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# Performance of Reinforced Concrete Beams Composed of Recycled Concrete with Varying Compressive Strengths Under the Effect of Repeated Shear Loads

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## Abstract:

A significant amount of research and studies have been conducted on recycling waste from construction and demolition projects on a large scale due to its benefits in preserving the environment and reducing pressure on natural resources. However, some countries, such as Iraq, plagued by a large amount of debris from the recent military activities here, are still behind in that regard. It has been shown that instantly, recycled alternatives can completely or substantially replace natural aggregates (NA). The shear behavior of reinforced concrete beams is the primary focus of this research project. Specific attention is paid to the effect of the total replacement ratios of recycled coarse concrete aggregates. The present study is innovative in investigating how adding recycled coarse concrete with different strengths affects the structural characteristics of reinforced concrete beams under static and repetitive loads. Eight beams measuring 150 mm in width and 250 mm in height with square cross sections were studied. The specimens were divided into four categories according to the type of aggregate: Three types of recycled concrete aggregate, i.e., 100% with low compressive strength, 100% with medium compressive strength, 100% with high compressive strength, and 100% with natural coarse aggregate (NCA). The results of using different types of recycled concrete aggregates were compared with conventional concrete as a point of reference. Every beam experienced a series of static and repetitive two-point stress tests until it broke. The different kinds of failure, the behavior of cracking, and the mechanical performance of all beams were investigated. Compared to natural aggregate concrete, the qualities of recycled aggregates derived from medium- and high-strength concrete waste were enhanced.

## Keywords:

Normal Coarse Aggregate; Reinforced concrete; Recycled Concrete Aggregate; Repeated loads; Shear strength; Shear-Crack width.

## Highlights:

- Reinforced concrete Beams made from recycled concrete aggregate.
- Shear behavior of reinforced concrete beams made from recycled concrete aggregate.
- The effect of repeated loads on the shear behavior of reinforced concrete beams made of recycled concrete aggregate

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## 1.INTRODUCTION

In the twenty-first century, there was ongoing growth in the construction of buildings, bridges, and highways, particularly in regions with continually rising populations. The ever-increasing human population means that many of the world's buildings and roads are reaching the end of their useful lifespans or no longer serving their original function, necessitating maintenance or replacement. As the pace of modern development increases, two urgent problems will become increasingly apparent to societies: a rising need for construction resources, particularly aggregates for concrete and asphalt, and an increasing generation of garbage from construction and destruction [1]. One of the most significant difficulties that the Arab countries are now confronting is waste. Population growth, the creation of new patterns and behaviors of life, the progression toward urbanization, and conflicts are only some factors that have contributed to the rise in the amount of trash produced. The rise in waste production is easily observable. As is the case in the vast majority of developing nations, Iraq faces a great deal of difficulty when it comes to effectively implementing policies for the management of solid waste for various reasons, including technical, economic, legal, cultural, and social causes. For the better part of the last several decades, research has been conducted on the properties of recycled aggregate (RA) and the essential components of recycled concrete aggregate (RCA) [2–9]. As a result, numerous countries have established statutes or recommendations encouraging using RA. In every instance, using recycled materials as a viable option for the whole or partial substitution of the NA was demonstrated to be a possibility. However, few studies have been done on structural behavior, such as activity under flexure circumstances, shear, bond, and torsion). This area of study is relatively new. Japan was where some of the earliest studies on the structural performance of RA were published [2]. The shear functionality of reinforced concrete (RC) beams with replacement aggregate (RA) is the subject of this research, and the study's primary focus is on the replacement ratio's effects. Also, to see if existing design formulas can be used in RC beams with RA, there must be a link between the experimental results and the code predictions. This connection may be made by comparing the outcomes of experiments to the projections made by the code. Several investigations have been conducted regarding concrete and reinforced concrete built in RA; however, this is not enough to offer a clear understanding of the behavior of the structural components that will lead to establishing a design technique [2]. Etxeberria et al. [10] studied commercially produced RA mix concrete batches with 25%, 50%, and 100% volume replacement ratios. Three longitudinally reinforced beams with three transverse steel shear reinforcement (stirrup) ratios were designed for every variety of concrete. The diagonal shear failure mode of the beams was developed. The results showed that although each beam's concrete compressive strength values were similar, the beams with higher replacement ratios of NA with RA had less capacity to support shear loads due to the high hardness of the NA type of aggregate compared to the other type, RA, because it consisted of only coarse aggregate particles, while the second type was a mixture of aggregate in addition to large-sized concrete remains. Arezoumandi et al. [11] investigated beams with three amounts of coarse aggregate replacement (0%, 50%, and 100%) and three amounts of longitudinal reinforcement (1.3, 2.0, and 2.7%). The concrete strength value was 35 MPa. The concrete beams investigated in this investigation, NA and RA50, had a more substantial shear capability than the RA100 beams, according to the findings of the statistical data analysis. The shear ability of the RA50 and NA concrete beams was noticeably indifferent. Aly et al. [12] examined several parameters that impact the structural behavior of supported RC beams manufactured from RA (coarse aggregates) with changing proportions of RA, as opposed to beams built with NA concrete. Their results showed that the investigated specimen's shear capability increased when the RA ratio reached 50%. The examined sample with a 75% RA replacement ratio, however, had a low ultimate load, indicating that a replacement ratio greater than 50% lowered the beam's shear capability. Furthermore, when a coarse aggregate beam's shear span-to-depth percentage (a/d) increased, its shear strength increased. To evaluate ten full-scale reinforced concrete beams built without stirrups, Katkhuda and Shatarat [13] used three mixes of coarse aggregates to create three types of concrete: NCA, untreated RCA, and treated RCA. Five replacement ratios of NCA were used to make the concrete mixes: 50% untreated RCA, 100% untreated RCA, 50% treated RCA, and 100% treated RCA. According to the authors' conclusion, untreated recycled aggregates decreased the shear capacity of the beams. However, shear capacity increased when treated recycled aggregates were used. The findings indicated that the shear capacity of the beams increased when 50% recycled concrete aggregate was used; however, the shear capacity decreased when 100% treated recycled aggregates were included in the combination.
Tinini et al. examined six RC square-section beams [14]. Loads inclined at 0, 22.5, and 45 degrees were applied to three beams during testing. The exact weights were applied to the

other three beams during testing; however, there was no shear reinforcement. Analytical, computational, and experimental studies were conducted on 300×300 mm square reinforcing beams. Compared to the other two specimens evaluated at 0 and 45 degrees, the specimen with shear reinforcement tested at a 22.5-degree load inclination had a significant ultimate shear load. The investigator concluded that the NLFEA and the experimental shear resistance and crack pattern results agreed. Furthermore, there was a quadratic relationship between the load inclination angle and the shear failure envelope. Ghorbel et al. [15] investigated the mechanical properties of RA concrete and included a sizable database of previously published experimental results from the literature. Because RA had a lower elastic modulus than NA and needed a larger volume of RA concrete paste to maintain the same sag, their research indicated that adding RA decreased the modulus of elasticity for the same compressive strength. Adding RA typically caused a decrease in tensile strength for the same compressive strength. According to Tirassa et al. [16], steel reinforcement is often erected and positioned to prevent cracks from propagating, reducing the possibility of shear failure by allowing tensile loads to pass through the beam more effectively. Tirassa et al. [16] stated that the aggregates resisted shear stresses resulting from the interaction between their components. The tensile tension on the particles and the frictional sliding effect caused aggregate interlock resistance in shear. If the shear force exceeded the aggregate, the stone's surface would peel off, leaving a smooth surface.

## 2.RESEARCH OBJECTIVES

A literature review indicates that little study has been done on recycled concrete aggregate and that concrete containing it is a relatively new concept. Further work is required as the RCA concrete examples have yet to be subjected to extensive shear testing. Consequently, the reason behind this study is to examine how the shear strength of RC beams is affected when reinforcing aggregate (RA) from structures that have been demolished and have varying design compressive strengths, depending on the kind of structure and the pressures applied to it. The effect of a complete replacement ratio is the investigation's main subject. The work's innovative feature investigates how recycled coarse addition affects RA beam shear strength under repeated and static loads. NA concrete was used as a reference when comparing recycled materials. Every beam underwent two-point loading testing until it failed. All beams' mechanical performance, failure mechanisms, and cracking behavior were investigated.

## 3.EXPERIMENTAL PROGRAM

The experimental program includes:

### *3.1.Materials*

The materials used in this research were

#### *3.1.1.Cement*

Ordinary Portland Cement (OPC) type I, which satisfied the requirements of EN 197-1-2011 and was utilized for the mixed concrete design, was employed to cast all of the examples. The cement was examined following Iraqi standard IQ.S. No5/1984 [17].

#### *3.1.2.Fine Aggregate*

Fine aggregate quality affects concrete properties, making up around 30% of the volume of ordinary concrete. The overall aggregate grading, cement content, particle form, coarse aggregate grading, and the intended use of the concrete all affect the appropriate amount of fine aggregate in workable concrete. Regular sand with a good fineness modulus was utilized as a fine aggregate. Sand had a fineness modulus (FM) of 2.6, while gravel had a specific gravity of 2.62. Its particles were smaller than 4.75 mm and, astonishingly, less than 0.075 mm. Based on the findings, it was determined that the graded fine aggregate complied with the Iraqi specification (I.O.S. No. 45, 1984) [18].

#### *3.1.3.Water*

The concrete was mixed, and the specimens were cured using regular tap water.

#### *3.1.4.Steel Reinforcement*

Deformed steel reinforcing bars measuring 16 and 8 mm in diameter were employed as longitudinal reinforcement in the tested beams, and for closed stirrups, 8 mm-diameter distorted steel reinforcing bars were utilized.
Following ASTM C370-05a, to assess the tensile characteristics of the reinforcement, tensile testing was performed on at least three specimens derived from each steel reinforcing bar used in the tested beam.

#### *3.1.5.Coarse Aggregate*

##### *3.1.5.1.Coarse Normal Aggregate (NA)*

In two thresholds poured for comparison, natural aggregate was used instead of recycled concrete aggregate, which consisted of spherical granules fractured to create a rough surface. The aggregate's granule size ranged from 19.5 to 4.75 mm, as illustrated in Fig. 1, and it was sourced from Tikrit City, Iraq. Between 50 and 70 kg were needed for each beam.

**Fig. 1** Normal Coarse Aggregate (NA).

The coarse-looking river aggregate was cleaned and washed with water before being allowed to air dry and used when saturated but with a dry surface. The Iraqi standards (I.O.S. No. 45, 1984) [18] describe the restrictions and the classification of coarse aggregate.

***3.1.5.2.Recycled Concrete Aggregate (RCA)***

Recycled aggregate was employed in six concrete beams, sourced from the remnants of failed specimens obtained from the structural materials examination laboratory at the College of Engineering, Tikrit University. These specimens were tested, resulting in low-, medium-, and high-strength rubble collection. The coarse recycled aggregate underwent multiple stages of processing. The recycled aggregate utilized in this study is categorized into three distinct sections:

- Recycled concrete aggregate with low strength fc (10-25) MPa.
- Recycled concrete aggregate with medium strength fc (25-40) MPa.
- Recycled concrete aggregate with high strength fc> 40 MPa.

The quantity required for each type ranged from 50-70 kilograms per beam obtained through several stages, as follows:

**a) First Stage**

A sufficient amount of the failed specimens' waste was brought as a result of exposure to different types of tests (checked cubes) to treat them, including grinding and sorting operations, until they were returned to pebbles similar to natural gravel, allowing accurate characterization and then determining the extent to which they could be used in producing laboratory concrete specimens. This process was done in several stages, as shown in Fig. 2.


**Fig.2** Waste Concrete Specimens Used in Research.

**b) Second Stage**

Using a special hammer designed for this purpose, large pieces of different sizes were manually crushed as part of a preliminary treatment process for the low, medium, and high resistance models, as seen in Fig. 3.

**Fig. 3** Breaking Concrete Blocks into Small Pieces with a Gradient Similar to Natural Gravel.

**c) Third Stage**

The crushing process was followed up, and the crushed specimens were converted into smaller models that passed through sieve No. 19.5 mm and remained on sieve No. 4.75 mm, as shown in Fig. 4.

**Fig. 4** Sieve Analysis of Crushed Concrete Waste Used in the Research.

**d.Fourth Stage**

After ensuring that the weight resulting from the sieve analysis process was sufficient, the specimens were washed to remove the dust suspended on the surface and filled with bags (each strength separately), as shown in Fig. 5. Figure 6 shows the sieves used 19.5 mm and 4.75 mm and the cracking hammer used to break models.

**Fig. 5** Packing Recycled Concrete Aggregate into Bags.

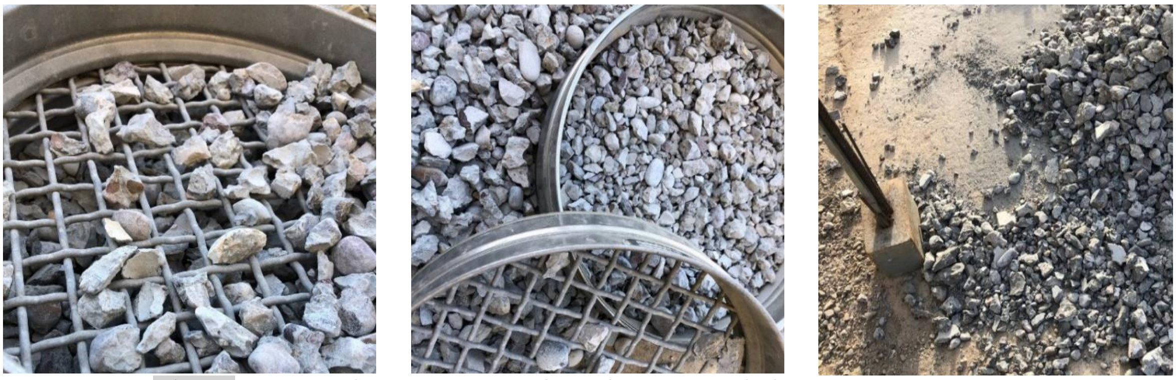


**Fig. 6** Sieves and Hammers Used to Obtain Recycled Concrete Aggregate.

***3.2.Specimen Details***

The beams had a 150 mm by 250 mm cross-section and a 1500 mm overall length. The stirrups' outside surface had a simple 20-mm concrete coating. The design guidelines of ACI 318M-19 were followed in arranging the longitudinal and transverse reinforcements. 2Ø10 mm longitudinal reinforcements at the top of the beams and 2 Ø 16 mm longitudinal reinforcements at the bottom of the sample provided reinforcement. Place stirrups with a diameter of Ø 8 @ 150 mm c/c in the area affected by shear forces on each side to stabilize the longitudinal steel structure.

***3.3.Mix Design***

ACI-318-211, an American technique, was used to construct concrete mixes having a 30 MPa cylindrical resistance. After determining the necessary proportions, experimental mixtures were created to ascertain the mixture's final component amounts. Details of the variants are shown in Table 1.

**Table 1** Mix Design.

| Mix design | Cement (kg/m³) | w/c | Water (kg/m³) | Sand (kg/m³) | Coarse aggregate (kg/m³) | |
|---|---|---|---|---|---|---|
| | | | | | NA | RCA |
| NA | 413.8 | 0.435 | 180 | 788 | 872 | 0 |
| RCA (low) | 413.8 | 0.435 | 180 | 788 | 0 | 872 |
| RCA (medium) | 413.8 | 0.435 | 180 | 788 | 0 | 872 |
| RCA (high) | 413.8 | 0.435 | 180 | 788 | 0 | 872 |

### *3.4.Molds Used for Casting*

The concrete beam specimens utilized in this experiment had the following dimensions: cross-sectional measurements: 1500 mm long, 150 mm wide, and 250 mm deep. Eight tested concrete reinforcement beams with four adjustable sides and a base were cast using plywood molds with an 18-mm plywood thickness. To create blocks at the ends, the sides were screwed in place before being screwed to the ground. The reinforcement mesh was positioned, and the molds were lubricated before casting. Twelve prism (100 mm × 100 mm × 500 mm) and eight standards (150 mm × 300 mm) cylinder molds were used to compute the modulus of rupture ($f_r$), indirect tensile strength ($f_t$), and compression strength ($f_c'$).

### *3.5.Mixing, Casting and Curing*

The following describes the mixing process:

1) All molds were meticulously cleaned and carefully oiled before casting to prevent solidified concrete from sticking to the interior of the molds.
2) The quantities were weighed and put in a sterile container before merging.
3) Each specimen's steel reinforcement was positioned carefully in the molds for the beam, and before concrete was poured into them, the designated protective cover was examined. Plastic fastening pieces were placed on the sides and bottom of the steel reinforcement to stop it from moving while the casting was done.
4) After two minutes of mixing the concrete with half of the water added, three minutes were spent mixing the concrete.
5) Using a hand-held electric vibrator (3000 rpm) intended to eliminate air bubbles from freshly laid concrete, the concrete was compacted. All specimens, prisms, and cylinder specimens were inserted into each layer using this vibrator for five seconds.
6) Three layers of concrete were poured into the prism and cylindrical molds, and each layer was shaken using a concrete vibrator. To guarantee adequate compaction, a concrete vibrator vibrated each of the three concrete layers poured into the plywood mold. The concrete surface was polished and leveled with a trowel. After that, a nylon sheet was placed over the specimens to stop the water from evaporating.
7) All specimens were kept in molds in the laboratory until the next day, when they were removed from the molds.

For 28 days, the cylindrical and prism molds were submerged in a water bath maintained at a temperature close to the laboratories. The beam specimen went through the same process. To cure the specimens for 28 days, the specimens were left in the casting position with the sides of the mold lifted. The models were then covered with burlap sacks and misted with water using an axial sprinkler. Subsequently, the water supply was disconnected, allowed to dry for a full day, and tested in compliance with the prescribed guidelines. All specimens were painted white to make it easy to see and photograph cracks.

### *3.6.Preparation of Test Specimens*

### *3.6.1.Preparing The RC Beams*

Before each casting process, reinforced concrete beam molds were prepared for each group, as shown in Fig. 7. Considering the dimensional requirements between the bars, according to the previously mentioned amount of rebar.

**Fig. 7** Sieves and Hammers Used to Obtain Recycled Concrete Aggregate.

### *3.6.2. Concrete Casting and Curing*

There were four main phases to the beams' experimental program. As illustrated in Fig. 8, the casting process started with the fine aggregate being added and mixed with the coarse aggregate for a minute. Next, 30% of the water was added and mixed for another minute, followed by cement, and finally, the remaining water was added and mixed for three minutes.

**Fig. 8** Concrete Mix.

The first stage consisted of casting two concrete beams in addition to six cylinders of 300 × 150 and three prisms of 100 × 100 × 500, using the mixture's components with natural aggregates NA and the previously mentioned proportions. In the details shown above, the same amount of specimens was poured in the case of recycled coarse aggregate from concrete with low strength once, from concrete with medium strength once, and from concrete with high strength again. After completing the casting process and for three days, the atmosphere surrounding the concrete beams was taken care of, as the specimens were allowed to remain in the frame for ventilation for 24 hours. After that, the forms were carefully prepared to ensure that there were no broken borders, and the name of the resistance was also written above the records to identify the conditions upon inspection. The specimens were put into groups based on the type of load used—static or repetitive—shown by the first part of the name (BR or BS). The second part of the name indicated the type of aggregate used in casting—natural coarse aggregate NC or recycled concrete aggregate—and the compressive strength used (LS, MS, or HS). The molds were opened more than a week after casting, and the concrete had initially solidified. Figure 9 shows the beams after opening the molds. After that, the specimens were kept for 28 days in a basin filled only with pure water. The models' preservation throughout the immersion phase should be ensured, as shown in Fig. 10. In the last stage, after 28 days, the concrete beams were painted to prepare them for examination to show the cracks that would occur during the test, as shown in Fig. 11.

**Fig. 9** Beams After Opening the Molds.

**Fig.10** Sample Processing in a Water Basin.

**Fig.11** Coating Test Specimens with Dye.

### *3.7.Instrumentation and Test Measurement*

After the curing time, a two-point load test was performed on each beam. Before failure, all beams were subjected to shear. With a clear span of 1300 mm and a shear span of 430 mm, each beam was set up on straightforward supports inside the machine. The beams were tested using a universal hydraulic machine with a 2000 kN capability. Positioned at the center of the shaft, an LVDT (linear variable displacement transducer) measures the maximum possible beam deflection. Because the beams were coated with white pigment, it was easy to see the crack patterns using a digital camera set up for the job. The beams were loaded at a rate of 1.5 mm/min. The deflections were automatically recorded at each beam loading stage using a computerized data recorder system. At every loading stage, the width and crack pattern were also noted. The stress face of the beams had marks indicating the cracks' locations and advancement. When the load lowered, and the deflection increased, severe crushing occurred near the bottom of the beam, revealing the ultimate load. The specifics of the beam testing are displayed in Fig. 12. Regarding the second set of specimens subjected to a repeated shear load examination, the loading procedure was repeated, with loads applied up to 60% of their peer specimens' final shear load, examined using a monotonic load analysis. After applying the shear force to these specimens up to the point of failure, the load was increased to a maximum of seven loading cycles. The beam's fundamental structural behavior characteristic was identified at every loading step during testing. For every test, a microcrack meter was used to measure the width and beginning cracks in the concrete with an accuracy of 0.02 mm., while the larger cracks were measured using a digital meter with a vernier scale with a length of 15 cm and an accuracy of 1.0 mm. Shear failure and displacement were measured. Failure was defined as a loss in load capacity as beam rotation rose.

## 4.RESULTS AND DISCUSSION

### *4.1.Mechanical Properties of Concrete Prepared from Recycled Demolition Aggregate Concrete.*

#### *4.1.1.Compressive Strength*

The compressive strength values at the 28-day study age are displayed in Fig. 13, along with various RCA replacement ratios; each value is the average of three cylinders.

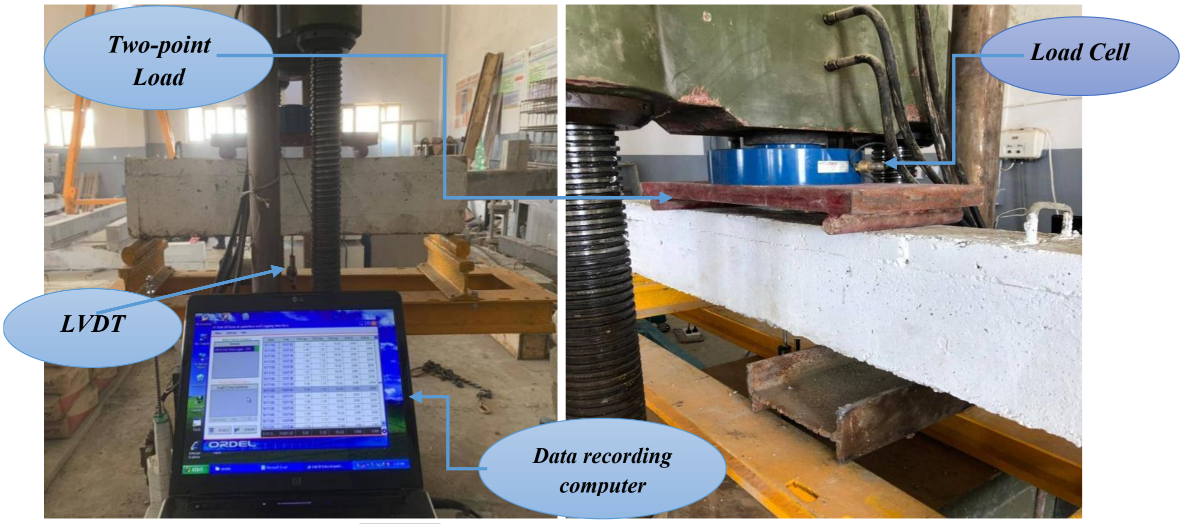



**Fig.12** Details of the Testing of Beams.

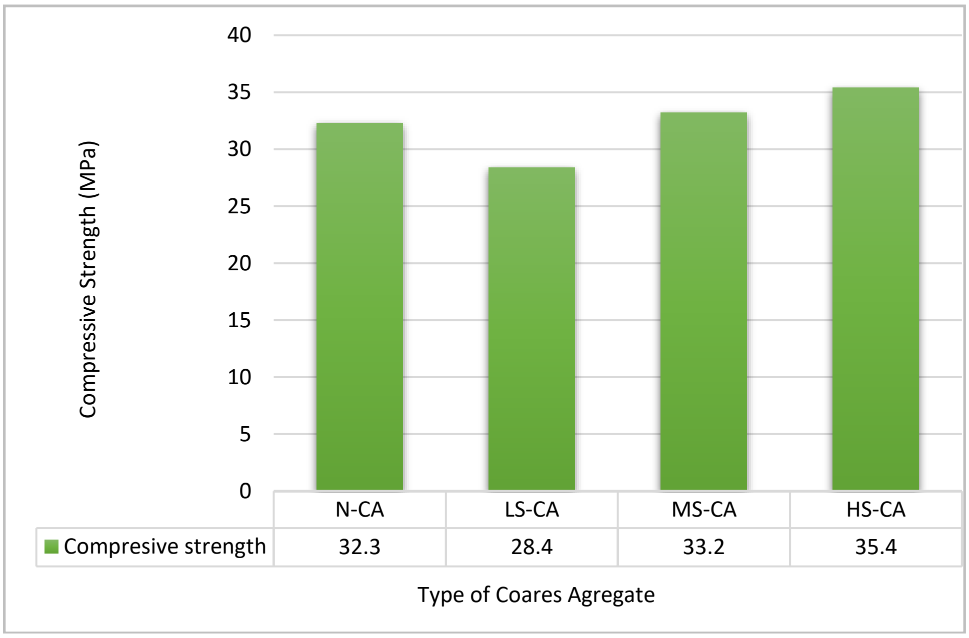



**Fig.13** Compressive Strength at Different Types of Coarse Aggregate Used in the Concrete Mix.

Figure 13 shows the compressive strength of concrete made from several coarse aggregates, resulting from replacing the coarse aggregate used from ordinary gravel aggregates with RCA. The results of the mixtures in which concrete aggregates with low resistance were used showed a decrease in compressive strength by 12.07% compared to the compressive strength of concrete made from ordinary aggregates. By contrast, the compressive strength values witnessed an apparent increase for concrete that used recycled aggregates from medium and high compressive strength concrete by 2.7% and 9.597% compared to the compressive strength of ordinary aggregate concrete. This behavior is because concrete with low compressive strength formed weak areas inside the concrete, which decreased the compressive strength values; in addition to that, the designed compressive strength values were less than the values of its compressive strength, while the high-strength concrete aggregates played a role and formed vital bonding areas inside the mixture, which was the reason for the difference in behavior between mixtures containing RCA and mixtures containing ordinary sum.

#### *4.1.2.Splitting Tensile Strength*

Figure 14 shows the specimens' cleavage tensile values when tested on the 28th day with different coarse aggregates used in the concrete mix. Each value was the average of three cylinders under the applied load.

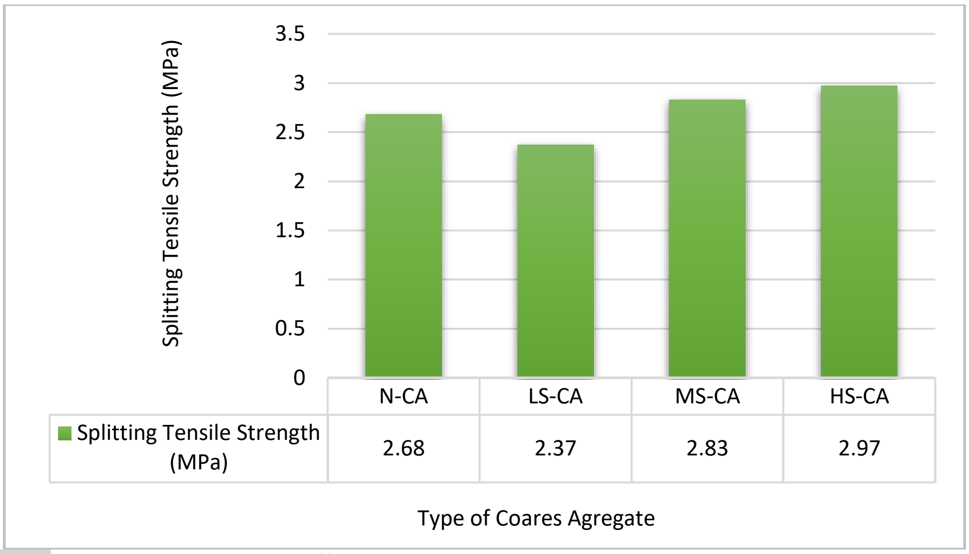



**Fig.14** Splitting Tensile at Different Types of Coarse Aggregate Used in the Concrete Mi

The results obtained and shown in the figure above show that the concrete made of recycled aggregates of low-strength concrete reduced the splitting tensile values by 11.5% compared with the tensile strength values of concrete made of normal coarse aggregates. The reason is that it weakens the bonding areas inside the concrete while using aggregates. Recycled concrete with high compressive strength increased the tensile strength values by 5.59% and 10.82%, respectively, compared to the importance of concrete containing natural coarse aggregate.

#### *4.1.3.Modulus of Rupture*

The modulus of rupture values is displayed in Fig. 15. The specimens were tested on the 28th day using various coarse aggregate types; the average of three values was obtained using concrete prisms with a three-point load.

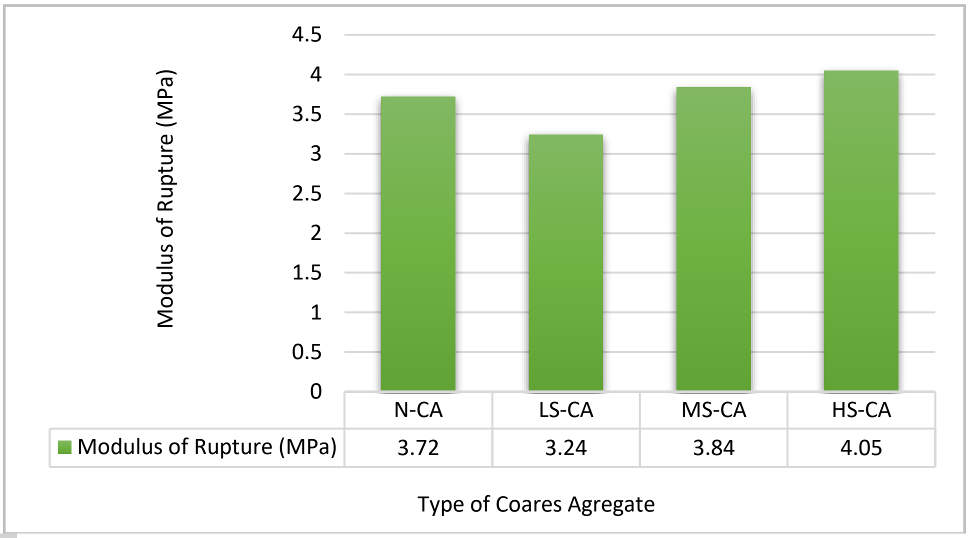



**Fig.15** Modulus of Rupture at Different Types of Coarse Aggregate Used in the Concrete Mix.

From the results shown above, which represent the fracture criteria values for the concrete used in the research, the results showed that there was a decrease in the denominator values for the fracture criteria for concrete made from recycled aggregate from low-strength concrete by 12.9%, while the importance of the fracture criteria for concrete made from recycled aggregate from concrete aggregates with high strength increased by 3.22% and 8.87% compared to the values of concrete made from the natural total.

### *4.2.Cracking and Ultimate Loads*

The load at which cracking appears, or the cracking load ($P_{cr}$), signifies that the applied stress has reached the concrete section's shear strength. However, the tested beam's shear-carrying capacity was indicated by the ultimate load ($P_u$), and the beam rapidly deforms as the applied load reading drops [19]. Shear characteristics evaluated included failure mechanism, cracking pattern, ultimate load, deflection at the initial fracture load, and deflection at the maximum load. Moreover, load deflection was constructed for the research specimens. The study was conducted in this axis on (8) concrete beams with measurements (150 × 250 × 1500) mm. All models were reinforced with regular reinforcement, and the type of coarse aggregate used in casting specimens and the load applied were considered variable during the research, as the model in which natural aggregate was used was regarded as a control model. For other models, the rest of the models were poured with recycled aggregates from damaged concrete with different compressive strengths, and the study included the effect of using recycled aggregates from various resistant concrete on the shear resistance of the beams under the effect of static and repeated loads. This axis includes identifying the effect of replacing natural aggregate with RA on the maximum load that the thresholds can bear and the effect of total replacement on the maximum load the points can carry. Table 2 and Fig. 16 show the results of examining concrete entries under the effect of static load, while Tables 3 and Fig. 17 show the results of reviewing concrete thresholds under the effect of Repeated load.

**Table 2** The Results from Testing the Beams Under Static Loads.

| Beam | Compressive strength (Mpa) | First crack load Pcr (kN) | Yield load Py (kN) | Ultimate load Pu (kN) |
|---|---|---|---|---|
| BS-NC | 32.3 | 31.1 | 58.9 | 84.2 |
| BS-LS | 28.4 | 28.5 | 55.1 | 78.7 |
| BS-MS | 33.2 | 31.9 | 62.65 | 89.5 |
| BS-HS | 35.4 | 32 | 68.2 | 92.4 |

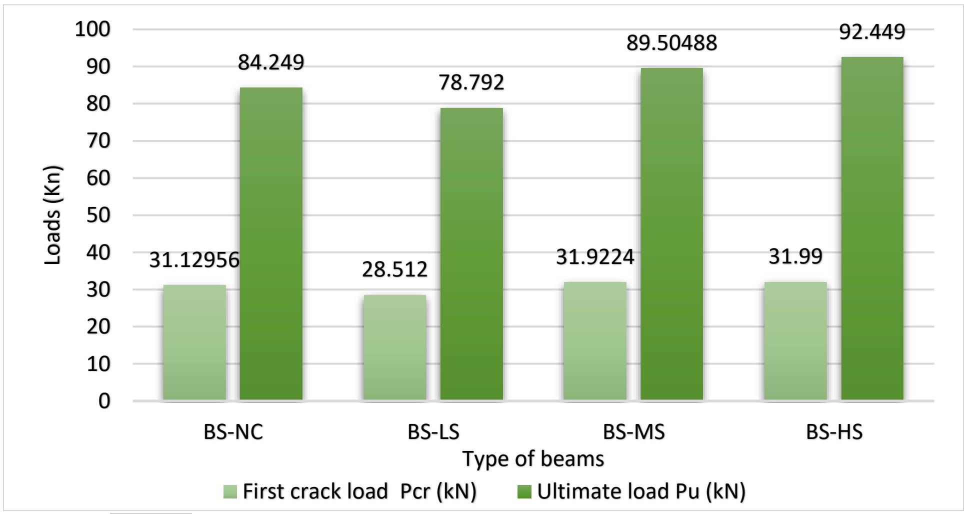



**Fig.16** Cracking and Ultimate Loads Under Static Loads Effect.

**Table 3** The Results from Testing the Beams under Repeated Loads.

| Beam | Compressive strength (Mpa) | First crack load Pcr (kN) | Yield load Py (kN) | Ultimate load Pu (kN) |
|---|---|---|---|---|
| BR-NC | 32.3 | 31.1 | 49.289 | 69.13 |
| BR-LS | 28.4 | 28.5 | 44.97 | 65.27 |
| BR-MS | 33.2 | 31.9 | 49.88 | 73.91 |
| BR-HS | 35.4 | 32 | 52.42 | 75.86 |

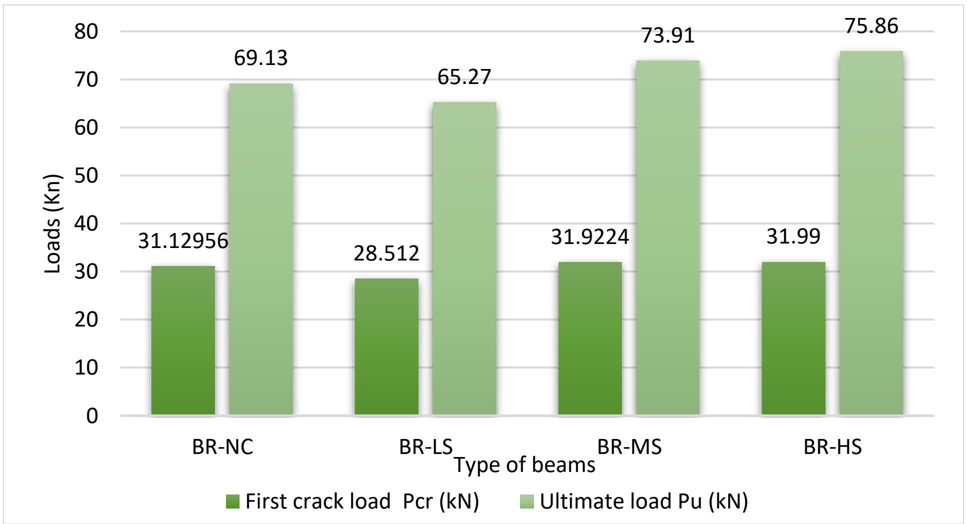



**Fig.17** Cracking and Ultimate loads under Repeated loads effect.

The results in Table 2 showed an apparent growth in the failure load for the beams in which the used coarse aggregate was replaced with recycled aggregate from high-strength concrete, compared to the beams that were poured using ordinary aggregate, where the growth in the maximum load values for failure occurred by 9.73 % for beams with recycled aggregate from high-strength concrete. In comparison, the increase was 6.29% for beams cast using medium-resistance aggregate, while it was noted that beams cast from low-resistance aggregate decreased in which the value of the maximum load causing failure reduced because of resistance. The design compression was greater than the compressive strength of low-strength aggregates. Concerning the outcomes displayed in Table 3 and Fig.17, it is noted that repeated loads affect the beams compared to their counterparts subjected to a static load due to the effect of the repeated reloading process on reducing the bond between the internal concrete components, making them less bonded, as the value of the maximum shear load causing failure decreased by (17.89%, 17.06%, 17.41%, and 17.9%) corresponding percentage compared to the specimens under the influence of static load, whether cast from either recycled or natural aggregate for concrete. The amount of deflection occurring in the middle of the beam to be examined was measured using the LVDTs sensor after installing the scale in the center of the concrete beam from the bottom and from the observation of Table 4, which shows the amount of deflection occurring in the middle of the concrete beams under static and repeated loads.

**Table 4** The Results Obtained from Testing the Thresholds Under Static and Repeated Loads.

| Beam | Compressive strength (Mpa) | Ultimate load Pu (kN) | Mid-span deflection (mm) |
|---|---|---|---|
| BS-NC | 32.3 | 84.2 | 9.3 |
| BR-NC | | 69.13 | 7.96 |
| BS-LS | 28.4 | 78.7 | 8.5 |
| BR-LS | | 65.27 | 7.12 |
| BS-MS | 33.2 | 89.5 | 9.79 |
| BR-MS | | 73.91 | 7.64 |
| BS-HS | 35.4 | 92.4 | 10.7 |
| BR-HS | | 75.86 | 8.25 |

### *4.3.Load-Deflection Relationships of the Shear Beams*

Figures (18-21) show the relationship between (load-deflection) for the reinforced beams in the four cases of coarse aggregate used and under static and repeated loads effect within the research axis. It is noted that the tolerance in the reference threshold increased with continuing the increase in the load, so the load increased. The reinforced points used high-resistance recycled aggregate increased the thickness of the thresholds with a rise in the thresholds' endurance. This increase depends, in turn, on the type of replacement, as this increase in the load worked to increase the thickness and curvature in the thresholds with the continued shedding of the load as cracks began by appearing and increasing in width until reaching a stage of crushing in the compression zone due to the concrete sill inability to withstand the forces exerted on it. The same is the case with the rest of the cases. Almost all beams initially showed linear elastic behavior, followed by a significant deflection increase and a slow load increase until failure. The ultimate load, or the highest load at which a beam will fail, and the crack load, or the load at which a diagonal crack first emerges, were found for each beam using load-deflection curves.

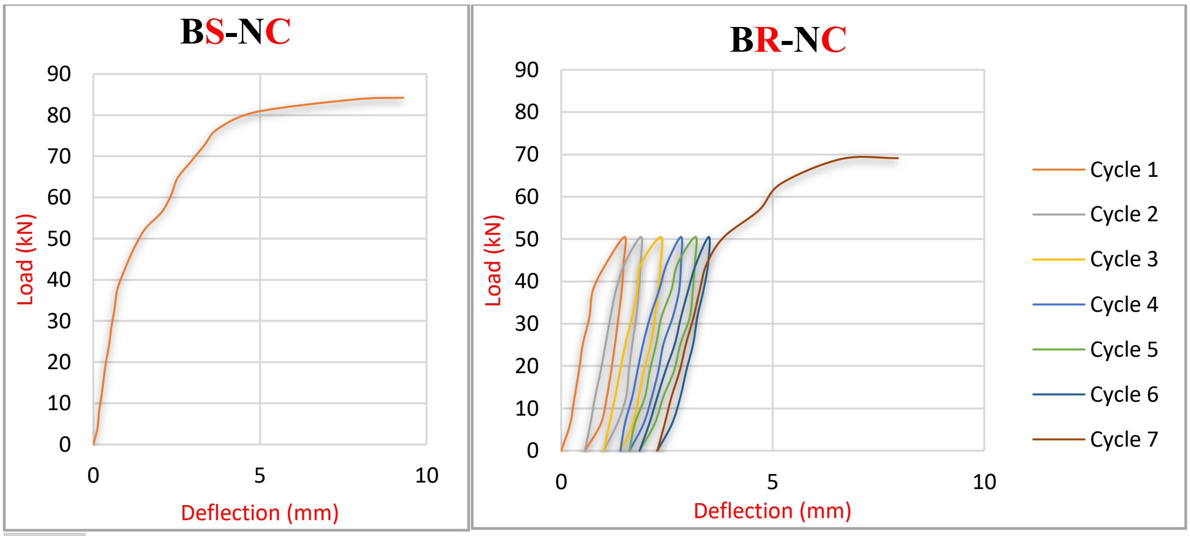



**Fig.18** Load-Deflection Relationships of the Beams Used Natural Coarse Aggregate Under Static and Repeated Loads.

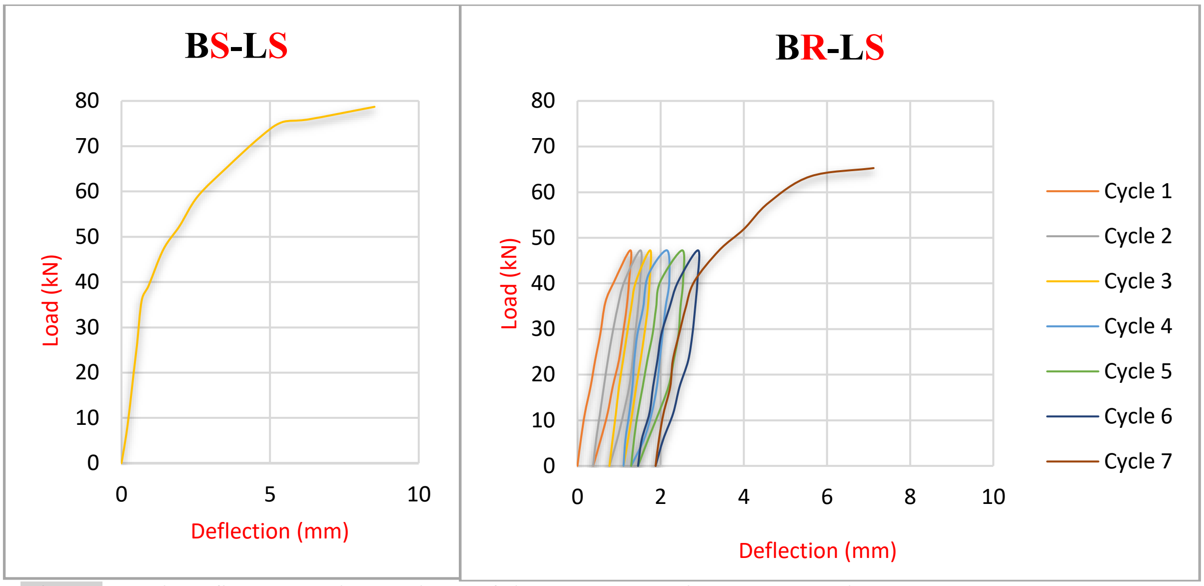



**Fig.19** Load-Deflection Relationships of the Beams Used Low-Strength Concrete Coarse Aggregate Under Static and Repeated Loads.

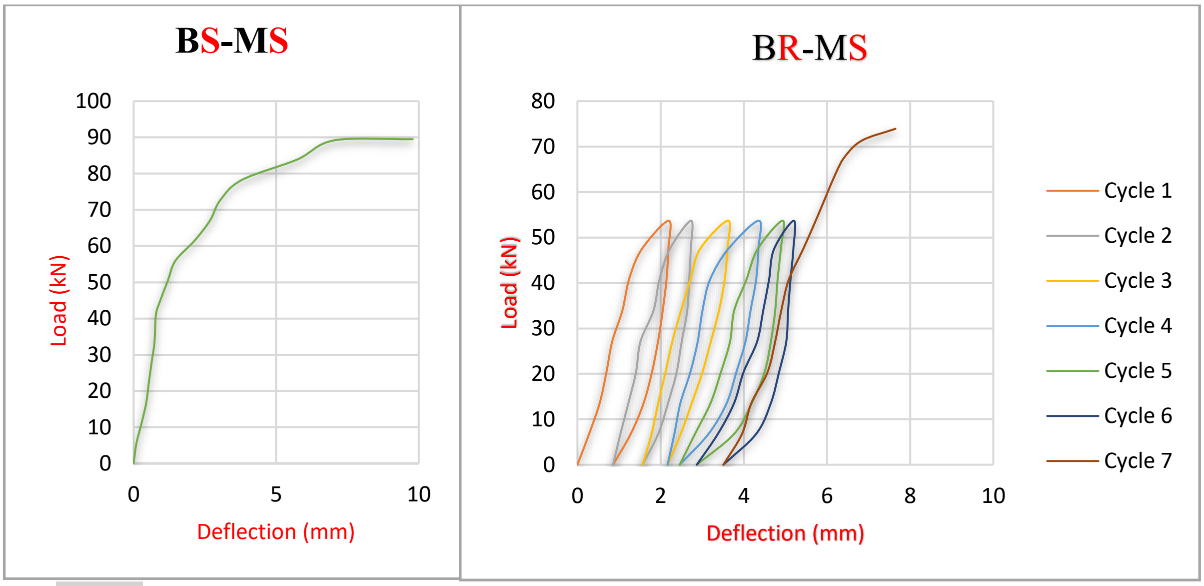



**Fig.20** Load-Deflection Relationships of the Beams Used Medium-Strength Concrete Coarse Aggregate Under Static and Repeated Loads.

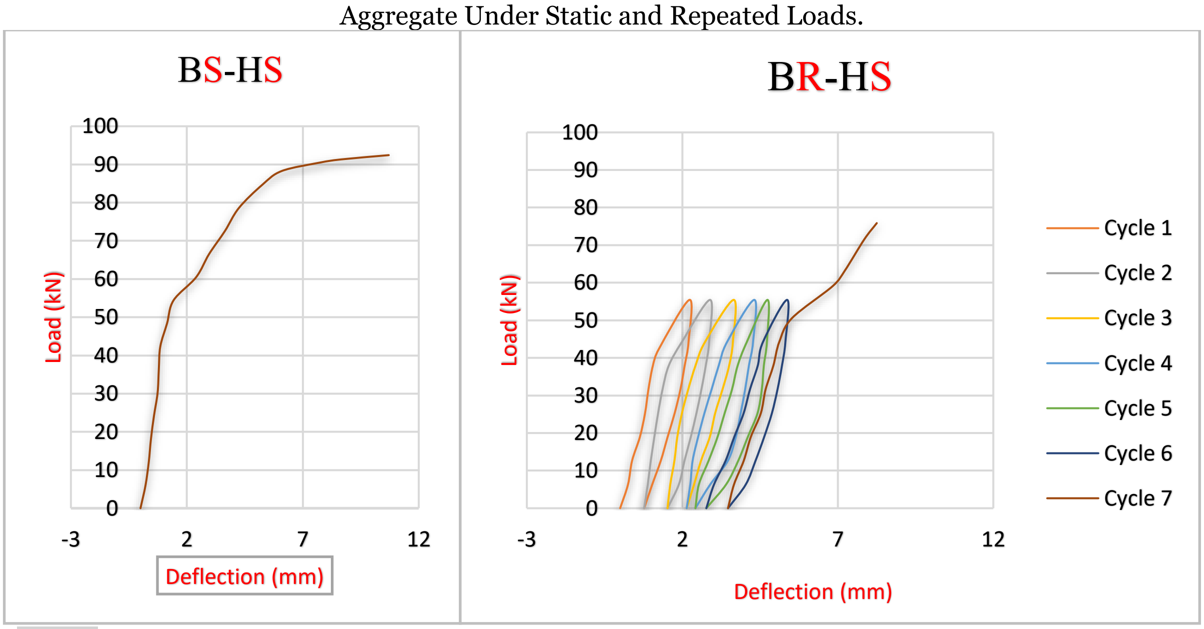



**Fig.21** Load-Deflection Relationships of the Beams Used High-Strength Concrete Coarse Aggregate Under Static and Repeated Loads.

### *4.4.Crack Width Performance*

One of the most important results from the investigation of all the models was the effect of the coarse aggregate and load types in the beam concrete on the measurement of the cracks developed on the models' surfaces [20]. During the test, the crack widths were measured and noted at each load increment using a micro-concrete crack width meter, as shown in Fig. 22. The concrete coarse aggregate, which had a different compressive strength than the natural coarse aggregate used in the controlled beams, reduced the crack width value at ultimate loads. Relationships between load and crack width for beams evaluated under static load are displayed in Fig. 23. To ascertain how repeated loading affects the width of cracks, a comparison would be made between repeatedly loaded models and specimens subjected to static loading. The maximum cracking widths in specimens subjected to restricted repeated loading cycles and specimens subjected to monotonic static loading are displayed in Fig. 24. Developing new, wide cracks due to the applied processes of repeating load and the decrease in ultimate load is primarily responsible for reducing crack width for beams assessed under monotonic load instead of those evaluated under repetitive load.

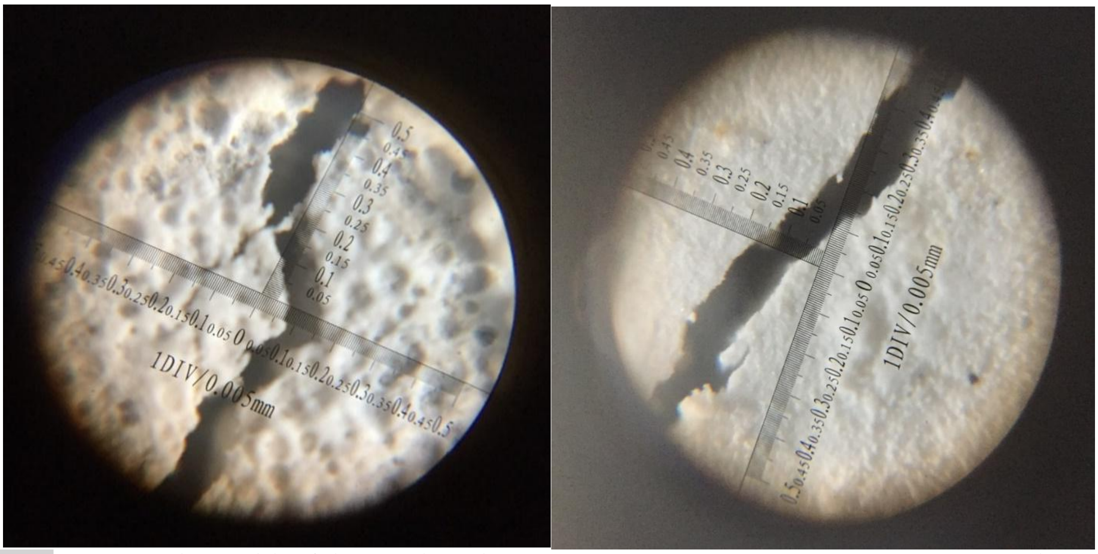



**Fig.22** Measure the Width of the Crack in the Concrete Beam using a Micro-Concrete Crack Width Meter.

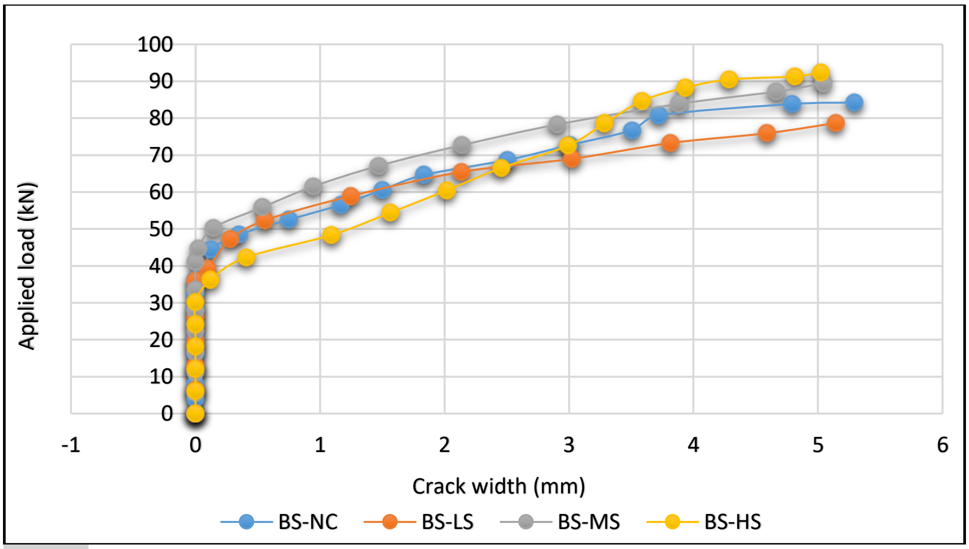
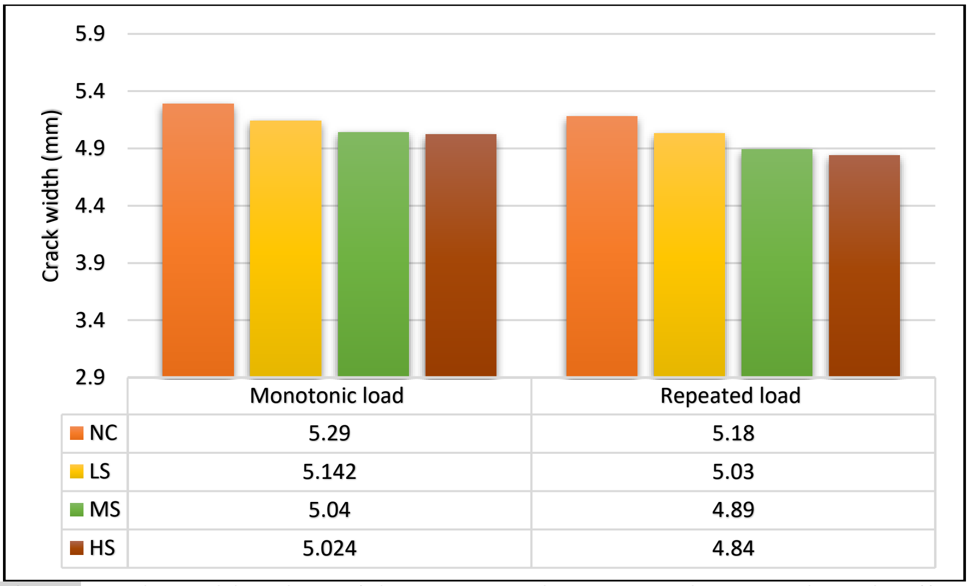



**Fig.23** Load-Cracks Width Relationships of the Beams Under Static Loads Effect.




| | Monotonic load | Repeated load |
|---|---|---|
| NC | 5.29 | 5.18 |
| LS | 5.142 | 5.03 |
| MS | 5.04 | 4.89 |
| HS | 5.024 | 4.84 |

**Fig.24** Cracks Width Values of the Beams Under Static and Repeated Loads Effect.

### *4.5.Shear Beam Failure Mechanism and Crack Pattern*

The crack pattern for the reinforced shear beams is depicted in Fig. 25. All of the specimens broke in the typical shear failure pattern, causing a main diagonal shear crack, transverse steel failure, concrete failure in the shear zone (struts failure), and local bond failure of the bottom reinforcement near the supports. Hair cracks were visible along the beam's lower edge, close to the support region. In these beams, the breadth and spacing of hair cracks were more significant and more widely distributed. The number of crashes along the span increased as the load increased, and the cracks soon propagated higher. The fissures got more expansive and longer as the applied force increased. The crack widths of these beams (BS-NC and BS-LS) were 5.29 mm and 5.142 mm, respectively, under the ultimate load. These beams cracked at a 45-degree angle from the support upward to the force application point. Notably, there was no visible spalling and no crushing at the top. These beams developed more cracks as the load increased. The crack sizes were considerably smaller than the control beams' BF-HS. The fissures grew more significant as the beams approached the failure load. The number of larger-width cracks was lower, and the fracture propagation rate was increased compared to the control specimen. Repeatedly loaded specimens exhibit the same behavior when it comes to failure behavior.

**Fig.25** Crack Pattern.

## 5.CONCLUSIONS

To examine the effects of recycling concrete waste and using it as a coarse aggregate in concrete with varying compressive strengths, the primary goal of this study was to investigate the behavior and structural performance of beams made of reinforced concrete under loading factors.

- The study examined the compressive strength of concrete composed of various coarse aggregate types. The results indicated that using recycled concrete aggregates instead of ordinary gravel aggregates reduced the compressive strength of the mixtures containing low-strength concrete aggregates. 12.07% less than concrete composed of regular particles in compressive strength. Compared to standard aggregate concrete, the compressive strength of concrete that used recycled aggregates from medium- and high-compressive strength concrete was 2.7% and 9.597% higher than that of regular aggregate concrete. Comparable patterns were observed when dividing the tensile strength of prefabricated concrete and rapture modules.
- Unlike beams poured with regular aggregate, those using recycled aggregate from high-strength concrete had a 9.73% increase in the maximum shear force values for failure. Comparatively, beams cast from medium-resistance aggregate showed a rise of 6.29%; however, beams cast from low-resistance aggregate showed a drop in which the maximum load-producing failure decreased due to resistance. Low-strength aggregates had a compressive strength lower than the design compression.
- In contrast to their counterparts subjected to a static load, repeated loads appeared to affect beams, resulting from the interior concrete components becoming less bonded due to the repeated reloading procedure.
- The concrete coarse aggregate, which had a different compressive strength than the natural coarse aggregate used in the controlled beams, reduced the crack width value at ultimate loads.
- When beams experienced repeated load testing, their cracks were narrower than those tested under monotonic stress, primarily due to the formation of new, wide cracks brought on by the cycles of recurring load and the decrease in ultimate load.

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## REFERENCES

**[1]** Ajdukiewicz A, Kliszczewicz A. **Influence of Recycled Aggregates on Mechanical Properties of HS/HPC.** *Cement Concrete Composite* 2002; **24**(2): 269–279.

**[2]** Yagishita F, Sano M, Yamada M. **Behavior of Reinforced Concrete Beams Containing Recycled Coarse Aggregate.** *Proceeding of the International RILEM Conference on Demolition and Reuse of Concrete & Masonry* 1994; **23**: 331–342.

**[3]** Otsuki N, Miyazato S, Yodsudjai W. **Influence of Recycled Aggregate on Interfacial Transition Zone, Strength, Chloride Penetration and Carbonation of Concrete.** *Journal of Materials in Civil Engineering* 2003; **15**(5): 443–451.

**[4]** Domingo-Cabo A, Lázaro C, López-Gayarre F, Serrano-López MA, Serna P, Castaño-Tabares JO. **Creep and Shrinkage of Recycled Aggregate Concrete.** *Construction and Building Materials* 2009; **23**(7): 2545–2553.

**[5]** Kou SC, Poon CS. **Enhancing the Durability Properties of Concrete Prepared with Coarse Recycled Aggregate.** *Construction and Building Materials* 2012; **35**: 69–76.

**[6]** Marthong C, Sangma AS, Choudhury SA, Pyrbot RN, Tron SL, Mawroh L, Bharti GS. **Structural Behavior of Recycled Aggregate Concrete Beam-Column Connection in the Presence of Micro Concrete at Joint Region.** *Structures* 2017; **11**: 243–251.

**[7]** Ataria RB, Wang YC. **Bending and Shear Behaviour of Two Layer Beams with One Layer of Rubber Recycled Aggregate Concrete in Tension.** *Structures* 2019; **20**: 214–225.

**[8]** Guo M, Grondin F, Loukili A. **Numerical Analysis of the Failure of Recycled Aggregate Concrete by Considering the Random Composition of Old Attached Mortar.** *Journal of Building Engineering* 2020; **28**: 101040.

**[9]** Nedeljković M, Visser J, Šavija B, Valcke S, Schlangen E. **Use of Fine Recycled Concrete Aggregates in Concrete: A Critical Review.** *Journal of Building Engineering* 2021; **38**: 102196.

**[10]** Etxeberria M, Mari AR, Vazquez E. **Recycled Aggregate Concrete as Structural Material.** *Materials and Structures* 2007; **40**(5): 529–541.

**[11]** Arezoumandi M, Drury J, Volz JS, Khayat KH. **Effect of Recycled Concrete Aggregate Replacement Level on Shear Strength of Reinforced Concrete Beams.** *ACI Materials Journal* 2015; **112**(4): 559.

**[12]** Aly SA, Ibrahim MA, Khttab MM. **Shear Behavior of Reinforced Concrete Beams Casted with Recycled Coarse Aggregate.** *European Journal of Advances in Engineering and Technology* 2015; **2**(9): 59–71.

**[13]** Katkhuda H, Shatarat N. **Shear Behavior of Reinforced Concrete Beams Using Treated Recycled Concrete Aggregate.** *Construction and Building Materials* 2016; **125**: 63–71.

**[14]** Tinini A, Minelli F, Belletti B, Scolari M. **Biaxial Shear in RC Square Beams: Experimental, Numerical and Analytical Program.** *Engineering Structures* 2016; **126**: 469–480.

**[15]** Ghorbel E, Sedran T, Wardeh G. **Instantaneous Mechanical Properties of Recycled Concrete.** *Concrete Recycling: Research and Practice* 2019; 161–186.

**[16]** Tirassa M, Ruiz MF, Muttoni A. **Influence of Cracking and Rough Surface Properties on the Transfer of Forces in Cracked Concrete.** *Engineering Structures* 2020; **225**: 111138.

**[17]** Iraqi Specification No 5/1984. **Portland Cement.** Central Agency for Standardization and Quality Control, Baghdad; 1984.