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EFFECT OF STEEL FIBERS ON SHEAR BEHAVIOR OF RECYCLED AGGREGATE REINFORCED CONCRETE BEAMS

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ABSTRACT

Sixteen beams were cast and tested to investigate the shear behavior of the reinforced concrete beams under the effect of the steel fibers and the recycled coarse aggregate (RCA). The steel fibers were added to concrete with (0, 0.5 and 1%) volume fractions. The recycled coarse aggregate used were (0, 25, 50 and 100%) replacement ratios by the natural coarse aggregate (NA). Only four beams were casted with shear reinforcement (stirrups φ 6mm @ 167mm) and 1% steel fibers to evaluate their effect on the shear behavior of beams and the remaining beams were without shear reinforcement. The effect of the steel fibers volume fraction, RCA replacement ratio and stirrups on the crack pattern, mode of failure, load-deflection relationship, first cracking load, ultimate load, ductility, stiffness, and energy absorption were discussed and analyzed. The experimental results were verified with the American and the Egyptian code's provisions in shear as well as with previous studies equations. The results showed that the steel fiber improves the shear behavior of recycled aggregate reinforced concrete beams especially concrete with high RCA replacement ratio.

KEYWORDS: Reinforced Concrete Beams, Steel fibers, Recycled, Shear.

1. INTRODUCTION

The amount of wastes resulting from demolition of buildings and traffic infrastructures recorded an increase at the recent few decades. The disposal of those wastes became a serious issue on the environment. The reconstruction of those buildings and infrastructures needs enormous amounts of raw building materials and this is not available in some places in the world, so the process of recycling could be a solution for this problem. The recycling of the demolition wastes could reduce the

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amount of demolition wastes and save some of the raw building materials. The crushed stones resulted from the demolished concrete or bricks could be reused as aggregate for the new concrete needed for renewing the demolished structures. The steel fibers will be added to RCA concrete to enhance its structural and mechanical properties.

This experimental study is interested in investigating the capability of using recycled concrete as coarse aggregate and the effect of adding the steel fibers on the shear behavior of RC beams. The results of this study in addition to the previous studies may produce a sufficient prediction of the both RCA with and without steel fibers.

2. LITERATURE REVIEW

Twenty reinforced concrete beams were prepared to study the shear strength of the recycled aggregate concrete compared with the natural aggregate concrete. The main experimental parameters were the recycled aggregate replacement ratio, the shear span-to-depth ratio and the longitudinal reinforcement ratio. The results showed that increasing RCA replacement ratio decreased the ultimate shear strength [1]. Fifteen beams were casted with (0, 50 and 100%) RCA replacement ratio to study the shear behavior of recycled concrete aggregate beams. The results indicated that beams of 50% and 100% RCA replacement ratio were very similar to those of 100% natural aggregate in crack pattern, shear behavior and strength characteristics when using RCA with 1.67% water absorption or less, regardless of RCA replacement ratio [2]. Beams with 0% and 100% RCA replacement ratio were tested and the test results were verified with international codes. The results of comparison gave that 0% RCA beams is higher than 100% RCA beams in shear strength capacity by approximately 12% [3].

Fourteen reinforced concrete beams with 100% recycled concrete aggregate were constructed. It was found that the beams with 100% RCA was similar to that with natural coarse aggregate in shear failure mode, shear deformation, load-deflection relationship and shear strength [4]. The results of the experimental test indicated that the ultimate shear strength of 20% RCA and 100% RCA replacement ratio specimens were less than 0% specimens by 5% and 9% respectively [5]. Two groups of beams based on their sizes were tested and each group contained four beams based on the quality of the used RCA. The results revealed that the shear strength of small beams with RCA was smaller than that with normal aggregate on the contrary of the large beams [6]. Twelve RC beams were made with (0, 0.5 and 0.75%) steel fibers volume fraction. The results clear that the strength of beams increased by increasing steel fiber volume fraction regardless of the concrete strength, the shear span to depth ratio and failure mode [7]. The results of tested beams showed that the using of hooked-end steel fibers with a volume fraction equal or greater than 0.75% improved the pattern of inclined cracking and improved the shear strength of beams without shear reinforcement by equal or greater than ($0.33(fc')^{0.5}$ MPa) [8]. The results of testing beams with 0.75% steel fibers concluded that the usage of steel fibers in beams without stirrups led to flexural-shear mode of failure, whereas the use of steel fiber in beams with stirrups led to flexural mode of failure [9].

Twenty-four steel fiber RC push-off specimens subjected to direct shear were made to investigate its behavior. The first crack shear strength increased due to the crack arrest mechanism of the fiber and the ultimate shear strength was up to fiber content of 1 %. Any increase in fiber content did not produce any improvement in shear strength [10]. The results of the tested RC beams indicated that the ultimate shear strength and the crack strength of beams increased by increasing the steel fiber volume fraction and decreasing the shear span-to-depth ratio [11]. The steel fiber reinforced concrete beams with 1.0 and 2.0% steel fibers and without stirrups had ultimate shear strength of 51% and 68% greater than that of beams without both of them [12]. Stirrups and steel fibers increased the stiffness and deflection at the ultimate and failure loads of beams, whereas the steel fibers effect decreased with increasing the stirrup ratio [13]. The use of steel fibers improved the load capacity and ductility of beams. Doubling the steel fibers volume fraction from 1% to 2% had a limited enhancement in the load capacity more than the ductility [14]. The addition of 0.75% steel fiber volume fraction in the beams without stirrups was sufficient to achieve the ultimate shear strength of beams with conventional shear reinforcement [15]. The using of steel fibers could effectively enhance the shear strength and the shear toughness of RCA concrete [16].

3. EXPEREMINTAL WORK

Twelve concrete mixtures were designed for casting the tested beams. Six cubes were taken from each mix during casting the beams. All concrete mixtures contain 400 kg/m^3 cement content, 600 kg/m^3 sand, 1200 kg/m^3 coarse aggregate, 0.5 water-to-cement ratio (W/C), (0, 0.5 and 1%) steel fibers volume fraction (V_f %) from the concrete volume and 1% superplasticizer from the cement weight. The coarse aggregate used were divided into two types, natural crushed stones (dolomite) and the recycled coarse aggregate obtained from the crushing of the tested cubes in the laboratory, both with a maximum nominal size of 20 mm. RCA replacement ratios were (0, 25, 50 and 100%) from the weight of the total used coarse aggregate. The used steel fibers were corrugated segment with length of 50 mm and 0.5 mm thickness and an aspect ratio of 100. The steel fibers volume fractions were (0, 0.5 and 1%) for the first, second and third groups respectively and 1% steel fibers with stirrups for the fourth group.

Sixteen reinforced concrete beams were designed and tested for the purpose of this research. All beams had the same dimensions and the same longitudinal reinforcement. The beams were divided into four groups according to the steel fibers volume fraction and stirrups. Each group consisted of four beams according to RCA replacement ratio. All beams were 120 mm width, 180 mm depth and 1300 mm long and reinforced with the same longitudinal reinforcement 3 bars 12 mm diameter as bottom reinforcement and 2 bars 8 mm diameter as top reinforcement. The first three groups were typical (A) that was without shear reinforcement in the shear zone only as shown in Fig. 1 and the fourth group is typical (B) that was with shear reinforcement (stirrups with two legs of 6 mm diameter and spaced at 167 mm in long direction) as shown in Fig. 2. The tested beams details and the compressive strength of each one are shown in Table 1.

After 24 hours from casting time, the concrete cubes were fully immersed in water containers in the laboratory for curing. The reinforced concrete beams were cured by wrapping them with pieces of wool and moisturizing them twice a day till the test time.

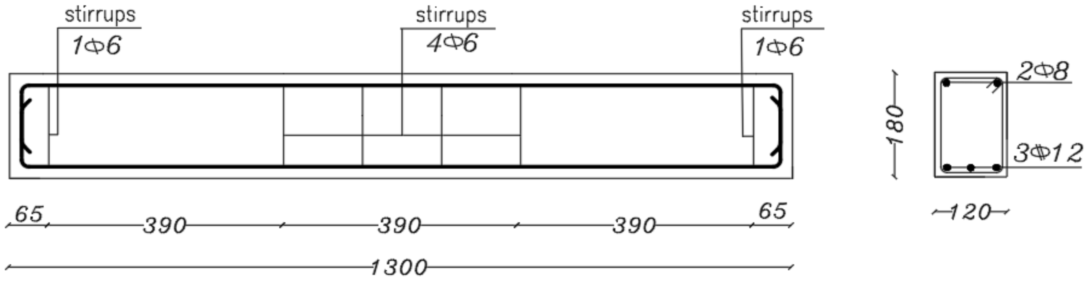

Fig. 1. Typical (A) beam without shear reinforcement.

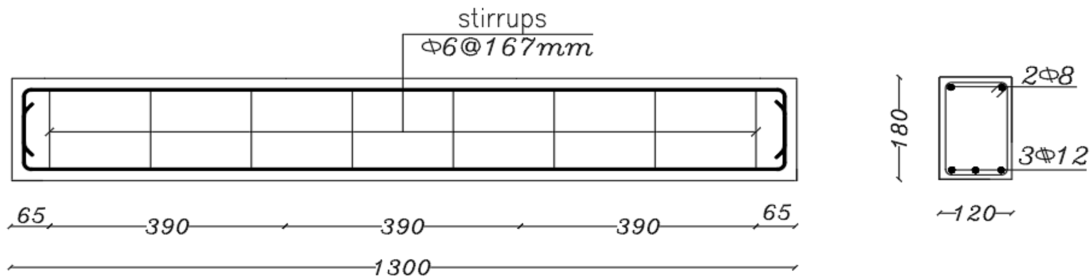

Fig. 2. Typical (B) beam with shear reinforcement.

Table 1. The properties of the tested beams and their compressive strength (F_{cu}).

Group	Beam	Typical	V_f%	RCA%	$F_{cu.}$ at 28 days (kg/cm^2)	$F_{cu.}$ at 50 days (kg/cm^2)
Gr.1	B13-0%-0%	A	0	0	378.8	408.45
	B14-0%-25%	A		25	346.3	367.97
	B15-0%-50%	A		50	307.2	313.8
	B16-0%-100%	A		100	275.8	304.17
Gr.2	B9-0.5%-0%	A	0.5	0	398.9	412.57
	B10-0.5%-25%	A		25	362.4	376.9
	B11-0.5%-50%	A		50	318.7	336
	B12-0.5%-100%	A		100	289.3	308.97
Gr.3	B1-1%-0%	A	1	0	405.6	422.7
	B3-1%-25%	A		25	375.7	382.53
	B5-1%-50%	A		50	328.4	340.6
	B7-1%-100%	A		100	300.8	316.8
Gr.4	B2-1%-0%-S	B	1	0	405.6	422.7
	B4-1%-25%-S	B		25	375.7	382.53
	B6-1%-50%-S	B		50	328.4	340.6
	B8-1%-100%-S	B		100	300.8	316.8

4. TEST SET-UP OF RC BEAMS

Figure 3 shows the loading frame, hydraulic jack and test setup of RC beams. The specimens were loaded under four points to represent the case of simply supported beam under two concentrated loads applied on the one third of the clear span (1170 mm). Three linear variable displacement transducers (LVDT) were used to measure the beams deflection. Two LVDTs were fixed under the two loading points and one LVDT was fixed at the mid span. The three LVDTs and the load cell were connected with data logger and the data were recorded through the connected computer.

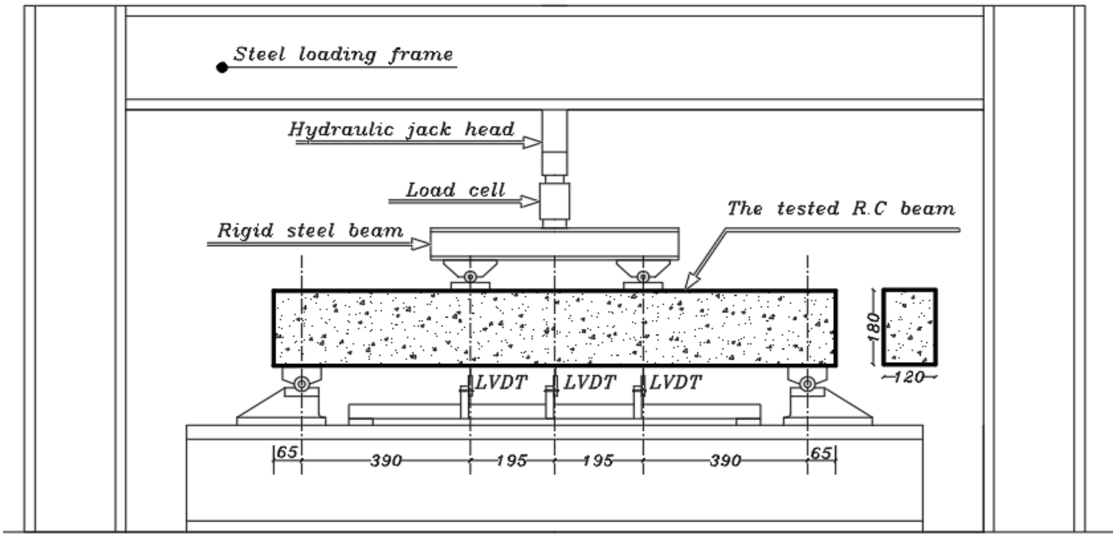

Fig. 3. Test setup and measurements.

5. EXPEREMINTAL RESULTS

The test results analyze the crack pattern, failure mode, cracking load, ultimate loads, load deflection curves, and energy absorption under the effect of RCA replacement ratio, steel fibers volume fraction and shear reinforcement.

5.1 Crack Pattern and Failure Mode

For all beams without stirrups, the first crack started vertically at the mid span then other vertical cracks appeared at the middle third of span. Inclined shear cracks started from the point of support upwards the point of loading. With increasing the load level, the cracks propagated and increased in their number and in their width, specially the inclined cracks. The failure mode was shear failure in beams without stirrups and only the beam B4 with stirrups. In beams with stirrups except B4, the mid span vertical crack was propagated upwards the compression zone of the beam and increased in its width until failure. At the same time, cracks appeared in the compression zone of the beams with stirrups and the failure mode was flexure failure. Figures 4-7 show the crack pattern of the four groups of the tested beams.

It was clear that for all beams, the failure mode and the crack pattern were not affected by RCA replacement ratio regardless of the steel fibers volume fraction. It was noticed only in the first group without steel fibers that the number and length of cracks increased by decreasing the RCA replacement ratio whereas, the width and number of cracks were smaller by increasing the steel fibers volume fraction for the beams without stirrups at the same load level. At failure the number and the length of cracks increased by increasing the steel fibers volume fraction. The width of cracks especially the diagonal failure crack increased by increasing the steel fibers volume fraction for all the tested beams without stirrups. It was also clear that, for the first three groups of beams beside beam B4 the failure mode was not affected by steel fiber volume fraction (shear failure) and the crack pattern improved by increasing the steel fiber volume fraction. It could be noticed that, using the steel fibers volume fraction with minimum stirrups made the beams fail in flexure. Thus the presence of 1% steel fibers volume fraction with stirrups could be able to change the failure mode from shear to flexure. All tested beams had the same shear span-to-depth ratio (a/d) of (390/162=2.4). Increasing a/d may change the failure mode to shear-flexure or flexure modes [1, 7]. This point will be considered in future work.

5.2 Load-Deflection Curves

Figures 8-11 show the load-deflection curves of all groups and it is clear that, all beam curves consisted of three main stages. The first stage (uncracked section) was linear until the load level of first crack at the mid span. The second stage (cracked section) was non-linear and started with the first crack accompanied with stiffness reduction and ended with huge number of vertical and inclined cracks until reaching the ultimate load. The third stage started with reaching the ultimate load and the curve started to descend where the beams were exposed to plastic deformation and increasing in crack width until failure load.

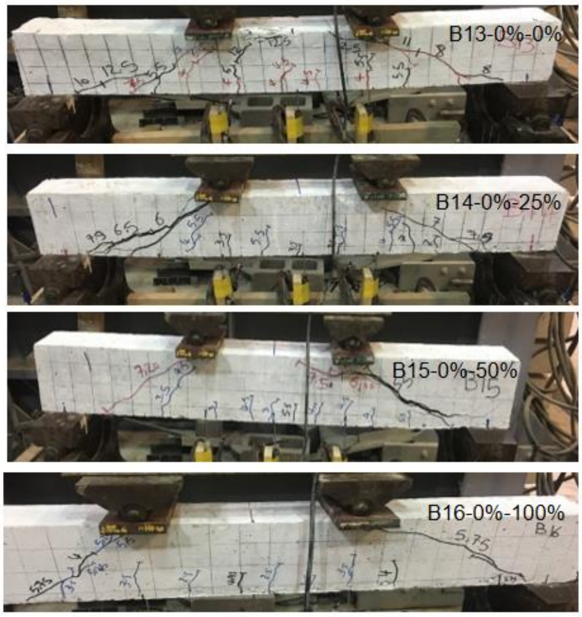

Fig. 4. The crack pattern of group (1).

Fig. 5. The crack pattern of group (2).

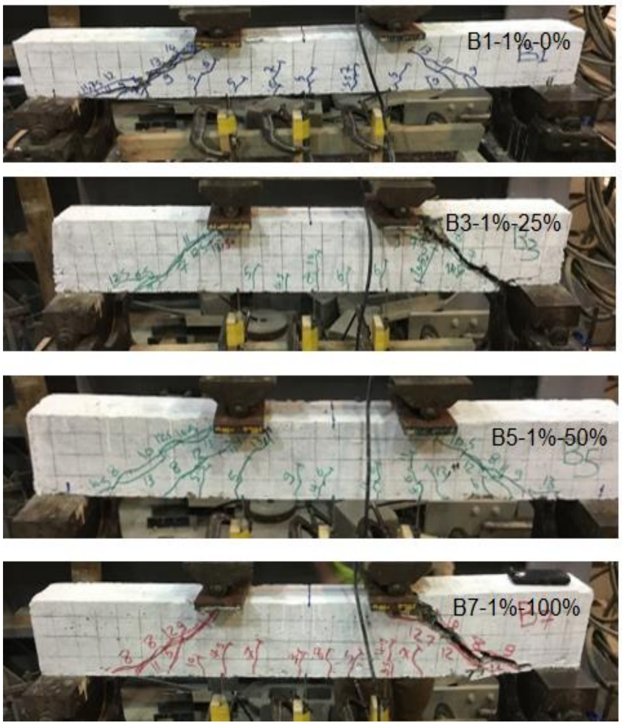

Fig. 6. The crack pattern of group (3).

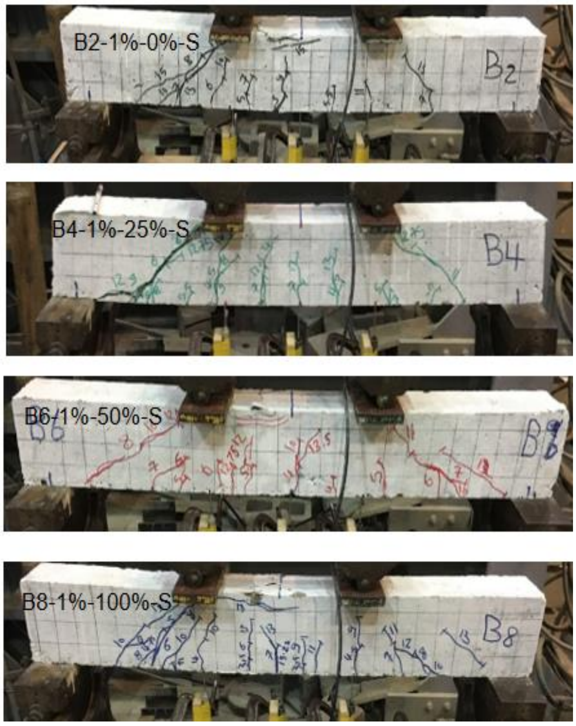

Fig. 7. The crack pattern group of (4).

It is clear that, the recycled coarse aggregate replacement ratio has no effect on the load-deflection behavior of beams. As well as the ductility decreased by increasing RCA replacement ratio in the first and second groups with 0% and 0.5% steel fibers respectively but the ductility was approximately the same for beams in the third and the fourth groups with 1% and 1% steel fibers with stirrups respectively. In the first and second groups, the slope of the linear stage of each beam was decreased by increasing RCA replacement ratio and that could represent the stiffness of the beam but the slope of beams in the third and fourth group was approximately the same.

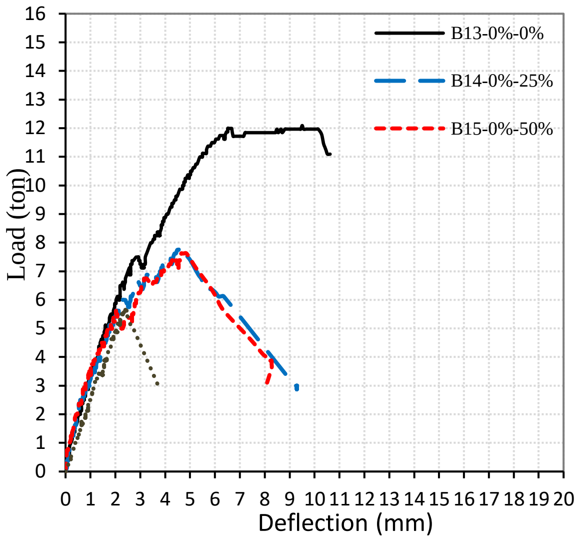

Fig. 8. Load-deflection curve of the first group of beams (Gr.1).

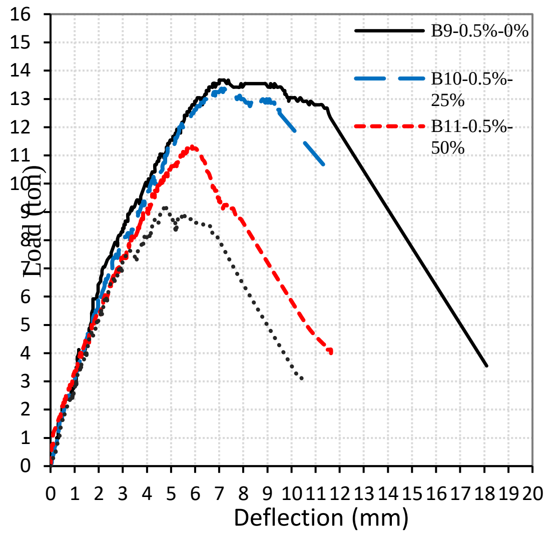

Fig. 9. Load-deflection curve of the second group of beams (Gr.2).

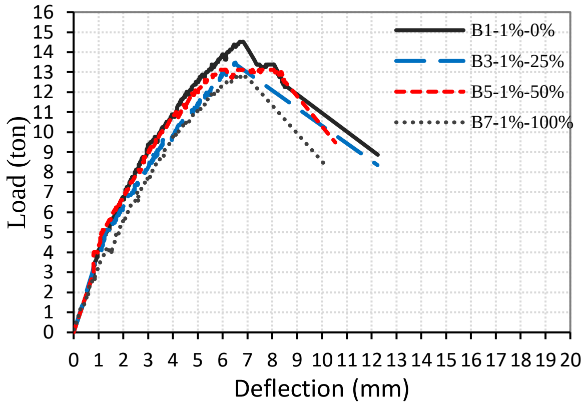

Fig. 10. Load-deflection curve of the third group of beams (Gr.3).

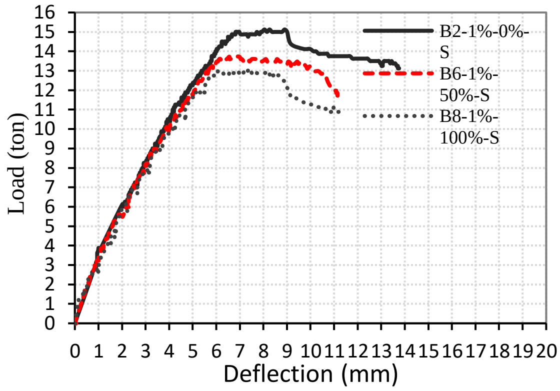

Fig. 11. Load-deflection curve of the fourth group of beams (Gr.4).

Figures 12-15 show the load-deflection curves of the beams with same RCA replacement ratio in all groups to show the effect of the steel fibers volume fraction and the effect of stirrups. The load-deflection behavior of all beams was affected by the steel fibers volume fraction where increasing the steel fibers volume fraction led to increase in the ductility in all beams especially in the beams with 50% RCA and 100% RCA respectively. This meant that the effect of the steel fibers was greater with high RCA replacement ratio. The stiffness of beams in all beams increased by increasing the steel fibers volume fraction as the slope of the linear stage increased regardless of RCA replacement ratio. The load-deflection behavior of the beams with 1% steel fibers volume fraction and stirrups was different from the other curves in the third stage where the descending of the other curves was sudden and with large slope, whereas the descending of the curves of the beams with stirrups was not sudden and was with very small slope. This meant that the elastic deformation of beams with stirrups was larger and its failure was ductile. It is cleared that, the ductility of beams with stirrups have an noticeable increase more than that without stirrups regardless of RCA replacement ratio, whereas the stiffness are not affected by adding stirrups.

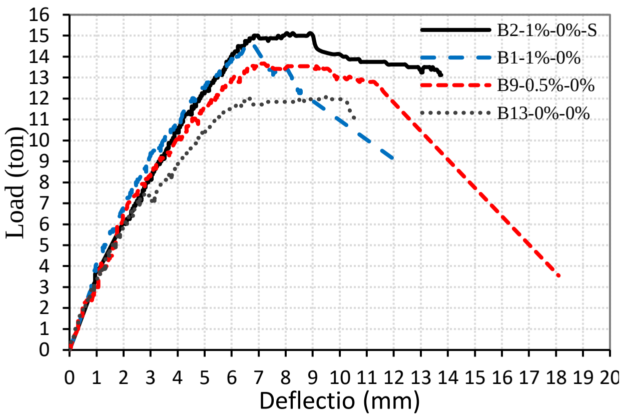

Fig. 12. Load-deflection curve of 0%RCA replacement ratio.

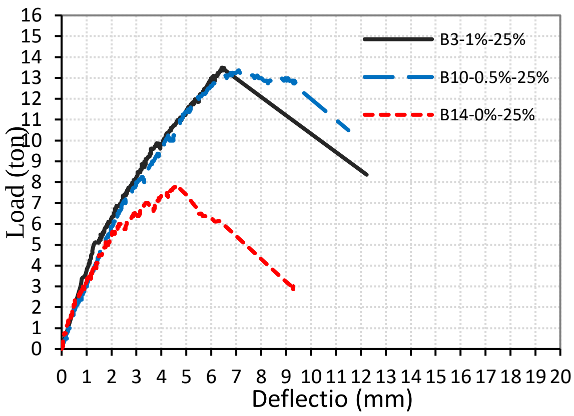

Fig. 13. Load-deflection curve of 25%RCA replacement ratio.

5.3 First Cracking Load.

The first crack in all beams was vertical crack at mid span. The first crack load was affected by the recycled coarse aggregate (RCA) replacement ratio in all beams as shown in Fig. 16 where the first cracking load at the mid span of the beams decreased by increasing RCA % replacement ratio.

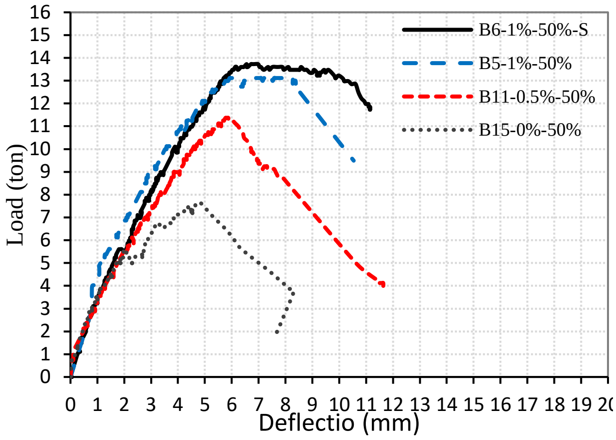

Fig. 14. Load-deflection curve of 50% RCA replacement ratio.

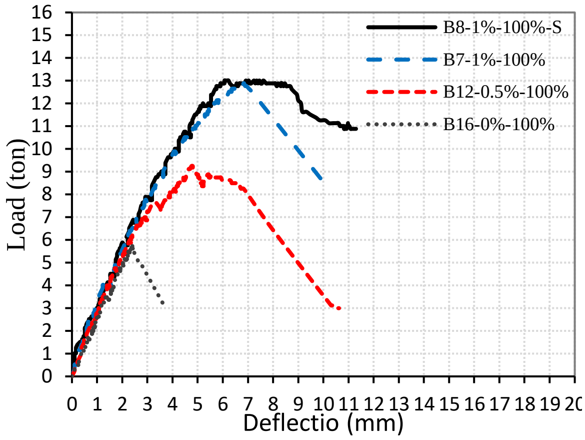

Fig. 15. Load-deflection curve of 100% RCA replacement ratio.

Although, the first cracking load at the mid span of the beams increased by increasing steel fibers volume fraction regardless of the RCA replacement ratio and the presence of stirrups not affect the first beam cracking load where it had the same effect of using 1% steel fibers without stirrups as shown in Fig. 17.

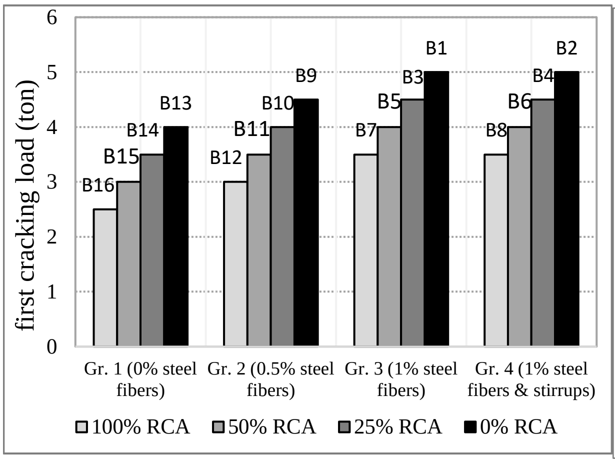

Fig. 16. The effect of RCA replacement ratio on the first cracking load.

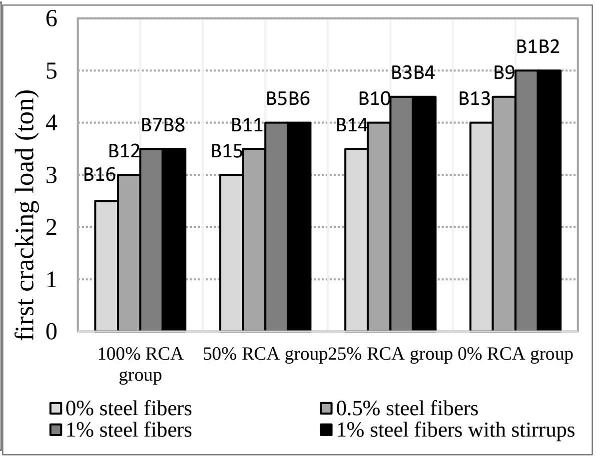

Fig. 17. The effect of the steel fibers and stirrups on the first cracking load.

The first diagonal crack (first shear crack) was investigated. The first shear crack appeared after mid span cracks. Figure 18 shows the effect of the RCA replacement ratio on the first shear cracking load for all beams. The first diagonal shear cracking load was affected by RCA replacement ratio in the first and second groups and not affected by RCA replacement ratio in the third and fourth groups. The first shear cracking load was affected by steel fibers volume fraction in all beams. The first shear cracking load increased by increasing the steel fibers volume fraction regardless of RCA replacement ratio and the presence of stirrups not affect the first diagonal cracking load where it had the same effect of using 1% steel fibers without stirrups as shown in Fig. 19.

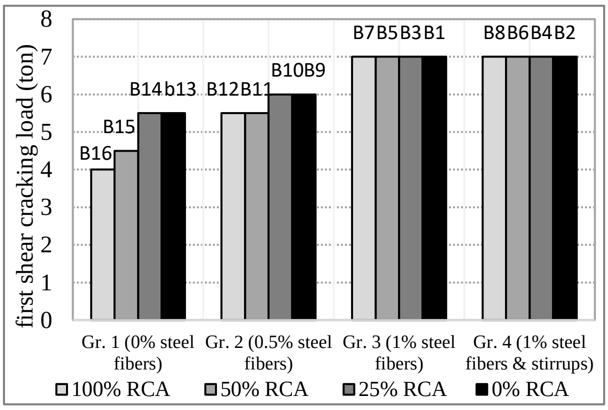

Fig. 18. The effect of RCA replacement ratio on the first diagonal cracking load.

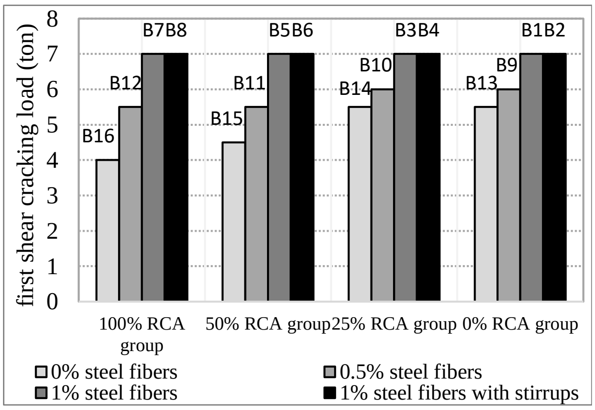

Fig. 19. The effect of steel fibers and stirrups on the first diagonal cracking load.

5.4 Tested Beams Ultimate Load

Figure 20 shows the ultimate load of the tested specimens. For the first group, which consists of four beams without steel fibers, the ultimate load of beams B14 with 25% RCA, B15 with 50% RCA and B16 with 100% RCA was lower than that of beam B13 without RCA by 37%, 39%, and 54% respectively. For the second group that consists of four beams with 0.5% steel fibers volume fraction, the ultimate load beams with 25%. 50% and 100% RCA were less than that of beam without RCA by 2%, 17%, and 32% respectively. For the third group, which consists of four beams with 1% steel fibers volume fraction, the ultimate load of beams with 25%. 50% and 100% RCA were less than that of beam without RCA by 7%, 9.5%, and 11% respectively. For the fourth group, which consists of four beams with 1% steel fibers volume fraction and with shear reinforcement, the flexural strength of beams B4 with 25%. 50% and 100% RCA were less than that of beam B2 without RCA by 7%, 9%, and 14% respectively.

Figure 21 shows the effect of the steel fibers volume fraction and the effect of stirrups on the ultimate load of the tested specimens. For the beams with 0% RCA replacement ratio, the ultimate load of beams with 0.5% and 1% steel fibers volume fraction were higher than the ultimate load of beam without steel fibers by 13.2% and 19.8% respectively. While for the beams with 25% RCA replacement ratio, the ultimate loads were increased by 69.6% and 70.8% for 0.5% and 1% V_f respectively. For the beams with 50% RCA replacement ratio, the ultimate load of beams with 0.5% and 1% V_f were higher than that of beam without steel fibers by 50% and 72.3% respectively. For the beams with 100% RCA replacement ratio, the ultimate loads increased by 58.6% and 122% for the case of 0.5% and 1% V_f respectively. On the other hand, using stirrups increased the ultimate load by 4.1%, 3.7%, 4.6%, and 0.7% for 0, 25%, 50%, and 100% RCA replacement ratio respectively for the specimens of 1% fiber volume fraction. Changing shear span-to-depth ratio that was (a/d=2.4) in all tested beams will affect the ultimate load. Increasing a/d decreased the ultimate load of the tested beams as cleared in previous researches [1, 7, 19].

It is clear that increasing the RCA replacement ratio decreased the compressive strength of concrete and this contributed to decrease the ultimate load of the tested beams regardless the steel fiber volume fraction whereas, increasing the steel fiber volume fraction increased the ultimate load of the tested beams especially in beams with 50% and 100% RCA. It is noticed that the efficiency of steel fiber was higher with the increase of RCA replacement ratio.

5.5 Energy Absorption

The energy absorption of beams was calculated as the area under the load-deflection curve up to 80% of the ultimate load at the descending part of the curve. The energy absorption decreased by increasing RCA replacement ratio regardless the steel fiber volume fraction and stirrups as shown in Fig. 22 but increasing the fibers content causes a lowering in energy absorption decreasing rate that was caused by using RCA replacement.

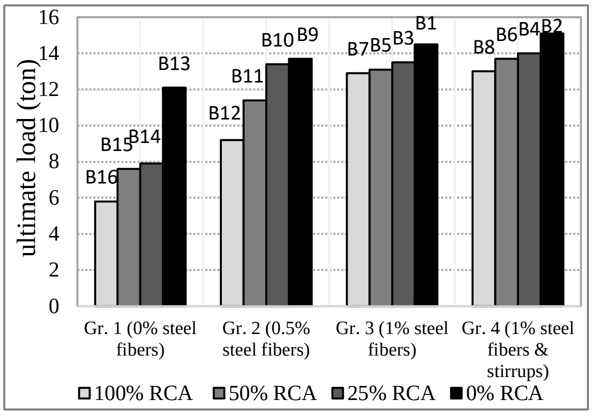

Fig. 20. The effect of RCA replacement ratio on the ultimate load.

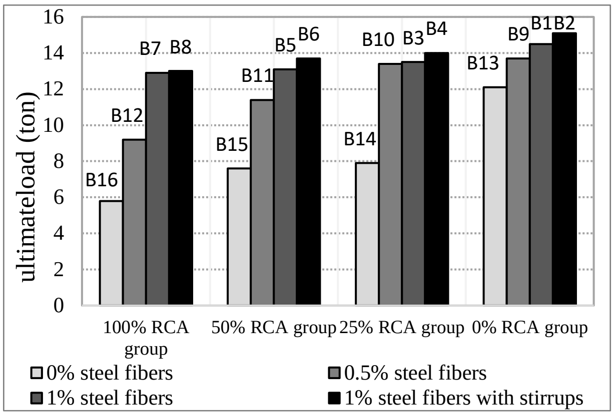

Fig. 21. The effect of the steel and stirrups on the ultimate load.

The energy absorption increased by increasing the steel fibers volume fraction and using stirrups regardless the RCA replacement ratio as shown in Fig. 23. Volume fraction of 0.5% steel fibers was more effective on the energy absorption in case of using 0% RCA and 25% RCA replacement ratio. The energy absorption increased by using stirrups with 1% steel fibers volume fraction so, the presence of stirrups increased the energy absorptions.

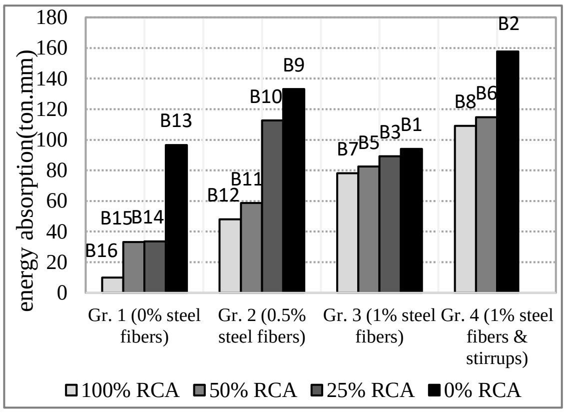

Fig. 22. The effect of RCA replacement ratio on the energy absorption.

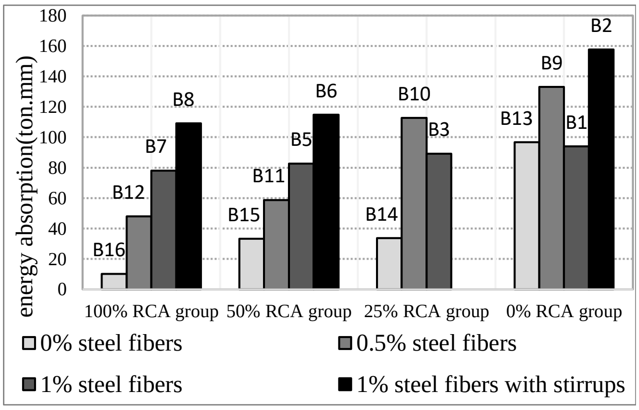

Fig. 23. The effect of the steel fibers and stirrups on the energy absorption.

5.6 Verification of the Experimental Results with Codes Equations

The experimental results were compared with the equations that belong to the shear design in both the Egyptian code (ECP 203-2018) [18] and the American code

(ACI 318-2014) [19]. The maximum limit of the ultimate shear force provided by the reinforced concrete beams (V_{max}) and the ultimate shear force provided by the reinforced concrete beams (V_u) were verified with experimental results. The results of verification showed that both ECP 203-2018 and ACI 318-2014 give a conservative values for all beams as shown in Fig. 24 and these code's equations could be applicable for all beams regardless of RCA replacement ratio and steel fibers volume fraction.

5.7 Verification of the Experimental Results with Previous Studies Equations

The experimental results of this study were verified with equations from previous studies that consider the effect of the steel fibers on the shear strength of beams. Six equations were verified. The results showed that all equations are conservative and could be applicable for all beams specimens regardless of RCA replacement ratio as shown in Fig. 25. Statistical analysis indicated that Eq. (6) is the most proper one for these specimens.

$$V_u = k f_{t'} \left(\frac{d}{a}\right)^{0.25} \quad \text{(MPa)} \qquad (1)[8]$$

Where;

(V_u) is the shear stress at shear failure, (k) =2/3, (a/d) is the shear span-to-depth ratio, $(f_{t'})$ is the split tensile strength of concrete cylinder and equal to $[0.79*(f_c)^{0.5}]$, (f_c) is the compressive strength of concrete cylinder.

$$V_u = e\left(0.24 f_{spfc} + \frac{80\rho d}{a}\right) + V_b \ (MPa) \qquad (2)[8]$$

$$V_u = (0.7(f_c)^{0.5} + F)\frac{d}{a} + 17.2\rho\frac{d}{a} \ \ (MPa) \qquad (3)[20]$$

$$V_u = 3.7e\left(f_{spfc}\right)^{\frac{2}{3}} \left(\frac{\rho d}{a}\right)^{\frac{1}{3}} + 0.8\, V_b \ (MPa) \qquad (4)[8]$$

Where;

(e) = 1 for $a/d > 2.8$ and 2.8d/a for $a/d \leq 2.8$, $(f_{spfc}) = (f_{cu}/\ (20-(F)^{0.5}) + 0.7 + (F)^{0.5})$, (f_{cu}) is the compressive strength of concrete cube, $(F) = (L_f/D_f)\ V_f\ d_f$, (d_f) is fiber bond factor which is 0.5, 0.75 and 1 for indented, crimped and round fibers respectively, (ρ) is the longitudinal reinforcement ratio, (L_f) is the fiber length, (D_f) is the fiber diameter and (V_f) is the fiber volume fraction, $V_b = 0.41\tau F$, (τ) is the bond strength of the steel fibers and equal 4.15MPa.

$$Vu = \left[k_0 k_1 k_2 k_3 (10\rho)^{0.5} (f_{cu})^{0.35} + 0.707 \sum_{i=1}^{n} F_i \, \tau(\ln \frac{d}{a} + 1) \, \rho^{\frac{1}{6}} + \frac{A_w}{bs} \, 0.9 \, f_{ywk}\right] bd \; (MPa) \qquad (5)[20]$$

Where;

(k_0) = 1 for four point loading test and *(k_0) = [L/ (l–a)]* for three point test where *L (mm)* theoretical span, $k_1 = (103/d)^{0.5}$, $k_2 = [5.4(d_a/100)2+1]$, $k_3 = [0.97\ln(d/a) + 1.04]$, *(a)* shear span of beams *(mm)*, *(d)* the effective depth of beams *(mm)*, *(d_a)* the maximum aggregate Size, $Fi = [h_{fi} \, (V_{fi} * l_{fi}) \, / \, d_{fi}]$ where h_{fi}, V_{fi}, l_{fi}, d_{fi} are bond factor, volume fraction, length and diameter of the type of fibers respectively, *(t)* Average fiber matrix interface bond stress *(N/mm^2)*, *(A_w)* cross-section area *(mm^2)* of longitudinal tensile rebars, *(b)* beam width *(mm)*, *(s)* stirrups bitch *(mm)*, *(f_{ywk})* stirrups yield stress *(N/mm^2)*.

$$Vu = \left(0.2 \, fc^{\frac{2}{3}} \left(\frac{c}{d}\right) + (\rho(1 + 4F) fc)^{0.5}\right) \left(\frac{3d}{a}\right)^{\frac{1}{3}} \qquad (6)[14]$$

Where;

$(c/d)^2 + (600\rho/f_c) \times (c/d) - 600\rho/f_c = 0$, From this equation, *(c/d)* could be obtained.

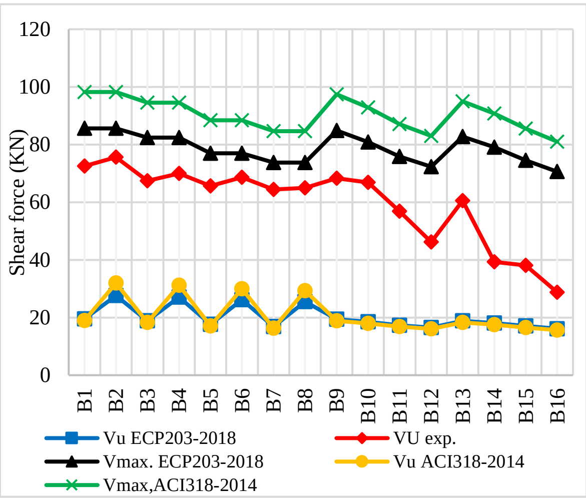

Fig. 24. Verification of the experimental results with ECP203-2018 and ACI318-2014 codes equations in shear.

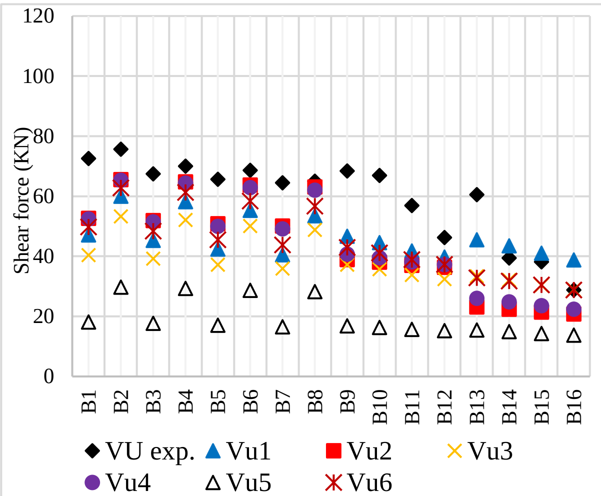

Fig. 25. Verification of the experimental results with previous studies equations in shear.

6. CONCLUSIONS

The experimental study investigated the shear behavior of the steel fibers recycled coarse aggregate reinforced concrete beams. The main variables in this study are the recycled coarse aggregate (RCA) replacement ratios (0, 25, 50 and 100%) and the steel fibers volume fractions (0, 0.5 and 1%). Sixteen R.C. beams with dimensions (120×180×1300 mm) were cast and tested under four loading points to study their shear behavior under various parameters. The main conclusions of this study are:

1) There is no clear difference in crack pattern and failure mode due to increasing the recycled coarse aggregate (RCA) replacement ratio.
2) The failure mode is sudden shear failure and it is not affected by steel fiber volume fraction. Whereas the crack pattern is improved by increasing the steel fibers volume fraction. Also the presence of both minimum stirrups and 1% steel fibers converted the failure from shear to flexure mode of failure.
3) Increasing the steel fibers volume fraction leads to increase in the ductility and stiffness of beams especially in beams with 50% and 100% RCA replacement ratio.
4) The ductility and stiffness of beams with 1% steel fibers and stirrups increase by using the minimum stirrups more than the beams with 1% steel fibers and without stirrups.
5) The first beam cracking load at mid span, the first diagonal shear load, the ultimate load and the energy absorption decrease by increasing RCA replacement ratio whereas, they increase by increasing the steel fiber volume fraction.
6) The presence of stirrups with 1% steel fibers does not affect the first cracking loads, slightly increases the ultimate load and noticeably increases the energy absorption.
7) The Egyptian (ECP 203-2018) and the American (ACI 318-2014) codes proposed equations in shear that could be applicable for any RCA replacement ratio regardless of the steel fibers volume fraction.
8) The experimental results were verified with equations from previous researches for the steel fibers RC beams in shear and these equations could be applicable at any RCA replacement ratio.
9) Generally, it is not recommended to use RCA with replacement ratio higher than 50% without using steel fibers with at least 0.5% volume fraction.
10) Using RCA instead of NA especially in countries that have a scarcity of raw buildings materials or countries that have large amounts of wastes resulting from

demolition of buildings or infrastructures due to wars or natural catastrophes is considered an economic solution in spite of using expensive steel fiber.

DECLARATION OF CONFLICT OF INTERESTS

The authors have declared no conflict of interests.

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تأثير الألياف المعدنية على سلوك القص للكمرات الخرسانية المسلحة المصنعة باستخدام ركام الخرسانة المعاد تدويره

يهدف البحث الى دراسة تأثير الالياف المعدنية على سلوك القص للكمرات الخرسانية المسلحة المصنعة باستخدام ركام الخرسانة المعاد تدويره. تم صب ستة عشر كمرة بأبعاد ثابتة ونسبة تسليح طولي ثابتة منهم اثنتي عشرة كمرة بدون إضافة حديد قص واربعة كمرات بحديد قص (كانات). تم استخدام الياف معدنية بنسب ٠% و٠,٥% و ١% من حجم الخرسانة واستخدام ركام خرسانة معاد تدويره بنسب ٠% و٢٥% و ٥٠% و ١٠٠% من الركام الخشن المستخدم في صب الكمرات. تم الاختبار باستخدام ٤ نقاط تحميل لتكون الكمرة بسيطة الارتكاز وتم تحليل النتائج لمعرفة تأثير ركام الخرسانة المعاد تدويره والالياف المعدنية والكانات على نمط الشروخ ونوع الانهيار وحمل التشرخ في منتصف البحر وحمل التشرخ القطري والحمل الاقصى والممطولية والجساءة وقابلية امتصاص الطاقة للكمرات. تمت المحاكاة مع معادلات الكود المصري والأمريكي والمعادلات المنشورة حيث اظهرت النتائج تحسين سلوك القص وزيادة حمل التشرخ والحمل الأقصى للكمرات بزيادة نسبة الالياف المعدنية خاصا مع استخدام نسب عالية من ركام الخرسانة المعاد تدويره.