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Reinforced fibrous recycled aggregate concrete element subjected to uniaxial tensile loading

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Abstract. In this study, effect of recycled aggregates and polypropylene fibers on the response of conventionally reinforced concrete element subjected to tensile loading in terms of tension stiffening and strain development was experimentally investigated. For this purpose, concrete prisms of 100 x 100 mm cross section and 500 mm length having one central deformed steel re-bar were cast using fibrous and non-fibrous Recycled Aggregate Concrete (RAC) with varying percentages of recycled aggregates (0%, 25%, 50%, 75% and 100%) and tested under uniaxial tensile load. For all fibrous RAC mixes, polypropylene fibers were used at constant dosage of 3.15 kg/m^3. Effect of recycled aggregates and fibers on the compressive strength of concrete was also explored in this study. Through studying tensile load versus global axial deformation of composite and strain development in concrete and steel, it was found that replacement of natural aggregates with recycled aggregates in concrete negatively affected the cracking load, tension stiffening and strain development, and this negative effect was observed to be increased with increasing contents of recycled aggregates in concrete. The results of this study showed that it was possible to minimize the negative effect of recycled aggregates in concrete by the addition of polypropylene fibers. Reinforced concrete element constructed using concrete containing 50% recycled aggregates and polypropylene fibers exhibited cracking behavior, tension stiffening and strain development response almost similar to that of concrete element constructed using natural aggregate concrete without fiber.

Keywords: reinforced concrete; recycled aggregates; polypropylene fiber; tension stiffening; cracking

1. Introduction

Among concrete constituents, aggregates account for 60 to 80 percent of the concrete volume and production of required quantity of aggregates is causing depletion of natural resources in many countries on the globe. Efforts have been made in the past to find different materials to be used as aggregates in concrete (Sarabèr *et al.* 2012, Geetha and Ramamurthy 2010, Ioanna and Christopher 2010, Mannan and Ganapathy 2002, Yun-Wang *et al.* 2005). Recycled Aggregates (RA) produced by recycling of Construction and Demolition (C&D) waste has received substantial attention as a potential substitute for Natural Aggregate (NA) in the production of concrete (Nik 2005, Jianzhuang *et al*. 2012, Subhash *et al*. 2016, Saha and Rajasekaran 2016, Djelloul *et al.* 2018). The main reason for the growing interest in the use of RA in concrete is the advantages offered by the recycling of waste concrete such as environmental protection, conservation of natural resources, saving of useful landfill space as well as the cost of disposal of C&D waste (Yasir *et al.* 2016). Recycling of C&D waste is a relatively simple process; it involves breaking and removing of existing concrete and crushing it into RA of required size. This ease of production is also another factor behind the augmented use of RA in construction industry.

In the last two decades, significant research work has been done on Recycled Aggregate Concrete (RAC) and most of the researchers investigated its basic mechanical properties (Akash *et al.* 2007). Previously carried out research studies revealed that RAC has lower strength and lesser durability as compared to Natural Aggregate Concrete (NAC) which is due to reduced stiffness and higher absorptivity of RA caused by the existence of adhered porous mortar (Tam *et al.* 2005). Because of this reason, use of RAC is generally recommended in non-structural applications only. As well as the structural use of RAC is concerned, significant research work is required to be carried out to fully understand the behavior of reinforced RAC under different modes of loading.

Concrete being weak in tension is prone to cracking when subjected to tensile loading. Cracking problem is more pronounced in case of RAC due to weaker bond between RA and cement matrix (Zaharieva *et al.* 2004, González-Fonteboaa *et al.* 2018). The cracking causes degradation of concrete and ultimately reduces its load carrying capacity, and also affects the durability of concrete structures (Ann *et al.* 2008). This is more particular in case of liquid retaining structures where leakage of liquid through the cracks not only affects the serviceability limits (ACI 224.2R-92 1997, Christiansen and Nielsen 2001) but also has detrimental effect on durability of reinforced concrete structures due to corrosion of steel reinforcing re-bars. Stiffness of the cracked concrete is decreased at higher

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Fig. 1 Natural and recycled coarse aggregates

Table 1 Properties of natural and recycled coarse aggregates

Properties	Natural Aggregates (NA)	Recycled Aggregate (RA)
Size (mm)	4 - 12	4 - 12
Water Absorption (%)	1.07	2.34
Impact Value (%)	17.2	22.4
Loose Bulk Density (kg/m^3)	1308	1192
Rodded Bulk Density (kg/m^3)	1508	1345

load levels which results in development of large number of cracks (Fields and Bischoff 2004) and ultimate failure of the structures. As for as the bond between RAC and steel is concerned, research studies in the past showed that recycled aggregates replacement percentage has nearly no influence on the bond strength between RAC and deformed steel rebar (Jianzhuang *et al.* 2012), therefore, the assumption of perfect bond as assumed by different design codes may also be considered valid for RAC.

In practice there are few situations where RC structural members are subjected to pure tensile loading, for example, vertical section of wall of circular tank and RC section with restrained volumetric deformation (Kianoush *et al.* 2008). When reinforced concrete element is cracked due to tensile loading, block of concrete present between primary cracks can still contribute to carry tensile forces mainly in the direction of reinforcement due to bond between concrete and deformed steel reinforcing re-bar and this phenomenon is termed as tension stiffening (Behfarnia 2009). Tension stiffening effect plays important role to control deformation, crack width and stiffness of the RC element (Fields and Bischoff 2004).

It is a well-established fact that the addition of short discrete fibers of various types in plain concrete has positive impact on its mechanical properties with the exception of compressive strength. The fibers effectively arrest the crack propagation within concrete matrix and limit the crack width, moreover, significant improvement in the post cracking response of concrete is also achieved (Banthia and Sappakittipakorn 2007, Hameed *et al.* 2009, Hameed *et al.* 2010, Mansour *et al.* 2017, Midhuna *et al.* 2018). Further, research investigations conducted in the last decade (Hameed *et al.* 2010b, Ganesana *et al.* 2017) have shown that the tension stiffening effect was improved by the addition of fibers in the concrete. Findings of research studies carried out to investigate the effect of adding fibers on the performance of RAC revealed that the detrimental effect of replacing NA with RA on the mechanical properties of concrete may be reduced by the addition of fibers (Carneiro *et al.* 2014, Sryh and Forth 2015, Gao *et al.* 2017, Kazmi *et al.* 2018, Alnahhal and Aljidda 2018, Kazmi *et al.* 2019, Chaboki *et al.* 2019). Since fibers present in concrete matrix come in action after when the matrix is cracked, early development of cracking in relatively weaker matrix of RAC may be considered useful with respect to initiation of fiber action.

It is a fact that if development and propagation of cracks in RC structural members is not controlled, complete collapse of the structure may occur. In case of liquid retaining structures, even micro-cracking of concrete can cause severe damage. With regard to structural application of conventionally reinforced RAC, study of its cracking behavior under different modes of loading is of great importance. Further, to control cracking and enhance tensioning stiffening by adding fibers in conventionally reinforced RAC is another important aspect which is required to be explored through experimental research work. In this regard, objective of this study is to investigate the behavior of RC elements constructed using RAC when subjected to pure tensile loading, besides this, effect of polypropylene fibers on the cracking response and tension stiffening effect has also been investigated. For this purpose concrete prisms with central steel bar were prepared using RAC containing varying percentage of RA from 0% to 100%. Compressive strength of each concrete mix was also determined to observe the effect of replacing NA with RA and adding polypropylene fibers in concrete. It is important to mention here that although RC structural members are rarely subjected to pure tensile loading in practice as mentioned above, it is always of great importance to carry out research studies to understand basic principles governing the behavior of new construction material, like fiber-reinforced RAC, when subjected to such loadings.

2. Experimental program

2.1 Concrete materials

The concrete mixes were prepared using ordinary Portland cement, natural and recycled coarse aggregates (Fig. 1) with maximum particle size of 12 mm, locally available clean river sand having maximum particle size of 4 mm and potable water. Recycled Aggregates (RA) were produced by crushing waste concrete specimens. For this purpose, the waste concrete specimens with nominal cylinder compressive strength of 28 MPa were obtained from a material testing laboratory. In order to maintain the required workability of concrete in the presence of polypropylene fibers as shown in Fig. 2, a super-plastisizer was used. Properties of the natural and recycled coarse aggregates are given in Table 1. Properties of polypropylene fibers and super-plasticizer used in the study are given in Table 2. For RAC mixes, required quantity of water was adjusted keeping in mind the higher water absorption capacity of recycled aggregates in order to achieve the same workability as that of NAC mixes with w/c ratio mentioned in Table 3.

Fig. 2 Polypropylene fibers

Table 2 Properties of polypropylene fibers and super plasticizer

SIKA Fiber-12		Chemrite 520 BA	
Type	Polypropylene Fiber	Type	HRWR Admixture
Density	0.91 Kg/Lit	Form	Organic Polymer Blend
Length	12 mm	Density	1.8 Kg/Lit
Diameter	18 micron	PH Value	Approx. 7
Surface Area	200 m^2/Kg	Chloride Content	NIL (EN 934-2)

2.2 Concrete mixes

A total ten (10) concrete mixes were designed and prepared for this study; two mixes of NAC and eight mixes of RAC. To prepare RAC mixes, NA were replaced with 25%, 50%, 75% and 100% of RA. As per ACI report (ACI 544.1R-96), synthetic fiber content of 0.1 to 0.3% by volume is considered as low dosage of fibers while high dosage ranges from 0.4% to 0.8% by volume. In this study, dosage of polypropylene fibers in all fibrous concrete mixes (five out of ten mixes) was kept as 0.35 % by volume (an intermediate value between low and high dosage) is used which is almost equivalent to 1% by weight of cement (i.e., 3.15 kg/m^3). Compared to conventional steel macro-fibers, main interest of using such flexible micro- fibers in this study was to control initiation and propagation of cracking in concrete matrix at the level of steel-concrete interface (mainly cement mortar present between steel rebar lugs and surrounding concrete matrix) after elastic deformation under the application of tensile load on the steel bars.

Concrete mixes were designated according to the replacement level of NA in concrete with RA such as NAC, RAC25, RAC50, RAC75 and RAC100 and also with respect to use of fibers. For example, designation NAC represents concrete mix with 100% NA without fibers which was taken as reference concrete in this study, while designation NAC-F represents concrete mix with 100% NA and with polypropylene fibers. Designation RAC25-F represents RAC mix containing 25% RA and polypropylene fibers. Similarly, RAC100 represents RAC mix without fibers containing 100% RA. Table 3 presents all concrete compositions along with their designation which were prepared for this study. For each concrete mix, three cylinders of diameter 150 mm and height 300 mm and three reinforced prismatic test specimens were prepared for compression test and uniaxial tensile loading test, respectively.

Table 3 Concrete mixes and their compositions

Mixes	Cement (kg/m^3)	PP Fiber (kg/m^3)	Sand (kg/m^3)	NA (kg/m^3)	RA (kg/m^3)	Water (kg/m^3)	SP (L/m^3)
NAC		---		1260	---		---
NAC-F		3.15		1260	---		2.52
RAC25		---		945	315		---
RAC25-F		3.15		945	315		2.52
RAC50	315	---	630	630	630	176.4	---
RAC50-F		3.15		630	630		2.52
RAC75		---		315	945		---
RAC75-F		3.15		315	945		2.52
RAC100		---		---	1260		---
RAC100-F		3.15		---	1260		2.52

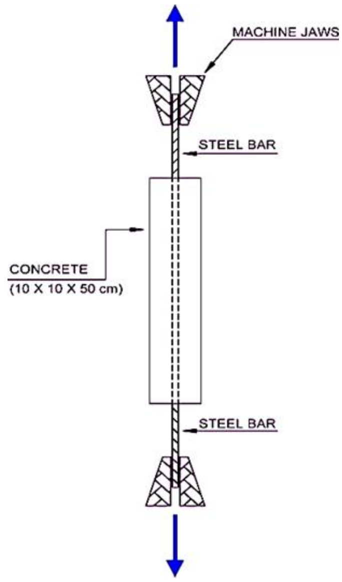

Fig. 3 Specimen for tensile loading test

2.3 Test specimens

Prismatic reinforced concrete test specimens of 100 x 100 mm cross section and 500 mm length with a 19 mm (#6) diameter steel bar at center as shown in Fig.3, were prepared to perform uni-axial tensile loading tests. In order to study the local strain development at the interface of concrete and steel, a strain gauge (SG-1) was pasted on steel bar at mid-section as shown in Fig. 4. Load deformation behavior of bare steel bar under tensile loading was observed by a control strain gauge (SG-2) pasted on steel bar out of the concrete at a distance of 75 mm from face of the concrete (refer to Fig. 4). The global deformation in concrete under tensile loading was measured using LVDT fixed on the test specimen over a gage length of 400 mm as shown in Fig. 5. To avoid pulling out of concrete from the ends during pure tensile loading, a bond free zone between concrete and steel bar was created up to a length of 50 mm from each end of the specimen. This was made possible by passing the steel bar through the PVC pipe of length 50 mm and fixing the pipe at the end of the mold as shown in Fig. 6. As mentioned earlier cylindrical specimens of diameter 150 mm and height 300 mm were also prepared to determine concrete compressive strength.

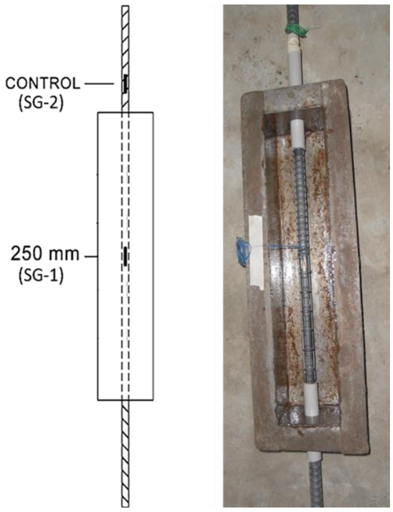

Fig. 4 Location of strain gauges

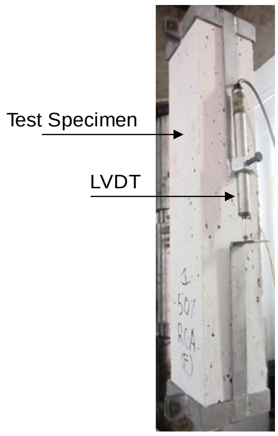

Fig. 5 LVDT to measure global axial deformation


Fig. 6 Bond free zone at both ends of test specimen

2.4 Testing setup

Testing set up of uniaxial tensile loading test is shown in Fig. 7. Both compression and tensile loading tests were performed on universal testing machine of 1000kN maximum loading capacity. To perform uniaxial tensile tests, test specimen was fixed between the lower and upper platen of the machine. Tensile loading was applied at a loading rate of 2mm/min. Loading was applied until the concrete specimen had shown overall displacement of 5 mm. All the displacement and strain data from LVDT and strain gauges, respectively as well as their corresponding load values from machine load cell were recorded automatically by using data acquisition system.

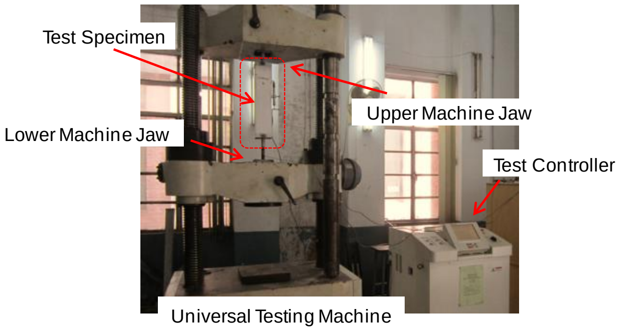

Fig. 7 Testing setup for uniaxial tensile loading test

3. Results and discussion

3.1 Compressive strength

The compressive strength tests were performed on cylindrical test specimens following the procedure specified by ASTM C39 (ASTM C39). Three specimens were tested for each composition of concrete and average value of the compressive strength for all compositions is presented Fig. 8. From the results, it is clear that compressive strength of concrete was decreased by replacing NA with RA and in comparison of control mix (NAC), this drop in strength was observed to be increased with the increasing contents of RA in concrete. This observation is in agreement with the findings of previous research studies (Bravo *et al.* 2015, Riaz *et al.* 2015, McGinnis *et al.* 2017, Lau *et al.* 2014, Abdulla 2015). The drop in compressive strength in case of RAC25, RAC50, RAC-75 and RAC100 was observed to be 4.6%, 11%, 25% and 33%, respectively when compared to compressive strength of NAC. Slight improvement in strength value by the addition of polypropylene fibers is obvious from the results presented in Fig. 8 and this was true for both NAC and RACs mixes. Among all concrete mixes tested in this study NAC mix with fibers (NAC-F) developed maximum compressive strength of 31.8 MPa. Although addition of polypropylene fibers caused slight increase in compressive strength of all mixes of RAC but it was not possible for any RAC mix with polypropylene fibers to obtain strength similar to that exhibited by NAC.

3.2 Uniaxial tensile test

3.2.1 Load-deformation response

To understand the load deformation response of reinforced RAC subjected to pure tensile loading, the axial tensile load is plotted versus global axial deformation. On the same plots, tensile load versus strain response of bare steel bar is also shown. These plots are shown in Fig. 9 to Fig. 13. From the load deformation response of each composition shown in these figures, behavior before the localization of first macro-crack, load at the first crack, drop in load value after first crack, rapid increase in deformation after macro-crack localization and tension stiffening effect have been studied. The difference between the deformation response of composite (reinforced concrete) and bare steel bar shows the tension stiffening. Before the localization of first transverse macro crack, the load versus deformation

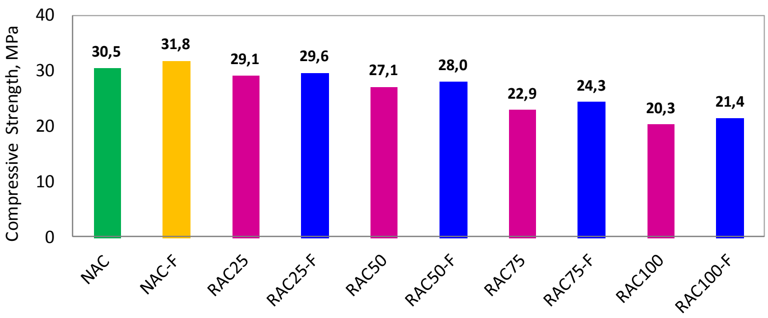

Fig. 8 Compressive strength values

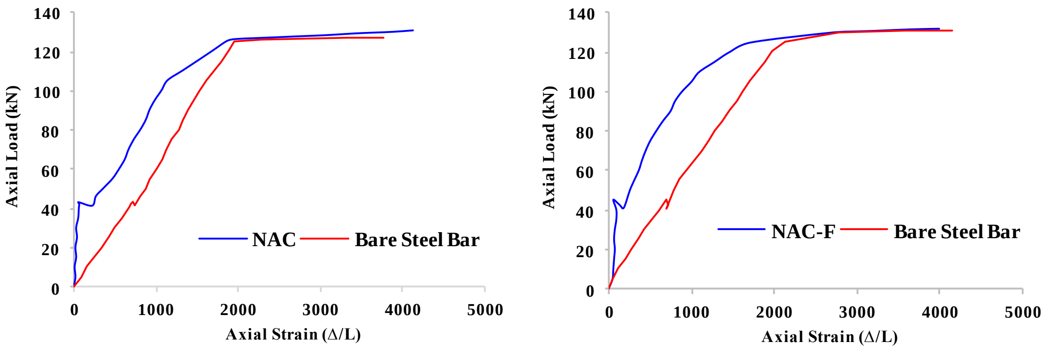

Fig. 9 Axial strain versus axial load response (NAC & NAC-F)

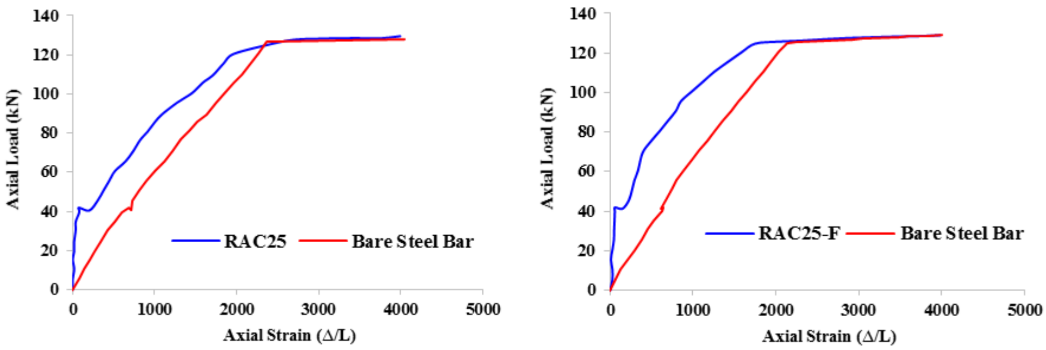

Fig. 10 Axial strain versus axial load response (RAC25 & RAC25-F)

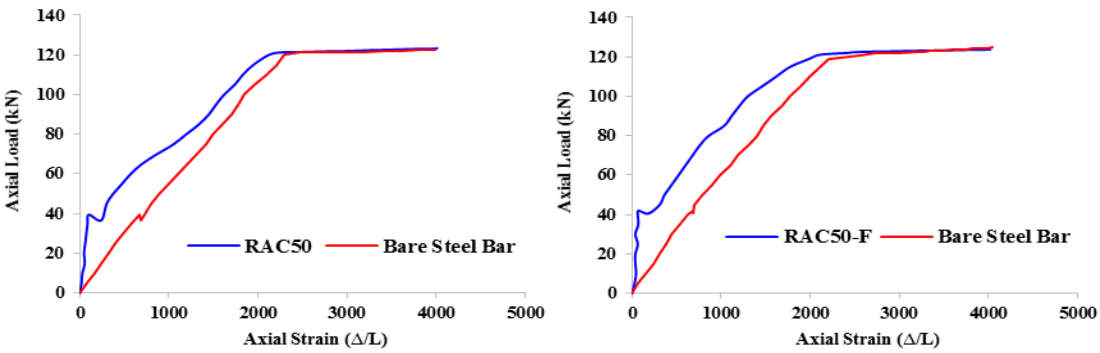

Fig. 11 Axial strain versus axial load response (RAC50 & RAC50-F)

behavior of NAC and all classes of RAC with and without fibers was observed to be almost similar. It can be observed in Fig. 14 where tensile load carrying capacity of all concrete compositions at first crack and just after it is shown that the maximum tensile load at first macro crack was carried by the NAC with fibers (NAC-F) and RAC25-F, which is about 5% higher than that for the reference concrete mix (NAC). A decrease of about 8% in load was exhibited by RAC-50 but addition of fibers in same concrete made it possible to recover this decrease and the load value of RAC50-F was found to be similar to that of NAC. Further increase of RA contents in concrete up to

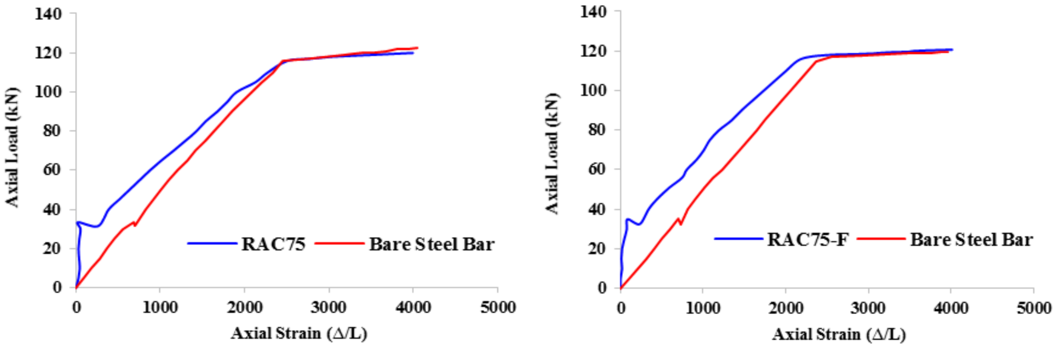

Fig. 12 Axial strain versus axial load response (RAC75 & RAC75-F)

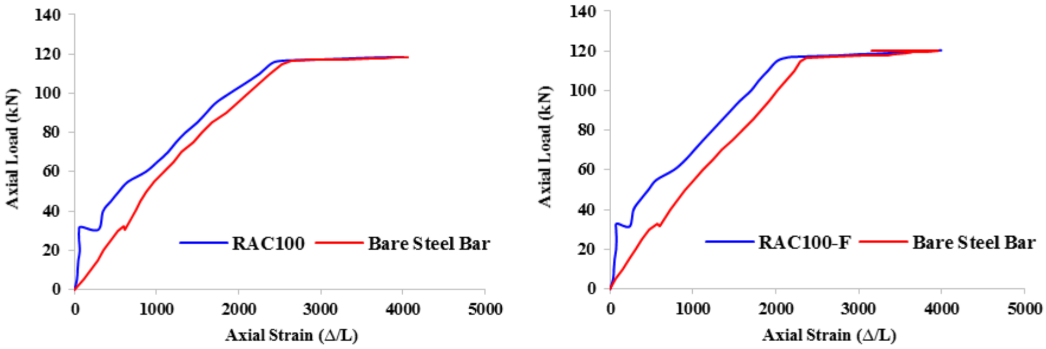

Fig. 13 Axial strain versus axial load response (RAC100 & RAC100-F)

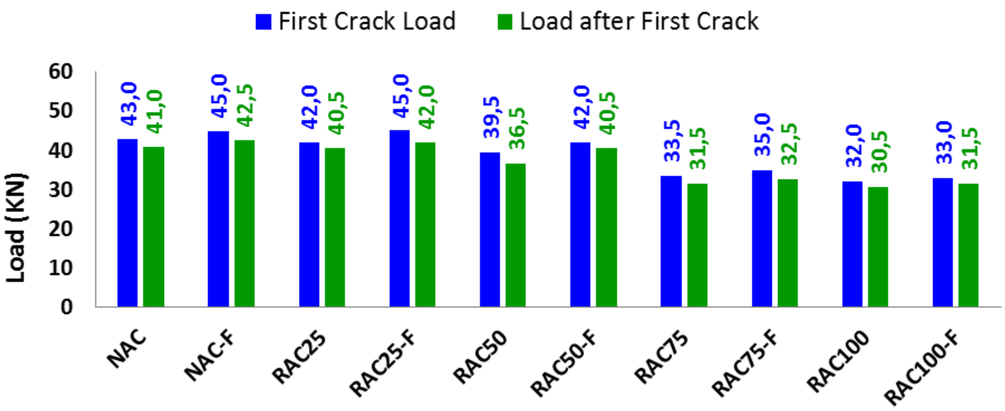

Fig. 14 Tensile load carrying capacity

75% and 100%, the first macro crack load was decreased by 22% and 26%, respectively. For these mixes (RAC75 & RAC100), although addition of fibers improved the load value but it remained less than the value of NAC. After the localization of first transverse macro-crack, sudden drop in the load value was noticed with all concrete mixes. It can be observed in Fig. 14 that an average drop in tensile load value up to 4% to 6% was observed. Further, presence of polypropylene fibers in the concrete mix did not influence this behavior of RC element subjected to pure tensile loading.

Besides drop in load value after crack localization, significant increase in axial deformation was also observed for both NAC and RAC mixes. Values of total increase in deformation for each concrete mix are presented in Fig. 15. It can be seen in this figure that in case of NAC and RAC25 mixes, sudden increase in axial deformation was almost same, however, increase in RA contents beyond 25%, total increment in axial deformation after the first crack localization was observed to increase with increasing contents of RA in concrete; maximum increment in axial deformation was exhibited by RAC100 mix which was 65% more than that of control mix (NAC). The results further revealed that addition of polypropylene fibers at dosage of 3.15 kg/m^3 effectively controlled the sudden increase in axial deformation after the localization of first macro crack. In case of NAC mix, presence of fibers caused 49% reduction in the value of total increment in axial deformation. Similar effect of fibers in case of RAC mixes was also evident. Compared to their corresponding non fibrous concrete mixes, total increment in axial deformation value was decreased by 37%, 36%, 32% and 30% for RAC25-F, RAC50-F, RAC75-F and RAC100-F, respectively. As a result, crack width in fibrous concrete

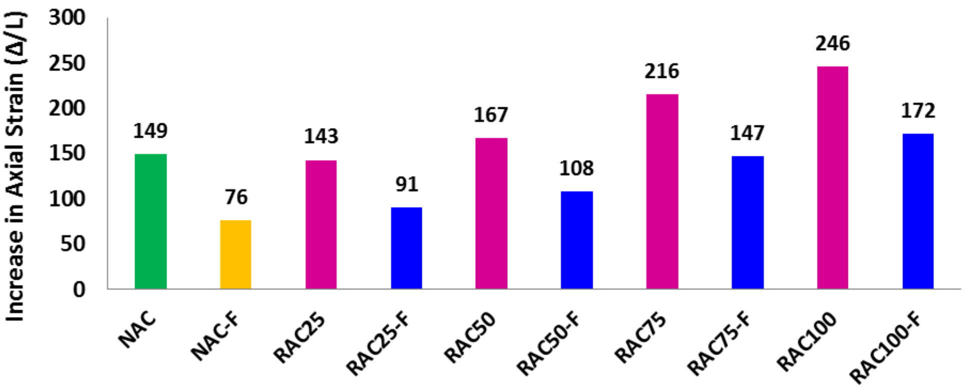

Fig. 15 Axial strain versus axial load response

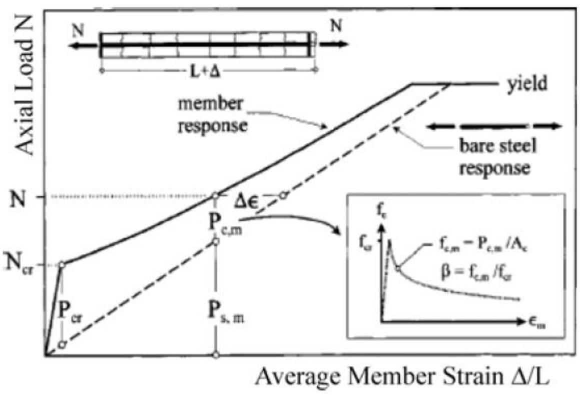

Fig. 16 Response of axially loaded tension member (Bischoff 2003)

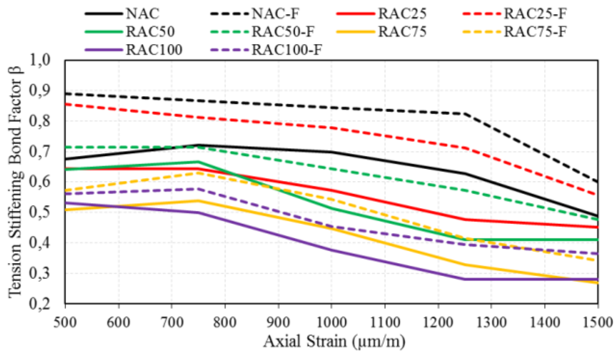

Fig. 17 Effect on tension stiffening

samples was observed to be less compared to non-fibrous concrete samples.

The tension stiffening effect has been assessed based on sharing of tensile load between concrete and steel re-bar and for this, β factor is calculated, where β is tension stiffening bond factor. This factor is calculated by dividing $P_{c,m}$ by P_{cr}. $P_{c,m}$ is average load taken by cracked concrete and is acquired by subtracting the load carried by steel re-bar from the load carried by composite (steel bar and concrete together) and P_{cr} is load carried by concrete at first cracking (Bischoff 2003) as shown in Fig. 16. Larger value of β factor indicates that the RC element is more stiffened. In this study, β factor has been calculated for all concretes between 500 and 1500 μm/m axial strain and results are presented in Fig. 17. It is obvious in this figure that replacement of NA with RA in concrete showed negative effect on the stiffness of RC element which is indicated by the lesser value of β factor attained by all RAC mixes. Further, with the increase of RA contents, it is clear from the results that β factor is also gradually decreased; lowest value of β factor was exhibited by RAC100. From the values of β factor for fibrous concrete mixes of NAC and RAC, it is clear that the addition of polypropylene fibers played positive role to enhance the stiffness of RC element. However, fibrous RAC mixes having RA contents greater than 25% were not able to attain stiffness similar to that control mix (NAC). RAC25 mix attained β factor value closer to that of NAC but RAC25-F mix exhibited β factor greater than NAC mix. Among all concrete mixes tested in this study, NAC mix containing fibers (NAC-F) attained maximum value of β for the range of axial deformation considered in this study.

3.2.2 Strain in concrete

In order to compare the value of axial deformation at a given tensile load attained by different concrete classes investigated in this study, load versus deformation curves of RAC mixes with and without polypropylene fibers are compared and presented in Fig. 18. It is obvious from the curves of RAC mix containing 25% RA (RAC25 & RAC25-F) in "*A*" part of Fig. 18 that axial deformation in concrete is slightly increased by replacing 25% NA with RA after tensile load of 60kN. However, polypropylene fibers improved the deformation response of RAC25 mix and importantly reduced the value of axial deformation after the occurrence of first macro-crack. Further, it can be observed from the curves of RAC25 and RAC25-F that presence of both RA and polypropylene fibers did not affect the

Curves of RAC mix containing 50% RA (RAC50 & RAC50-F) in "*B*" part of Fig. 18 indicate that similar to RAC25 mix, axial deformation in concrete is increased by replacing 50% NA with RA after tensile load of 60 kN. However, compared to RAC25 mix, at given tensile load value deformation is higher in the concrete. Polypropylene fibers improved the deformation response of RAC50-F and response was found to be similar to NAC up to 80 kN tensile load. After this value of tensile load, magnitude of axial deformation attained by RAC50-F mix was observed to be less than NAC but greater than RAC50 mix. Due to

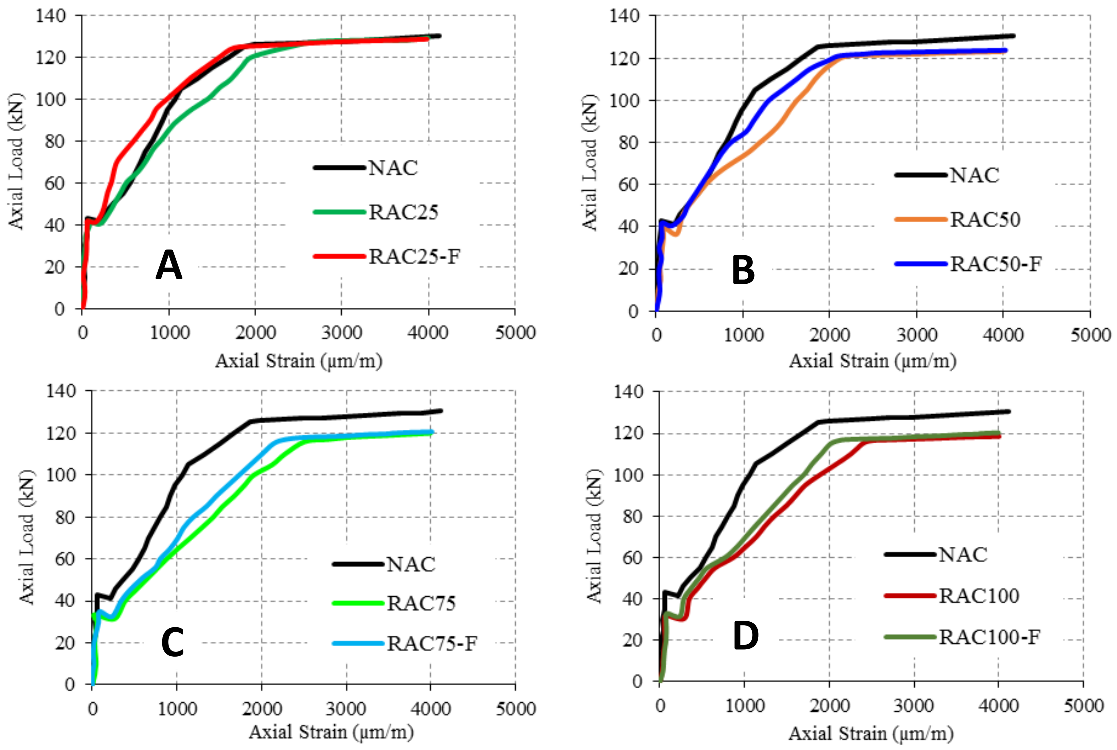

Fig. 18 Concrete strain in all specimens

replacing 50% of NA with RA, composite yield load value was also slightly decreased and in this regard, no positive effect of polypropylene fibers was noticed and yield load value of RAC50-F composite remained less than that of control composite (NAC).

In "*C*" and "*D*" parts of Fig. 18, curves of RAC mix containing 75% RA (RAC75 & RAC75-F) and 100% RA (RAC100 & RAC100-F) are shown, respectively. With these both classes of concrete, at a given tensile load, axial deformation was significantly higher than that with NAC. Addition of fibers slightly improved the response and resulted in axial deformation marginally less than control concrete (NAC). Replacement of 75% and 100% NA with RA caused 8% reduction in yield load value of the composite and fibers did not play any positive role to get yield load similar to that of NAC.

3.3.3 Cracking behavior

During testing, after a certain load value depending upon the concrete composition, development of localized transverse macro crack in each test specimen was noticed. Further increase of tensile load caused widening of exiting transverse crack along with development of new transverse cracks. Finally, due to steel bar yielding, significant widening of cracks was noticed in all test specimens. In no case, yielding of steel bar outside the concrete occurred. Crack opening was visually observed to be more in RAC mixes without fibers at all loading stages when compared to NAC mix without fibers. Cracked specimens of all concrete mixes are shown in Fig. 19. where it can be observed that in test specimens constructed using non-fibrous mixes of NAC and RAC, along with transverse cracking longitudinal cracks also developed, while in test specimens constructed using NAC and RAC concretes mixes containing polypropylene fibers, only transverse cracking occurred. This was due to improved tension stiffening effect in the presence of fibers that no longitudinal cracking in concrete block between two cracks occurred. It was further observed that compared to NAC, in RAC mixes without fibers, longitudinal cracking was more severe in terms of crack opening, crack length and number of cracks.

4. Conclusions

Response of reinforced fibrous recycled aggregates concrete element under uniaxial tensile loading was experimentally investigated in this study. The analysis of experimental results made it possible to draw the following conclusions:

• Before the localization of macro crack, axial strain versus tensile load response of NAC and all classes of RAC investigated in this study with and without fibers was observed to be almost similar.

• Replacement of NA with RA in concrete caused reduction in first crack load of composite. It was found in this study that replacing 25%, 50%, 75% and 100% NA with RA in concrete caused 2.3%, 8.1%, 22% and 25.5% reduction in first crack load value of composite, respectively. However, addition of polypropylene fibers increased the first crack load value in all concrete mixes. RAC containing up to 50% RA and polypropylene fibers exhibited cracking load value similar or greater than that of NAC. Fibrous RAC mixes containing 75% and 100% RA were not able to attain first crack load similar to that of NAC. Maximum increase of 7% in

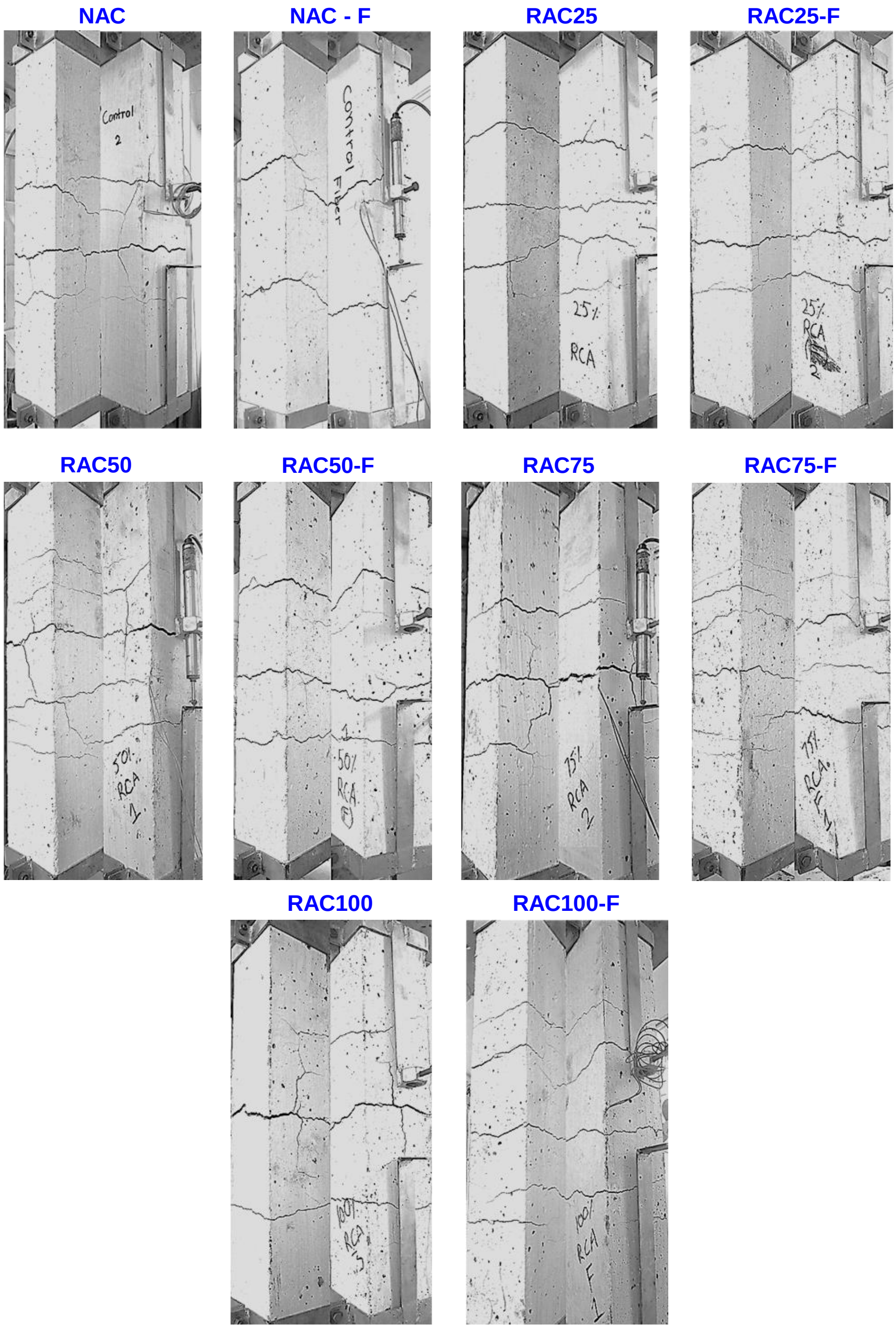

Fig. 19 Cracking pattern of all specimens

load due to addition of polypropylene fibers was shown by RAC mix containing 25% RA.

• Compared to NAC, sudden increase in axial strain after cracking was further enhanced in the presence of RA in the concrete mix. This was true for RAC mixes containing 50%, 75% and 100% RA. Axial strain value in case of RAC mixes with 50%, 75% and 100% RA was 12%, 44%, and 65% more, respectively, when compared to NAC mix. Similar to first crack load, addition of polypropylene fibers in concrete played positive role to decrease the sudden increment in axial strain of composite. This was true for all concrete mixes (both NAC and RACs) investigated in this study. NAC mix containing fibers exhibited 49% decrease in value of axial strain. Compared to their corresponding non fibrous concrete mixes, total increment in axial deformation value after cracking was decreased by 37%, 36%, 32% and 30% for fibrous RAC mixes containing 25%, 50%, 75% and 100% RA, respectively.

• Tension stiffening bond factor β calculated for all concrete mixes between axial strain of 500 and 1500 μm/m indicated that tension stiffening of concrete is negatively affected by replacing NA with RA in concrete. This was true for all RAC mixes prepared and tested in this study. Slight improvement in tension stiffening effect was achieved by the addition of polypropylene fibers for both NAC and RAC mixes. RAC mix containing 50% RA and fibers exhibited β

factor almost similar to that of NAC. However, RAC mix containing 25% RA and fibers exhibited β factor even greater than that of NAC mix.

• Replacement of NA with RA up to 100% showed insignificant effect on the composite yield load. Maximum reduction of 8% in yield load was exhibited by RAC containing 75% and 100% RA. Addition of polypropylene fibers in concrete did not show any positive effect on composite yield load.

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Abbreviations

RA	Recycled Aggregates
NA	Natural Aggregates
RAC	Recycled Aggregate Concrete
NAC	Natural Aggregate Concrete
C&D	Construction & Demolition