Effect of Size and Location of Repair on Flexure Strength of RC Beams

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الملخص

معظم الدراسات السابقة اهتمت بالترابط بين خرسانة الأساس وخرسانة الترميم، وباعتبار ان المعلومات المتوفرة لهذا الموضوع غير كافية لدراسة السلوك الإنشائي للكمرات الخرسانية المرممه وللمقارنة بين مواد الترميم المختلفة المستخدمه للترابط، وخواص التشققات التي تظهر في منطقة الترابط اثناء عمليه التحميل، ودراسة أبعادها الطول والعرض، وأيضا تأثير تخشين سطح خرسانة الاساس المرممه.

تهدف هذه الدراسة العمليه لدراسة تأثير حجم وموقع المعالجة على السلوك الإنشائي للكمرات الخرسانية وعلى السعة التحميلية ومقارنتها بعينة المرجعية تم اعدادها واختبارها بدون معالجة.

في هذه الدراسة ،عينات من الكمرات الخرسانية كانت 15 كمرة بأحجام ومواقع مختلفة للمعالجة لدراسة السلوك الإنشائي للكمرات الخرسانية. والنتائج التى تم الحصول عليها تلخصت في أن زيادة حجم المعالجة يقلل من مقاومة الانحناء، ولوحظ ان تماثل المعالجة من حيث الطول والعرض على طول الكمرة عامل مهم في تحسن السلوك الإنشائي تتحقق من خلاله قيم ترخيم عالية مما يساعد على زيادة احتمالات الانهيار الاستطالي وخاصة في منطقة الشد وزيادة مقاومة المقطع للانحناء.

ABSTRACT:

Most of the recent studies were interested in the bonding between the base concrete and repair concrete. Considering that the information about this subject was insufficient to study the structural behaviour of the repaired concrete beams and to compare the different treatment materials used for bonding, also to compare the properties of appeared cracks in the bonding zone during the loading process in terms of the cracks lengths and widths, as well as the effect of making the surface of base concrete rougher. This field study aims to investigate the effect of the size and location of the repair on the structural behaviour and the loading capacity of the samples and compare the repaired samples to a control sample which was prepared and tested without treatment. In this study, samples of concrete beams were 15 beams with different sizes and locations for the treatment to study the structural behaviour of concrete beams. The results revealed that the increase of the treatment decreases the flexural strength, and it was observed that the symmetric treatment in concrete beams in terms of length and width along the concrete beam is an important factor in enhancing the structural behaviour, and helps to achieve high deflection values to increase the possibility of having a ductility failure, especially in the tension zone and to increase the flexure strength.

Keywords: bonding, flexure strength, concrete beams, repair concrete.

1. INTRODUCTION:

Reinforced concrete is a composite material and it can achieve its designated purposes only if there exists a sufficient bond between the reinforcement and concrete [1]. Numerous studies examining the effectiveness of concrete

structures with bonded exterior composite materials have disregarded adhesion issues and the proper surface preparations for adhesive bonding. There is no consensus on the ideal adhesive qualities needed for plate bonding applications [2], [3]. Previous studies indicate the importance of preparing the surface for interconnection to obtain a good bonding between the base concrete and the repair concrete to operate as one unit preparing the surface of the bonding with the increase of roughness is carried out in many ways, including manual scaling, using electric hammers, or blowing sand under high air pressure, or using compressed water, or using an iron brush to scratch the surface. It was found that the samples prepared with a manual scaling surface gave about 25% higher correlation resistance% than that used to prepare the surface of the scaling needle and the samples prepared by the rough wire gave the results of higher resistance than those obtained from preparation by the scaling needle[4]–[7]. According to the information now available, dry substrate specimens typically perform equally well or better in shear tests[8].
In another investigation [9] it was noted that there is no significant difference in the results obtained using rough or soft surfaces for restoration cases. The study [10] has shown that to get a good bonding it is preferable to use bond materials with a elasticity coefficient less than the base concrete elasticity coefficient. Whereas, the difference in the elasticity factor and the ratio of Poisson causes unequal strain under the influence of loads in the bonding area and severe stress[11]. The roughness of the existing bonding interface will greatly affect the bonding behaviour [4]. The same study [10] also indicates that the difference in the properties of the cracks appearing on the samples of engineering cement mixtures is in the number of cracks produced and their length, as it was noted that the cracks are more in the case of samples that

contain 0.6 w/c = while the cracks in the case of samples that contain 0.28 w/c = are twice as long. Also, the restoration material must have a colour and surface appearance similar to the base concrete to maintain the consistency of the external shape and appearance of the structure, and the restoration material must be workable and easy to prepare on-site, and in the case of pumping concrete, pumpable materials must be used that can penetrate the places behind the reinforcing bars for sectors that have a high density of reinforcing steel, taking into account the element to be restored whether it is horizontal or inclined, i.e. it needs flowing materials, or there are deep openings that need a specific pouring method and at different stages.

As for the effect of the thickness of the bonding material, it has not been studied on a large scale, but the appropriate thickness is often between 3-6 mm to give a good bond, and when carrying out the repair process, the bond is usually weak between the base concrete and the restoration concrete, so it is preferable to use binders with high bonding resistance to ensure good bonding between the base concrete and the restoration concrete so that the bonding area is not the weakest in the repaired element[6], [11]–[13].

In the research [14], experimental tests were conducted on concrete beams with dimensions of 450×200×75 mm, and the water mixing ratio used was w/c=0.55, these beams were treated for 28 days by water immersion and dried under normal environmental conditions for 45 days, and their pressure resistance after 28 days was about 26.4 N/mm², and the surface was roughened before putting the restoration material on it. Also, the tensile bonding strength was measured by a modified split tensile test, where the shear strength was imposed equal to twice the tensile bonding strength. The repair material was placed on a rough surface with a thickness of 51 mm and cured for about 17 hours in a room with environmental conditions (50% humidity, 23 °C temperature). From the experimental measurements, it was found that bonded concrete overlays have a strong tendency toward early-age debonding. In another investigation [15], a comparison was made to monitor the appearance of cracks for samples that were treated with different restoration materials with and without additives, as well as with the use of steel fibers, and by applying the same conditions of surface preparation and loading for all cases. As for the modified concrete with additives, it gave better results than the reinforced concrete with steel fibres, and it was more solid and controlled in the width of the cracks. It was also found that the failure occurs first in the bonding region, that is, between the base concrete and the restoration material, and this region is considered the weakest in the repaired concrete structure. Mechanical bond strength testing was typically used to observe the interfacial adhesion [16][17]. The adhesion properties of the restoration materials and the length of the bonding area must be taken into account, which is one of the obvious defects in the study. Also, in the study the samples were designed to find out the defect resulting from cracks in the bonding area between the repair material and the base concrete, considering the applying of uniform loading conditions [7].

Some researchers provided emphasis on determining the bond strength and some others emphasized the cracks of concrete due to bonding effect. However, in reality, both parameters are important for determining the bond strength of the concrete Therefore, this study is conducted to understand the relationship between these two factors for assessing the bond strength between base concrete and repair concrete where it emphasises size and location of the treatment, also the cracks on concrete due to treatment behaviour.

2. Experimental Method

2.1 Materials.

The tests conducted on the raw materials used in concrete mixtures were carried out in the concrete lab at the faculty of Engineering, Almergib University, and the results were within the British Standards1992: BS882, ACI 318-19(22)[18]–[20]. Materials and mix design proportions are shown in Table 1

Table 1 Materials and mix design proportions for base concrete

Coarse aggregate	Fine aggregate	Cement	water	Water cement ratio (w/c)
1205 Kg	805 Kg	300 Kg	150 Kg	0.5

2.2 Rebar

The reinforcing steel used was produced by the Misurata factory of the Libyan Iron and Steel Company. In this study, the main reinforcement 2 with a diameter of 10 mm was used, and the stirrups with a diameter of 6 mm with 150 mm spacing. The yield stress of the main steel was 414 MPa, which was obtained from the factory’s lab.

2.3 The binder

A liquid epoxy was used as a binder between the old (base) concrete and the new (repair) concrete, as well as a catalyst to increase the bonding of steel with concrete.

2.4 Repair Concrete

High-performance concrete was used to treat the virtual voids that were identified in the beams. Figure (3) shows Mortar as repair concrete.

2.5 Sample preparation

Wooden moulds with dimensions of 150x 200 x1200 mm were used. It was painted from the inside with oil to prevent the adhesion of concrete to the wooden mould. An electric vibrator was used when casting and compacting. Figure (2) shows the shape of the mould with locations of the treatment area.

2.6 Test setup

Concrete beams were prepared according to the study plan for different cases, and the dimensions of the voids around the reinforcing steel were determined for determining presumed failure cases, based on which the samples were divided into groups according to the dimensions of these voids (L/6, L/3, 2L/3), as the L is the length of the sample as shown in Table (2). Figure (1) shows a drawing of the location of treatment areas which shows the difference between each sample on another. These samples were prepared by making virtual voids with compressed polyethylene of different lengths and a square section of 40 mm.

The samples were poured with a concrete mixture with a water-cement ratio of 0.5. After 24 hours, the samples were placed in treatment basins for 28 days. After this period, the voids around the reinforcing steel were well-cleaned using a metal brush. The reinforcement and concrete were painted with a binder, and the repair concrete was poured inside these voids. The voids, noting that the casting was done immediately after painting, for the bonding process to be well completed, according to the specification of use for this material in its technical bulletin, and after treatment with repair concrete, these samples were painted with white paint to follow the cracks on the surface. All samples were tested with a flexure strength test for beams, focusing on following up and monitoring the cracks that appeared on the surface during the loading process, by measuring the length and width at all stages of loading and recording the value of the failure load and the value of deflection at specific periods. In addition, some concrete cubes with dimensions of 150×150×50 mm were prepared to find out the compressive strength of the concrete.

Table 2 Groups of length voids with the number of samples

Length of voids for samples	No Void	L/6	L/3	2L/3
Number of samples	**B1**	**B2,B3,B4,B5, B6,B7,B8**	**B9,B10,B11, B12,B13**	**B14,B15**

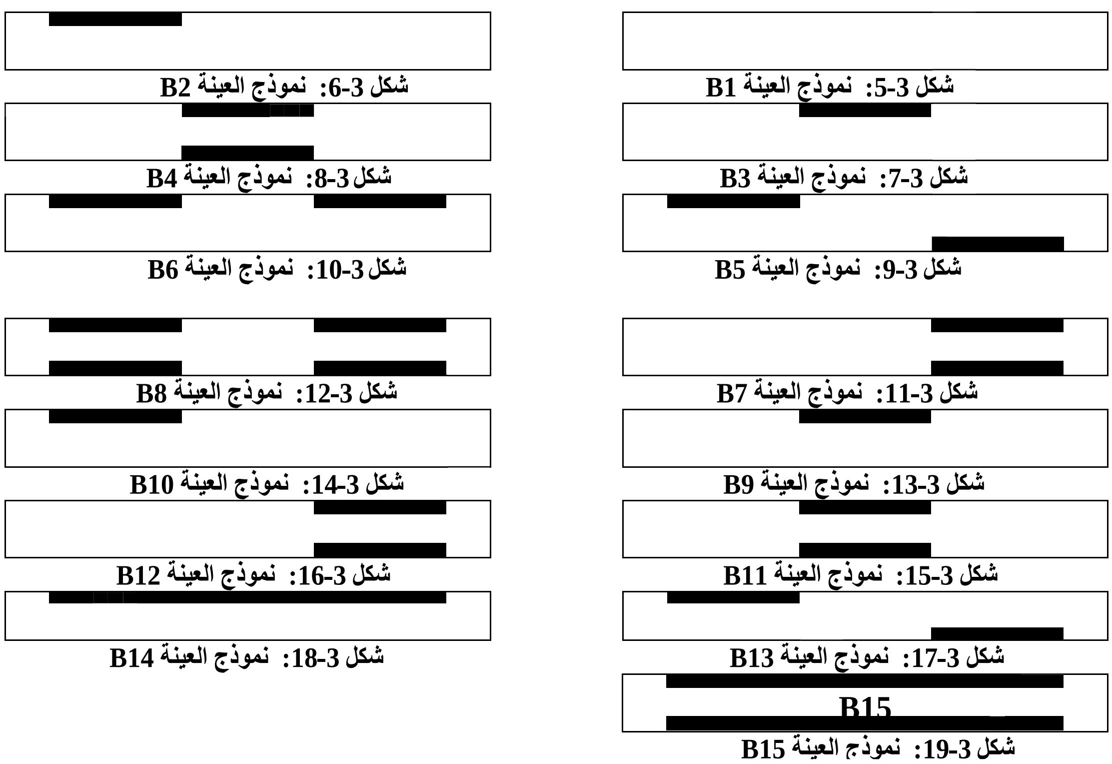


Figure (1) Drawing of the location of treatment areas

Figure (2) shape of the mould ready to cast

Figure (3) Mortar as repair concrete

2.7 Mechanical Mixer

The concrete components were mixed using a mechanical mixer.

2.8 Samples curing

After unmoulding, the samples were placed with a compressive strength test for cubes in the curing basins for 28 days to reach the target resistance value according to the mixture design.

2.7 Concrete Tests

2.7.1 Slump test

The workability of the concrete was measured by measuring the slump of 85 mm, which is within the design slump of the mixture (50-120 mm).

2.7.2 Compressive strength test

A compressive strength test was carried out for 150×150×150 mm concrete cubes using a compressive strength machine with a loading rate of (0.5 MPa/sec) and the average results were 36MPa.

$f'c = 0.8fcu$

$f'c = 0.8 \times 36 = 28.8 \approx 29MPa$

2.7.3 Measure cracks

The width of the cracks was measured using a high-resolution microscope, and the lengths of the cracks were measured by a ruler

2.7.4 Flexure Strength Test

The beams were tested with a Flexure Strength Machine as shown in Figure (4) until the failure stage, as well as the study of cracks during the loading stages.

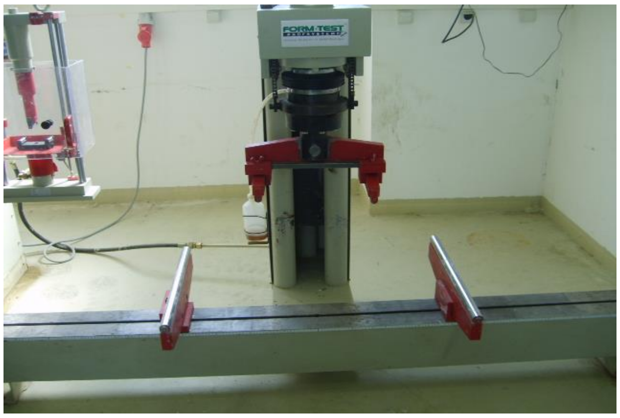


Figure (4) Flexure Strength Machine

3. Results and discussion

3.1 Effect of length and size of treatments on the flexural strength of the sample

The study samples were divided into three groups according to the length and size of the treatments. L/6 treatment samples B2, B3, B4, B5, B6, B7, B8 and L/3 treatment samples B9, B10, B11, B12, B13 and L/32 treatment samples B14, B15 and a reference sample It has no treatment which is B1. The results of the tests for the samples of the first group show that the failure loads for the samples range from 83 KN to 90 KN, and these results represent approximately 154% of the design load value and about 92% of the maximum resistance of the reference sample, and it is noted that these results were very close compared to the reference sample due to the length of the treatments which was the least in this study and since it has a significant effect on the load-bearing capacity of the section in all samples relative to the first group. In the second group, the sample B9 achieved a failure load of 80.9 KN, which is 145% of the value of the design load and 87% of the maximum resistance of the reference sample, and the reason for the decrease in the load value was the increase in the treatment length compared to the first group. As for sample B10, it achieved a failure load of 68 KN, which is 121% of the value of the design load and 73% of the maximum resistance of the reference sample is also due to the increase in the size of the treatment and the location of the treatment. As for sample B11, it failure at the load of 83.4 KN, which is 150% of the value of the design load and 89% of the maximum resistance of the reference sample. Sample B10's difference in values is likely due to the different locations of the bonding region. As for samples B12 and sample B13, the results were close to sample B10 for the same reason. As for the third group, the sample B14 has achieved 73 KN, where is 130% of the value of the design load and 78% of the maximum resistance of the reference sample, and because the treatment was along the sample and in one edge in the tension area, the sample B15, which achieved an improvement compared to B14, and the value of the load was 80 KN That is, 143% of the value of the design load and 86% of the maximum resistance of the reference sample, and this suggests that the treatment was in both edges and on the entire length of the sample, which shows the balance in the distribution of stress transmission. In general, it is clear from these results in all groups that with increasing the length of the treatments, the sample resistance decreases relatively compared to the maximum resistance of the reference sample, but all these treated samples did not failure before the design load value, meaning that the treatment did not affect the effect that causes the sample to failure before the required resistance.

3.2 The relationship between the load and the deflection

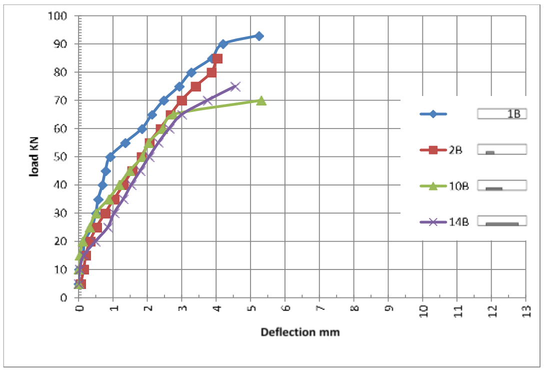
Figures (5) to (13) show the relationship between the load and the deflection of all samples, where it was observed in general, as expected, that the deflection increases with the increase of the load until the failure of the sample. The results of the samples differ according to the size and location of the treatment compared to the reference sample B1, where it was found that the shape of the curves changes when the first crack appears, and later the deflection values increase with a greater increase with the appearance of a large number of cracks, especially near the occurrence of failure, and in general deflection in all samples, it did not exceed the limits permitted by the American specifications (ACI 318-08-9.5a) (**14).**

3.2.1 Effect of length and volume of treatments on the relationship between load and deflection of the sample

Figure (5) shows the effect of the length and size of the treatment in one of the edges in the shearing area on the relationship between the load and the deflection. It was noted that all the results of the samples shown in the Figure from the beginning of the loading until the appearance of the first crack were almost identical, and with the appearance of the first crack, the curve of the reference sample deviated Then it continued semi-linear until the load of 50 KN, and near the occurrence of failure, the deflection increases clearly.

Samples B2, B10, and B14 were processed in the same position with a difference in the length treated. It was observed that all of its curves after the occurrence of the first crack had a decrease in its resistance to flexure, especially at load 50KN. It was compared to the reference sample, but before the occurrence of failure, the results of sample B2 showed some improvement while sample B10 achieved lower readings than other samples. In general, the results show that the treatment in the shear zone has an effect on the load capacity of the beams subject to flexure, and this effect depends on the treatment length.

Figure (6) shows the effect of the length and size of the treatment in one of the edges in the flexure area on the relationship between the load and the deflection of the samples (B1, B3, B9, B14), where it was found that the sample B3 had results before the occurrence of the first crack, which was the least in terms of structural behaviour due to the occurrence of the first crack in the treatment area, in addition to that the length of treatment was the least, which caused the inability to redistribute the tensile stress homogeneously between the treated and untreated area compared to samples B14 and B9, and there was a better possibility to redistribute the tensile stresses between the two stages before the occurrence of the first crack and the following cracks. The results shown present the extent of the effect of treatment length on the load capacity and structural behaviour of the samples, where the effect was only in increasing the deflection values whenever the treatment length was shorter.



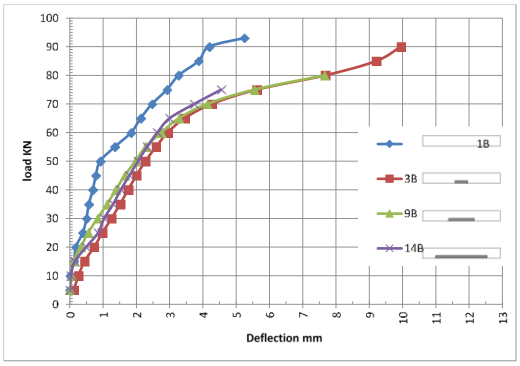


Figure (5) Effect of treatment length and size on one of the edges in the shearing area

Figure (6) Effect of treatment length and size on one of the edges in the flexure area

Figure (7) shows the effect of the length and size of treatment on both edges of the flexure zone on the relationship between load and deflection of samples (B1, B4, B11, and B15). The results for all samples are almost identical and with the same effect as shown in Figure (6), except that the symmetry of the treatment in both edges had a clear effect by increasing the improvement in deflection and load-bearing capacity, and after the occurrence of the first crack, the curves of the samples (B4, B11, B15) moved away A little from the curve of the reference sample, the increase in flexibility in the samples as a result of the increase in the size of the treatment and the symmetry in the treatment led to an increase in the number of cracks until the failure stage, and the sample B4 achieved higher deflection values before failure compared with the other samples.

Figure (8) shows the effect of the length and size of treatment in two symmetrical edges in the two shear zones on the relationship between loads and deflection. The Figure shows that the results of samples B5 and B13 have the same relationship until the failure stage, but sample B5 showed an improvement in increasing the deflection values compared to the reference sample, and the deflection values increased before the occurrence of the failure and reached more than 6.6 mm. The sample B13, because of the size of the treatment that gave it flexibility, led to an increase in the number of cracks, but it collapsed before the other samples due to the presence of the bonding area in the flexure area.

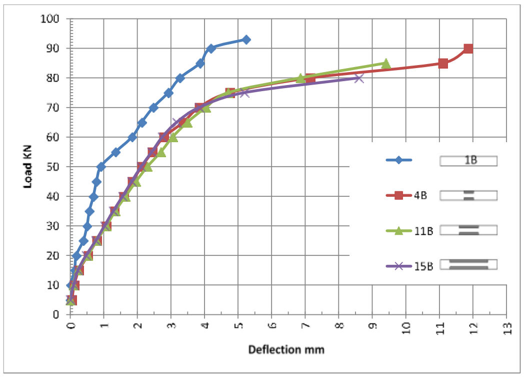


Figure (7) Effect of treatment length and size on both edges in the flexure area

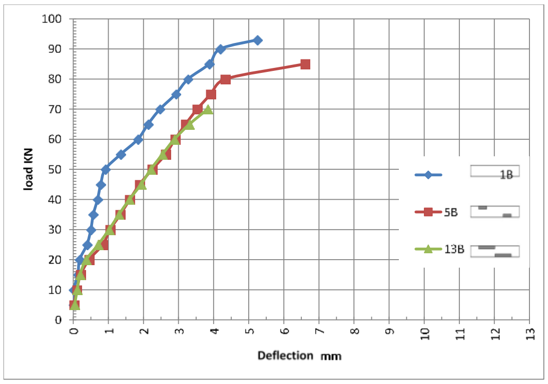


Figure (8) Effect of treatment length and size on two symmetrical edges in the two shear zones

Figure (9) shows the effect of treatment in one edge of the entire sample compared to treatment in the two shear regions on the relationship between load and deflection. The results of the two samples, B6 and B14, were close until the value of the load was 40 KN. After that, it was noted that the results showed an improvement in the structural behaviour and better flexibility by achieving higher deflection values compared to the reference sample, which indicates that the treatment in the shear and flexure areas had a significant effect after the appearance of the first crack on the capacity loading gave fewer results. Sample B14 was better compared to the reference sample, as the improvement in the deflection values continued due to the size of the treatment, which gave elasticity and deflection values high before failure and recorded 13 mm.

Figure (10) shows the effect of the length and size of treatment at the two edges of the tension area on the relationship between load and deflection. Compared with the obtained results, which were presented in Figure (9), we note that there is some improvement in the results, which indicates that symmetry in treatment, especially in the tension region, affects increasing the section's resistance to flexure. It was also noted by reading the results in the Figure for the sample that the treatment in the shear area on one side of two edges B7, as well as for sample B15, was identical until the load was 75 KN. At this load, sample B7 achieved an increase in the value of the load, while sample B15 achieved an increase in deflection, due to the increase in the volume of treatment for the full length of sample B15. The same Figure showed that the treatment of sample B12, which was extending from the shear area to the flexure area in the tension side, as the extension of the treatment in the two impact areas had a clear effect on the asymmetry of the distribution and transmission of stresses, especially when the treatment was in one side. This is compared to sample B15, which as we have mentioned achieved good structural behaviour compared to the reference sample, regardless of the weakness in the load-bearing capacity due to the treatment.

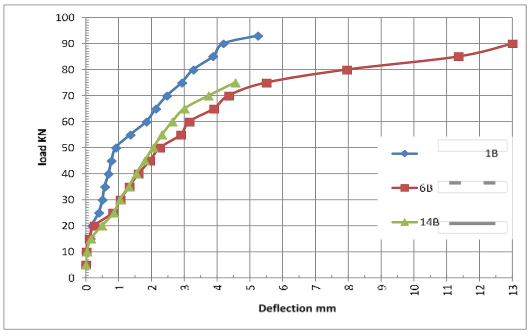


Figure (9) Effect of treatment on one edge of the whole sample and the two shear regions

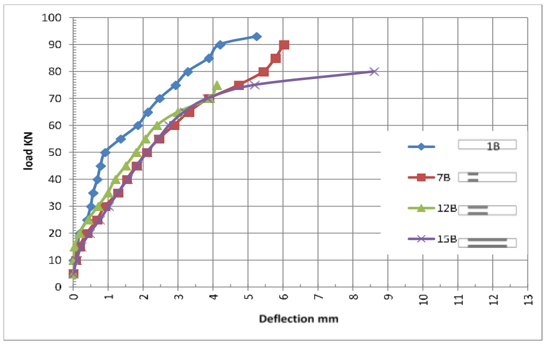


Figure (10) Effect of treatment length and size on edges in tension regions

Figure (11) shows the effect of treatment at the two edges of the shear zone, compared with treatment at the two edges of the entire sample, on the relationship between load and deflection. The deflection values of sample B15 were the largest in the samples shown in the Figure, due to the size of the treatment, which achieved an increase in the number of cracks compared to sample B8, except for the final value before failure, for the sample B8 was greater, and these results confirm that the uniformity of the treatment on the entire section improves the structural behaviour and achieves values high deflection, which helps to increase the potential for elongation failure.

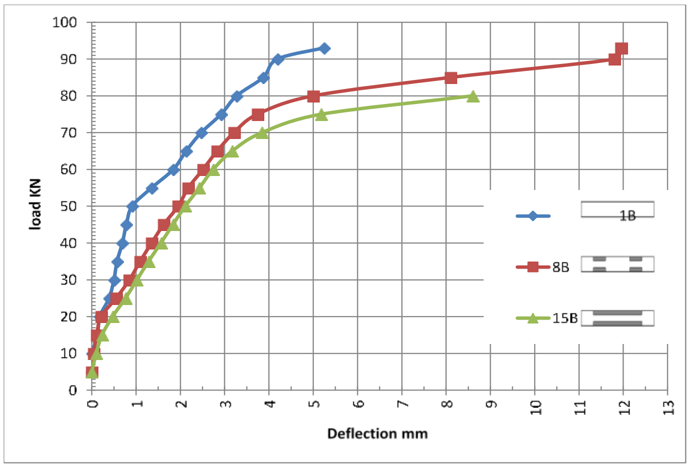


Figure (11) Effect of treatment on both edges of the shear regions and both edges of the whole sample

3.2.2 Effect of location of treatments and bonding area on the relationship between load and deflection

Figure (12) shows the effect of the treatment location in one of the edges in the shear and flexure regions on the relationship between load and deflection for samples B1, B9, and B10. The results shown in the Figure present the extent of the effect of the treatment in the flexure region compared to the treatment in the shearing region. The treatment in the flexure region gives the sample better flexibility due to the redistribution of the resulting stresses when several cracks appear, which helped in increasing the deflection values at the same load values for sample B10.

Figure (13) shows the effect of the treatment location of the two edges of the sample in different positions of the sample on the relationship between the load and the deflection of the samples. From the study of the shape, it was noted that the structural behaviour of the two samples B4 and B7 was very close until the load was 75 KN, and then sample B4 showed greater deflection values due to the treatment in the bending area that helped increase flexibility, while the sample B8 gave an improvement in the structural behaviour due to the symmetry in the two edges and ends The sample, although the treatment was in the shear area. Table (3) shows the results of failure loads and maximum deflection. Also, Figure 14 shows the difference between the failure load of B1 and other samples.

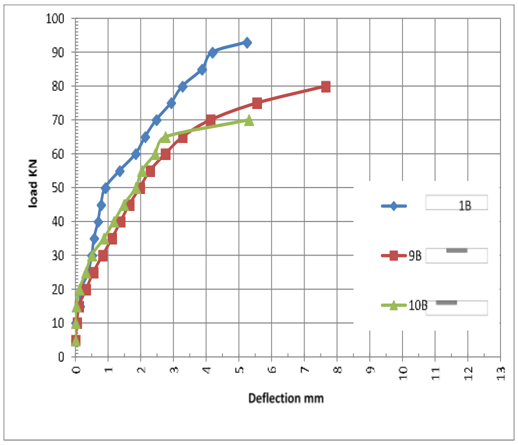


Figure (12) Effect of treatment on one edge of the whole sample and the two shear regions

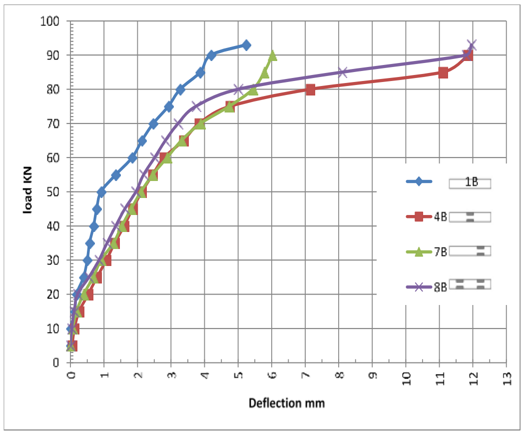


Figure (13) Effect of treatment length and size on edges in tension regions

Table (3) Results of failure loads and maximum deflection

maximum deflection (mm)	Column 5 Column 2	Loose of load Due to treatment	Column5 Column3	Failure load (KN)	A load of the first crack (KN)	Failure load for reference sample (KN)	Design load (KN)	Sample No.
9	8	7	6	5	4	3	2	1
5.2	1.66	0	1	93.0	27.5	93	55.75	B1
4.0	1.50	0.10	0.90	83.4	25.5			B2
9.3	1.54	0.07	0.93	86.2	21.6			B3
11.9	1.53	0.08	0.92	85.6	18.4			B4
6.6	1.48	0.11	0.89	82.7	23.8			B5
13.0	1.56	0.07	0.93	87.3	23.0			B6
6.0	1.55	0.07	0.93	86.7	25.0			B7
12.0	1.61	0.04	0.96	90.1	22.8			B8
7.7	1.45	0.13	0.87	81.0	21.6			B9
5.3	1.22	0.27	0.73	68.0	17.7			B10
9.4	1.50	0.11	0.89	83.4	18.0			B11
4.1	1.27	0.24	0.76	71.0	19.9			B12
3.8	1.25	0.25	0.75	69.6	18.6			B13
4.6	1.31	0.22	0.78	73.0	21.9			B14
8.6	1.43	0.14	0.86	80.0	22.3			B15

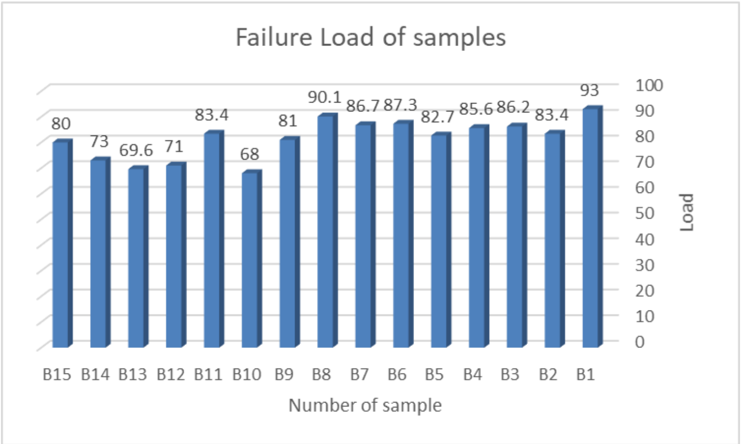


Figure (14) Failure load of samples

3.3 Characteristics of the First Crack

Table (4) shows a summary of the properties of the first crack for all samples. The results indicate that there is no direct relationship between the length and width of the crack. It can be also noted that the value of the load depends on the structural behaviour of the samples and the treatment condition. Therefore, it can be seen that it is difficult to develop a scientific explanation that clarifies the essential differences in the effect of the properties of the first crack. The structural behaviour of the samples, in this regard, can be reviewed in each case separately, with a list of observations, differences, and scientific interpretations of some cases.

The first crack of the reference sample B1 appeared at the load of 27.5 KN and was 40 mm long and 0.1 mm wide. As for the first crack load in samples B3, and B4 it was 72% of the crack load value and almost the same length and width compared to the reference sample, due to the treatment that took place for the samples in the middle, of the area of appearance of the first crack.

As for samples B2, B6, and B7, the first crack appeared and achieved 89% of the crack load value of the reference sample, and the length and width are also almost equal to the reference sample, due to the small size of the treatment and its distance from the middle area, while the samples B5, B8 achieved 83% of the load value The cracking of the reference sample and the length of the cracking reached 50 mm due to the increase in the treatment volume. In sample B9, the value of the load for the first crack was only 72% of the load for the first crack in the reference sample, and the length and width recorded readings greater than the crack length of the reference sample, due to the location of the treatment and the asymmetry between the two edges of the sample. As for the sample B11, it achieved 65% of the value of the crack load. For the reference sample due to the size of the treatment, the samples B13, B12, and B10 achieved the lowest value of the first crack load and moved away from the value of the crack load of the reference sample by only 66%, due to the presence of the bonding area in the bending region of the sample, which is often the first crack appearance area, and the crack width was close, but The crack length was different due to the asymmetry in the treatment at the two edges of the sample, it was the shortest in sample B12 in which the treatment at the two edges was similar. In samples B15 and B14, the first crack appeared and achieved values of about 80% of the load for the first crack of the reference sample, because the treatment was carried out along the sample, which gave homogeneity to the sample, so its resistance increased compared to other samples, and the treatment length was greater in sample B14, which confirms that the asymmetry increases the length of the first crack.

Table (4) Characteristics of the first crack

First crack			Sample No.
Width (mm)	Length (mm)	Load (KN)	
0.1	40	27.5	B1
0.08	39	25.5	B2
0.08	47	21.5	B3
0.04	31	18.4	B4
0.06	42	23.8	B5
0.08	37	23.0	B6
0.05	39	25.0	B7
0.06	50	22.8	B8
0.04	67	21.6	B9
0.06	29	17.7	B10
0.06	48	18.0	B11
0.04	18	19.1	B12
0.04	33	18.6	B13

0.06	50	21.3	B14
0.06	28	22.9	B15

3.4 Failure patterns

The photographs shown in Figures (15 to 28) show the failure patterns for all samples. During the tests, several notes were taken that could be elaborated upon for further clarification. The failure load of sample B1, which is the reference sample, occurred at 93 KN and was accompanied by the appearance of several cracks in the flexure and shearing regions, and the spread and distribution of these cracks were confined to the entire face of the sample symmetrically. In sample B2, a sudden failure occurred in the shear zone at load 83 KN, due to the treatment being in the shear zone at one end, and 8 cracks appeared, including a crack in the bonding zone. Sample B3 collapsed suddenly in the shear and flexure region at load 86 KN due to the asymmetry of the treatment on the two edges of the sample, and the number of cracks reached 11 cracks and were distributed over the entire sample, most of them in the treatment area. As for sample 4B, the failure occurred at load 86 KN in the flexure area, and the failure was elongated due to the symmetry in the treatment, and the number of cracks was 12, most of which were oblique cracks, and some were vertical. The elasticity of the sample is a result of stress redistribution.

While sample B5 collapsed at load 82.7 in the shear area, a sudden failure. Separation occurred in the bonding area between the repair concrete and the base concrete because the bonding area in this sample was in the line of influence of the load. As for the number of cracks, it reached 10 cracks distributed between the flexure and shearing areas. In sample B6, an elongated failure occurred at load 87 KN in the flexure area, and the number of cracks reached 11 cracks, most of them in the flexure area. As for sample B7, it collapsed at load 87 KN in the flexure area due to the asymmetry between the two sides of the sample in the treatment, and separation occurred between the base concrete and the repair mortar, the number of cracks at the moment of collapse was 10, slanting in the shear area and vertical in the bending area. While sample B8 collapsed at load 90 KN in the flexure region, an elongated failure and its maximum resistance were greater compared to the previous samples, because the treatment was in the two shear areas at the two edges of the sample identical, and the size of the treatment was not large, and the number of cracks was less, which is 9 cracks distributed between the flexure and shearing areas as well, a separation occurred between the base concrete and the repair mortar. In the sample B9, which was treated extended between the flexure area and the shearing area, the number of cracks was greater and reached 13 cracks due to the increase in flexibility, which led to redistribution of the stresses of the sample, and the failure occurred at load 81KN, and it was a sudden failure in the flexure area, and most of the cracks occurred in the repair mortar.

As for the sample B10, there was a sudden failure in the flexure area at the load of 68 KN, which is only 73% of what was achieved by the reference sample, due to the presence of the bonding area in the bending area of the sample, which is the area of the appearance of the first crack, which led to an early separation between the base concrete and the repair mortar, and the number of cracks was 8. In sample B11, which was treated in the flexure region, it collapsed upon load 83 KN, and there was a sudden failure in the shear and flexure regions, due to asymmetry, as the treatment was at one end on both edges of the sample, but because the bonding region was relatively far from the flexure region, it gave greater resistance. As for the number of cracks, it reached 13, which are continuous slanting cracks on the entire face of the sample. In sample B12, it collapsed suddenly in the shear and bending regions at load 71 KN, and one of the factors for the early collapse is the presence of the bonding region in the flexure region and the shear region of the sample. The treatment is not symmetrical on both ends of the sample and the number of cracks is 9. While sample B13 collapsed at load 69.6 KN there was a sudden collapse in the shear zone due to the bonding zone in the middle and the 9 slanted cracks distributed between the flexure and shear zones. As for the sample B14, the collapse occurred at load 73 KN, and it was a sudden collapse in the flexure and shearing area because the treatment on the entire sample was not symmetrical, and the number of cracks was 10, all of which were in the treatment area. Whereas the sample B15 collapsed into an elongated failure at load 80 KN in the flexure and shearing zone, as the treatment was done on the entire sample symmetrically, which gave homogeneity to the sample, and the number of cracks was 11 at the moment of collapse distributed between the flexure and shearing zones.

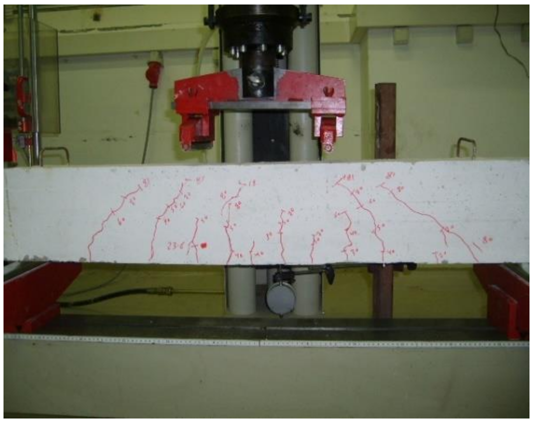


Figure (15) Failure for sample B1

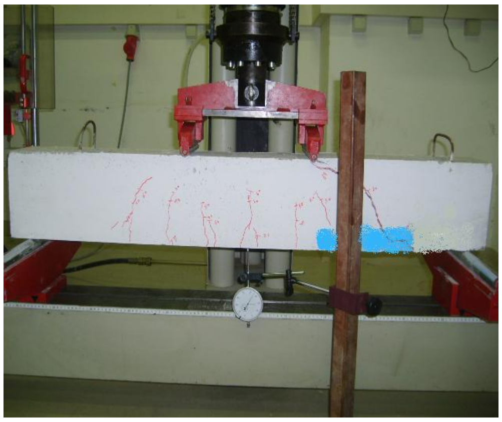


Figure (16) Failure for sample B2

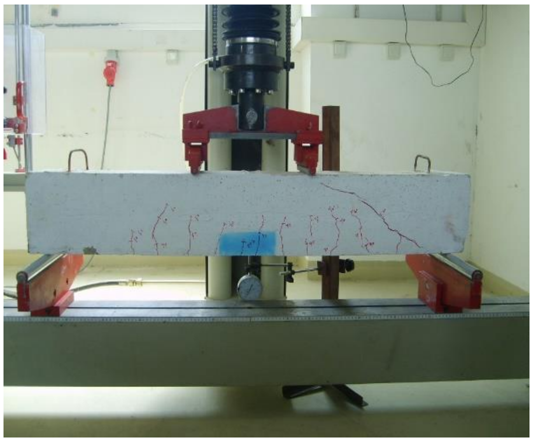


Figure (17) Failure for sample B3

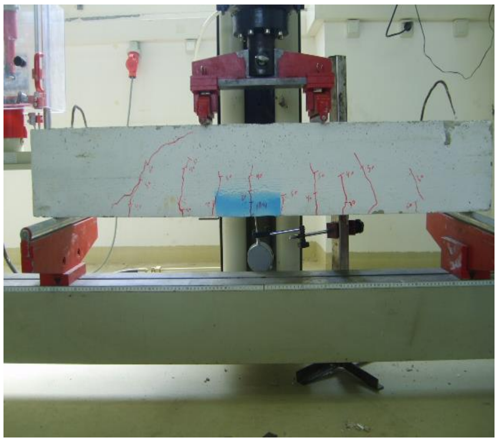


Figure (18) Failure for sample B4

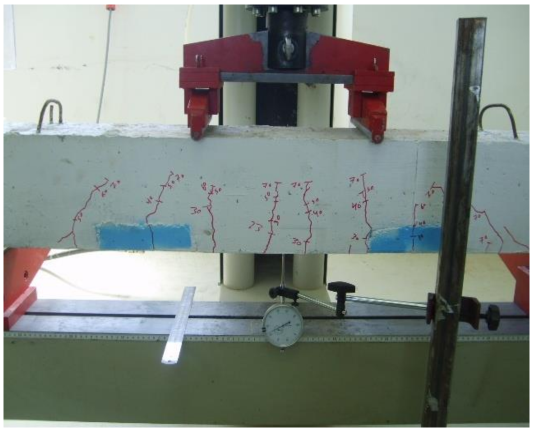


Figure (19) Failure for sample B6

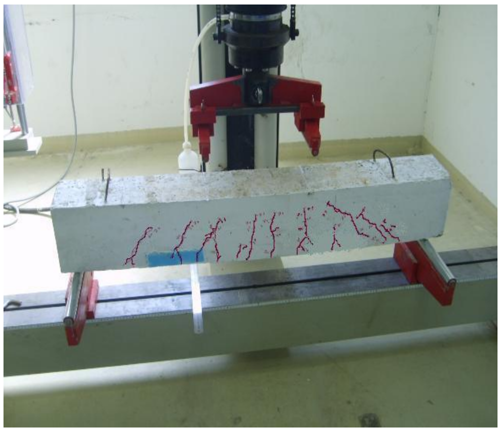


Figure (20) Failure for sample B7

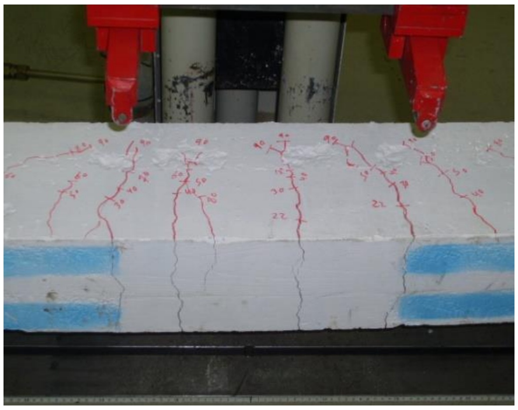


Figure (21) Failure for sample B8

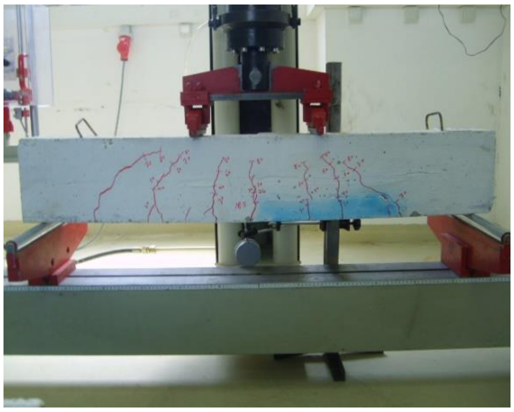


Figure (22) Failure for sample B9

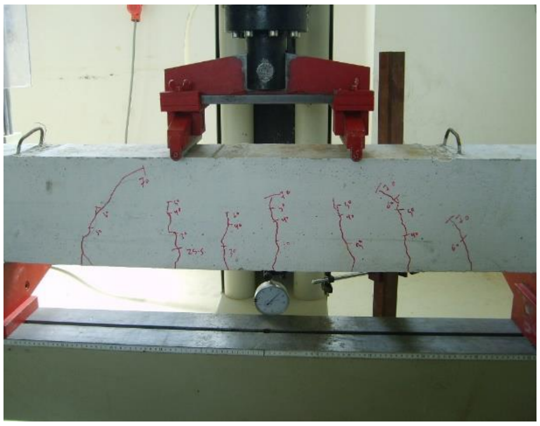


Figure (23) Failure for sample B10

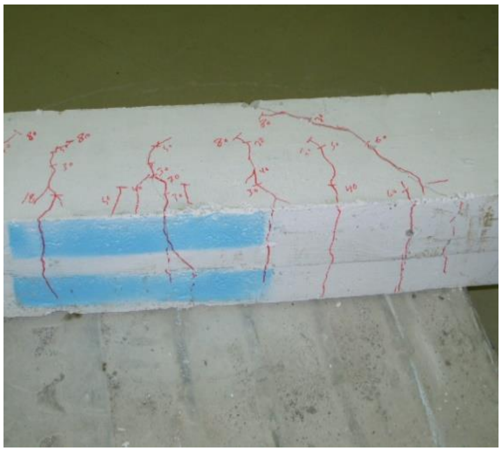


Figure (24) Failure for sample B11

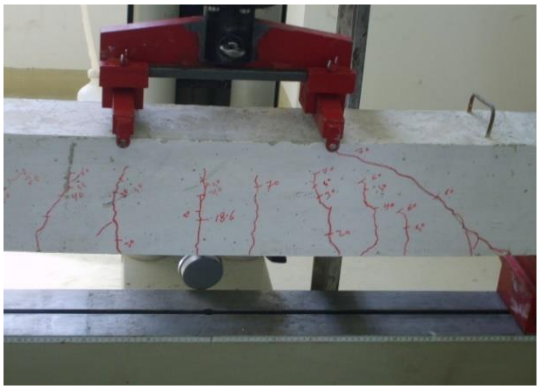


Figure (25) Failure for sample B12

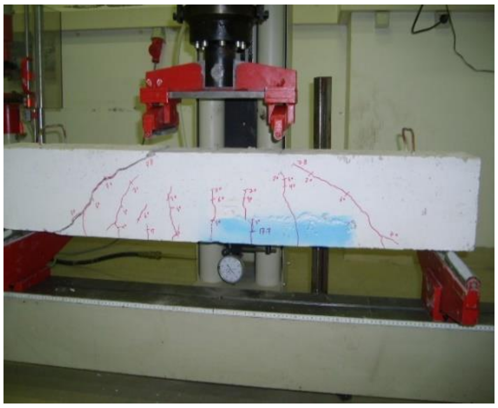


Figure (26) Failure for sample B13

Figure (27) Failure for sample B14

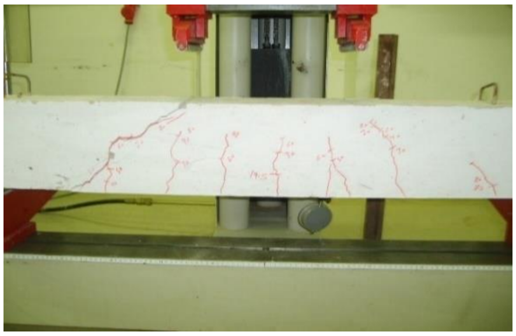


Figure (28) Failure for sample B15

4. Conclusion

The following points were drawn from this study:

1. Increasing the treatment volume of reinforced concrete beams reduces the flexural strength of the sample

2. The deflection values were high due to the similarity in the size of the treated cracks along the entire length of the reinforced concrete beams, which achieved an improvement in the structural behaviour and an increase in the probabilities of elongation failure.

3. The cracks treated in the shear zone had a significant effect on the load capacity of the beams subject to flexure.

4. The treated cracks in the flexure area contributed to the increase in flexibility, the redistribution of stresses and the appearance of several cracks.

5. The properties of cracks and the values of the applied load for each stage at loading differ due to the different cracks of the samples and the treatment conditions.

6. The increase in size and length of repair, the less value of load carrying capacity of a beam.

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