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Structural Behavior of Recycled Aggregate Concrete Continuous Beams

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Abstract

The structural behavior of continuous recycled aggregate concrete (RAC) beams under point loading at each span is examined experimentally in this work. Nine continuous beams, each 225 mm deep, 150 mm wide, and 3000 mm long, were tested as part of the program. As references, there were two beams made of normal concrete, one intended for shear failure and the other for flexural failure. Three beams were cast with different replacement ratios of recycled concrete Aggregate (20%, 40%, and 70%) to assess the effect of RAC content. The impact of RCA placement was also investigated using two flexure-critical beams and two shear-critical beams, each developed with a particular recycled aggregate location. The main experimental parameters included steel fiber, the position of recycled Aggregate, and the ratio of recycled aggregate replacement.

According to the results, recycled Aggregate reduced the ultimate load by up to 5.38%. On the other hand, the ultimate load increased by as much as 10% when steel fiber was added. Additionally, flexural strength was reduced by up to 10% when recycled Aggregate was moved within beams intended for flexural failure. In contrast, shear-critical beams had a shear strength drop of up to 23% when the same modification was made.

Keywords: Continuous beam, Recycled Aggregate, Steel fiber, Shear strength, Flexural strength,

1. Introduction

The main structural component that can support and transfer load is a beam, which is mainly designed for shearing and bending. The structural member that provides resistance against bending when the load is applied is a continuous beam. A continuous beam is primarily utilized in bridges. A continuous beam containing three supports speared along the whole length of the beam. The spans located between the supports are in one straight line, and these supports are located at the same horizontal level (1)

The need for construction and infrastructure projects is growing quickly, which has raised interest in concrete mix designs that are inexpensive, efficient, and ideal. Nevertheless, it releases 1,183 million tonnes of construction trash annually worldwide, raising related environmental concerns. This creates the need for a more sustainable strategy to protect the environment by conserving resources and lowering the quantity of landfill space needed. (2)

India's industrialization has led to a very rapid increase in urbanization. India's GDP is growing at a rate of 9%. Growing infrastructure quickly requires a lot of space, location, and building materials. Because of its higher performance, longer lifespan, and reduced maintenance needs, concrete is the material of choice for large-scale construction projects. New towers are constructed to raise the GDP rate, while smaller buildings are demolished. Environmental protection is a critical part of human survival. (3)

The most significant waste in human history has been produced due to the consumer society and the technological revolution. Due to this issue, most countries seek ways to reduce pollution levels. [4]. Landfill disposal has been the most widely used technique for handling waste debris. Large amounts of construction waste are thus produced, which leads to a unique issue of environmental contamination caused by humans. [5]

Recycling damaged concrete to substitute Aggregate for structural concrete is one technique that could address these issues. Recycled concrete Aggregate (RCA) is typically created by two-stage crushing destroyed concrete, followed by screening and removing impurities such as reinforcement, paper, wood, plastics, and gypsum. [5]

Recycled Aggregate (RA) is extracted from demolition and building crushing debris. When it contains crushed concrete, more aggregate than usually is recycled (RA), or a significant proportion of materials other than crushed concrete, it can be referred to as recycled concrete Aggregate (RCA) [6]. The natural aggregate shortage, residual concrete removal, and other environmental issues can all be solved successfully with RAC. [3]

Based on examples of structural behavior (behavior under flexural conditions, shear, bond, compression, etc.), recycled aggregate concrete (RAC), which is primarily used for nonstructural purposes (aggregates in granular base or sub-base applications, for embankment construction, and earth construction works), has the potential to be applied over a wide range of structural member types. Nevertheless, not much research has been done on the structural behavior of RC members. [7]

Building on the introduction's emphasis on the urgent need for environmentally friendly building materials, it is crucial to conduct a comprehensive analysis of the body of information currently available on recycled aggregate concrete (RAC). Although using recycled aggregates has obvious environmental benefits, it is essential to carefully assess how they may affect concrete's basic mechanical characteristics and structural performance. As a result, the following part offers a thorough analysis of earlier studies, describing the impact of recycled aggregate incorporation on several concrete properties and structural behaviors. However, there is a disadvantage to using recycled Aggregate. The disadvantage of using recycled Aggregate is:[8]

1-When recycled Aggregate is obtained through demolishing concrete, it may be contaminated with gypsum plaster, which causes a high sulfate content within the recycled concrete, affecting the reaction when reusing concrete.

2-elastic and plastic energy capacity and toughness decrease with increased recycled Aggregate in a concrete mixture.

3-Possibility of interaction with alkaline water, and the result of this reaction can cause cracks and partial damage to the concrete.

4-lower quality due to a 10–30% decrease in compressive strength.

5-inflation in the cost because of the requirement of unique equipment as well as land

6-significant absorption of water, up to 6%.

7-Higher creep and drying shrinkage

From the past until the present day, various investigations have been carried out to study the performance of beams with recycled Aggregate. In 2007, etxeberria, M. et al. [9] examined the potential application of RCA as a structural component. For that reason, an experimental investigation into the shear behavior and capacity of beams composed of RCA was carried out. The percentage of recycled concrete aggregate replacement used was (0%,25%,50%, and 100%). The test findings showed that the percentage of recycled Aggregate is less than 25%, which has less influence on the shear-carrying capacity of specimens, as long as all measures attached to durability and dosage aspects have been adopted. In 2009 Kou, S.C. and Poon, C.S,[10] investigated the hardened and fresh characteristics of SCC by utilizing recycled Aggregate as both fine and coarse. The findings show that the SCC properties produced from crushed fine recycled aggregates and river sand showed only a slight difference. In 2010, Malešev, M. et al. [5] studied the properties of fresh and hardened concrete with varying natural and recycled coarse aggregate replacement ratios. Three percentages of recycled Aggregate were used: concrete produced completely with NCA as the control specimen, and the other specimens' percentage of coarse recycled Aggregate of 50% and 100% as a replacement ratio of coarse crushed Aggregate. The test findings showed that the elasticity models of concrete increased with decreases in the ratio of the recycled Aggregate because the elasticity modulus of recycled Aggregate is smaller than the elasticity modulus of natural Aggregate. In 2012, Bhikshma, V., and Manipal, K.,[11] studied the mechanical properties of recycled aggregate concrete containing steel fiber. The beam with steel fiber appeared to have significant increases in compression strength, tensile strength, flexural strength, and electrical modules for recycled aggregate concrete. In 2013, Hameed, S.A.,[12] studied the effect of using steel fiber and the RCA made by the destruction of concrete as a coarse aggregate on the mechanical properties of concrete. The test results show that the tensile and compressive strength will decrease as the percentage ratio of recycled aggregate increases. However, the mixture with steel fiber increased tensile and compressive strength. In 2013, Khudair and Mahdi [13]studied the performance of structural concrete produced with RCA as a partial replacement of natural Aggregate. The experimental work results exhibited that the specimen produced with RCA showed (12%) higher deflection than the specimen produced with normal concrete and almost identical ultimate moment capacity.

In 2014, Kosior-Kazberuk, M., and Grzywa, M., [14] studied an experimental program to analyze the effect of steel fiber on the load-strain performance of specimens produced with recycled Aggregate. The experimental results showed that the specimens that included recycled aggregate and steel fibers improved mechanical strength and modified the flexural performance and fracture behavior compared to specimens with recycled Aggregate. In 2016, Rangel, C.S. [15]investigated the effect of employing Recycled Concrete Aggregates (RCAs) in beams loaded in bending. The findings exhibited that for both high and normal-strength concrete under study, employing recycled Aggregate influenced neither the findings of the structural behavior nor the mechanical materials characteristics of the tested sample. In 2016, Salman, M.M. et al. [16] studied the influence of steel fiber and RCA on reinforced beams' shear and flexural performance. The test findings exhibited that the ultimate carrying capacity (pu) of beams produced with natural Aggregate is approximately similar to the findings of beams made with recycled Aggregate. The ultimate capacity decreased by about 10.1% and 6.2% for shear and flexural performance, respectively. Using steel fiber in the mixture of concrete beams led to increases in the maximum deflection by about 31.7% for shear and 38.55% for flexure. In 2018, Seara-Paz et al. [17] investigated the flexural behavior of beams with recycled Aggregate exposed to the load until failure. The test results show that conventional concrete's yielding, service, and ultimate state generally behaved like recycled concrete. However, the carking performance exhibits differences between the conventional and recycled Aggregate.Kovacs, R., et al (2019) [18]. Presented experimental work to assess the age of the original concrete and the percentage of recycled aggregate replacement on the tensile and compressive strength of recycled Aggregate at 14,7 and 28 days. The test results exhibit that tensile and compressive strength decreased for all ages when the percentage of recycled Aggregate increased. In 2020, Yang, I.H. et al. [19] investigated the effect of recycled Aggregate on concrete beams' structural behavior. The experimental work results showed that the crack pattern of the specimens with NCA is identical to the crack pattern of the specimens with RCA; despite that, the specimens with NCA showed larger crack spacing than the RCA specimens. The recycled aggregate percentage slightly influenced the flexural strength of the specimen.

Nevertheless, the beam ductility was not considerably affected by recycled aggregate contents. In 2022, Elsadany R. et al. [20] investigated the flexural performance of Recycled Aggregate Concrete Beams with Reinforcement with various ratios of steel and GFRP areas. The test findings exhibit that the beam containing recycled Aggregate reinforced with GFRP showed a lower first crack, lower ultimate load, and higher deflections. In 2023, Hemida, O.A.R., (21) investigated the flexural behavior of beams that were strengthened by CFRP and contained recycled concrete Aggregate. The test results exhibit that when the replacement ratios of recycled concrete Aggregate were increased, the carrying capacity of the beams decreased, for recycled aggregate ratios 50%, 25%, and100%, the drop in carrying capacity in beams was 25.5%,4.8%, and 26.5%, respectively relative to control beam without recycled Aggregate.

Previous studies have demonstrated limited structural behavior of continuous beams with recycled Aggregate. It can also be noticed that most studies investigated the structural behavior of beams with recycled Aggregate. The objective of this research is to experimentally examine how continuous recycled aggregate concrete (RAC) beams behave structurally under point loading at each span, paying particular attention to the following crucial elements: Impact of the Replacement Ratio for Recycled Aggregate:

Analyze the effects of varying recycled concrete aggregate (RCA) replacement ratios (20%, 40%, and 70%) on the continuous beams' ultimate load capacity, flexural strength, and shear strength. Impact of RCA Positioning: Examine the effects of recycled aggregate placement on structural performance, especially in the beam's flexure- and shear-critical zones. Effects of Reinforcement with Steel Fiber: Examine whether adding steel fibers can increase the load-bearing capability and counteract any possible RCA-induced strength losses.

Advantages of the Research:

Sustainability Advancement: By lowering the need for natural aggregates and cutting down on building waste, the study encourages using recycled concrete Aggregate (RCA), thus promoting sustainable construction.

Performance Insights: Although RAC beams' structural capacity has somewhat decreased, they nevertheless exhibit respectable performance, particularly when replacement ratios are moderate (20%–40%), which makes them suitable for structural use in some applications.

Effectiveness of Steel Fibers: By adding steel fibers, the ultimate load capacity is increased by up to 10%, which helps to compensate for the strength loss brought on by RCA and increases the toughness of RAC beams.

New to This Research:

Focus on Continuous Beams: This work explicitly examines continuous RAC beams under dual-point loads, which is more indicative of actual structural systems than most prior research, which focuses on simply supported beams.

Examining the effects of recycled aggregate placement (in compression versus tension zones) on beam performance under flexural and shear-critical circumstances is a novel approach. This is an area that has received little attention in the past.

Combined Effects of RCA Ratio, Location, and Steel Fibers: This study offers a more thorough knowledge of how various parameters affect beam behavior by evaluating the combined effects of RCA ratio, placement, and steel fiber inclusion.

2. Materials and Methods

2.1 Material properties

The cement used is ordinary Portland cement (salt resistance cement), named taluka cement. The chemical and physical properties of cement are listed in Tables 1 and 2, respectively. Natural sand taken from the sea of Najaf is used as fine Aggregate. The result of the sieve analysis is listed in Table 3. Crushed gravel was utilized as coarse Aggregate. The size of the gravel is 5-19mm. It was washed with water and dried in the air. Table 4 shows the results of the sieve analysis. Recycled Aggregate used in this study was prepared from the destruction of old normal concrete, then crushed by hand to different sizes to get the same maximum size of natural Aggregate (5-19). After that, a sieving analysis test was performed, and the results are listed in Table 5. Sika Viscocrete-905 S is used in all mixtures as a high-water-reducing mixture. Properties of superplasticizers are listed in Table 6. Hooked steel fiber was used in this study. Figure 1 exhibits the steel fiber used in this experimental work. The properties of steel fiber are listed in Table 7. Sikalatex SBR used in this study is a super-modified styrene-butadiene emulsion mixed with cement slurry, cement mortar, concrete, or cementitious grout for improved adhesion and water resistance properties. The properties of SBR are listed in Table 8. Sika Antisol WB is a ready-to-use, solvent-free, water-based liquid curing compound that prevents the evaporation of mixing water in concrete. Table 9 shows the properties of Sika antisol WB. The result of the steel bar is listed in Table 10.

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Table 1: Physical properties of cement

Physical property	Test result	Limit Iraqi specification No.5/1984
Specific surface area, Blaine method (m^2/kg)	317	Not less than280(m^2/kg)
Initial setting time (Vicat minute)	103	Not less than 45 minutes
final setting time (Vicat minute)	4:11	Not more than 10 hours
Compressive strength at age (2 days) N/mm^2	17.3	Not less than 10 N/mm^2
Compressive strength at age (7days) N/mm^2	29.87	Not less than 23 N/mm^2

Table 2: Chemical properties of cement

Chemical compound	Test result	(IQ.S No.5/1984
SiO2	19.3	--------------------
Cao	61.38	--------------------
Fe_2 O3	5.04	-------------------
MgO	3.84	Not more than 5%
SO3	2.22	Not more than 2.5%
Al2O3	19.3	-----------------
Insoluble residue	0.44	Not more than 1.5%
Loss on ignition	3.7	Not more than 4%
C3A	2.41	Not more than 3.5%
C3S	41.3%	------------------
C2S	26.841	------------------
C4AF	10.6%	-----------------
M.S	2.15	--------------------
M.A	1.7	-------------------
Free lime	0.63%	----------------

Table (3) Sieve analysis of fine aggregates

Sieve size	Percent passing%	Iraqi specification (IQ.S NO 45/1984
10	100	100
4.75	99	90-100
2.36	95	85-100
1.18	81	75-100
0.6	67	60-79
0.3	25	12-40
0.15	5	0-10

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Table (4) sieve analysis of coarse Aggregate

Sieve size	Percent of passing%	Iraqi specification (IQ.S NO 45/1984 (5-20)
75	100	-
63	100	-
37.5	100	100
20	95	95-100
10	40	30-60
5	1	0-10

Table (5) Sieve analysis of recycled coarse Aggregate

Sieve size	Percent Passing	Iraqi specification (IQ.S NO 45/1984 (5-20)
75	100	-
37.5	100	-
19	95	95-100
9.5	32	30-60
4.75	7	0-10
pan	0	-
SO3	0.03%	Not more than1

Table (6) Properties of superplasticizer

Composition	Aqueous solution of modified polycarboxylates
packaging	1000LTRs IBS 20Kg pail
Shelf life	12 months from the date of production if stored properly in undamaged, unopened, original sealed packaging
Storage conditions	In dry conditions at temperatures between +5 C and +35. Protect from direct sunlight. It requires recirculation when held in storage for extended periods.
Appearance and color	Light brownish
Specific gravity	1070± (0.02) g/cm^3
Ph- value	4-6

Table (7) Properties of steel fiber

property	specification
shape	Hooked end
length	35
diameter	0.5
Aspect ratio	70
Density	7850
Tensile strength (MPa)	1100

Table (8) Properties of SPR

Chemical base	Styrene butadiene rubber (latex) emulsion
packaging	250g, 500g, 1kg, 5kg, 10kg, 20kg, 100kg container
Shelf life	18 months from the date of production
Storage conditions	The product must be appropriately stored in undamaged and unopened original sealed packaging, in dry conditions at temperatures between +5 C and +35 C., protected from frost and direct sunlight.
Appearance	Liquid/milky white
Specific gravity	1.02
Ph-value	8±1
Tensile adhesion strength	>1.5MPa (concrete failure)

Table (9) properties of sika antisocial wb

composition	Aqueous solution of acrylic copolymer dispersion
packaging	20L cans 200L drums
appearance	White milky liquid
Shelf life	12 months from the date of production if stored properly
Storage conditions	Store in undamaged, unopened, original sealed packaging in dry conditions at temperatures between +5C and +45C. Protect from direct sunlight, heat, moisture, and frost
density	1.00kg/l(+25C)
consumption	The coverage depends on wind, humidity, and temperature as a general guide 0.2-0.5 kg/m^2
Ambient air temperature	+5C min /+50C max

Table (10) test result of steel

Bar diameter mm	Actual bar diameter mm	Ultimate tensile strength (MPa)	Yield strength (MPa)	Elongation mm	ASTM A615 Requirements			
					grade	Min Yield Strength (MPa)	Min Tensile Strength (MPa)	Min elongation
8	7.9	646	500	21%	60	420	620	9
10	9.9	676	589	11.5	60	420	620	9

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Fig (1) steel fiber

2.2 trial mixes

Six trial mixes were made, the first produced with normal concrete with a compressive strength equal to 34 MPa. The second one is made for concrete with a 20% percentage of RCA. The third mix includes casting concrete with 40% recycled aggregate. The fourth one includes casting concrete with 70% recycled coarse Aggregate. The fifth trial mix includes casting the concrete with 40% RCA and 1% steel fiber. The sixth one includes only RCA with a 100% percentage ratio of RCA. For each mix, six cubes were cast, 3 testing after 7 days and the other 3 testing after 28 days. For each mix, three cylinders were cast and tested after 28 days. The trial mix was made to achieve a mix of the optimum properties in hardened concrete. The quantities of the materials used in the concrete mix are listed in Table 11. The result of tensile strength is listed in Table 12

Table 11: The quantities of the materials used in the concrete mix of NC and RCA

mix	R%	Cement kg/m^3	fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	Water L/m^3	Recycled Aggregate kg/m^3	Steel fiber kg/m^3	Admixture (L/m^3)	FC 28 days	FC 7 days
1	0	400	704	1056	180	0	0	1	30	25
2	20	400	704	845	180	211.2	0	1	23.4	18.64
3	40	400	704	634	180	422.4	0	1	23.3	19.23
4	70	400	704	317	180	739	0	1	22.2	17.96
5	40	400	704	634	180	422.4	78	1	31.2	25.54
6	100	400	704	0	180	1056	0	1	22.03	17.23

Table (4-2) Results of tensile strength for different replacement ratios of RCA

Spacemen name	ft
R0%	2.891
R20%	1.604
R40%	1.427
R70%	1.313
R100%	1.22
R40%V	4.15

2.3. experimental procedure

The experimental work includes casting 10 RC continuous beams. One beam is cast from normal concrete without recycled Aggregate and is treated as a reference for the other beams. The other specimens are cast to examine the effect of using RCA as a partial replacement for coarse Aggregate. All the beams have dimensions 150mm wide x 225 mm deep x 3000mm long, consisting of two equal spans of 1400mm for each span. They were tested under a two-point load. The type of reinforcement bars is 3Ø10 at the top and bottom. The top and bottom covers are 25mm. The compressive strength of concrete was about 34.08. The dimensions and reinforcement of the continuous control beam are shown in Fig (2).

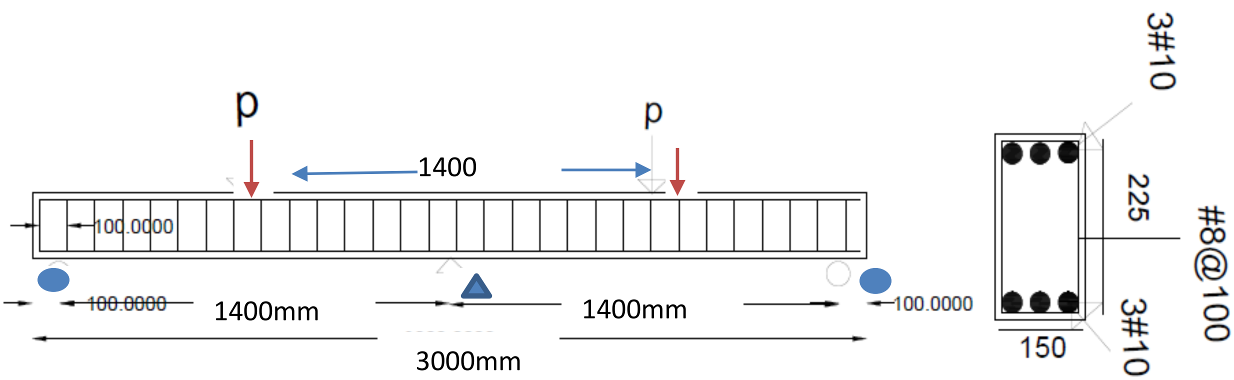

Fig (2) Dimension and reinforcement of the control continuous

Group one contains the control beam as a reference beam for other beams in the group. The second beam in this group includes a 20% replacement ratio of RCA, while the third beam contains a 40% percent ratio of RCA. The last beam consists of a 70% replacement ratio. The details of group one are listed in Table (13).

Tables (13) details of group one

sample	Percent Ratio of RCA	Top reinforcement	Bottom reinforcement	Type of loading	note
BR0F1	0%	3Ø10 steel	3Ø10 steel	Monotonic load	Change the percentage ratio of RCA
BR20F1	20%	3Ø10 steel	3Ø10 steel		
BR40F1	40%	3Ø10 steel	3Ø10 steel		
BR70F1	70%	3Ø10 steel	3Ø10 steel		
BR40VF1	40%	3Ø10 steel	3Ø10 steel		Add steel fiber

Group two consists of three beams divided according to the location of RCA. The first beam is the control beam, which is treated as a reference beam for other beams. The second beam in which RCA is at the top layer at a depth of 112.5 from the top, while the third beam, in which the RCA is located at the bottom layer. The details of group two are listed in Table (14).

Table (14) details of group two

sample	Percent Ratio of RCA	Top reinforcement	Bottom reinforcement	Type of loading	note
BR0F1	0%	3Ø10 steel	3Ø10 steel	Monotonic load	Change the location of RCA for flexural
BR100TF1	100% at the top layer	3Ø10 steel	3Ø10 steel		
BR100BF1	100 at the bottom layer	3Ø10 steel	3Ø10 steel		

Group three contains three specimens. The first one, treated as a reference beam for the group, includes the exact details of the control specimen (the specimen failed in flexural). Still, it differs in design (the specimen was designed to fail in shear rather than flexure). The details of this group are similar to those of Group Two, but the specimen's failure mode is shear in this group. The details of Group Three are listed in the Table (15).

Table (15) details of group three

sample	Percent Ratio of RCA	Top reinforcement	Bottom reinforcement	Type of loading	note
BR0F1	0%	3Ø10 steel	3Ø10 steel	Monotonic load	Change the location of RCA for shear
BR100TS1	100% at the top layer	3Ø10 steel	3Ø10 steel		
BR100BS1	100 at the bottom layer	3Ø10 steel	3Ø10 steel		

The experimental work includes casting one beam similar to a specimen that contains 40% RCA, but, in this case, the specimen consists of 1% steel fiber The details of beam failure in shear are shown in Fig (3), and the location of RCA at the top layer and bottom layer are shown in Fig (4).

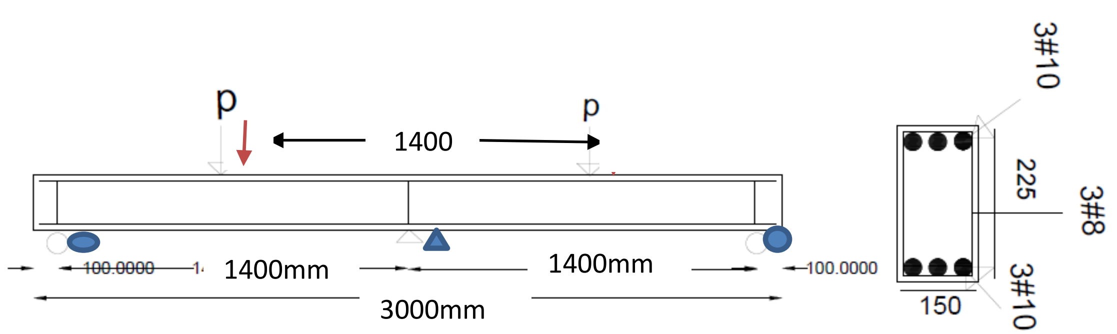

Fig (3) details of beams failed in shear

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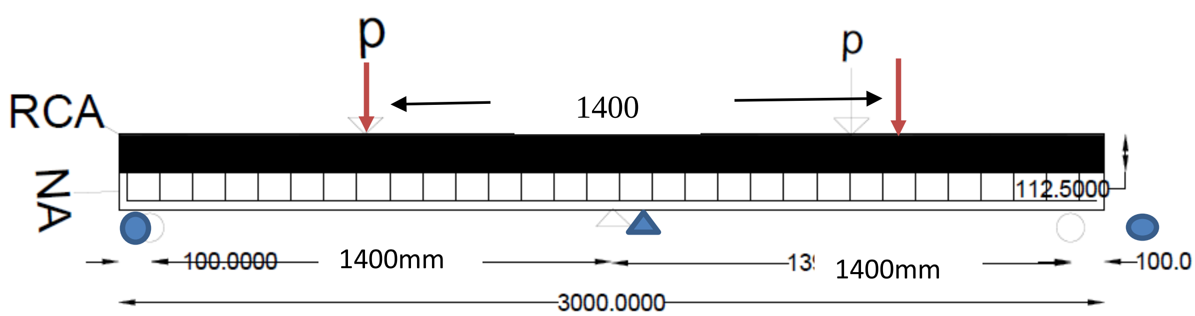
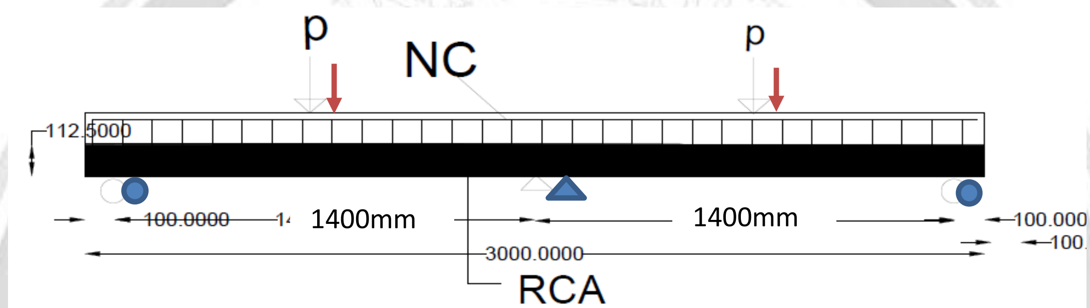
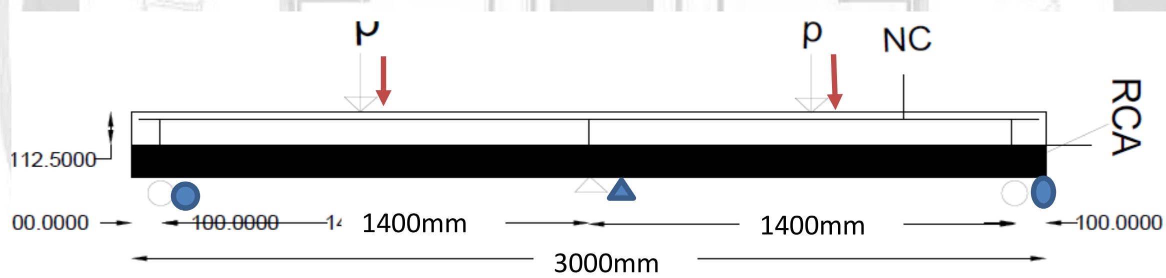


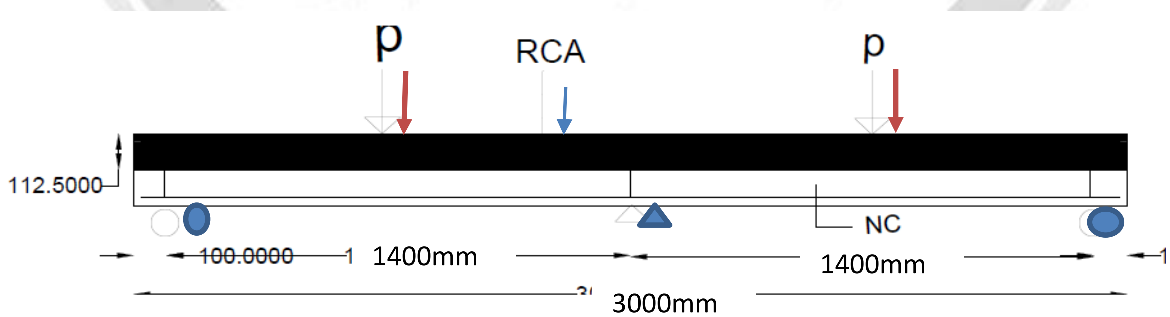
a) The location of RCA at top layer of concrete (flexural behavior)



b) The location of RCA at the bottom layer of concrete (flexural behavior)



c) The location of RCA at the bottom layer of concrete (shear behavior)



d) The location of RCA at the top layer of concrete (shear behavior)

Fig (4) location of RCA

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According to this study, two main bonding types apply to concrete:

The recycled aggregate concrete's (RAC) interfacial transition zone (ITZ): This link forms between the recycled aggregate particles—including, particularly, old, attached mortar—and the fresh cement paste. Composite Interface Bond (if applicable): When many concrete mixes (such as normal concrete and RAC) are cast together inside a single beam due to the placement of recycled Aggregate in particular places, a monolithic bond forms at their interface during the casting process.

3-test setup

After 28 days, the specimens were painted white before testing to distinguish the crack propagation. A universal testing machine tested the 10 continuous beams at the University of Kufa. The capacity of the machine is 2000 kN. A bearing plate was put under each point load to distribute the load from rigid beam to beam, as shown in Fig (5(b)). The continuous beam is fixed above three supports, two roller supports (achieved by using steel shift) at a distance 100 from the edge of the beam, and a hinged support at the center of the beam. To avoid crushing the concrete, the rubber plate with dimensions (100x150x6mm) and the bearing plate with dimensions (100x150x15mm) were utilized at supports, as shown in Fig (6(c)). The deflection was measured using 2 dial gages with an accuracy of 0.01 fixed at each mid-span of the continuous beam. A blackboard pen was utilized to indicate the propagation of the crack. The setup of the beam is shown in Fig (5(A)). A crack meter was used to measure the crack width.

A) preparation of the specimen for testing

b) loading point

C) supporting point

Fig (6) test setup

4. Conduct the test

Before starting the test, a data logger was run to record the load. The load read every 5kN until the first crack was noticed; the load increment was raised to 10kN. The crack propagation was drawn every 5 kN, and the deflection was read every 10-load increment. Crack width was measured at every load step. At the end of the, the beam loaded up to failure occurred. Then, the data logger captured the data and stored it in the computer.

5. Test result and discussion

5.1 Effect of changing the replacement ratio of recycled Aggregate and adding steel fiber

To examine the effects of changing the recycled concrete aggregate (RCA) replacement ratio, four beams were made: a control beam with a 0% replacement ratio of RCA (BR0F1) and three with RCA replacement ratios of 20%, 40%, and 70% (designated BR20F1, BR40F1, and BR70F1, respectively). The result in Table 16 shows a decrease in the ultimate load of about 5.38% for the beams BR70F1, compared with beam BR0F1The inherent weakness of the recycled aggregates themselves is the main reason why recycled aggregate concrete (RAC) usually exhibits a slight decrease in ultimate load, specifically: Adhered Mortar: Old cement mortar is affixed to the surfaces of recycled aggregates. This older mortar is frequently weaker and more porous than virgin Aggregate. Weaker Interfacial Transition Zone (ITZ): Unlike traditional concrete, the link between the recycled Aggregate and the new cement paste, including its old mortar, frequently creates a weaker and more porous ITZ. This "double ITZ" may result in microcracking and weakened bonds. Microcracks: The aggregate particles' overall strength may be decreased by introducing new microcracks during the crushing process used to create recycled aggregates. In contrast, the specimens BR20F1 and BR40F1 didn't show any reduction compared with specimens without recycled Aggregate. Beams with RCA experienced a smaller drop in ultimate load capacity than the control beam (BR0F1), which did not have RCA. This behavior may be attributed to the fact that the yielding of the steel reinforcement primarily controls the flexural failure mode rather than the concrete's compressive strength, which is usually more sensitive to the recycled aggregate quality. Adding steel fiber (with a volume fraction of about 1%) in specimen BR40VF1 led to an increase in ultimate load of about 10% compared with BR40F1. Concrete becomes stronger when steel fibers are added, primarily because the fibers that span microcracks prevent them from spreading and widening. This is known as crack bridging. Improved Energy Absorption: They increase ductility and toughness by absorbing energy during cracking. Better Post-Cracking Behavior: Fibers maintain residual strength even after concrete cracks, carrying loads.

5.2 Effect of changing the location of RCA (at comparison or tension locations)

Changing the recycled concrete Aggregate (RCA) 's position reduces the continuous beams' load-carrying capacity. Table 15 demonstrates that beam BR100TF1 and beam

BR100bF1 have an ultimate load reduction of approximately 5.8% and 10%, respectively, compared to the control beams BR0F1.changing the location of RCA has a negative effect on the ultimate load of the continuous beam designed to fail in shear. Table (16) shows that the decrease in ultimate load is about 11.5% and 23% for beams BR100TS1 and BR100bS1, respectively, compared with BR0S1. Because recycled concrete Aggregate (RCA) has worse mechanical qualities (e.g., lower strength, more porosity, weaker ITZ) than natural Aggregate, changing the RCA position lowers the load-carrying capability of a continuous beam. This weaker material's placement in highly stressed areas reduces the section's overall load-carrying capacity. It minimizes the section's ability to withstand those forces, especially in tension zones (which affect flexural strength) or shear zones (which affect shear strength), where the concrete matrix is crucial.

The reduction in carrying capacity of specimen BR100bs1 is about 13% compared with specimen BR100TS1. The results show that using recycled Aggregate in the compression zone is better than using it in the tension zone. Because concrete is naturally considerably stronger in compression than tension, it is preferable to use recycled Aggregate in the compression zone rather than the tension zone. The load-carrying capacity of the beam is significantly reduced, and its cracking behavior is worsened, when the comparatively weaker recycled aggregate concrete is placed in the already weakened tension zone. Table (16) details the load and deflection for specimens under monotonic load.

Specimen name	Pu(Kn)	Increase and decrease %in pu	Max deflection(mm)	Service deflection(mm)
BR0F1	223	----------------	14.8	6.2
BR20F1	223	----------------	17.25	6
BR40F1	223	----------------	22.35	6
BR40VF1	245	10%	22.39	5.1
BR70F1	211	-5.38%	22.4	6.5
BR100TF1	210	-5.8%	18.89	6
BR100BF1	200	-10.3%	8.35	5.7
BR0S1	130	--------------	6.22	4.8
BR100TS1	115	-11.5	17.1	3.5
BR100bS1	100	-23%	14.47	4.3

6-crack patterns

Specimen BR0F1 was considered the control beam for this group, which used conventional concrete without steel fibers. When the load is applied gradually, a flexural crack appears at a load of 25 kN (11% of the ultimate load) at the mid-span of the beam. As the load increased, new cracks formed at the middle support section at 50 kN (22.4% of the ultimate load), and existing cracks propagated vertically and widened. Then, the inclined tensile crack appears at mid-span and at the middle support at 100 kN (45% of the carrying capacity). After that, at 210kN (94% of the ultimate load), the formation of cracks stopped, and the first crack widened until the flexural failure load occurred at the middle support at 223kN. The crack pattern and failure mode for specimen BROF1 are shown in Fig (7). Because tensile cracks began, propagated, and widened considerably in the tension zones (mid-span and middle support) as the load increased, the continuous beam with normal concrete (BR0F1) displayed flexural failure (tension failure). According to the description, the cracks widened until flexural failure occurred, suggesting that the steel reinforcement's tensile capacity was reached and utilized, resulting in the ductile failure typical of tension-controlled flexural failure in under-reinforced concrete beams.

Fig (7) crack patterns and failure mode of specimen BR0F1

In Group 1, the first crack appears in the mid-span region and at the middle support of the specimen. As the load increased, the crack initially propagated and widened, and a new inclined crack emerged as the load continued to rise. The inclined crack extended to the compression zone and widened. After that, new cracks appeared in the mid-span region and middle support zone, and the existing crack propagated toward the compression zone until it occurred. The failure of the specimen in group one is due to compression failure, except for specimen BR70F1, which failed in flexure. The failure mode and crack pattern are shown in Fig (8---10). Table (17) shows the results of Group one. The majority of Group 1 specimens experienced compression failure due to the recycled aggregate concrete (RAC) in the compression zone crushing prematurely, despite having reached its maximum compressive strength. This occurred before the tensile reinforcement could completely yield or rupture, suggesting that the ultimate load-carrying capacity of the beam was limited by the concrete's compressive capacity, which is normally weakened by recycled aggregates (because of lower ITZ, higher porosity, and decreased inherent strength).

Fig (8) The failure mode and crack pattern for specimen BR20F1

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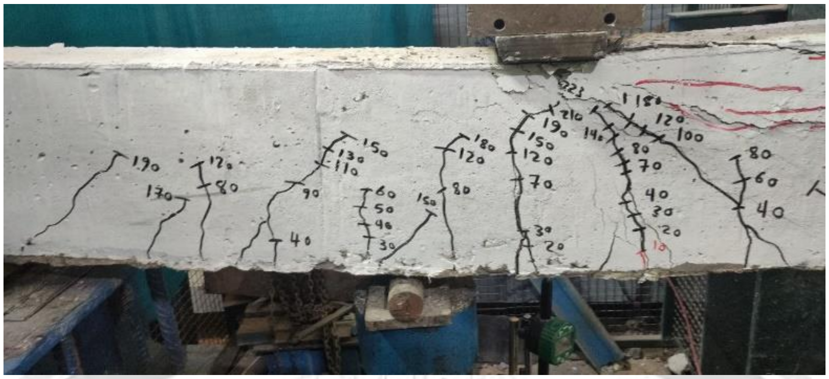

Fig (9) The failure mode and crack pattern for specimen BR40F1

Fig (10) The failure mode and crack pattern for specimen BR40F

Table (17) Results of group one

specimen	Pcr (kN)	Decrease/ Increase in PCR %	Pu (kN)	Decrease/ Increase in pu%	Mode of failure
BR0F1	25	--------	223	-----	flexural
BR20F1	30	20	220	-1.3	Flexural+ compression
BR40F1	10	-60	223	0	Compression
BR70F1	15	-40	210	-5.8	flexural

For group two, the initial crack in this specimen appeared mid-span in the tension zone. As the load increased, a new crack appeared in the positive moment region. As the load increased, a new inclined crack appeared on the left side of the positive moment region. After that, new cracks appeared at the middle support. Then, the initial crack and the existing crack propagated to the compression crack. At the late loading stage, the cracks ceased to appear, and existing cracks propagated and widened until failure occurred. All the specimens exhibit the same type of failure, which is compression failure..Because recycled aggregate concrete (RAC) has a weaker Interfacial Transition Zone (ITZ) and decreased compressive strength, stiffness, and ductility, the failure mode in RAC beams changes from ductile flexural (tension) failure in conventional concrete to more brittle compression failure.

In other words, because the RCA makes the concrete in the compression zone weaker by nature, it reaches its ultimate compressive strain and crashes before the tensile reinforcement can completely give and permit a ductile tension-controlled failure. Which particular area's weakness (compression vs. indirect effects in tension) determines this early compressive failure is further influenced by the shift in RCA placement (upper vs. lower). Fig (11) and Fig (12) show the crack patterns and failure mode of specimens BR100TF1 and BR100Bf. Table (18) shows the results of group two

Fig (11) Crack patterns and failure mode of specimens BR100bf

Fig (12) Crack patterns and failure mode of specimens BR100Tf

Table (18) result of group two

specimen	Pcr (kN)	Decrease in PCR %	Pu (kN)	Decrease pu%	Mode of failure
BR0F1	25	-----------	223	---------	flexural
BR40F1	10	-60	223	----------	compression
BR100TF1	15	-40	210	-5.8	compression
BR100BF1	20	-20	200	-10	compression

For group three, the specimens began to crack in the mid-span region. The first crack gradually increased in width when the load continued to be applied, and a new crack formed in the mid-span region. After that, the crack at the middle support appeared. The failure for all specimens is similar. When the applied load increased, a sudden shear failure occurred between the support and loading point. The crack pattern and failure mode are shown in Fig (13---15). Table (19) shows the test results for group three.

Fig (13) The crack pattern and mode of failure of specimen BR0S1

Fig (14) The crack pattern and mode of failure of specimen BR100bS1

Fig (15) The crack pattern and mode of failure of specimen BR100TS1

Table (19) result of group three

specimen	Pcr (kN)	increase in PCR %	Pu (kN)	Decrease pu%	Mode of failure
BR0S1	10	-----------	130	---------	shear
BR100bs1	20	100	100	-23	shear
BR100TS1	30	200	115	-11.5	shear

The decreased tensile strength, decreased stiffness, and weaker Interfacial Transition Zone (ITZ) of recycled aggregate concrete (RAC) are the main causes of the altered crack pattern, particularly the inclined ones. Because of these characteristics, RAC is more vulnerable to diagonal tension strains than normal concrete beams, which may lead to inclined (shear-related) cracks forming more quickly, spreading more widely, and possibly becoming more prominent.

7. load-mid span deflection

Load-deflection behavior for group one is shown in Fig (16). specimen, BR0F1, showed a linear load-deflection response. Figure 16 also shows that the specimens with lower RCA replacement ratios (20% and 40%) performed similarly to the control beam. However, the specimen with the highest RCA replacement ratio (70%) exhibited a different behavior. BR70F1 exhibited a higher deflection in the specimen than the control beam. This similar performance continued until a load of 200 kN. Beyond this point, the beams containing RCA exhibited increased deflection, reaching a load of 223 kN. At this load, the deflections of the beams with 20%, 40%, and 70% RCA were approximately 033%, 1%, and 11%, respectively, greater than the deflection of the control beam (BR0F1). In the control beam (BR0F1), the crack spread to the compression zone, causing a rapid increase in deflection. In contrast, RCA-containing beams produced more cracks than the control beam. This increased cracking contributed to the greater deflections noticed in the RCA sample. However, adding steel fiber decreased deflection by about 15% compared with specimen BR40F1, as shown in Fig (17).

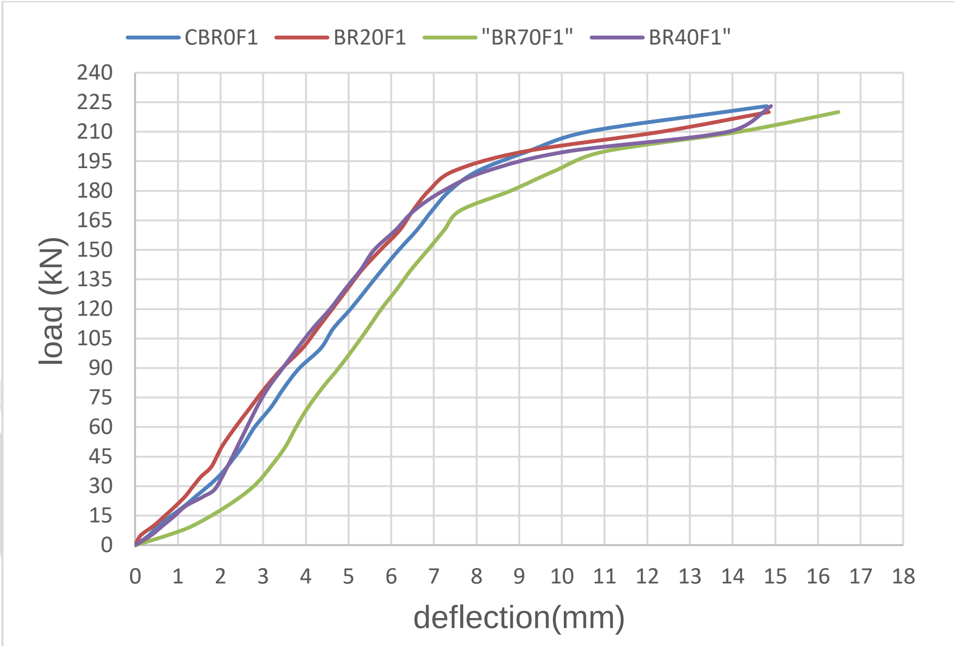

Fig (16) Effect of replacement ratio on the load-deflection curve

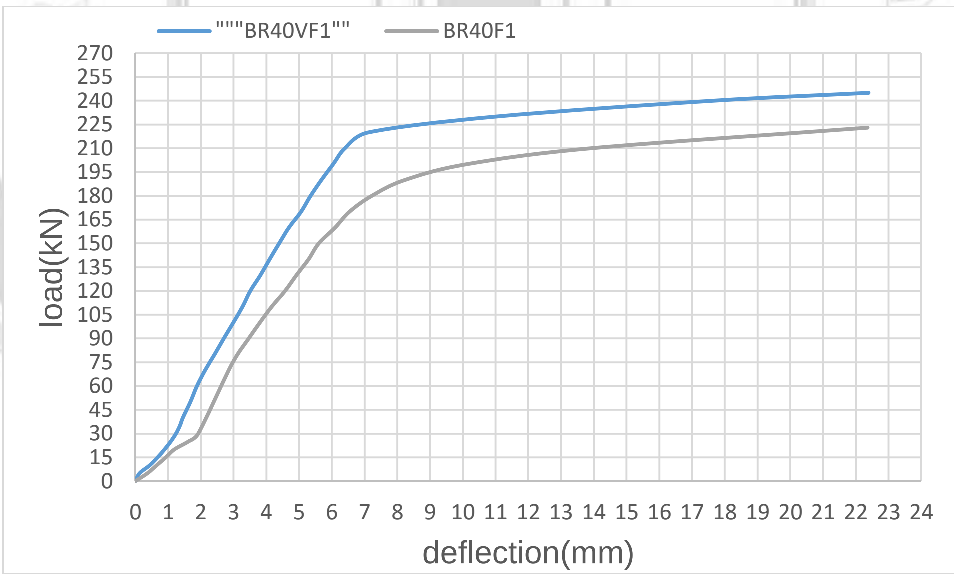

Fig (17) Effect of steel fiber on load-deflection curve

Figure 18 displays the load-deflection responses for the flexural specimens (BR40F1, BR100TF1, BR100BF1, and BR0F1), and Figure 19 shows the load-deflection performance of the specimens that were shear-tested (BR0S1, BR100TS1, and BR100BS1). Beam BR100TF1 (with RCA in the tension zone) showed a 27% more deflection in the flexural testing (Figure 18) than the conventional concrete reference beam, BR0F1. In contrast to BR100TF1, beam BR100BF1 (with RCA in the compression zone) displayed a 4.7% decrease in deflection. The presence of recycled aggregate in the tension zone, which is naturally an area of weakness in concrete, is the cause of this increased deflection, especially in BR100TF1.A noteworthy distinction was also noted for the shear-critical beams (Figure 19): the maximum deflection of beam BR100BS1 (RCA in the tension zone) was 16% greater than that of beam BR100TS1 (RCA in the compression zone).These findings consistently demonstrate that incorporating recycled aggregate into the compression zone of concrete beams enhances structural performance and deflection control compared to its use in the tension zone.

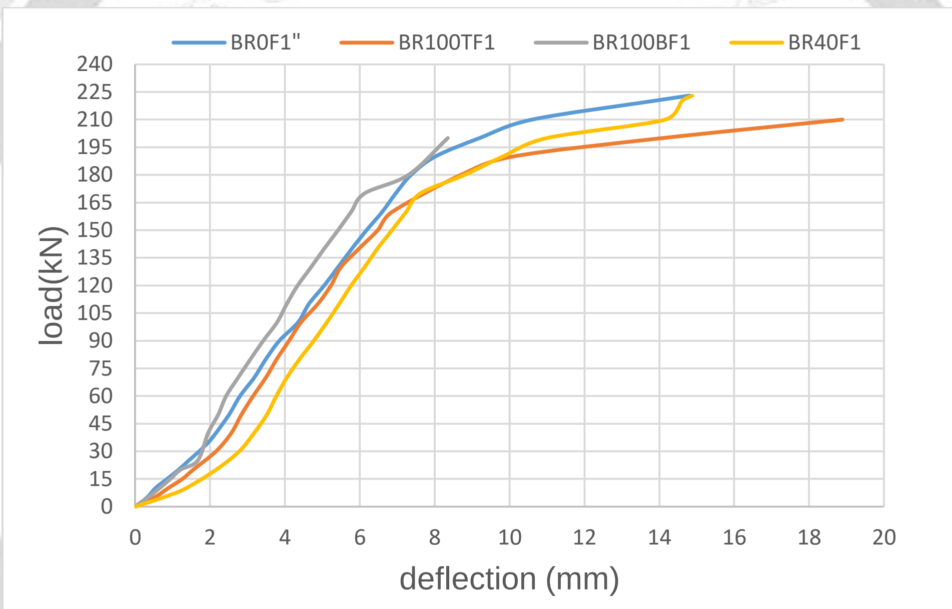

Fig (18) Effect of changing the location of RCA on flexural behavior

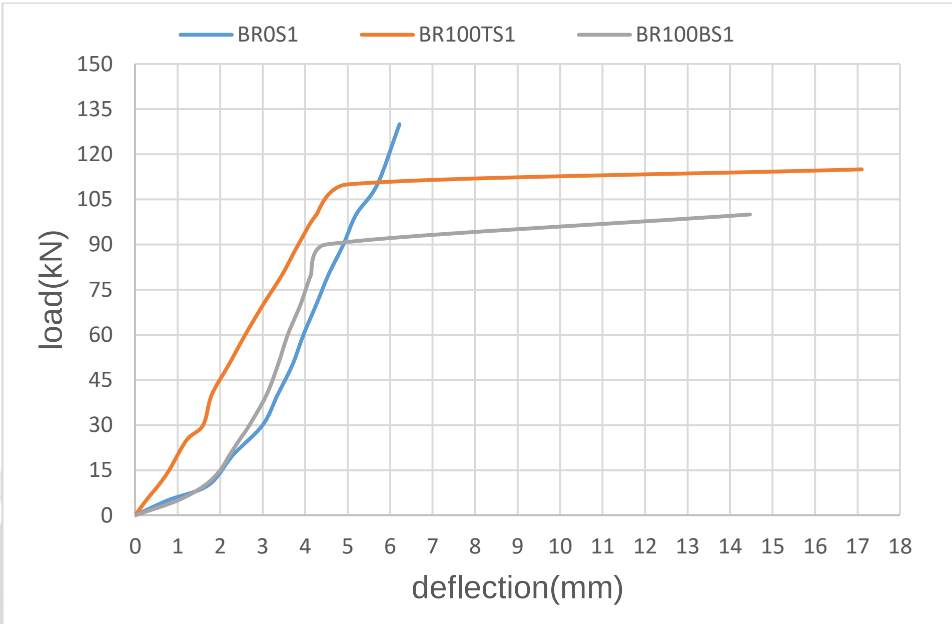

Fig (19) Effect of changing the location of RCA on shear behavior

8. Conclusion

This work includes an experimental study on the structural behavior of recycled aggregate concrete continuous beams under monotonic. From this study, the following conclusion can be drawn.

1- The specimen with recycled Aggregate showed a slight decrease in the ultimate load up to 5.38. This behavior may be attributed to the fact that the yielding of the steel reinforcement primarily controls the flexural failure mode rather than the concrete's compressive strength, which is usually more sensitive to the recycled aggregate quality.

2- Adding steel fiber (with a volume fraction of about 1%) led to an increase in ultimate load of about 10%. Steel fibers act as tiny reinforcement bridges across microcracks within the RCA concrete. This bridging action resists the propagation of cracks and requires more energy for the cracks to grow. This increased resistance directly translates to a higher ultimate load.

3- The beam specimen with recycled Aggregate in the compression zone and the specimen with recycled Aggregate in the tension zone have an ultimate load reduction of about 5.8% and 10%, respectively.

4- Changing the location of RCA in continuous beams that are designed to fail in shear has a negative effect on the ultimate load. The decrease in the ultimate load was about 11.5% and 23% for beams with recycled Aggregate at the compression zone and the specimen with recycled Aggregate at the tension zone, respectively.

5- Higher performance is typically achieved by dispersing the RCA along the full length of the beam rather than concentrating it in one place.

6- The deflection of the beam with 20%, 40%, and 70% RCA was about 16.5%, 51%, and 52%, respectively, greater than the deflection of the control beam.

7- Adding steel fiber (with a volume fraction of about 1%) led to a decrease in deflection of about 15%.

8- The deflection specimen with recycled Aggregate in the compression zone was 27% higher than that of the specimen without recycled Aggregate

11. References

[1] Arevalo M., and Distefano D., ***"What is* Continuous *Beam"*** Conjecture Corporation, 2013-2016.

[2] Aslani, F., Hou, L., Nejadi, S., Sun, J. and Abbasi, S., "Experimental analysis of fiber-reinforced recycled aggregate self-compacting concrete using waste recycled concrete aggregates, polypropylene, and steel fibers". *Structural Concrete*, vol.20,no.5, pp.1670-1683,2019.

[3] Zhou, C. and Chen, Z., "Mechanical properties of recycled concrete made with different types of coarse Aggregate", *Construction and Building Materials*, vol. 134, pp.497-506, 2017.

[4] Bravo-German, A.M., Bravo-Gómez, I.D., Mesa, J.A. and Maury-Ramírez, A., "Mechanical properties of concrete using recycled aggregates obtained from old paving stones", *Sustainability*. Vol.13,no.6, p.3044,2021

[5] Malešev, M., Radonjanin, V. and Marinković, S., "2010. Recycled concrete as Aggregate for structural concrete production", *Sustainability*, vol.*2*, no.5, pp.1204-1225.,2015.

[6] Ftnan, A. and Makki, R., "Behaviour of recycled aggregate concrete beams strengthened with FRP", *Kufa Journal of Engineering*, vol.13, no. 4, pp.13-2,2022.

[7] Kosior-Kazberuk, M. and Grzywa, M., " Recycled aggregate concrete as a material for reinforced concrete structures", *Journal of Sustainable Architecture and Civil Engineering*, vol.*2*, no.7, pp.60-66, 2014.

[8] Abdullah, "Influence of Concrete Strength Including Recycled Aggregate on Beam Torsional Behavior". PhD thesis, University of Technology, Baghdad, Iraq,2018.

[9] Etxeberria, M., Marí, A.R. and Vázquez, E., "Recycled aggregate concrete as a structural material", Materials and structures, Vol 40, pp.529-541,2007.

[10] Kou, S.C. and Poon, C.S., "Properties of self-compacting concrete prepared with coarse and fine recycled concrete aggregates", *Cement and Concrete composites*, vol.31, no.9, pp.622-627,2009.

[11] Bhikshma, V., and K. Manipal, "Study on mechanical properties of recycled aggregate concrete containing steel fibers" ,Asian Journal of Civil Engineering (building and housing), vol.13, no.2, pp.155-164,2012.

[12] Hameed, S.A., "Mechanical properties of fiberous recycled aggregate concrete", Tikrit Journal of Engineering Sciences, vol.20, no. 4, pp.42-52,2013.

[13] Katkhuda, H. and Shatarat, N., "Shear behavior of reinforced concrete beams using treated recycled concrete Aggregate", Construction and Building Materials, vol. 125, pp.63-71,2016.

[14] Evangelista, L.M.F.D.R. and De Brito, J.M.C.L., "Concrete with fine recycled aggregates: a review", European Journal of Environmental and Civil Engineering, vol. 18, no.2, pp.129-172, 2014.

[15] Rangel, C.S., Amario, M., Pepe, M., Martinelli, E. and Filho, R.T., "Flexural behavior of RC beams made from normal and high-strength recycled aggregate concrete", In the 4th Workshop on the New Boundaries of Structural Concrete, Anacapri, 2016.

[16] Salman, M.M., Abdul-Ameer, J.S. and Abd, L.M., "Effect of recycled aggregates and steel fibers on flexural and shear behavior of reinforced normal concrete beams", Journal of Engineering and Sustainable Development, vol.20, no.1, pp.178-193, 2016.

[17] Seara-Paz, S., González-Fonteboa, B., Martínez-Abella, F. and Eiras-López, J, "Flexural performance of reinforced concrete beams made with recycled concrete coarse Aggregate" Engineering Structures, vol. 156, pp.32-45, 2018.

[18] Kovacs, R., Shamass, R., Limbachiya, V. and Datoo, M.," Experimental Investigation on the Behaviour of Recycled Aggregate Concrete" In 5th International Conference *on* Sustainable Construction Materials & Technologies,2019.

[19] Yang, I.H., Park, J., Kim, K.C. and Lee, H., "Structural behavior of concrete beams containing recycled coarse aggregates under flexure". Advances in Materials Science and Engineering, no.1, p.8037131, 2020.

[20] Elsadany, R., Al-Tersawy, S.H. and Sallam, H.E.D.M., "Effect of reinforcement type on structural behavior of RC beams containing recycled Aggregate" Frattura ed Integrità Strutturale, vol.16, no 61, pp.294-307,2022.

[21] Hemida, O.A.R., Abdalla, H.A. and Fouad, H.E.E., "Flexural behavior of recycled reinforced concrete beams strengthened/repaired with CFRP laminates", Journal of Engineering and Applied Science, vol.70, no.1, p.64,2023.

Nomenclatures

% Percentage
Fcu Compressive strength of concrete (cube) MPa
Fc' Compressive strength of concrete (cylinder), MPa
Ft Tensile strength of concrete, MPa
Fy Steel yield stress, MPa
Ø Diameter of reinforcement bar, mm
Kg/m^3 kilogram per meter cube
kN kilonewton
L/m^3 liter per meter cube
Mm millimeter
MPa mega Pascal
w/c water cement ratio

Abbreviations
B beam
R percentage ratio of recycled Aggregate
0% zero percentage ratio
20% Twente percentage ratio
40% forurty percentage ratio
70% seventy percentage ratios
100 one hundred percentage ratios
F refers to flexural
1 referers to monotonic load
2 refers to repeated load
S referrers to shear
T refers to RCA at top layer
b refers to RCA at bottom layer
V refer to steel fiber

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السلوك الهيكلي للعوارض الخرسانية المستمرة من الركام المعاد تدويره

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الخلاصة

يتضمن هذا البحث دراسة تجريبية حول السلوك الهيكلي للعوارض الخرسانية المستمرة من الركام المعاد تدويره. يتضمن العمل التجريبي اختبار عشر عوارض مستمرة تحت حمل نقطي، واحدة في كل امتداد. يتم صب عارضين من إجمالي الخرسانة العادية ويتم التعامل معها كمرجع للعوارض الأخرى. تم تصميم إحدى العارضتين لتفشل في الانحناء، بينما تم تصميم الأخرى لتفشل في القص. أبعاد جميع العينات هي 225 مم في العمق، و 150 مم في العرض، و 3000 مم في الطول. تحتوي ثلاث عوارض على نسب مئوية مختلفة من RCA. تحتوي العينة الأولى على نسبة استبدال 20٪ من الركام المعاد تدويره، بينما تحتوي الثانية على نسبة استبدال 40٪. العينة الثالثة مع 70٪ من الركام المعاد تدويره. يتم تقسيم عينتين وفقًا لموقع الركام المعاد تدويره (فشل في الانحناء)، بينما يتم اختبار عينتين لفشلهما في القص وتقسيمهما وفقًا لموقع الركام المعاد تدويره. المعاملات الرئيسية هي نسبة استبدال الركام المعاد تدويره، وموقع الركام المعاد تدويره، وإضافة الألياف الفولاذية. أظهرت النتيجة أن استخدام الركام المُعاد تدويره يُؤدي إلى انخفاض طفيف في الحمل الأقصى يصل إلى 1.35%. وأدت إضافة ألياف الفولاذ إلى زيادة الحمل الأقصى بنسبة تصل إلى 10%. كما أدى تغيير موقع الركام المُعاد تدويره (في العوارض التي تنهار عند الانحناء) إلى انخفاض في مقاومة الانحناء بنسبة تصل إلى 10%، بينما أدى تغيير موقع الركام المُعاد تدويره (في العوارض التي تنهار عند القص) إلى انخفاض في مقاومة القص بنسبة تصل إلى 23%.

الكلمات الدالة : العتبات المستمرة, الركام المعاد تدويره, الياف الفولاذ, مقاومة الانحناء , مقاومة القص.