fig.8: MOR for series-I and series-II

3.2.2 Load Deflection Curves (P-δ and P-CMOD)

The load deflection curve is particularly important to determine the effect of steel fiber on post cracking behavior of the beam. The representative curves representing Load P (kN) as ordinate and mid-span Deflection δ (mm) is shown in Fig. 9 for series-1 concrete mixes. The slope of the initial line is reduced as the percentage replacement of RCA is increased. The peak load and mid-span deflection associated with peak load are decreased with increasing percentage replacement level of RCA.

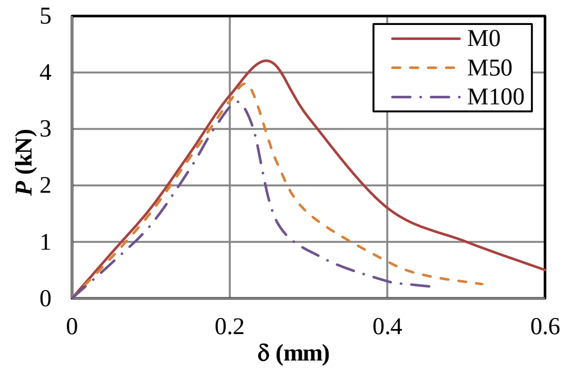

Fig.9: P-δcurve for series-I

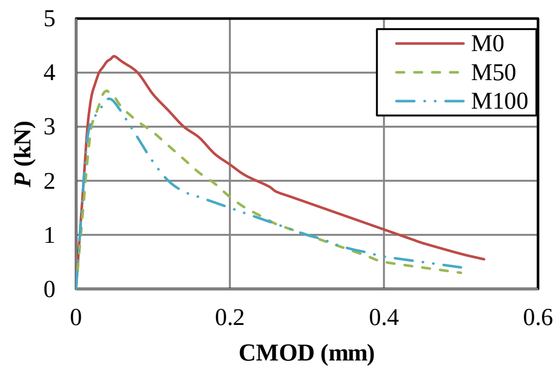

Fig.10: P-CMOD curve for series-I

The representative behavior curves of concrete mixes in series-II are shown in Fig. 11, the initial part of P-δ curves for concrete mixes of series-II exhibit almost a similar trend as of series-I with exception that the post peak behavior is largely positively influenced by the addition of steel fibers. The initial slope is reduced indicating a degradation of flexural stiffness with increasing percentage replacement level of RCA.

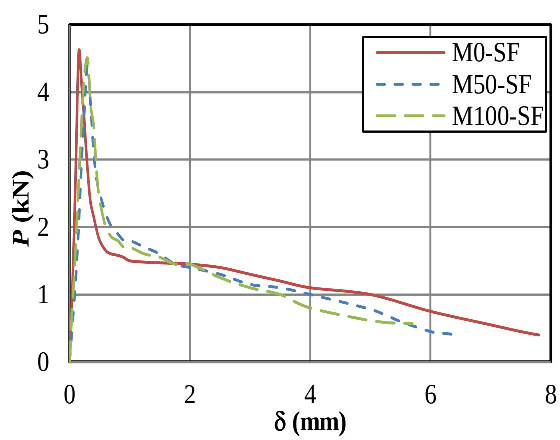

Fig.11: P-δcurve for series-II

P-CMOD curve for Series-II as shown in Fig. 12 also exhibited same characteristics as that of P-δ curves for Series-II.

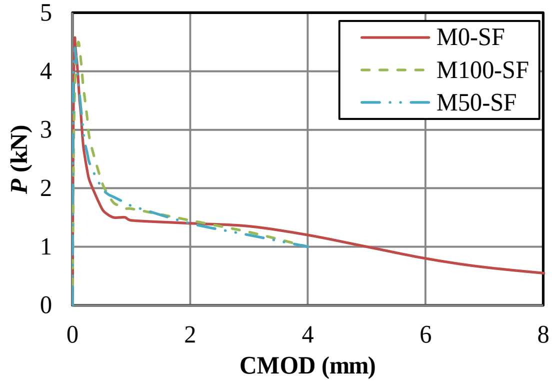

Fig.12: P-CMOD for series-II

From load deflection curves shown in above figures, it is obvious that the ductility of the fiber reinforced RAC mixes in post cracking is importantly increased by the addition of steel fibers.

4. CONCLUSIONS

In this paper, experimental results for the compressive strength and flexural behavior of recycled aggregate concrete and fiber reinforced recycled aggregate concrete are presented and discussed. From the results, following conclusions are drawn:

- For recycled aggregate concrete, the 28 days cylindrical compressive strength is reduced with increasing percentage replacement of natural aggregates with recycled aggregates. The compressive strength is found to be decreased by 6% upon 50% replacement, whereas, 20% reduction in compressive strength was observed upon 100% replacement of natural aggregates with recycled aggregates. This reduction was found in accordance with other researchers.
- Addition of steel-fibers not only restores the drop in compressive strength of RAC but also enhanced, particularly in case of M100 which was 17%.
- The modulus of elasticity is reduced by11% for concrete mix with 50% replacement of NA with recycled aggregates, whereas a reduction of 38% was observed in case of 100% replacement level. Addition of steel-fibers did not affect modulus of elasticity significantly for concrete mixes with 0% and 50% replacement level of NA with recycled aggregates. However, modulus of elasticity of concrete mix with 100% replacement of NA with recycled aggregates was improved by 14%.
- The modulus of rupture is consistently decreased by 2.8% and 13.9% upon 50% and 100%, replacement of NA with recycled aggregates respectively. However, addition of steel-fibers exhibited a contrary behavior and modulus of rupture is increased in direct relation to replacement level of NA with recycled aggregates.
- Enhancement in ultimate load carrying capacity of RAC in flexure and compression, ductility and reduction in crack width during post peak behavior is possible by the addition of steel-fibers at a constant low dosage of 40 kg/m^3.

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