Civil and Environmental Engineering
Vol. 0, Issue 0, DOI: 10.2478/cee-2025-0057

SHEAR BEHAVIOUR OF RC DEEP BEAMS MADE WITH RECYCLED BRICKS: COMPARATIVE STUDY

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Abstract

This study presents a comprehensive examination of the shear behavior in reinforced concrete deep beams, with a particular focus on the incorporation of recycled bricks (RB) as a partial replacement for conventional coarse aggregates. The research explores both experimental and numerical approaches to assess how various factors influence the failure characteristics of these beams. A total of nine beams were tested experimentally to evaluate the effects of different variables, including the proportion of recycled brick aggregate, the grading size of the material, and the shear span-to-depth ratio (a/d). Simultaneously, a numerical analysis was performed using ANSYS APDL to model ten deep beams, concentrating on the layers of recycled brick and varying a/d ratios. Reducing cracking and ultimate load capabilities were the outcomes of raising the recycled brick replacement to 5% and 10%, according to the research. The cracking load, for instance, dropped 10.4% at 5% RB and 29.9% at 10% RB. Beam shear strength also decreased with increasing replacement ratio. Notably, beams with a finer grading size of recycled bricks experienced significant reductions in cracking load 18.5% for 5% RB and 38.5% for 10% RB. The ultimate load capacities of these beams also dropped by 10.4% and 28.9%, respectively. From the numerical simulations, it was observed that the addition of transverse reinforcement enhanced the shear strength of the deep beams. When compared to ordinary concrete deep beams, the installation of steel reinforcement in places crucial to shear performance significantly improved ultimate shear strength by 39.6%, 27.46%, and 21.2%, respectively. Alternatively, compared to beams made completely of regular concrete, the ultimate shear strength was lower when recycled bricks were included into the hybrid cross-sectional regions. The relationship between reinforcement and material composition was presented, which impacts deep beams' shear capability. It noted beams that were loaded from two directions showed a drop in ultimate shear strength when the shear span-to-depth ratio (a/d) was reduced.

Keywords:

Bricks;
Shear behavior;
Ductility;
Energy absorption;
Stiffness.

1 Introduction

The demolition of older structures results in a significant amount of debris. Since this waste can be used as a raw material for new concrete, it makes sense to look into the possibility of recycling it. Given the large amount of aggregates used in concrete, it is only natural to look for ways to repurpose construction waste in the production of new concrete. It makes sense to employ these recycled materials in place of natural aggregate, which accounts for the majority of concrete volume, in either a partial or full capacity [1]. This concept sparked an investigation by numerous researchers on the feasibility of using recycled materials to make concrete [1-4]. Making fresh concrete from recycled materials has many benefits, the most important of which is cutting down on buried construction waste, which helps with land resource management and also helps keep building costs down. The aggregate makes up the biggest portion of the concrete mixture, and its production is associated with a significant cost due to its extraction, transportation, and usage in concrete construction. Concrete production is one of the biggest consumer manufacture, exhaustion of concrete almost 10 billion tons in every year, which countries pay a massive price for this production. Using recycled materials makes concrete production more sustainable. Nonetheless, the matter of manufacturing has been addressed rigorously by several nations. Most countries are trying to lessen the environmental concerns caused by trash accumulation, therefore concrete has embraced recycling and reusing resources in its production process [3, 4]. Reducing energy usage and carbon emissions, these steps have a positive influence on the environment. Therefore, this aligns with the objectives of eco-friendly construction methods and preserving resources [5]. Technologies for processing waste concrete and using recycled materials are attracting a lot of attention because of the possible environmental and economic benefits. Experts in the field are constantly looking for new and better ways to recycle concrete scraps and add recycled elements to new concrete recipes. More sustainable and effective use of resources in construction is the goal here [6,7].

It is essential to study how recycled materials behave when mixed with concrete, despite the fact that doing so has several advantages. Numerous studies have shown that recycled concrete materials (RCM) aren't as reliable as their natural counterparts, thus it's best to use them in moderate amounts. The material-level characteristics of both regular and recycled concrete have been the subject of extensive experimental study [8–10]. Esraa Kh. Mohsin Abuzaid et al. [11] conducted an experimental study on the flexural behavior of reinforced concrete beams, where the coarse aggregate was fully (100%) or partially (50%) replaced with waste materials, specifically crushed concrete or crushed bricks. Depending on the depth of the beams, the replacement might have happened at full or half depth. A reference beam composed solely of natural aggregates was one of nine beams that were subjected to testing under a simply supported span. The other beams varied in the depth and replacement ratio of waste aggregates. Crushed bricks were used for four beams and crushed concrete for four more. Beams reinforced with waste aggregates exhibited comparable structural behaviour to the reference beam, according to the data, with a strength loss of 3% to 20%. Crushed concrete beams were often more robust and rigid than their brick counterparts. Not only that, but going from a 50% to 100% replacement ratio or a 50% to full replacement depth only reduced strength by around 10%. This provides support for the idea that concrete constructions may make good use of waste resources. A separate study by Seare-Paz et al. [12] further investigated the structural behavior of concrete beams incorporating varying amounts of recycled concrete. The study's recycled concrete came from the crushing of concrete cubes that were brought to the lab for testing reasons. The three distinct percentages of recycled concrete content that piqued the interest of the researchers were 20%, 50%, and 100%. Their research proved that the amount of recycled material in concrete has an effect on its mechanical qualities. The flexural, tensile, and compressive strengths of concrete are diminished when recycled materials are used in place of natural aggregate, according to most studies. Researchers have shown that using a higher amount of recycled aggregate in concrete improves its mechanical properties. Esraa et al. [13], studied the flexural behaviour of RC partly replacement of coarse aggregate by 50% 0f smashed concrete or smashed bricks. Showed that the replacement of coarse aggregate by smashed concrete given better strengthen than replacement coarse aggregate by smashed bricks. Mahmoud et al. [14] examined the shear behaviour of RC beams built with recycled material and discovered that the inclusion of recycled aggregate significantly changed the shear strength. More than 15% of the shear strength was lost compared to regular concrete beams. In spite of this, the concrete beams continued to act similarly to conventional concrete beams when using natural aggregate. Using recycled aggregate in concrete has recently shown promising results, and researchers are eager to learn more about how to make recycled concrete stronger and more efficient without sacrificing sustainability or environmental norms. The shear behavior of concrete beams made from recycled aggregate without shear reinforcement was the subject of an experimental and numerical study carried out by Wardeh and Ghorbel [14] in 2019. Beams made of recycled aggregate concrete showed identical crack patterns to those of traditional concrete, according to experimental tests. The tensile strength of recycled aggregate concrete was lowered due to the complete replacement of conventional aggregate with recycled material. In 2021, the researchers Zhang et al. [15] examined the durability of cement produced from repurposed building components. Tests were performed on specimens of varying ages using an energy dispersive spectrometer (EDS) and a scanning electron microscope (SEM). In order to investigate the tensile and compressive strengths, specimens with different weight percentages of recycled aggregate were tested. These percentages ranged from 0% to 100%. Consideration of three distinct recycled brick/aggregate ratios (1:9, 3:7, and 5:5) for each recycled aggregate proportion showed that mechanical properties of cement stabilized mixtures changed linearly between 25% and 50% of the total, but suddenly dropped off between 50% and 75%. Pavement performance is less affected by recycled brick content as recycled aggregate content rises. Concrete reinforced with recycled brick and concrete was the subject of an investigation of its flexural behavior in 2024 by basit et al. [17]. Researchers looked at how well the concrete bonded. The density was marginally influenced by using recycled concrete and brick aggregate in place of natural aggregate, according to the results of the concrete tests. Compressive strength was significantly affected, and the rate of partial replacement increased. The strength of the connection between the concrete and the steel reinforcement is impacted when recycled concrete is used in part instead of natural aggregate. Recycled concrete, in comparison to recycled bricks, had a stronger bond. While prior research explored recycled bricks in a narrow context, the significance of using recycled materials was underappreciated. Incorporating broken clay bricks (CBA) and recycled concrete aggregate (RCA) into concrete should follow the same mix design as regular concrete up to specific percentage levels, as stated in BS EN Standards [18–22]. using a mixture of up to 30% RCA and 5% CBA, as is commonly recommended. The resulting concrete characteristics often do not vary noticeably within these limitations. Since the shear performance of reinforced concrete deep beams using recycled bricks has been largely ignored in previous research, this study aims to rectify that oversight. This study takes into account not just the a/d ratio, but also the replacement ratio and grading size of the recycled bricks, two additional variables known to influence the shear behaviour of concrete deep beams. All aspects of the beams' behaviour, including cracking and ultimate loads, stiffness, ductility, energy absorption, and the load-displacement relationship, were investigated.

2 Material Properties

The practicality of using broken bricks as a substitute for coarse aggregate (gravel) in concrete is investigated in the experimental section of the article. Natural gravel, cement, sand, water, silica fume, superplasticizer, and recycled bricks more especially, crushed and crushed burned bricks are the components that make up the concrete mix, as seen in Table 1 and Fig. 1. At Misan University's College of Engineering, all of the materials used to make concrete undergo stringent physical and chemical testing before mixing. Testing for sieve analysis, grading, and compressive strength is carried out in accordance with ASTM C109 [23], ASTM C-136 [24], and ASTM C191 [25], respectively, while cement is subjected to testing in accordance with Iraqi standards No. 45/1984 [26]. Evaluated are the physical and chemical properties in accordance with Iraqi standard specification No. 45/1984 [26]. Silica fume of grey condenser grade 920 D is an ingredient in the concrete mixture. The experimental superplasticizer component meets the requirements of ASTM C494-99 [27]. Four distinct concrete mixtures are made for the experimental study; the reference mixture, which is used as a starting point, does not contain any crushed bricks (NC). There is a ratio of 1:1.50:3 between the various parts. Crushed brick (CBAC) treated with cement solution is the second option; it entails adding crushed bricks to the mix in different weights according to their percentage of coarse aggregate weight and then treating the mixture with cement. Thirdly, there's burned brick mixture, also known as B-CBAC, which is a combination of burned bricks and cement. Lastly, there is hydrochloric acid (HCL) treated crushed brick, which has been treated with concentrations of 5% and 10%. The best results were obtained while fabricating the deep beams using mix no. 4. It is worth mentioning that the crushed and recycled bricks were subjected to compression tests for various treatment scenarios, as shown in Table 1.

Table 1: Concrete Mixes details.

Material /[kg/m^3]	**Mix 1 [NC]**	**Mix 2 [CBAC]**	**Mix 3 [B-CBAC]**	**Mix 4 [BCBAC-HCL]**
Cement.	500	500	500	667.125
Sand.	750	750	750	667.125
Coarse aggregate [kg/m^3].	1500	1350	1350	1267.53
Super PS.	0.5%	0.5%		0.5%
CBC [kg/m^3]	-	105	105	126.753
Silica fume.	-	-	-	10%
w/c.	0.42%	0.38%	0.38	0.35
fcu (28 days)	53.95	36.49	33.38	50.4
$f_{t.}$	7.29	2.48	2.75	3.3
$f_{r.}$	9.62	4.83	5.78	6.23
Compressive strength for bricks	-	2.13	1.86	2.67

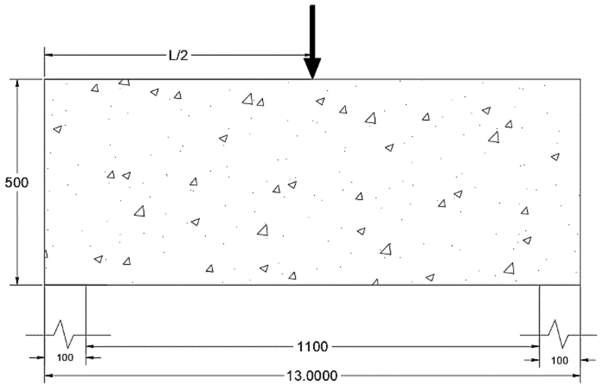
Fig. 1: Fabricating and casting the specimens.

Fig. 2: Laboratory tests specimens.

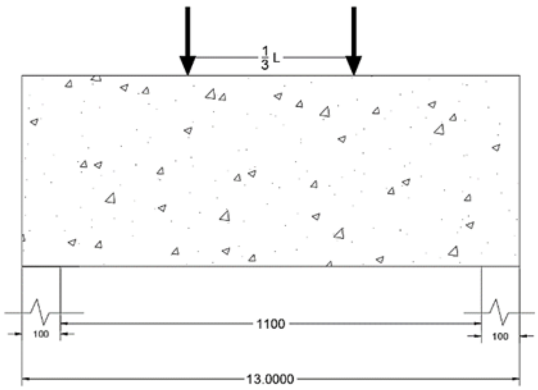
3 Beam details and casting procedure

Casting and testing concrete deep beams were integral parts of this study's exhaustive analysis. The experimental design and fabrication of nine concrete beams took into account a number of criteria. The principal reinforcement for the rectangular beams, which had dimensions of 150 x 500 mm, was bottom steel rebar of (2Ø16) and (3Ø12). Figure 3 shows all the beam specimens that were used for the investigation. The amount of recycled concrete bricks used in the three distinct mixtures ranged from 0% to 10%. The crushed brick aggregate (CBA) was mixed with water in a two-to-one ratio according to weight, then stirred for two or three minutes. Hydrochloric acid (HCL) was then added and left to soak the CBA for a week. Following the soaking time, the CBA was extracted from the HCL solution and allowed to air dry for a duration of three days. After that, the CBA was rinsed and dried with water to remove any traces of HCL from the concrete. Careful removal of any surplus loose materials from the hardened CBA was performed. The dimensions of the manufactured beams (150 x 500 mm) were identical to those of the molds utilized for casting them. Using a scraper and steel brush, the molds were cleaned and coated with oil to make demolding easier. Multiple factors came together to lead to the conclusion that the models would perform best on a smaller size, with the goal of simulating the full-scale models as closely as possible in real dimensions. A feasibility study was conducted to determine the best scale factor, taking into consideration factors like weight and size to guarantee compatibility with laboratory equipment. We used 100 kilogram mixers to mix the concrete.

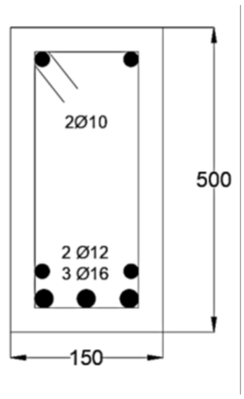
As shown in Figure 4, the forms and control molds were oiled before adding the reinforcement, cages, or control specimens to ensure proper coverage. Prior to mixing, all components were combined in a pristine metal container after being precisely measured. The concrete was cast using plywood form molds, as illustrated in Figure 4. The strain was incrementally increased up until the crack first appeared. As shown in Figure 3, the loads are applied in either one-point or two-point configurations. The testing process relied on the use of linear variable differential transformers (LVDTs) to precisely quantify the vertical deflection.



(a) GA and GB-series.



(b) GC-series.



(C) beam cross section.

Fig. 3: Details of RC deep beams.

Fig. 4: Steel Reinforcement of deep beams.

4 Results and Discussion

Table 4 displays the results of an investigation into the shear behavior of deep beams that used three distinct beam series. The replacement ratio, recycled brick gradation size, and a/d were among the variables studied for their potential impacts. The study's nine deep reinforced concrete beams were custom-made using varying recycled brick (RB) replacement ratios. The beams were subjected to continuous loads until they gave way. The breaking shear strength was found to be between 233 and 441 kN. The displacements varied from 4.83 mm to 6.67 mm and the attained strengths were 366 kN to 571 kN, as indicated in Table 2. Deep beam performance in displacement and maximum load-bearing capacity was affected by variations in shear span to depth ratio (a/d), RB (grading size of the recycled bricks), and replacement ratio of recycled bricks.

4.1 Effect of replacement ratio

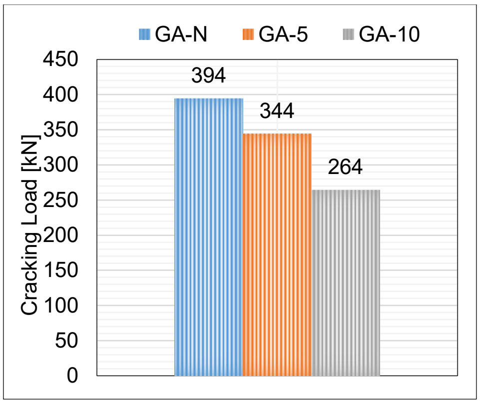
To analyze shear behavior, the experimental study examined three categories of parametric beams. The shear strength of deep reinforced concrete beams was affected by the replacement ratio, which is the proportion of one material that was switched out for another. Cracking load values of 394 kN, 441 kN, and 423 kN were observed in the standard concrete beams with a 0% replacement ratio (GA-N, GB-N, and GC-N), respectively, according to Table 2. There was a range of 522–537 kN for the ultimate strength of these beams. As the replacement ratio increased to 5% for GA-5 and 10% for GA-10, the cracking and ultimate load capacities of the beams decreased, respectively. The cracking load for GA-5 decreased to 344 kN and for GA-10 to 264 kN as the replacement ratio increased from 0% to 5% and 10%, respectively. In a similar vein, increasing the replacement ratio from 5% to 10% resulted in a 10.4% drop in GA-N shear strength, a 29.9% drop in GA-5 shear strength, and a combined loss of 7.1% in GA-10 ultimate load capacity. These findings demonstrate that shear strength declines with increasing replacement ratio, most likely as a consequence of a diminished connection between the particles of concrete. This trend is further illustrated in Figures 5a and 5b, where both cracking load and ultimate load show a progressive decline as the replacement ratio increases.

Table 2: Test results of concrete deep beams..

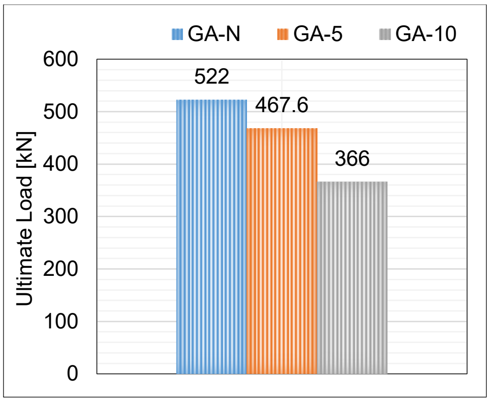
Beam Status/Var.		Beam ID	a/d	Grading	Pcr [kN]	Pu [kN]	Pcr/Pu	Deflection [mm]	I.S [kN/mm]	D.I	Energy absorption [kN.mm]
Experimental Shear Beams	Grading Size (19—20) mm	GA-N	a	20	394	522	75.48%	6.230	421.62	2.09	920.48
		GA-5	a	20	344	467.6	73.57%	6.110	375.34	1.91	788.19
		GA-10	a	20	264	366	72.13%	4.830	364.39	1.89	478.17
	Grading Size (10—12) mm	GB-N	a	12	433	566	76.50%	6.670	432.78	2.14	1083.04
		GB-5	a	12	360	521	69.10%	6.540	366.97	1.99	882.90
		GB-10	a	12	271	444	61.04%	6.490	278.38	1.71	659.55
	Shear-to-depth ratio	GC-N	b	20	423	537	78.77%	4.880	577.87	2.75	774.09
		GC-5	b	20	355	483	73.50%	330	461.34	2.35	682.93
		GC-10	b	20	233	392	59.44%	5.440	285.54	1.80	475.32

Figure 5 (C: GA-series) shows that the cracking load reduced significantly in the second set of beams (GB-N, GB-5, and GB-10), which used recycled bricks (RB) with a finer grading size. Specifically, GB-5 saw a reduction of 87.3% and GB-10 saw a reduction of 67%. Furthermore, as shown in Figure 5 (dň, the shear strength decreased by 8.8% and 23.3%, respectively, when the replacement ratio rose to 5% and 10%. Consequently, the ultimate load also decreased. Beams exposed to two-point loading (GC-N, GC-5, and GC-10), following a similar pattern, had their cracking load reduced by 16% and 45%, respectively, when the replacement ratio was increased. Also, as can be seen in Figures 5 (e) and 5f, the ultimate shear strength dropped by 10.1% and 27% at 5% and 10% replacement ratios, respectively. Concrete deep beams' cracking load and ultimate shear strength were significantly affected by the use of recycled bricks as a partial substitute for coarse particles. There were a number of causes for the decline in mechanical performance. Recycled bricks have different mechanical characteristics than regular coarse aggregates, including less strength, more porosity, and different particle shapes and sizes. These features diminished the end shear strength and cracking load as a result of weakening the bond between the recycled brick particles and the concrete matrix. Furthermore, the composite material was weak due to the recycled bricks' increased porosity and reduced strength, which led to poor bonding within the concrete matrix. The shear capacity was further diminished because cracks and debonding were more likely to occur in the interfacial transition zone (ITZ) between the cementitious materials and the recycled bricks. Another

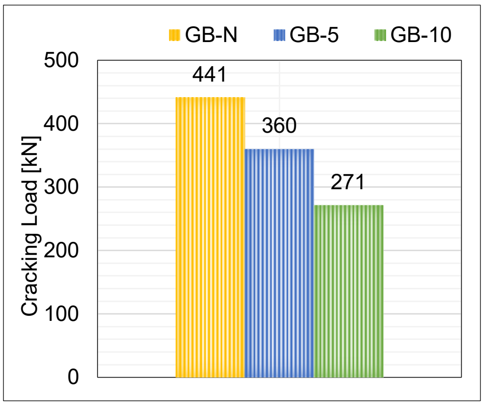
contributing factor was particle packing and grading. The packing efficiency of recycled bricks was lower than that of conventional coarse aggregates, leading to voids within the concrete mix. The beams' structural integrity was damaged by these voids, which allowed fractures to form and propagate. As a result, the cracking load and ultimate shear strength were lowered. Moreover, while recycled bricks contribute to sustainability by reducing construction waste, they may also contain pollutants or residual materials that adversely affect the concrete matrix. Contaminants present in recycled bricks can hinder the hydration process, diminishing both strength and durability. Chemical incompatibilities between recycled materials and the cement matrix may further deteriorate structural performance. The most significant decrease in maximum beam deflection was seen at a 10% replacement ratio, as compared to a 5% ratio. This trend was maintained as the replacement ratio increased. Figure 6 shows that reasons such less-than-ideal particle packing, inhomogeneities, interface effects, and less-than-ideal bonding between the concrete matrix and recycled bricks are to blame for this behaviour.



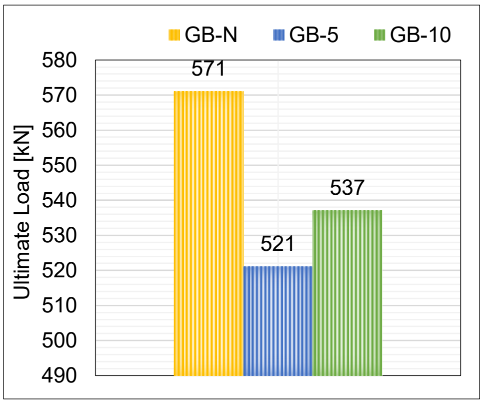
(a) Cracking load of GA-series.



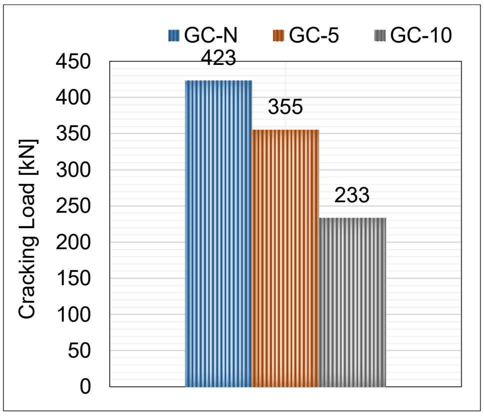
(b) Cracking load of GA-series.



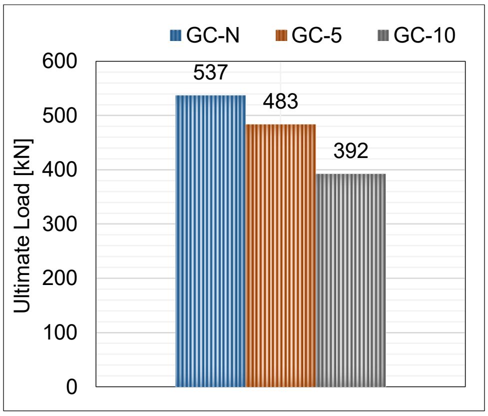
(c) Cracking load of GA-series.



(d) Cracking load of GA-series.



(e) Cracking load of GA-series.



(f) Cracking load of GA-series.

Fig.5: Tested beams results.

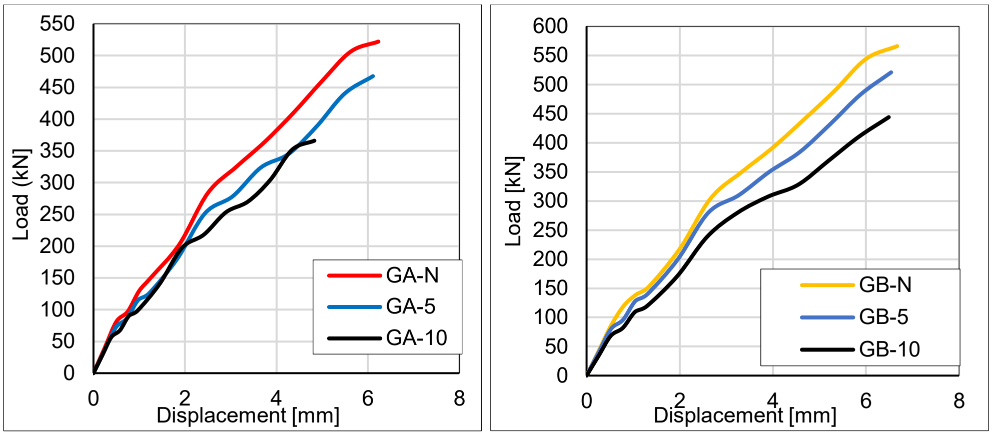
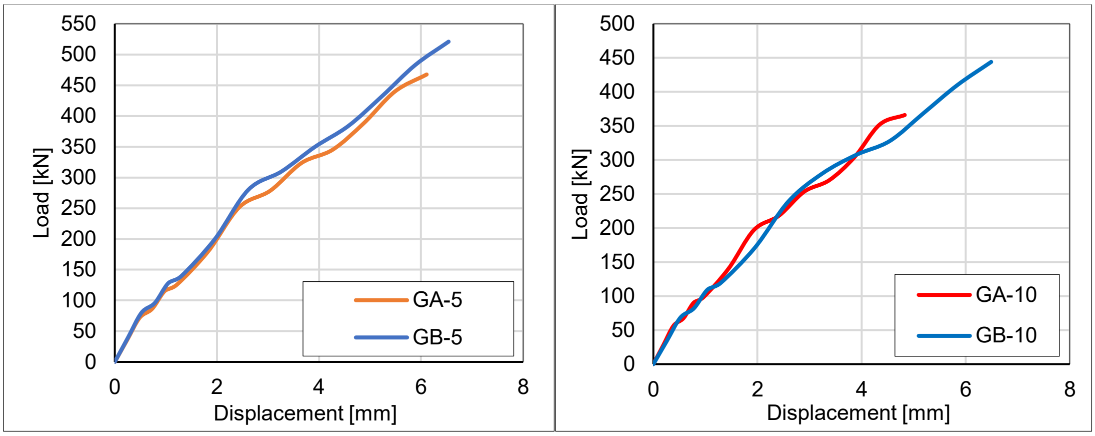


Fig. 6: Load deflection results of GA and GB-series.

4.2 Effect of grading size of rb

Recycled concrete deep beams' load-displacement curve is affected by grading size, as seen in Figure 7. Recycling the bricks partly substituted coarse materials, but their grading size significantly affected the deep beams' shear strength. The results showed that deep beams with a grading size of 19-20 mm had lower ultimate stresses and cracking than those with other grading sizes. However, this reduction was determined by the cracking load and the final load bearing capability. As the replacement ratio increased from 0% to 5% and 10% for the GA-5 and GA-10 beams, respectively, the cracking load decreased by 13% and the ultimate load capacity decreased by 33%. The decrease in cracking stress was much more noticeable for beams that used recycled bricks with a lower grading size. It is clear that the reduction in the grading size of recycled bricks significantly affected the cracking load, as the cracking stress for beam GB-5 reduced by 18.5% and for beam GB-10 it decreased by 38.5%. Reducing the grading size had a lower impact on the ultimate load, which meant that the deep beams' ultimate shear strength was less impacted. In comparison to beams GB-5 and GB-10, which demonstrated ultimate shear strength reductions of 8.75% and 22.3%, respectively, GA-5 and GA-10 demonstrated a 10.4% and 28.9% decrease in ultimate load, respectively .As shown in Figure 7, a comparison of the load-displacement curves for the fracture load, ultimate strength, and deflection between beams GA-5 and GB-5 indicates the following: The cracking load for beam GA-5 was 344 kN, while for beam GB-5, it was 366 kN, which is 4.65% higher. The ultimate load for beam GA-5 was 467.6 kN, 10.3% lower than that of beam GB-5, and the deflection difference between the two was 7%. The effects of grading size on beams with a 10% replacement ratio were more pronounced, especially with the higher replacement percentage. Beam GB-10 had a breaking load that was 2.65 times higher than beam GA-10, at 271 kN. The deflection difference between GB-10 and GA-10 was 34.4%, while the latter's maximum load was 366 kN, which was 17.5% lower. Interlocking and shear transfer were two of the many elements that affected the deep beams' shear strengths in relation to grading size. Recycled bricks' grading size affects the deep beam's shear transmission and interlocking mechanisms. Recycled bricks, especially those that are smaller in size, have an advantage when it comes to shear transfer and interlocking with the concrete matrix, both of which boost the beam's overall performance.



(a) GX-5 series. (b) GX-10 series.

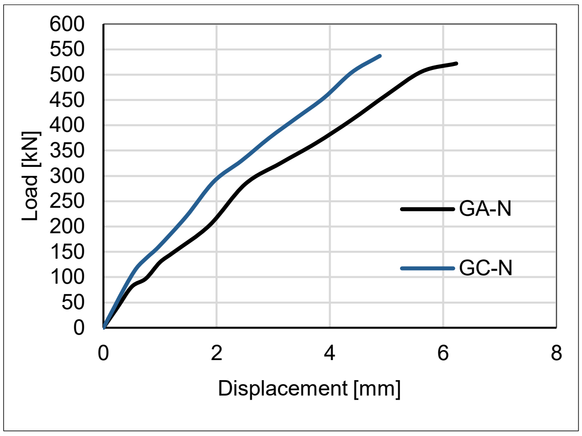
Fig. 7: Load deflection results of GA-5 and GB-5.

The shear strength of the deep beam can be enhanced by this improved interlocking. The particle packaging and void content of the concrete mix are influenced by the grading size of recycled bricks. In order to optimize the shear strength of the deep beam, it is desirable to have minimal cavities and optimal particle packing. A well-graded mix that includes a variety of brick sizes results in enhanced shear strength by reducing voids and achieving better particle packing. Additionally, this phenomenon is significant in terms of the shear plane development, which is influenced by the grading size of recycled bricks in the deep beam. Multiple potential shear planes can be promoted by a well-graded blend that includes a suitable range of brick sizes, which can more effectively distribute the shear forces. The shear strength was enhanced as a result of the distribution of shear forces. Additionally, the compactness and density of the concrete blend are influenced by the grading size of recycled bricks. The voids between larger bricks can be filled by smaller-sized recycled bricks, which leads to a more compact and denser concrete matrix. In general, a compound that is denser demonstrates a greater shear strength.

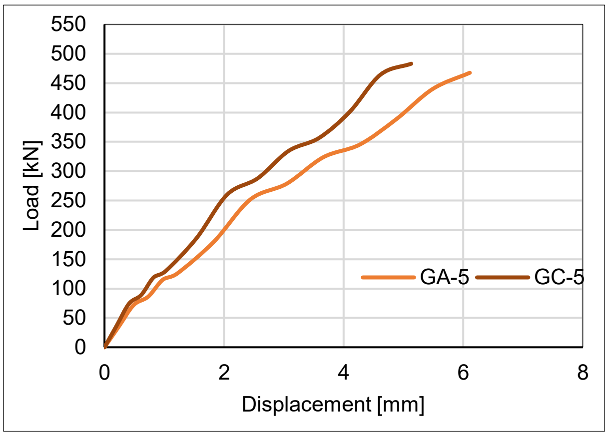
4.3 Effect of Shear Span-to-Depth Ratio (a/d)

The shear span-to-depth ratio (a/d) significantly influences the structural behavior of deep beams. In particular, applying a two-point load to deep beams containing recycled bricks of the same grading size resulted in a higher cracking load and a more substantial increase compared to beams subjected to a one-point load with an a/d ratio of 2. The cracking load in the standard concrete models (GA-N and GC-N) reached 394 kN, which is much greater than in the normal concrete models with a lower a/d ratio. The cracking load rose to 423 kN when a two-point load was used in lieu of the one-point load under the same circumstances. Similarly, a slight difference was observed in ultimate shear strength, where values of 537 kN and 522 kN were recorded for models GA-N and GC-N, respectively. The displacement response of these beams varied significantly. The maximum displacement reduced by 21.7% from 6.23 mm to 4.88 mm when one-point loading was replaced with two-point loading, as seen in Figure 8.With a variance of just 3.2%, the cracking load for GA-5 and GC-5 recycled concrete deep beams was 344 kN and 355 kN, respectively.

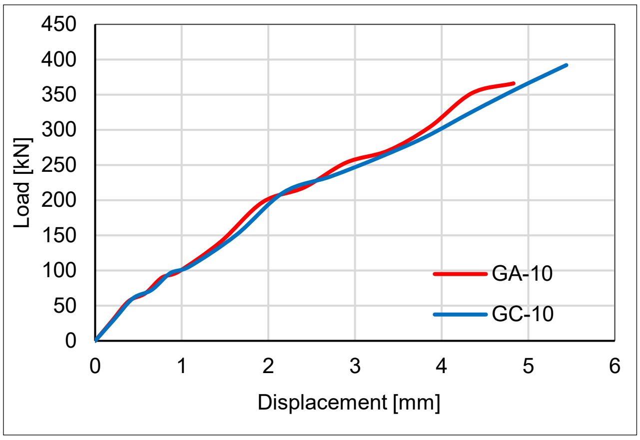
These beams exhibited similar ultimate loads, differing by just 3.3%. However, their displacement responses were unique, increasing from 6.11 mm to 33 mm, reflecting a variation of approximately 16%, as illustrated in Figure 8. In the case of GA-10 and GC-10 beams, the cracking loads were 264 kN and 233 kN, respectively, showing a 13.3% variation. The ultimate load differed by 7.1% between these two beams, though their displacement behaviors varied considerably. As the a/d ratio changed, the displacement for the one-point load increased from 4.83 mm to 5.44 mm, representing a 12.6% rise. Notably, beam GC-10, which exhibited weaker bonding between concrete particles, experienced greater deformation. Meanwhile, beam GA-10, containing a higher percentage of recycled bricks, showed greater displacement than beam GC-10, as demonstrated in Figure 8.



(a) GX-N series.



(b) GX-5 series.

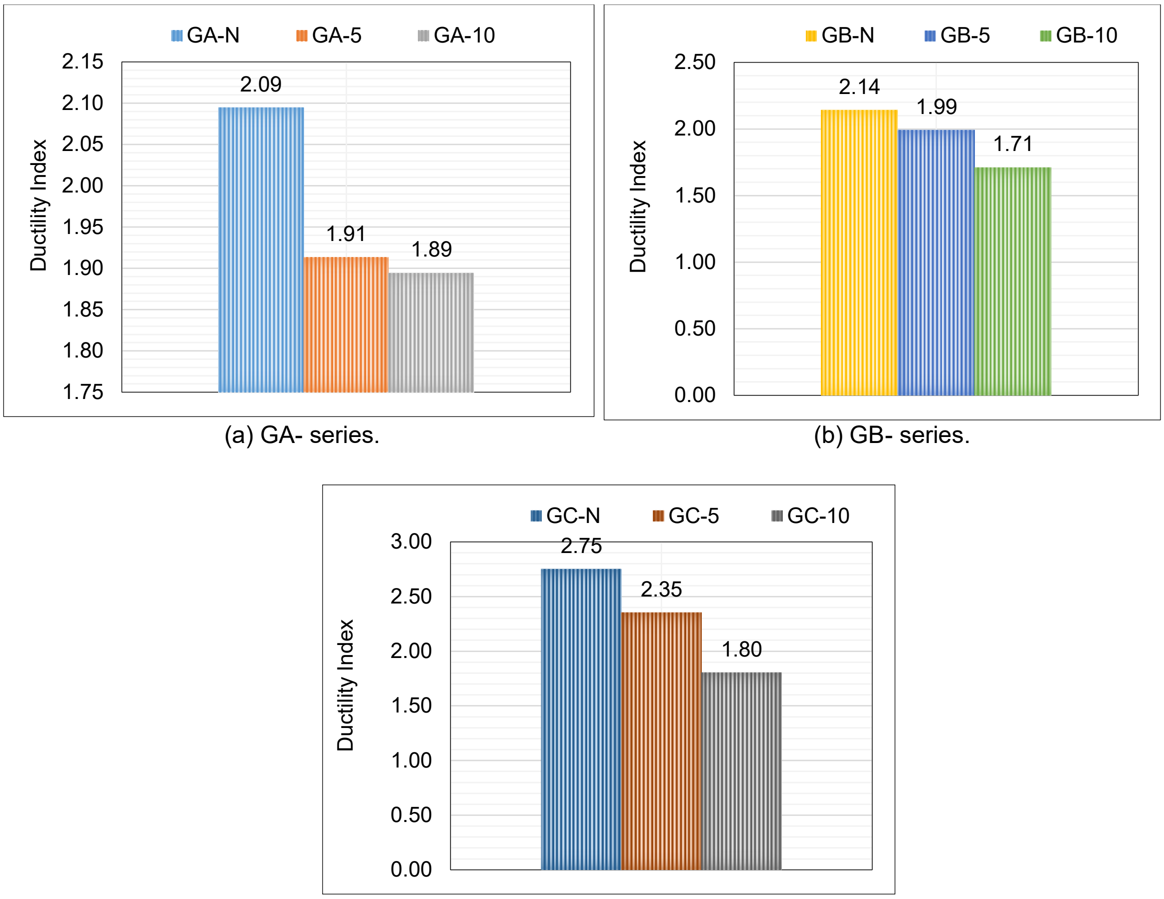


(c) GX-10 series.

Fig. 8: Load deflection results of GA-10 and GC-10.

4.4 Ductility of deep beams

The ductility index of concrete is a measure of how much deformation the material can take before breaking. Ductile concrete constructions are susceptible to observable deformations such cracking and bending when subjected to shear forces. One of the key factors influencing concrete ductility is the presence of recycled bricks, which helps mitigate cracking in control and distribution systems, thereby reducing the likelihood of brittle failure. Ductility is typically measured using the ratio of ultimate deflection (Δu) to yield deflection (Δy), which serves as an indicator of material ductility. As depicted in Figure 9, the results of the ductility index for deep beams reveal that incorporating recycled brick material led to a reduction in ductility, a crucial factor in structural design. Among all the beams that were evaluated, the control beam (GA-N) had the maximum ductility, while the beam with 5% recycled brick content (GA-5) had the lowest. The main reason for this decrease is because recycled bricks lose some of their original features during recycling, which makes them less ductile. Beams GA-5 and GA-10 showed a 9.5% decrease in ductility when compared to the control beam, with ductility indices of 1.91 and 1.89, respectively. Deep beams with lower grading sizes, such GB-N, GB-5, and GB-10, demonstrated better ductility than GA-X beams, drawing attention to a notable difference between the two varieties. The beams exhibited ductility improvements of 2.4%, 7%, and 20.1%, respectively. When subjected to two-point loading, the ductility of normal concrete deep beams saw a significant increase of 31.6%, highlighting a notable enhancement in their ability to deform before failure .However, when the replacement ratio was raised to 5% and 10%, ductility decreased by 14.4% and 34.5%, respectively, as illustrated in Figure 9. These findings highlight the notable effect of the shear span-to-depth ratio (a/d), demonstrating that using a two-point load instead of a one-point load results in a higher ductility index for deep beams incorporating recycled bricks.



(a) GA- series.

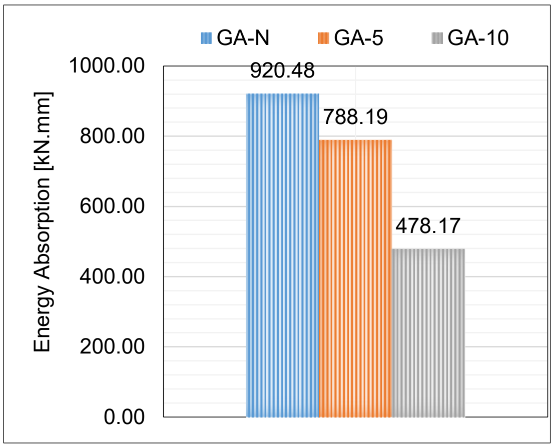
(b) GB- series.

(c) GC-series.

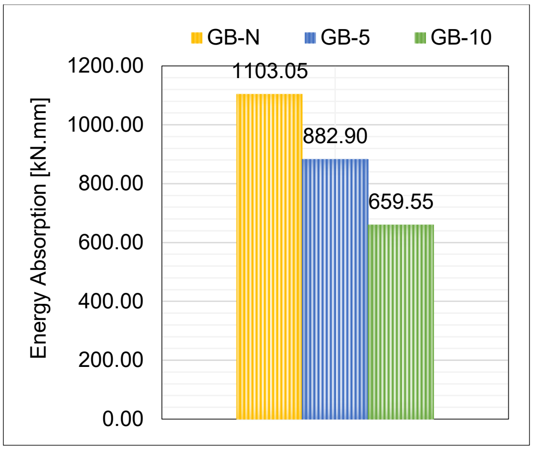
Fig. 9: Ductility index of Deep beams.

4.5 Energy absorption of deep beams

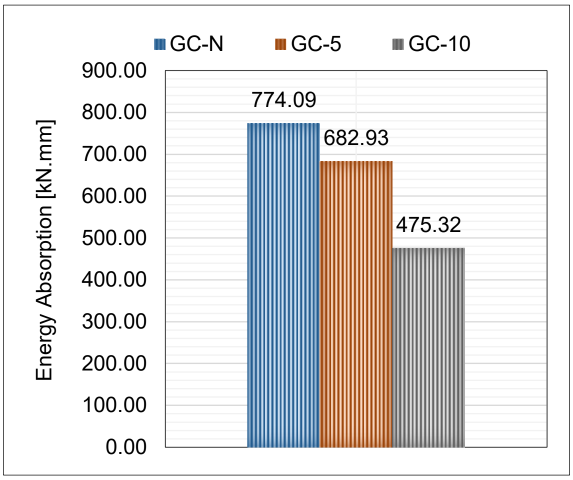
An essential metric for a material's energy absorption is the area under the load-deflection curve. A considerable influence of the replacement ratio of recycled bricks on the energy absorption capacity of concrete deep beams was seen, with a distinct drop in absorption as the replacement ratio rose. The control beam (GA-N) had the highest energy absorption value of 920.48 kN.mm, outperforming the other beams. However, when recycled bricks were added to the concrete mixture, energy absorption was reduced, though the control beam still maintained superior energy absorption. Beam GA-5, with 5% recycled brick content, exhibited a lower energy absorption compared to the control beam. This reduction can be attributed to the lower energy absorption properties of recycled bricks, which tend to lose some of their strength and characteristics during previous usage. The energy absorption for GA-5 and GA-10 decreased by 14.4% and 48.1%, respectively, when compared to the control beam, with energy absorption values of 788.2 kN.mm and 478.2 kN.mm for GA-5 and GA-10, respectively. In contrast, deep beams with smaller grading sizes (GB-5 and GB-10) displayed higher energy absorption than the GA-X beams. The reduction in energy absorption for these beams was 20% and 40.2%, respectively, as shown in Figure 10, confirming that smaller grading sizes resulted in improved energy absorption. When deep beams were subjected to a two-point load, energy absorption for the normal concrete beams decreased by 15.9%. For beams with a 5% and 10% replacement ratio, energy absorption declined further by 11.8% and 38.6%, respectively, as depicted in Figure 10. Additionally, the impact of the a/d ratio revealed that beams incorporating recycled bricks experienced a decrease in ductility when subjected to a two-point load, in contrast to those tested under a one-point load. This suggests that the type of loading configuration significantly affects the performance of recycled brick beams in terms of their deformability.



(a) GA- series.



(b) GB- series.

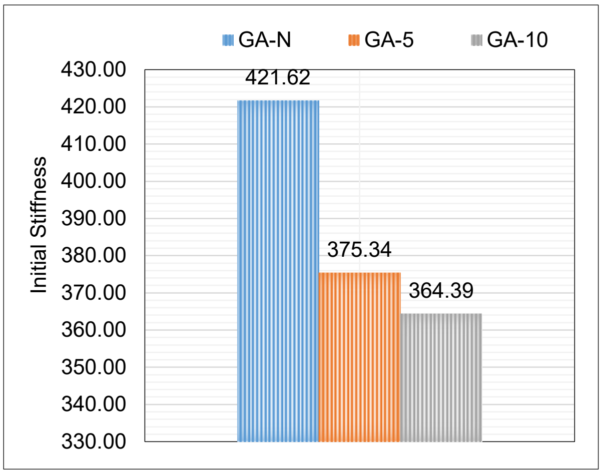


(c) GC-series.

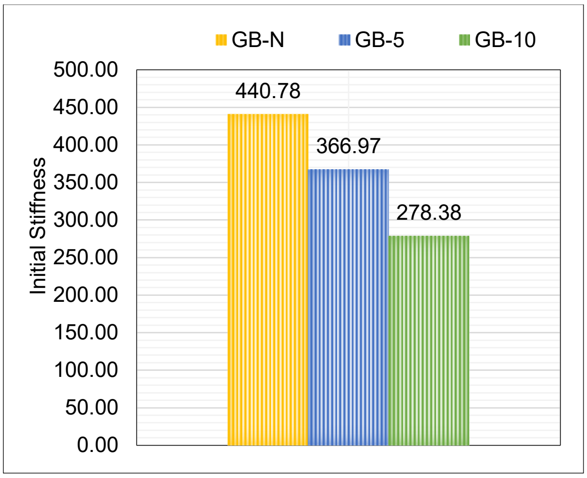
Fig. 10: Energy absorption of Deep beams.

4.6 Initial stiffness of deep beams

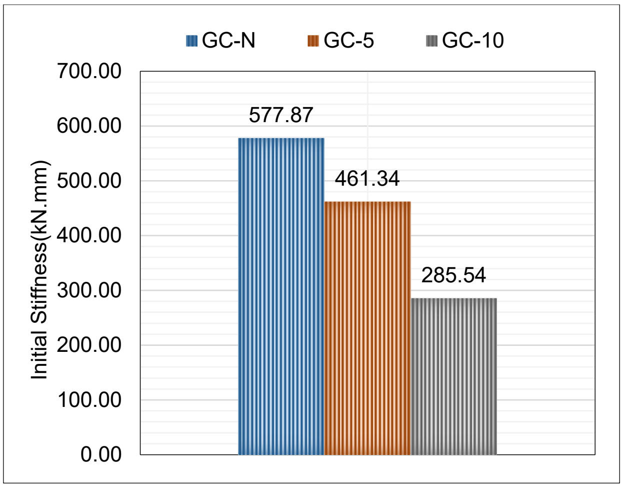
Based on the slope of the initial portion of the load-deflection curve, the initial stiffness of a concrete deep beam can be estimated. By dividing the yield load (Py) by the yield deflection (Δy), one can accomplish the calculation of this value [28]. The inclusion of recycled bricks along the beams significantly affects the initial stiffness of the concrete deep beam since recycled materials tend to diminish stiffness. The initial rigidity of the concrete deep beam is heavily dependent on the replacement ratio of recycled bricks. It was found that the initial stiffness was reduced more noticeably with higher replacement ratios. An initial stiffness value of 421.62 kN/mm was recorded for the control beam GA-N, which was the beam that had the highest initial stiffness among the beams. The initial rigidity of the concrete mixture was reduced, however, as a consequence of the incorporation of reclaimed bricks into the mixture. As a result of the loss of characteristics that occurs during previous usage, recycled materials often have lower beginning stiffness than control beams. Beam GA-5, which was constructed out of recycled brick material, has a lower initial stiffness than the control beam. Beams GA-5 and GA-10 had starting stiffness values of 375.34 kN/mm and 364.4 kN/mm, respectively. This represents a drop in stiffness of 11% and 13.6%, respectively, in comparison to the control beam. While GA-X beams displayed higher initial stiffness, deep beams with smaller grading sizes (GB-5 and GB-10) exhibited lower initial stiffness. When compared to GA-X beams, these beams had a drop in initial stiffness that was 26.9% and 16.7%, respectively. It was noticed that the initial stiffness of regular concrete deep beams rose by 37.1% when compared to deep beams that were subjected to two-point loads as opposed to those that were subjected to one-point loads. when seen in Figure 11, the initial stiffness dropped by an average value of 11.5% when the replacement ratio grew to 5% and 10%. This data is presented in the figure.



(a) GA- series.



(b) GB- series.



(c) GC-series.

Fig. 11: The initial stiffness of Deep beams.

4.7 Cracking And Failure Mode

With regard to each beam that was examined, the crack features and failure manner are depicted in Figure 12. The cracking manner of the beams that were evaluated demonstrated a different behavior of failure related to the kind of beam, with the RBC beams exhibiting a failure mode that was distinct from that of the NC beams. Cracks can appear in shear-deep beams regardless of whether or not recycled bricks are used in their construction. Shear pressures that are greater than the capacity of the beam are the primary cause of cracking in conventional concrete deep beams. Due to their large depth-to-span ratio, these beams are more prone to shear failure compared to beams with a lower depth-to-span ratio. A cracking mechanism that is comparable to that of conventional deep beams can be found in shear deep beams that do not contain recycled bricks. The diagonal tension is the principal mode of cracking that occurs in shear-deep beams when they are subjected to various shear forces. When the shear force is increased, diagonal cracks begin to appear in the beam, and they radiate outward from the place where the shear stress is at its greatest. The cracks that were formed at a 45-degree angle with the horizontal axis spread out and extended to the regions of the support. RC beams saw a decrease in their stiffness and strength against deformations as a result of the cracks being initiated. It is important to investigate a new technique in order to effectively limit the fracture propagation in the beams that are constructed using recycled bricks. It was challenging to maintain control over concrete that was prepared with recycled bricks because of the high percentage of recycled bricks in the concrete sample. Additionally, the properties of recycled crushed bricks have an effect on the behavior of concrete deep beams, which suggests that there is a need to improve the properties of the bricks in order to lessen the adverse impact that these aggregates have. These differences have an effect on the cracking behavior of deep beams that were constructed using reclaimed bricks. Because of the recycled bricks' weaker strength or bonding characteristics, the beams succumbed to failure and cracking at an earlier stage than they should have. The weaker bricks are unable to properly resist the shear stresses, which leads to premature cracking and a reduction in the load-carrying capacity of the bricks. Moreover, implementing proper reinforcement detailing, including the addition of shear reinforcement, is essential for enhancing the overall structural strength and preventing significant cracking, thus ensuring the beam's long-term durability and stability.

(a) GA-N (b) GA-5 (c) GB-N

(d) GB-5 (e) GB-10

Fig. 12: Cracks pattern for beams.

4.8 Theoretical Study (Finite Element Study)

A. Verification

Using existing experimental data, this work models the structural behaviour of deep beams that are simply supported. Based on experimental experiments, this inquiry analyzed fifteen deep beams in total. Results from numerical models and actual data for specimens GA-N to GC-10 are compared in Table 3 and Figure 13. Maximum deflection, fracture patterns, load-deflection behaviour, and ultimate load were the main areas of comparison. The anticipated load-deflection curves match the actual data quite well, as shown in Figure 13, showing that numerical and physical testing are highly correlated. Table 3 displays the ultimate load values; these data show that the numerical model is reliable, with a ratio of experimental to numerical ultimate load ranging from 97% to 108%. Furthermore, Table 3 presents both experimental and numerical values for maximum deflection, showing generally acceptable ratios. However, the deflection ratio is slightly lower than that of the load values, which can be attributed to the brittle nature of concrete and bricks. One key difference between the numerical and experimental results lies in crack propagation. The observed discrepancies primarily stem from the simplifications and assumptions inherent in the finite element method (FEM). These factors make it challenging to precisely replicate crack development as seen in physical experiments. Additional differences between theoretical and experimental conditions further contribute to variations in results, but the primary influence remains the material behavior of concrete. Notably, the numerical model predicted larger cracks compared to those observed experimentally, with some extending into areas where no physical cracks were detected. This discrepancy arises because finite element models tend to predict more extensive cracking due to higher stress concentrations at the nodes. The cracking model used in the FEM distributes material degradation across the entire volume of the element, which may lead to exaggerated crack formation. Moreover, the assumption of a perfect bond between elements within the FEM contributes to higher localized stress concentrations in the concrete elements, further influencing crack propagation predictions.

Table 3: Verification results include the failure load.

Beam Status/Var.		Beam ID	Vu, ANS. [kN]	Vu, Exp. [kN])	$\frac{Vu, Exp}{Vu, ANS.}$	Δ, N, [mm]	Δ, Exp, [mm]	$\frac{\Delta, ANS}{\Delta, Exp.}$
Experimental Shear Beams	Grading Size (19—20) mm	GA-N	542	522	103.83%	5.64	6.230	90.55%
		GA-5	491	467.6	105.00%	34	6.110	84.06%
		GA-10	379	366	103.55%	4.67	4.830	96.69%
	Grading Size (10—12) mm	GB-N	612	566	108.13%	5.36	6.670	80.36%
		GB-5	515	521	98.85%	4.99	6.540	76.35%
		GB-10	431	444	97.07%	7.42	6.490	114.27%
	Shear to depth ratio	GC-N	556	537	103.54%	5.51	4.880	112.99%
		GC-5	496	483	102.69%	4.71	330	91.81%
		GC-10	424	392	108.16%	4.59	5.440	84.38%

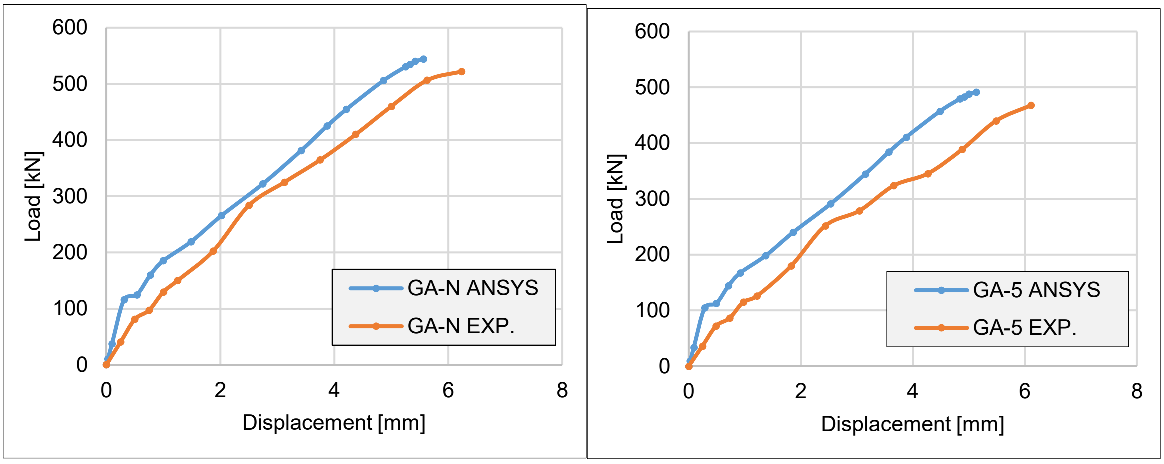


Fig. 13: Verification relationship between Numerical and experimental beams.

B. Effect of Shear Reinforcement Ratio

The investigation into shear behavior was carried out through three distinct series, each subdivided into three groups. Table 3 shows the results of the first set of numerical simulations conducted on deep beam specimens evaluated under a one-point load on recycled brick deep beams, which aimed to assess the impact of shear reinforcement spacing. The impact of recycled brick layers on beam performance in relation to the shear span-to-depth ratio (a/d) was examined in the second and third series of the research by modelling 10 deep beams using ANSYS APDL. The simulation results revealed a wide variation in cracking loads, ranging from 87 kN to 382 kN, with the plain concrete deep beam exhibiting the lowest capacity to resist cracking .In terms of ultimate load and maximum displacement, the ultimate strength varied between 335 kN and 515 kN, while the maximum displacement ranged from 3.44 mm to 5.86 mm, as illustrated in Figure 14. The observed variations in results were attributed to different factors considered in the simulation. A significant improvement in the shear performance of deep beams was seen when recycled bricks were added to the concrete mix. The first stage of the experiment included numerically fabricating and testing three deep beams of reinforced concrete (RC) with different transverse steel reinforcement ratios until they failed. The beams were subjected to static stress. As summarized in Table 3, the findings demonstrated cracking loads ranging from 87 kN to 301 kN, ultimate strength values between 335 kN and 427 kN, and displacements spanning from 3.44 mm to 4.03 mm. The differences in ultimate load capacity were influenced by multiple factors, including the transverse steel reinforcement ratio, the shear span-to-depth ratio (a/d), and the constant replacement ratio of recycled bricks (RB). For example, the GA-5 beam, which contained 5% recycled brick content but lacked shear reinforcement, exhibited the lowest cracking load at 87 kN. However, the incorporation of shear reinforcement significantly enhanced structural performance, increasing the cracking load by over threefold .Adding shear stirrups at 10 cm, 15 cm, and 20 cm spacing, respectively, enhanced the shear strength by 39.6%, 27.46%, and 21.2% compared to the unreinforced shear plain concrete beam (GA-5-0). Furthermore, maximum displacement was significantly increased when steel rebars were used to reinforce the shear zones. Beams GA-5, GA-5-15, and GA-5-20 all showed increases of 77.6%, 12.5%, and 17.2%, respectively, when compared to GA-5-0. The importance of transverse steel reinforcement in RC deep beam performance optimization is highlighted by these results. Increases in ultimate strength, cracking load capacity, and deformation capability may be achieved by increasing the transverse reinforcement ratio. Modifying the shear span-to-depth ratio and the RB replacement ratio strategically may enhance the structural behaviour and load-bearing efficiency of RC deep beams even more.

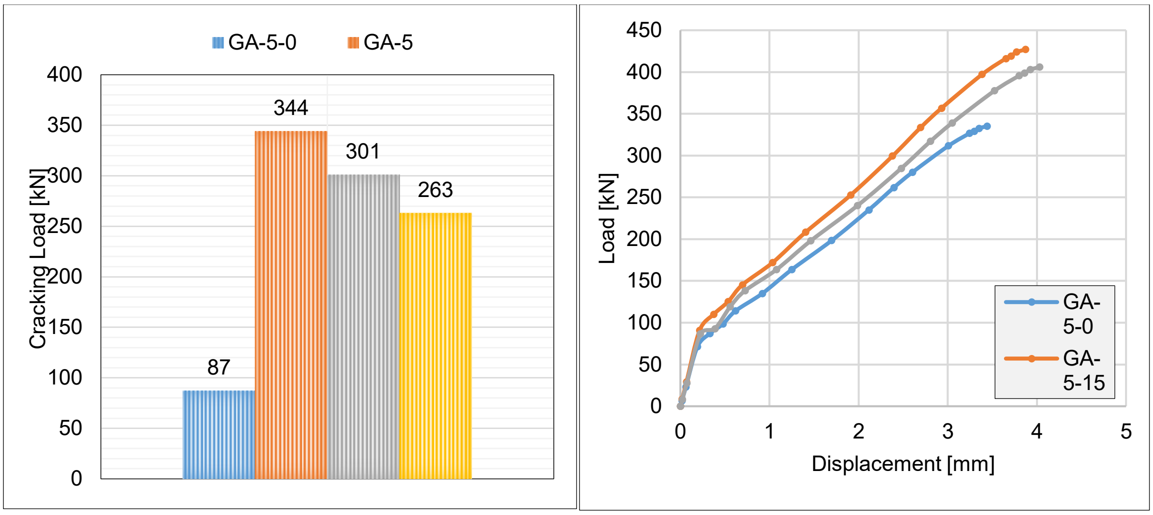


Fig. 14: load deflection curve of GA-5 and GA-5-0.

C. Influence of Recycled Brick Layers

The second experimental series involved testing three numerically simulated reinforced concrete (RC) deep beams, each containing recycled brick layers of different thicknesses within the concrete matrix. Static stress was applied to the deep beams until they failed structurally. The layers of reclaimed brick used for reinforcement ranged in thickness from 5 cm to 40 cm from the top of the cross-section. The ultimate strength varied between 481 and 514 kN for beams with a shear span-to-depth ratio (a/d) of 2, while the cracking loads were 341 to 381 kN. Table 3 shows that the maximum displacements were all within a very small range, from 5.71 mm to 5.86 mm. Among the many variables that affected the load-bearing capacities of the beams, the recycled brick layers' thickness was the most important in determining how the beams mechanically performed as a whole. The structural response differences were also caused by the a/d ratio and the recycled brick (RB) replacement ratio. Figure 15 shows that the beam with the lowest breaking load of 341 kN was the one that included 5% recycled bricks and had a 40 cm recycled brick layer (GA-40CM). Both the ultimate shear strength and maximum displacement were affected by the addition of recycled bricks to the hybridised cross-section of deep beams. The presence of these recycled layers influenced stress distribution, load transfer efficiency, and overall deformation characteristics, thereby modifying the beams' structural integrity and failure mechanisms. Lower ultimate shear strengths (varying from 1.5% for a 5 cm layer to 7.9% for a 40 cm layer) were seen in comparison to the typical concrete deep beam (GA-N), according to the findings. However, the inclusion of recycled bricks had a minimal effect on displacement behavior, as the displacement values of the hybridized beams were comparable to those of the conventional concrete beam (GA-N). This suggests that, despite the slight reduction in shear strength, maximum displacement remained largely unaffected, as illustrated in Figure 16. When deep beams with a shear span-to-depth ratio (a/d) of 1 were subjected to two-point loading, incorporating recycled brick layers within the cross-section significantly affected their structural performance. The introduction of recycled brick layers of different thicknesses ranging from 5 cm to 40 cm altered both the ultimate strength and maximum displacement. As the proportion of recycled brick increased, a noticeable decline in ultimate shear strength was observed, highlighting a trade-off between material sustainability and mechanical performance. Compared to the conventional concrete deep beam (GC-N), the hybridized beams exhibited reduced shear resistance, emphasizing the influence of recycled brick distribution on load-bearing capacity. The reduction ranged from 4.1% for a 5 cm layer to 9% for a 40 cm layer. Similar to the one-point loading scenario, the presence of recycled bricks had a negligible effect on displacement in deep beams subjected to two-point loads. The displacement values remained comparable to those of the conventional concrete deep beam (GC-N), indicating that variations in recycled brick thickness did not substantially alter displacement behavior. In summary, the results indicate that integrating recycled bricks within the cross-section of deep beams leads to a modest decline in ultimate shear strength. However, this modification has a negligible effect on the displacement characteristics of the beams, as illustrated in Figure 17. This suggests that while recycled brick incorporation influences load-bearing capacity, it does not significantly alter the deformation behavior under applied loads.

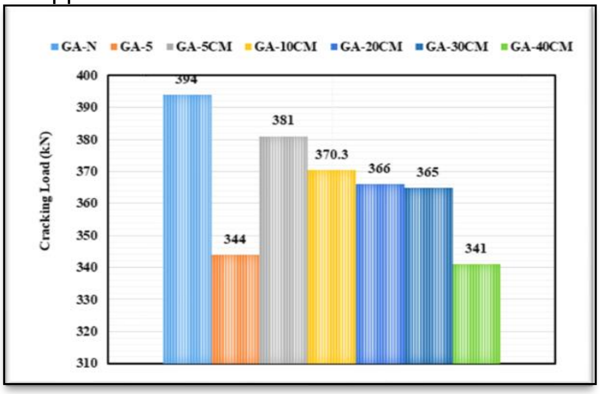


Fig. 15: Cracking load of GA numerical series.

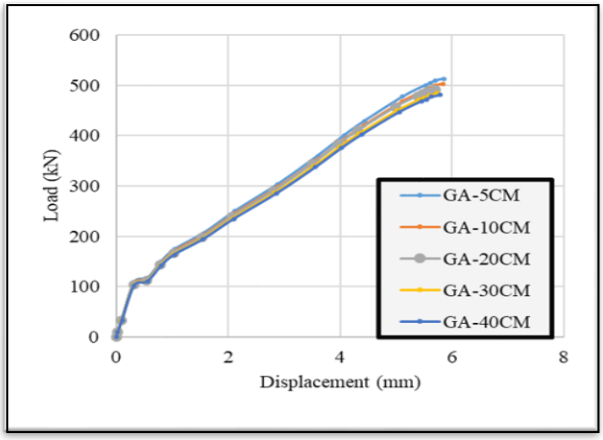


Fig. 16: load-displacement curve numerical series.

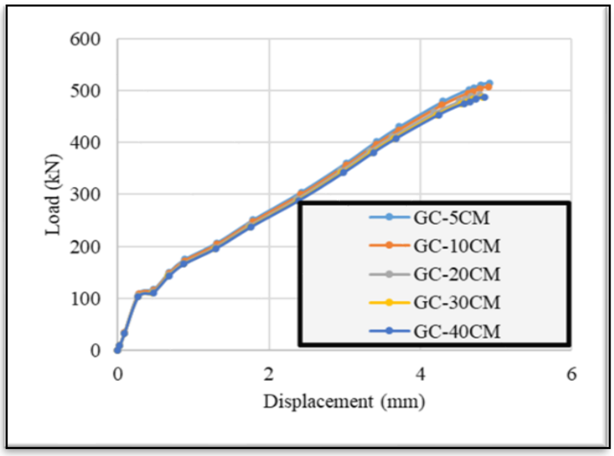


Fig. 17: load-displacement curve numerical series.

D. Ductility

Stirrups increased ductility in the first numerical series, as was predicted. Concrete beams reinforced with recycled bricks exhibited significantly different structural behaviour compared to regular concrete beams. Specifically, deep beams containing 5% recycled bricks had their ductility properties greatly affected by modifying the transverse steel reinforcement. The ductility index of the plain concrete deep beam without reinforcement was 1.9. Nevertheless, the ductility was enhanced for beams GA-5-0, GA-5-15, and GA-5-20 when shear stirrups were inserted at 15 cm and 20 cm spacing, respectively, with values of 2.09, 2.76, and 2.52. These variations, as depicted in Figure 18, highlight the role of shear reinforcement in enhancing the deformation capacity of recycled brick-infused deep beams. In the second numerical series, as anticipated, the introduction of recycled materials led to a reduction in ductility. However, concrete beams incorporating recycled bricks displayed a distinct behavior. Incorporating recycled brick layers of varying thicknesses (5, 10, 20, 30, and 40 cm) into the upper section of deep beams had a noticeable impact on ductility. The beam with the thinnest recycled brick layer (5 cm) exhibited the highest ductility, with a value of 2.19. However, as the thickness of the recycled brick layers increased, a progressive decline in ductility was observed. Specifically, ductility reductions of 1.9%, 1.9%, 3.8%, and 5.2% were recorded for beams GA-10CM, GA-20CM, GA-30CM, and GA-40CM, respectively. These results, illustrated in Figure 19, suggest that increasing the proportion of recycled bricks in the cross-section reduces the beam's ability to undergo deformation before failure. A comparable trend was identified in the third numerical series. A beam with a 5 cm recycled brick layer showed a ductility of 2.62 when deep concrete beams were hybridised with layers of 10, 20, 30, and 40 cm. Ductility progressively decreased when the layers of reclaimed bricks were thickened to 10, 20, 30, and 40 cm. The GC-5CM, GC-10CM, GC-20CM, GC-30CM, and GC-40CM models exhibited decreases of 1.2%, 1.5%, 3.1%, and 4%, respectively, as seen in Figure 20. These findings highlight how recycled brick layers affect deep concrete beams' ductility. While the inclusion of stirrups generally enhanced ductility, the presence of recycled bricks, particularly at greater thicknesses, caused a slight reduction. This highlights the importance of carefully evaluating material properties when designing beams incorporating recycled components.

E. Stiffness

In the first numerical series, as anticipated, the inclusion of stirrups contributed to an increase in stiffness. However, concrete beams incorporating recycled bricks displayed a distinct response. Adjusting the transverse steel reinforcement in deep beams containing 5% recycled bricks resulted in different stiffness characteristics compared to conventional concrete. The stiffness of the plain concrete deep beam was measured at 168.6, but this value significantly increased when shear reinforcement was introduced. Specifically, beams reinforced with stirrups at 15 cm and 20 cm spacing exhibited enhanced stiffness values of 518.52 and 435.07, respectively, as depicted in Figure 21. In a separate numerical analysis, the incorporation of recycled brick layers with varying thicknesses (5 cm, 10 cm, 20 cm, 30 cm, and 40 cm) from the top of the cross-section altered the mechanical behavior of deep beams, resulting in distinct structural responses compared to conventional concrete beams.

The deep beam with the 5 cm layer of reclaimed bricks showed a rigidity of 433.45. Stiffness progressively decreased as the recycled brick layer thickness rose to 10, 20, 30, and 40 cm. As shown in Figure 22, the stiffness reduction percentages for models GA-5CM, GA-10CM, GA-20CM, GA-30CM, and GA-40CM were 2.65%, 1.3%, 2.1%, and 9.3%, respectively. The third number series also revealed a similar pattern. A noticeable difference was seen when compared to regular concrete when concrete deep beams were hybridised with 5–10–20–30–40 cm layers of reclaimed bricks. The beam incorporating a 5 cm recycled brick layer recorded a stiffness of 2.62. As the recycled brick layer thickness increased to 10 cm, 20 cm, 30 cm, and 40 cm, a gradual reduction in stiffness was observed. As shown in Figure 23, the equivalent percentage reductions for models GC-5CM, GC-10CM, GC-20CM, GC-30CM, and GC-40CM were 1.2%, 1.5%, 3.1%, and 4%, respectively. These findings highlight the influence of recycled brick layers on the stiffness of deep concrete beams. While the incorporation of stirrups generally enhanced stiffness, the addition of recycled bricks led to a gradual decline, particularly as the thickness of the recycled brick layers increased.

F. Energy Absorption

In the first numerical series, incorporating stirrups, as anticipated, resulted in an increase in energy absorption. However, concrete beams containing recycled bricks displayed a unique response. Modifying the transverse steel reinforcement in deep beams with 5% recycled bricks produced outcomes that differed from those observed in conventional concrete. The unreinforced deep beam made of plain concrete had an energy absorption value of 112.23, which rose to 788.2, 436.83, and 397 for beams reinforced with stirrups spaced at 10 cm, 15 cm, and 20 cm, respectively, as illustrated in Figure 23. The second set of numbers shows that compared to regular concrete, the energy absorption pattern of hybrid concrete deep beams made of recycled bricks with layers of 5, 10, 20, 30, and 40 cm in thickness is very different. A value of 920.48 for energy absorption was shown by the deep beam (GA-5) that did not include recycled bricks. Energy absorption decreased with increasing recycled brick layer thickness from 10 cm to 40 cm. Figure 25 shows that models GA-5CM, GA-10CM, GA-20CM, GA-30CM, and GA-40CM individually reduced energy absorption by 9.1%, 11.8%, 14.9%, 14.65%, and 19.6%. A similar trend emerged in the third numerical series. When deep beams were hybridized with recycled brick layers of 5 cm, 10 cm, 20 cm, 30 cm, and 40 cm, their energy absorption characteristics differed from those of conventional concrete. The deep beam incorporating a 5 cm layer of recycled bricks had an energy absorption value of 2.62. As the recycled brick layer thickness increased to 10 cm, 20 cm, 30 cm, and 40 cm, energy absorption gradually decreased. Reductions of 1.2%, 1.5%, 3.1%, and 4% were obtained for models GC-5CM, GC-10CM, GC-20CM, GC-30CM, and GC-40CM, respectively, as shown in Figure 25.

These findings suggest that while the inclusion of stirrups generally enhances energy absorption, the introduction of recycled bricks leads to a progressive decline in energy absorption, particularly as the thickness of the recycled brick layers increases.

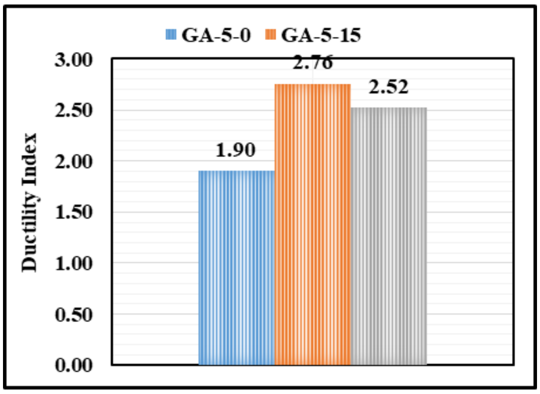


Fig. 18: Ductility index of numerical series.

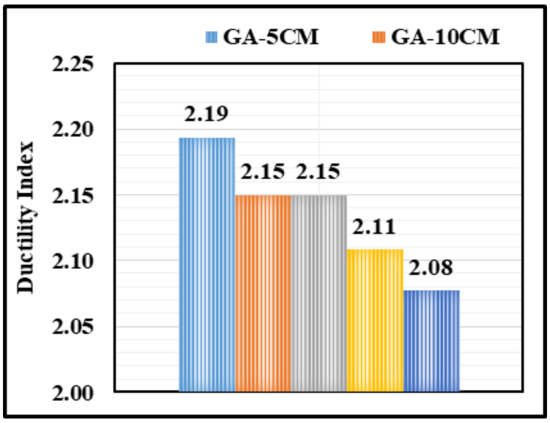


Fig. 19: Ductility index of numerical series.

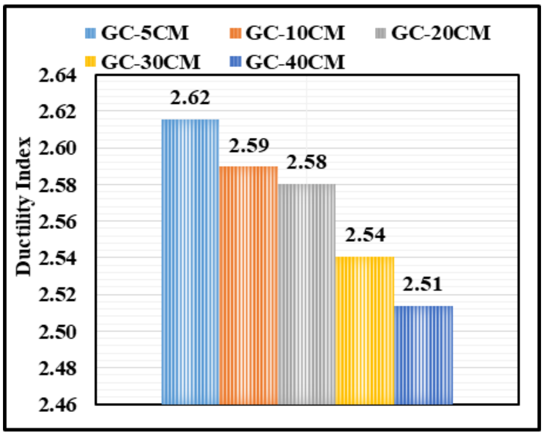


Fig. 20: Ductility index of numerical series.

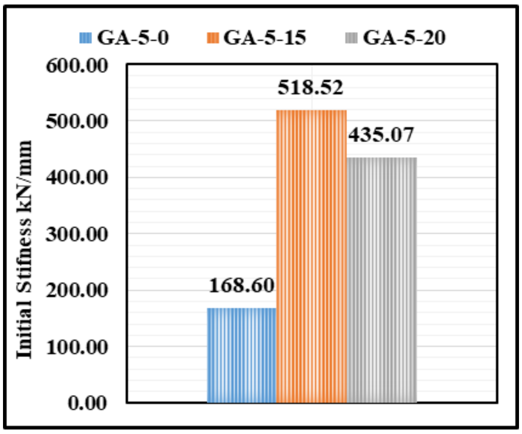


Fig. 21: Stiffness of numerical series.

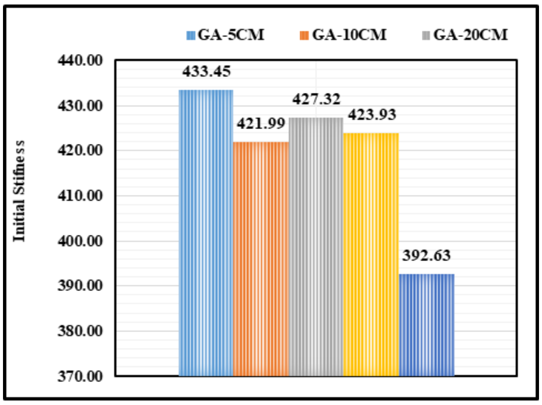


Fig. 22: Stiffness of numerical series.

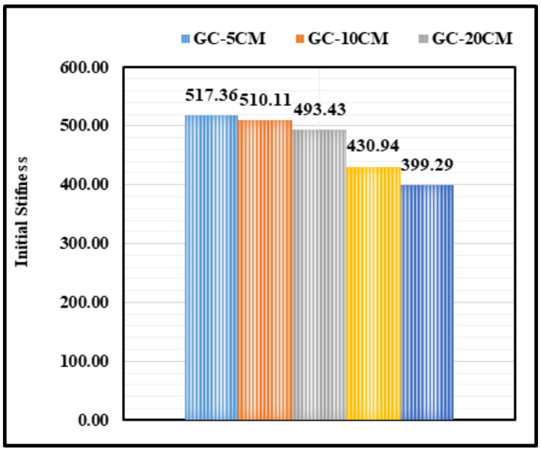


Fig. 23: Stiffness of numerical series.

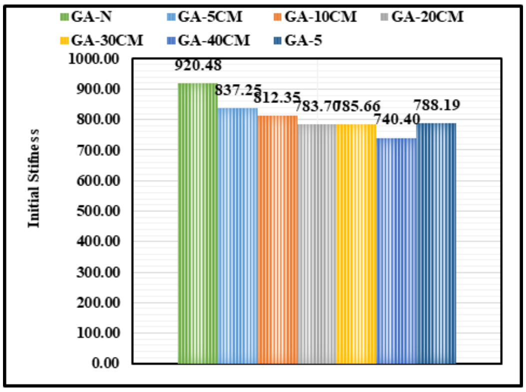


Fig. 24: Energy absorption of numerical series.

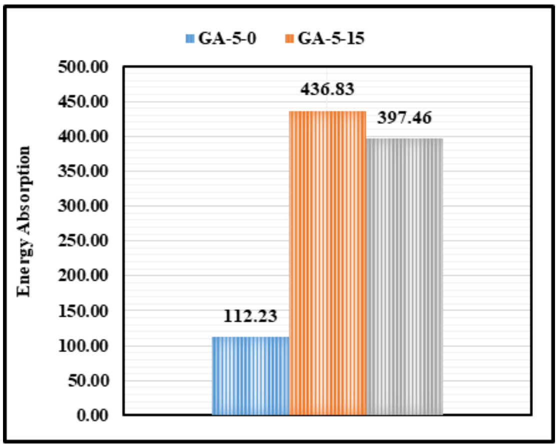
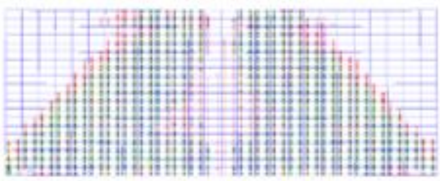
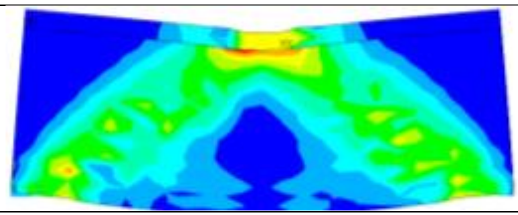
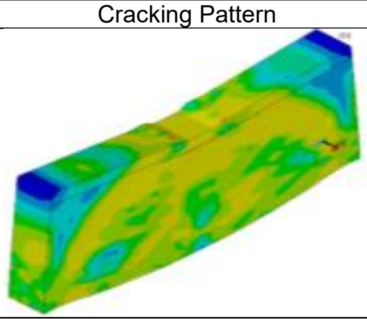
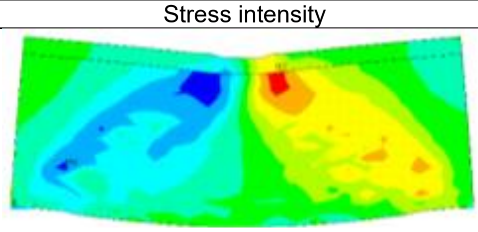


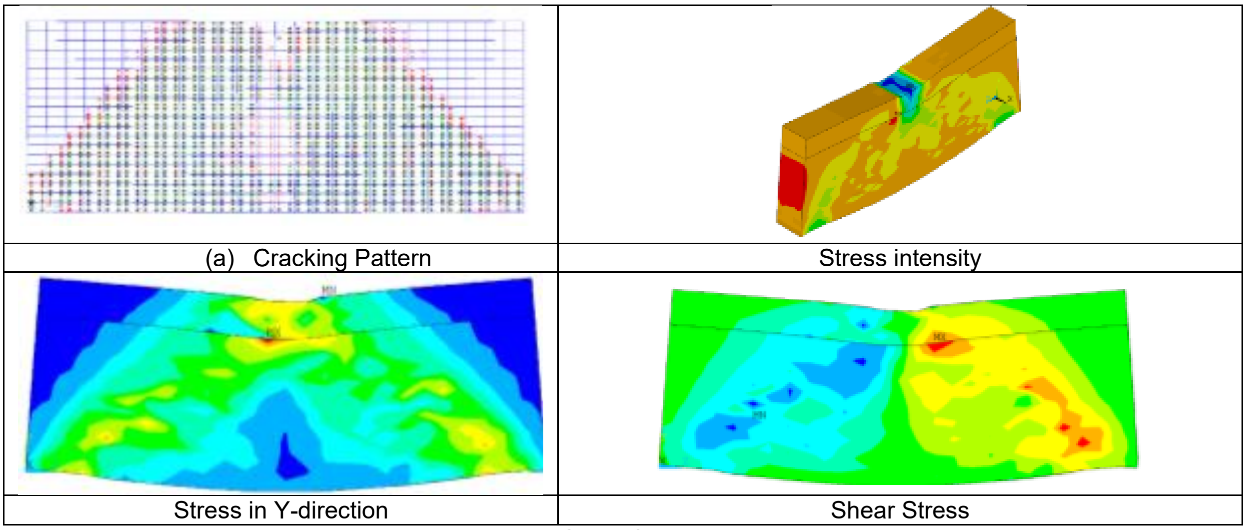
Fig. 25: Energy absorption of numerical series.

G. Cracking Pattern, Shear Stress and Strains

A deep beam's shear stress trajectory contours show the distribution and transmission of shear forces over the beam's cross-section in great detail. These shapes demonstrate the several load-bearing channels' intricate relationships by drawing attention to the redistribution and passage of shear stresses across various regions. In deep beams, shear stress trajectories are particularly intricate, as they involve various mechanisms for transferring forces, leading to distinct variations in the intensity and direction of shear stresses at different locations within the structure. This visual representation helps to better understand the force distribution and its impact on the beam's overall behavior. Near the locations where loads are applied, the shear stress trajectories generally indicate regions of elevated stress concentration. As the shear forces progress towards the supports, the contours broaden and distribute more evenly. This phenomenon is particularly noticeable in the central span of the beam. In the case of the standard deep beam made of traditional concrete, cracks primarily emerged in the shear zones and propagated toward the loaded areas at both extremities. Shear-controlled failure was observed in all concrete deep beams. For the parametric beams, integrating layers of recycled brick had a significant effect on both crack progression and the internal stress distribution within the deep beams, as demonstrated in the figure below. This indicates that the incorporation of recycled bricks alters the manner in which shear forces are transferred, potentially impacting the beam's overall response and failure mechanism.

	
Cracking Pattern	Stress intensity
	
Stress in Y-direction	(d) Shear Stress

1. GA-5CM



(a) Cracking Pattern | Stress intensity

Stress in Y-direction | Shear Stress

2. GA-10CM

Fig. 26: Failure mode and stress distribution for numerical beams.

5 Conclusion

The primary goal of this study was to investigate the impact of substituting aggregates with recycled bricks on the shear behavior of concrete deep beams. The following conclusions were drawn from the research:

• The incorporation of crushed bricks into concrete mixtures significantly influenced cracking load, ultimate load, and deep beam deflection.

• As the replacement ratio increased from 0% to 5% and 10%, both cracking load and ultimate load capacity declined. The results demonstrated that shear strength capacity decreased as the replacement ratio increased, indicating a progressive reduction in both ultimate and cracking loads.

• The reduction in cracking and ultimate load capacity was more pronounced in beams with smaller grading sizes when the replacement ratio was increased. When recycled bricks were used as a partial replacement for coarse aggregates, their grading size played a crucial role in determining the shear strength of deep beams. Beams with larger grading sizes (19-20 mm) exhibited an average reduction of 13% in cracking load and 33% in ultimate load, whereas beams with smaller grading sizes of recycled bricks (RB) experienced a greater reduction of 18.5% and 38.5% in cracking and ultimate loads, respectively.

• The shear span-to-depth ratio (a/d) had a significant impact on the behavior of recycled concrete beams. Variations in beam displacement were observed, and switching from a one-point load to a two-point load resulted in a 21.7% reduction in maximum displacement. In recycled concrete deep beams, cracking and ultimate loads fluctuated within a range of 3% to 7%, while a single-point load induced a 16% shift in displacement, albeit in different directions.

• The inclusion of recycled bricks along the concrete deep beam significantly altered its early stiffness, while the presence of recycled materials decreased the initial stiffness of the RC beams. Beams reinforced with 5% and 10% recycled bricks had an initial stiffness of 11% and 13.6%, respectively, lower than the control concrete beam. Compared to (16.7%) and (26.9%), respectively, for the identical replacement percentages, the initial stiffness of deep beams with smaller grading sizes was lower. Normal concrete deep beams had an initial stiffness increase of 37.1% when tested with a/d load (one-point load), but this initial stiffness reduced by an average of 11.5% when the replacement ratio was raised to 5% and 10%.

• The energy absorption of the concrete deep beam was found to be significantly reduced when the replacement ratio of recycled bricks was increased. Adding recycled bricks to the concrete mixture reduces the energy of the control beam by 14.4% and the energy of the recycled bricks concrete beams by 48.1%. In comparison to GA-X beams, the energy absorption decrease value for the smaller grading sizes of the deep beams (GB-5 and GB-10) was 20% and 40.2%, respectively.

• In comparison to recycled brick concrete (CBA) deep beams, which are less ductile, normal concrete deep beams are more ductile. In comparison to traditional concrete beams, those reinforced with recycled bricks had a 9.5% reduction in flexibility, according to the ductility index. When compared to regular concrete beams, the ductility of the Deep beams with reduced grading sizes was higher. A study comparing deep beams subjected to two-point loads found that ductility rose by 31.6% for regular concrete deep beams, declined by 14.4% for 5 % replacement ratio, and reduced by 34.5% for 10 % replacement ratio.

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