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BEHAVIOR OF REPAIRED COMPOSITE MODIFIED REACTIVE POWDER CONCRETE I-SECTION BEAMS WITH OPENING UNDER PURE TORQUE

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Abstract: In this paper, an experimental study has been conducted to investigate the behavior of composite concrete beams damaged and cracked under pure torsion , and then repaired by external strengthening with high strength CFRP(Carbon Fiber Reinforced Polymer) laminates bonded with epoxy after doing all the appropriate preparations for the concrete adhesion substrate. Four composite modify reactive powder concrete (MRPC) I- beams,1300mm length,100mm web width and 320mm height, with different type of section (Solid & with opening) were tested to obtain the effect of amount of CFRP laminate on beams cracking torque behavior, angle of twist and failure modes. The results obtained from the adopted repairing technique showed a significant effect of external high strength CFRP laminates on effectively restore of section solid the range of 84% to 85.33% of crack torsional strength effectively restore. As well as the results show that effectively restore of section opening by 80%- 82.22% of crack torsional strength.

Keywords: *MRPC, repairing, carbon fiber reinforced polymer (CFRP), crack torsional strength, Composite, solid, opening,*

سلوك العتبات المركبة بعد التاهيل ذات المقطع (I) والمحتوية على خرسانة المساحيق الفعالة المطورة مع فتحات تحت عزم اللي الصافي

الخلاصة :هذ البحث هو دراسه عمليه للتحري عن سلوك العتبات الخرسانيه المركبه المتضرره والمتشققه تحت تاثير احمال اللي الصافيه ،ومن ثم تم معالجتها خارجيًا بشرائح من ألياف الكربون والتي ألصقت بإستخدام مادة الإيبوكسي بعد عمل كافة التحضيرات على سطح الخرسانة اللاصق.تم فحص اربعه عتبات خرسانيه مركبه من خرسانه المساحيق الفعاله المطوره ذات مقطع (I) بطول 1300mm وعرض الويب 100mm وارتفاع 320mm لمقاطع مختلفه (صلده& مع فتحات) لمعرفه تاثير كميه شرائح الياف الكربون على مقاومه عزم التشقق ،وزاويه الدوران ونوع الفشل .ان النتائج المستحصله من هذه الطريقه المستخدمه للمعالجه اثبتت التاثير الفعال لاستخدام شرائح الياف الكاربون في استرجاع المقاومه للمقاطع الصلده بحدود %84 الى %85.33 من مقاومه عزم التشقق لهذه العتبات. وكذلك اظهرت النتائج استرجاع المقاومه للمقاطع ذات الفتحات بحدود %80 الى %82.22 من مقاومه عزم التشقق لهذه العتبات.

1. Introduction

FRP composite materials have experienced a continuous increase of use in structural strengthening and repair applications around the world, in the last decade [1].

In addition, when the FRP was compared with steel materials, it was found that it

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provided unique opportunities to develop the shapes and forms to facilitate their use in construction. Although, the materials used in FRP for example, fiber and resins are relatively expensive when compared with traditional materials, noting that the crises of equipment for the installation of FRP systems are lower in cost [2].

The use of carbon fiber-reinforced polymers (CFRP) can now be considered common practice in the field of strengthening and rehabilitation of reinforced concrete structures. The effectiveness of this technique is widely documented by theoretical and experimental researches and by applications on real structures. As a consequence, the need of codes is necessary, leading to the development of guidelines in different countries[3].The CFRP strengthening provides additional flexural or shear reinforcement, the reliability for this material application depends on how well they are bonded and can transfer stress from the concrete component to CFRP laminate [4].

Adhikary et al (2004) [5], carried out the tests of eight simply supported RC beams strengthened for shear with CFRP sheet using two different wrapping schemas; U-wrap and two sides of the beam. He investigated the effectiveness of cross plies one over another, vertical and horizontal; the main parameter, direction of fiber alignment (90°,0°and 90°+0°) and number of layers (1 and 2). They observed that the maximum shear strength was obtained for the beam with full U-wrapped sheets having vertically aligned fibers. Horizontally aligned fibers also showed enhanced shear strengths as compared to beam with no CFRP. On the other part, they found that the lowest concrete strain was the same load range among all beams. The beam with full U-wrapping of a single layer of CFRP with vertically aligned fibers, was observed at a maximum of 119% increase in shear strength. Also, they compared with the experimental value, using models for the prediction of shear contribution of sheet to shear capacity of CFRP bonded beams.

K. Olivova, J. Bilcik (2008) [6], presented the results of an experiment at study on the structural behavior of reinforced concrete columns strengthened with carbon fiber sheets and strips in pre-cut grooves The observed behavior of the confined columns was similar to the unconfined columns up to the peak load of the unconfined columns. Increase in the lateral deflection of the confined columns resulted in the concrete failing in compression and rupturing the FRP confining jacket at approximately mid-height. The deflected shape of the columns at peak load was symmetrical, and there was no local buckling in the columns.

Bukhaari et al (2010) [7], studied the shear strengthening of reinforced concrete beams with Carbone Fiber Reinforced Polymer (CFRP) sheet. Seven, two span continuous reinforced concrete (RC) rectangular beams. The cross section of rectangular was 152mmx305mm and beam length 3400mm. One beam was un-strengthened (control beam) and, the remaining six were strengthened with different arrangements of CFRP sheet. They studied orientation of fiber (0/90 and 45/135) as main variables. The tests showed that it is beneficial to orientate the fibres in the CFRP sheet at 45 so that they are approximately perpendicular to the shear cracks.

2. Research Objective

The objective of this work is to evaluate the effectiveness of CFRP repairing of composite I-section beams with opening in web subjected to pure torsion. The composite beams are made of a modify reactive powder concrete beams connected with steel plates at the bottom of beam by means of headed stud shear connectors.

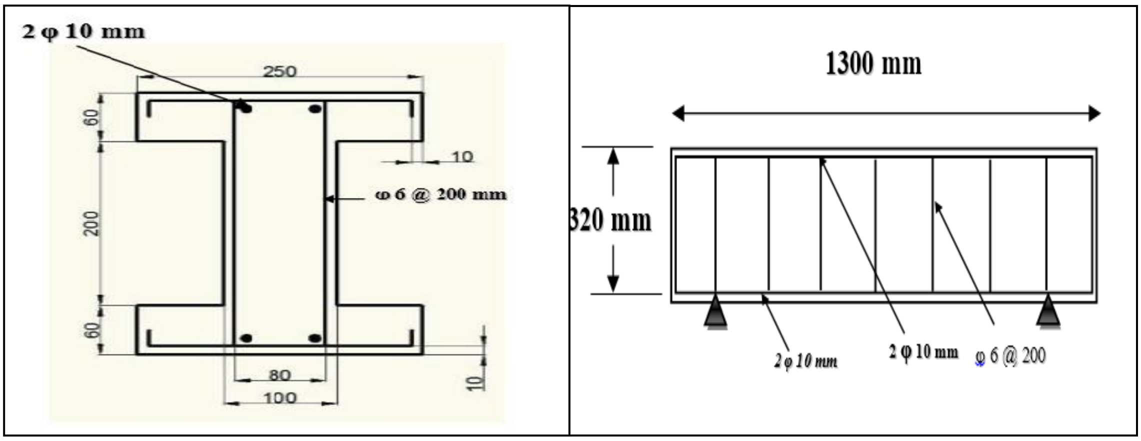
3. Experimental Program

The experimental program concluded by of testing of four specimens to investigate the cracking resistance of MRPC composite beams under pure torsion. This specimens were casted and tested by (Ahmed and Saad) [8]. The main variables considered in the test were the opening location. The cast beams dimensions were (1300 × 320 ×100 mm). Specimen details and main study parameters were summarized in Table (1) and Figures (1) and (2). Cracking torque- twisting angle curves crack pattern and failure mode were observed throughout the study. In all the repaired beams, one layer of CFRP was used with the same repairing scheme using 100 mm wide CFRP strips spaced 200 mm c/c with a development length of (120 mm), the total length of each strip was (940 mm).

Table (1) General Details of the Tests Beams

Beam No.	Name of repaired beam	Dimension of opening (mm)	Location of opening
Rep.1	I-beam solid without steel plate(reference)	---------	---------
Rep.2	I-beam solid with steel plate	---------	---------
Rep.3	I-beam with steel plate and circular opening in web	(* d=100)	Mid span
Rep.4	I-beam with steel plate and circular opening in web	(* d=100)	Third span

* d= diameter of opening



(a) (b)

(c)

Figure (1): Defiles of Beams Reinforcement
(a) Cros Section of Steel Reinforcement.
(b) Reinforcement Profile along the Beam
(c) Reinforcement Cage of the Concrete Beam.

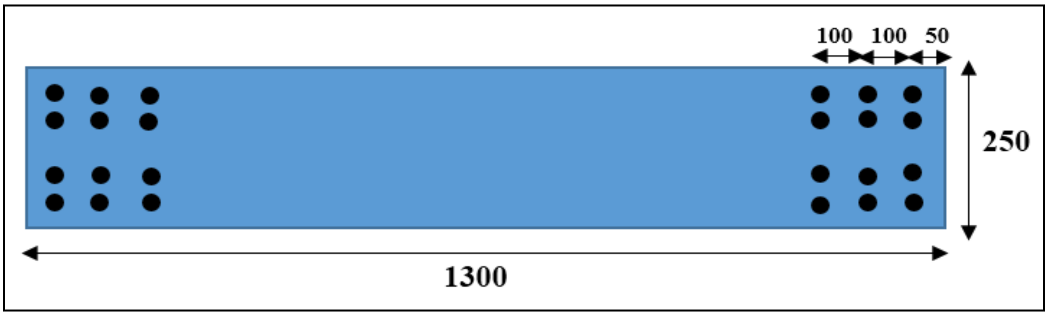


Figure (2) Details of steel plate with shear connector (Bottom view)' (all the dimension in(mm)

3.1 Materials and Mixing Proportions

MRPC matrix consisted of ordinary Portland cement locally available [9] and natural sand with fineness of 2.36[10] and 8 % by weight of cement was replaced by silka fume [11]. The crush coarse aggregate with maximum size of 10 mm was used as a gravel [10]. The water to binder ratios by weight were chosen to be 0.27. Supper plastcizer type (Gelinume 51) [12], was used as high range water reducer. The dose of super plasticizer used was 0.41% by total binder weight. Potable water was used in the experimental work for both mixing and curing.

The steel fiber with hook ended was used in this study and having unit weight of 7850 kg/m^3 with tensile strength 1150 MPa. A steel fiber of 0.5 mm diameter and 60 mm length was manufactured in Bekaert factory in UAE. The cylinder compressive strength was (90.3MPa) at (28) days.

The steel reinforcement of the tested beams consisted of two 10 mm diameter bars at the bottom and two10 mm diameter bars at the top of the beam. Stirrups were made of 6 mm diameter bars. The center-to-center spacing of the stirrups was 200 mm. The steel plate of 2mm thickness and 1300 mm length was used in strengthened composite I beams. The head stud connectors are used in this study with diameter of 8 mm and length 50 mm. The average shear force is (20) kN. The yield stress, ultimate strength and longitudinal elongation of steel reinforcing bars and steel plate used in this study are summarized in Table (2).

Table (2): Specification and test results of steel reinforcing bar values

Diameter of Bar (mm)	Yield Stress (MPa)	Ultimate Strength (MPa)	Elongation %
6	383	545	16
10	521	615.7	19
2 mm steel plate	386.3	426.6	15.2

3.2 Mechanical Properties of MRPC

The experimental results of tests for mechanical properties (compressive strength, modulus of elasticity, flexural strength and splitting tensile strength) of MRPC were listed in Table (3).

Table (3): Properties of Hardened Concrete.

Concrete Type	f_{cu}^* MPa	$f'_c{}^*$ MPa	f_{ct}^* MPa	f_r^* MPa	E_c^* MPa
MRPC	102.8	90.3	10.8	14.6	4512

*Each value was an average of three specimens.

3.3 Cfrp Material Properties

The Sika Wrap Hex – 230C is an externally applied strengthening or repairing system for structural members made of reinforced concrete. This system was supplied by (Sika near East s. a, I. Beirut – Lebanon). Epoxy based impregnating resin Sikadur– 330 was used with fabric. The following information related to this system is listed in Table (4) and Table (5).

Table (4) Sika Wrap Hex-230C (Carbon Fiber Fabric) (*)

Fiber type	High strength carbon fibers
Fiber orientation	0◦ (unidirectional). The fabric is equipped with special weft fibers which prevent loosening of the roving (heatset process).
Areal weight	225 g/m2
Fabric design thickness	0.13 mm (based on total area of carbon fibers)
Tensile strength of fibers	3500 MPa
Tensile E – modulus of fibers	230 GPa
Elongation at break	1.5 %
Fabric length/roll	□□45.7 m
Fabric width	305/610 mm

(*) Provided by the manufacturer

Table (5) Sikadur-330 (Impregnating Resin) (*)

Appearance	Comp. a: white Comp. b: grey
Density	1.31 kg/l (mixed)
Mixing ratio	A : B = 4 : 1 by weight
Open time	30 min (at + 35◦C)
Viscosity	Pasty, not flowable
Application temperature	+ 15◦C to + 35◦C (ambient and substrate)
Tensile strength	30 MPa (cured 7 days at +23◦C)
Flexural E-modulus	3800 MPa (cured 7 days at +23◦C)

(*) Provided by the manufacturer

4. Testing Procedure

The hydraulic universal testing machine (MFL system) was used to test the beam specimens. The testing machine has a capacity of (3000 kN). This machine was calibrated by the "Iraqi central organization for standardization and quality control. The normal load can just be applied by this machine on the specimen at several points and the supports should be remaining fixed without rotating around the longitudinal axis.

In this research the applied loads outside the bed of the universal machine are needed in order to get torsional movement. The experimental requirements need to move the supports circularly (ball bearing) and transmitting the load from the center of the universal machine to the two external points that represent the moment arm the idea of this loading arrangement was mentioned by (Zararis and Penelis) [13] as shown in Figure (3). The special clamping loading frame on each end of the beam used in this research is shown in Figure (4).

This frame consists of two large steel clamps which work as arms for applied torque with separated faces to connect them over the sample by large bolts; four bolts are used for each arm. This frame is made of thick steel plate (12 mm) with two steel shafts attached by welding. This final shape is similar to a bracket. These arms were capable of providing a maximum eccentricity of (500 mm) with respect to the longitudinal axis of the beam. In order to get pure torsion the center of support should coincide with the center of the moment arm.

The steel girder of (300 mm) depth and (3 m) length is used to transmit the loads from the center of the universal machine to the two arms (pure torsion), in addition, two lines load are used to transmit the load of bending (combined stresses) as shown in Figure (4).All beams were tested under monotonically increasing torque up to failure, the load was applied gradually. For each (5 kN) load increment, readings were acquired manually. The torque was increased gradually up to failure of the beam.

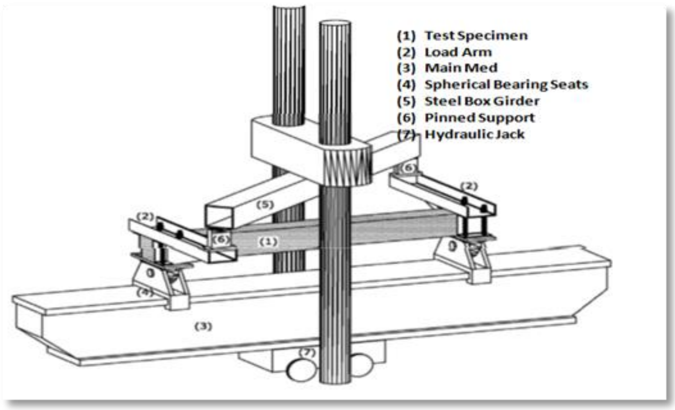


Figure (3): Suggestions of load Arrangement Showing the Test Rig [13]

Figure (4): Arrangement of Beam Testing

5. Results and Discussion

5.1. Efficiency of first cracking torque and angle of twist

The efficiency of repairing is defined as the ratio of repaired beams to its original strength (on percentage basis).Figures (5) to (8) show the relationships between cracking torque with cracking angle of twist, for original and repaired beams. For each specimen, the general relationship between cracking torque and cracking angle of twist behavior was approximately linear elastic until the first diagonal cracks. As well as Table (6) shows the experimental results to first cracking torque.

Table (6) first crack Torque Results of the Experimentally Tested Beams.

Beam No.	Cracking torque (kN.m)	Repaired original (%)	Angle of twist (rad)	Repaired original (%)	T_{cr} / T_{ult} % (Repairing)
B1	25	84	0.002	135.8	43.64
Rep1	21		0.002715		
B2	37.5	85.33	0.00489	127.2	61.69
Rep2	32		0.00622		
B7	22.5	82.22	0.002	108	45.54
Rep3	18.5		0.002731		
B6	20	80	0.00216	124.9	42.95
Rep4	16		0.002698		

The general Test results show that the repaired beams strengthened with steel plate gain high efficiency in cracking torsional strength over that of the unplated repaired beam (Rep.1). As well as the results showed that the composite repaired beams that contain the opening in the web gives a lowest efficiency in cracking torque more than repaired beams without opening in the web where the openings are considered zones the weakness of the repaired beams. The largest efficiency at cracking torques were recorded for the composite repaired beam (Rep.2) without opening in web where it has shown an efficiency of (85.33**%**) compared with reference repaired beam (Rep.1) and efficiency recorded was indicated in repaired beam (Rep.1) with efficiency of (84**%**)**.** As well as note the gradual decrease in efficiency of the cracking of the reinforced concrete composite two repaired beams other containing opening in the web. Where the decrease efficiency in cracking torque in composite repaired beam (Rep.3) with circular opening in center web (82.22 %), and come after a decrease efficiency in cracking torque the composite repaired beam (Rep.4) with circular opening in side web(80%) .As shown in Table (6). The results show that in similar relations between repaired and original beams. There was a small rise in angle of twist in the repaired beam compared to the originals one, up to failure. Beams (Rep.1,Rep.2, Rep.3, Rep.4) are repaired beams recorded an increase in the angle of twist at cracking torque there was of 35.8 %, 27.2%, 8 % and 24.9 % respectively compared original beams. On the other hand it is clear that the beams after repairing have the same behavior and the cracks would be appear at first time near the opening.

At cracking torque, Beams (Rep.1, Rep.2, Rep.3, Rep.4) repaired beams recorded 135.8 %, 127.2%, 108% and124.9 % respectively. As shown in Table (6).

We conclude from the above that the presence of steel plates in the repaired section gives best efficiency in the first cracking torsional resistance and the small rise in angle of twist for repaired beam. As well as the presence of opening in the web lead to a decrease efficiency in cracking torsional where effect the location opening in the web of the ratio first cracking torque. It can be noticed that the best location for the opening is within the center of the span.

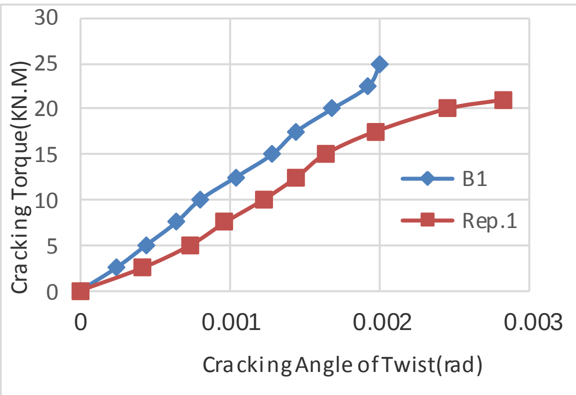


Figure (5): Cracking Torque–angle of Twist

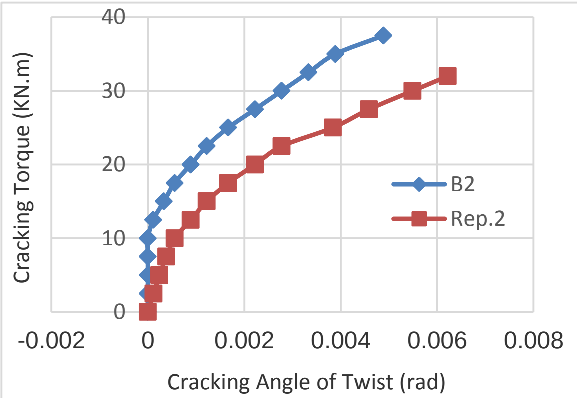


Figure (6): Cracking Torque–angle of Twist

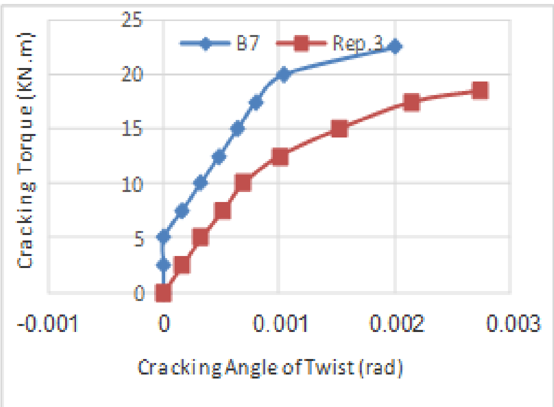


Figure (7): Cracking Torque–angle of Twist

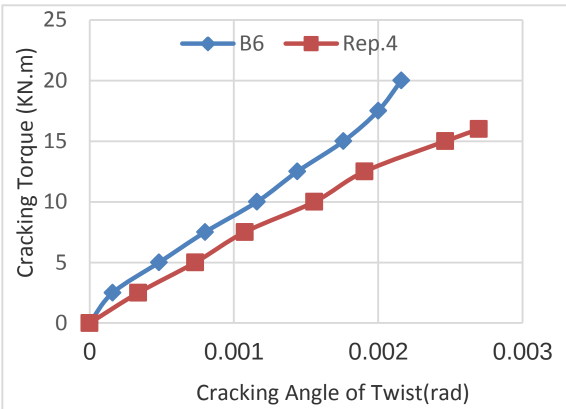


Figure (8): Cracking Torque–angle of Twist

5.2. Angle Of Twist-Distance Along Beam Curves

Figures (9) to (12), demonstrate the relationship between the cracking angle of twist with the distance along the beams for original and repaired beams. The results show that in similar relations between repaired and original beams .The solid repaired beams and repaired beam with central opening have a symmetrical behavior along the beam. The maximum angle of twist occurs at the begin of the beam (when support) and the gradually decreased till to approximately zero at the mid span, then the angle of twist began to increase gradually but in opposite direction (reverse clockwise) until reaching to maximum value at the begin of the beam from the other end.

While the repaired beam with opening at a third span, it can be observed that the behavior along the beam seems unsymmetrical. The maximum angle of twist occurs at the begin of the beam and the gradually decreased till to approximately zero at the third span, Where opening location, then the angle of twist began to increase gradually but in opposite direction until reaching to maximum value at the begin of the beam from the other end.

It is concluded from the above that the critical angle of twist is gradually decrease, the closer to the mid distance and gradually increases the closer supported in both directions.

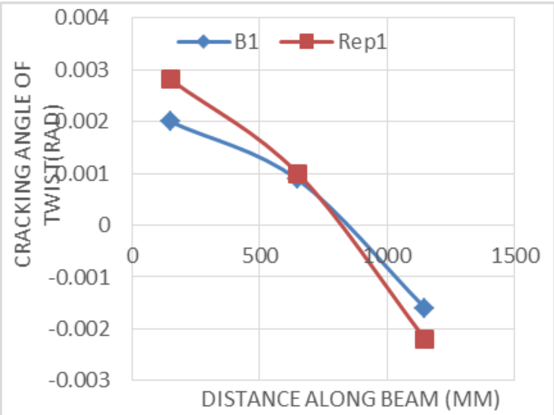


Figure (9): Cracking angle of Twist with distance (mm)

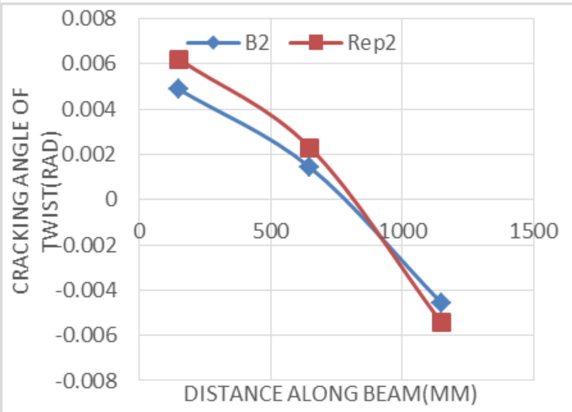


Figure (10): Cracking angle of Twist with distance (mm)

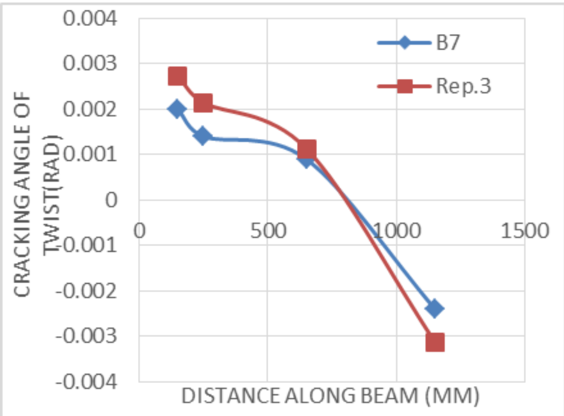


Figure (11): Cracking angle of Twist with distance (mm)

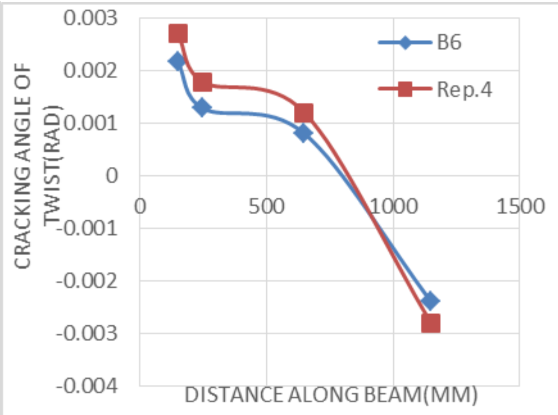


Figure (12): Cracking angle of Twist with distance (mm)

5.3. Crack Pattern

All the reinforced concrete beams were tested under pure torsion loading failed in torsion. Figures (13) to (20) show the crack pattern and modes of failure for original and repaired beams. Where the angle of the first crack were close to 45 degree in every case. The mode of failure of repaired beams was extensive diagonal concrete crack (torsional spiral cracks).

Figure (13): unrepaired composite beam (B1)

Figure (14): repaired of composite beam (Rep1)

Figure (15): unrepaired composite beam (B2)

Figure (16): repaired of composite beam (Rep2)

Figure (17): unrepaired composite beam (B7)

Figure (18): repaired composite beam(Rep3)

Figure (19): unrepaired composite beam (B6)

Figure (20): repaired composite beam (Rep4)

6. Conclusion

Based on the results obtained from the experimental work, the following conclusions are presented.

1. The presence of external steel plates connected to tension face of repaired beam gain high efficiency in cracking torsional strength over that of the unplated repaired beam.
2. Presence of openings in web decreases of efficiency the crack strength of composite repaired beams.
3. According to first cracking torque, the best location for the opening is within the center of the span
4. The angle of twist gradually decrease, the closer to the mid distance and gradually increase the closer supported in both directions (positive and negative).
5. There was a small rise in angle of twist in the repaired beam compared to the originals.

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