Jordan Journal of Civil Engineering, Volume **18**, No. **3**, **2024**
DOI: https://doi.org/10.14525/JJCE.v18i3.07

Jordan Journal of Civil Engineering

Journal homepage: https://jjce.just.edu.jo

Effect of Ferrocement with Styrene-Butadiene Rubber Connection on Concrete Beams under Torsional Impact

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ARTICLE INFO

Article History:
Received: 1/9/2023
Accepted: 24/5/2024

ABSTRACT

Improvements of reinforced concrete beams against the impact of torsional forces are among the most researched issues in construction studies. In this paper, repairing and strengthening reinforced concrete beams using ferrocement laminates attached onto the surface of the beams and exposed to torsion were reviewed. This study aims to reveal the efficacy of the wrapping sides of ferrocement laminates. Previous experimental studies were conducted by using SBR as a slurry for strengthening beams by ferrocement from two-and three-side wrapping. Alternatively, the influence of using SBR as an ingredient of the mortar on the performance of the strengthened beams under torsion was discussed. The results showed that ferrocement is a practical alternative strengthening component for rehabilitating and repairing reinforced concrete beams. It was demonstrated that three-side wrapping improves the torsional behaviour in comparison with two-side wrapping. Also, the SBR preserved the required joining until failure for all the strengthened beams.

Keywords: Ferrocement, Torsion, Styrene-Butadiene Rubber (SBR), Strengthening, Beams.

INTRODUCTION

It is axiomatic that concrete structures are necessary for society function and essential for our safety, prosperity and economical growth. It is no exaggeration to say that too many structures around the world are at risk of deterioration. The causative factors, such as the aggressive physical factors, corrosion and other chemical attacks, play an inevitable role in affecting the life span and the maximum ability of the structure to bear loading. Hence, repairing and rehabilitation processes will be a requisite to maintain the continued serviceability in an efficient manner. Although, great strides have been made in the field of structural strengthening research, with excessive attention paid to the analysis of different types and forms of composite materials (EL Khouddar et al., 2022). The behavior of reinforced elements during their service life can deteriorate due to overloading, environmental influences and exposure to external deteriorating factors, such as fire, among other causes (Takla and Tarsha, 2020). However, the mechanical properties of such materials are still mysterious, especially when they are subjected to torsion.

Ferrocement over the years has proved its effectiveness and durability as a versatile material and strengthening technique for damaged RC structures (Al Khador et al., 2023). Its ingredients are easily available and it does not require highly qualified workers (Rajguru and Patkar, 2021).

In accordance to the Guide for Design, Construction and Repair of Ferrocement (ACI 549.1R-93) Definitions, "ferrocement is a type of reinforced concrete that is commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of relatively small wire diameter mesh. The mesh may be made of metallic or other suitable materials".

Ferrocement as a thin composite material has proved not only efficacy to obtain a proper strength, but also the results connected with stiffness, cracking control, ductility and impact resistance were applauded by scholars (Rajkumar and Vidvelli, 2010). Another notable point is that being wrapped with composites, ferrocement is an effective way of retrofitting in order to tackle the torsional deficiency of distressed reinforced concrete (RC) beams and to achieve the transition from brittle to ductile failure mode.

Cement mortar has many weaknesses, such as low tensile strength, large drying shrinkage and low chemical resistance. Several methods have been used to develop mortar properties. One of these approaches is by adding of polymer to the mortar (Yao and Ge, 2012). The use of Styrene Butadiene Rubber (SBR) emulsions in mortar has increased, which affects the bond on the connection between the R-C beam and ferrocement (Barluenga and Hernández-Olivares, 2004). However, in comparison with conventional mortar, it is believed that adding SBR changes the properties of the mortar, enhances the bonding strength and reduces permeability (Siddiqi et al., 2013). While many studies were carried on to estimate the effectiveness of this material on the adhesion between ferrocement and R-C beams, these studies were limited to the use of SBR as a slurry (cement-SBR-water) (AL-Belal, 2019). However, we approach this study by mixing SBR with mortar to detect the effectiveness of SBR as a connection.

The torsion moment as a structural action is presented as spiral cracks which can be observed on the external faces of beams. However, the application of ferrocement as a wrapping material would be productive to protect distressed structures against torsion by upgrading the beams' load bearing capacities and ductility (Behera et al., 2014).

Moreover, conventional evaluation can lead to inaccurate safety conclusions if the damages which occur very often are being ignored. These damages create discontinuities in the bending stiffness of the material and cause damping changes at the damaged locations. The prediction of cracking behaviour and deformation of reinforced concrete beams is a complex problem (Falah et al., 2023). Consequently, it is important to identify the locations and sizes of cracks (Outassafte et al., 2022) with changing values of torsion strength and investigate the effects of the stiffness (EL Hantati et al., 2023), by the assessment of the twist angles according to the testing variables.

According to the softened truss model by HUS (Behera et al., 2014), a ferrocement composite is made up of a mortar matrix and a mesh reinforcement which is finely dispersed across the section. Therefore, the resistance provided by the ferrocement section can be idealized as the sum of the resistance provided by the mortar matrix which is added to the concrete resistance and the mesh reinforcement which is added to the transverse reinforcement of the R-C beam.

RESEARCH SIGNIFICANCE

Due to the torsion circulatory nature, such force can be resisted by a closed form of wrapping, but inaccessibility and extension of flanges over the web dictated strengthening the beams by “U”-wrap retrofitting or from two opposite sides rather than using full wrap (Behera et al., 2014).

Not many studies have been casting light on evaluating the torsional strength of ferrocement “U” and two-side-wrapped beams (Rajguru and Patkar, 2021).

This present experimental study aims at investigating the torsional resistance capacity of the beam that was strengthened by ferrocement from three sides and two sides and by utilizing SBR as a connection material.

In this study, six beam specimens are cast and tested under pure torsion. The objective of this experiment is to compare the results of torsional strength, angle of twist and crack development and finally to estimate the resistance of the tested wrapping types.

EXPERIMENTAL WORK

Six beams with a cross-section of (125 mm×250mm) and-1700-mm overall span (1500-mm effective span) were cast and tested.

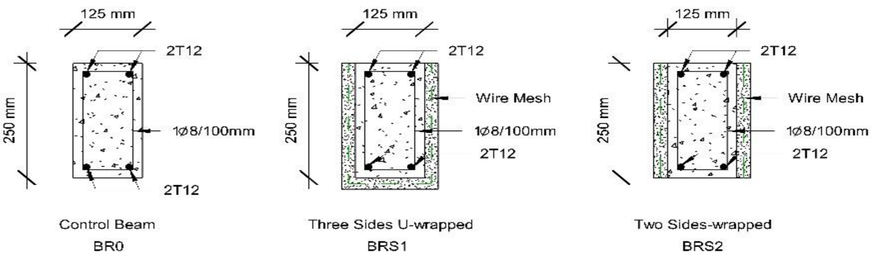

Figure (1): The cross-sections of control beam and strengthened beams

All beams were reinforced with 2 bars of 12-mm diameter at tension and 2 bars of 12-mm diameter at the compression side with a yield stress of 445 MPa. Also, beams were provided with stirrups of normal mild steel of 8-mm diameter and 100-mm spacing with a yield stress of 408 MPa, as shown in Fig. 1.

The concrete mixture of reinforced-concrete beams was made up of cement, sand and coarse aggregates and then, the concrete components were properly mixed by adding Portland cement with water. The water–cement ratio is 0.5 and for achieving a good workability and a high strength concrete with a low water cement ratio, we added Flocrete SP33 as 1.5% of the cement weight. The compressive strength of concrete cubes after 28 days was observed to be 25 MPa and tensile strength measured was 2.8 MPa.

Out of the six beams, two (BR0-1 and BR0-2) were considered as perfect beams (control beams) and the remaining four were divided into two categories (BRS1 and BRS2) by adopting the shape of ferrocement wrapping (U-wrapping, two-side warping) as a criterion.

Our mortar mixture was designed as an integral adhesion to achieve the desired connection. The motors were prepared with cement, sand and water in a ratio of 1:2.5:0.3 mixed with an SBR (polymer emulsion)-cement ratio of 20% (mass of solid phase of polymer emulsion divided by mass of cement) to attain a high strength. The use of SBR with that ratio in this study to connect ferrocement and RC beams was encouraged by the recommendation of the manufacturing company (CEMPOL SBR) (the product is widely used in the construction sector and available especially in Arabic markets) and by its positive results proved by many experimental studies that confirmed the effectiveness of this ratio regarding strength and workability (Siddiqi et al., 2013) and in particular the highly adhesion provided between ferrocement and beams, in addition to being a cost-effective solution (Yao and Ge, 2012).

Before starting with retrofitting process, the surfaces of the beams and the bonding face of laminates were sandblasted to expose the aggregates and roughen the surfaces of the beams. Debris was meticulously cleaned off the surfaces by utilizing an air jet (AL-Belal, 2019).

To implement the ferrocement strengthening system, an iron square woven wire mesh has been used with a diameter of 2.5 mm, spaces between the wires of 20 mm and the yield strength of the mesh was 568 MPa. The required length of the mesh layer was cut and bent to the desired shape according to the variations of wrapping from two sides, and from three sides, as shown in Fig. 2.

Figure (2): The concrete beams with mesh reinforcement

TESTING AND DATA

According to the performed test (as shown in Fig. 3), all RC tested beams were of 1700-mm length. The beams were supported over two roller supports placed 1600mm apart. The supports provided led to free rotations of the ends of our tested beams. All beams were subjected to a twist from both ends by using two opposite twist arms. These arms have 40-cm lengths and are located at either support of the beam. The distance between the connecting points of the arms with the beam is 1500mm. **I**-steel beams were placed on the twist arms to transform the load from the mechanical screw for the testing device to the arms. To avoid any possibility of bending the beam, reasonable care was exercised to provide a perpendicularity between the longitudinal axis of the beam and the loading generated from twisting arms. Thus, the beam between the two supports was subjected to pure torsion. The beams were tested using hydraulically operated jacks connected to a data acquisition system through the load cells (AL-Salamah et al., 2020).

With the increasing in load, displacements in the beams were recorded by using five dial gauges located at the quarter span points, one on the middle and two on the upper and lower fibers of the beam from right and left sides and, consequently, the angle of twist of the beam was estimated. All specimens were tested for the ultimate torsional strength and the corresponding angle of twist up to the total failure of the specimen.

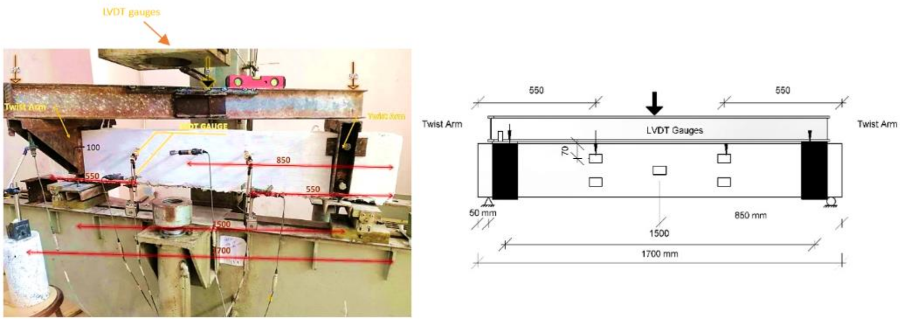

Figure (3): Torsion test rig after modification

RESULTS AND DISCUSSION

The beams were tested using the test set-up at the Civil Engineering Faculty Laboratory – Al Baath University.

The load was gradually applied until failure; so, displacements were measured by dial gauges. The average readings of dial gauges were recorded and the twist angles of the beams were estimated. All beams were tested for cracking torsional strength (the torsion associated with the appearance of the first crack), ultimate torsional strength and the corresponding angle of twist up to total failure.

The results of tested beams are presented in Table1 in the form of cracking torque, ultimate torque, twist at cracking and ultimate torque. This allows for a comparison between the variations of strengthening by ferrocement.

Table 1. Experimental results of control beams and strengthened beams

Beam Type	Beam Symbol	Cracking Torque T_{cr} (kN.m)	Cracking Torque Average (kN.m)	Twist (First Cracking) $Ø \times 10^{-3}$ rad/m	Twist average $Ø \times 10^{-3}$ rad/m	Ultimate Torque T_{ult} (kN.m)	Ultimate Torque Average (kN.m)	Twist (Ultimate) $Ø \times 10^{-3}$ rad/m	Twist average $Ø \times 10^{-3}$ rad/m
Control beams BR0	**BR0-1**	4.6	4.723	10. 393	10.9	8.79	8.65	25.82	25.1
	BR0-2	4.848		16.974		8.49		25.04	
BR1 (U)	**BR1-1**	6.5	6.6	1.62	1.56	13.95	13.89	12.63	12.7
	BR1-2	6.7		1. 51		13.86		12.78	
BR2 2 SIDES	**BR2-1**	6.4	6.2	1.212	1.146	12.52	12.54	18.28	20.08
	BR2-2	6		1.08		12.56		22.08	

The table shows that the cracking torque of the strengthening beams (BR1 and BR2) considerably increased in comparison with that of the control beam (BR0).

At the same time, the twist value at the first crack significantly decreased from10.9*10^{-3}rad/m for BR0 to 1.56*10^{-3}rad/m for BR1 and 1.146*10^{-3}rad/m for BR2. Based on these figures, it is obvious that the torsion behaviour of the strengthening beams and the cracking control ability have improved. Coincidentally, the appearance of the first crack needed more torsion compared with the control beams. These results can fairly be ascribed to the facts that the torsional cracks are spiral and the tensile forces resulting from torsion affect the outside facets of the beams (ferrocement) without any resistance generated from the core. Accordingly, the resistive forces acting against torsion were solely generated from the ferrocement, which also enhanced the ultimate torque of the strengthening beams, as can be seen in the bar graph illustrated in Figure (4). The graph gives information about the difference between the ultimate torque of the control beam and the retrofitting beams.

Strengthening beams from three-side aims to increase the ultimate torque by 60%, whereas the strengthening from two-side has improved the ultimate torque by 43%. Noticeably, the improvement of the ultimate torque of the U-beams approximately doubled while the enhancement of the ultimate torque by using two-side wrapping was just around one fourth. The improvement can also be shown by the comparison between the values of the ultimate twist of the U-wrapping, two-side wrapping and the control beam provided in Table 1, where the value of BR1 has substantially decreased by more than a half of the one of BR0, while the value of BR2 just shows a decrease of about only a quarter.

Studying the relationship between the torque and the twist of control beams, U-wrapping and 2-sides wrapping with SBR connection can give a good indication about the effect of the strengthening on the behaviour of the failure.

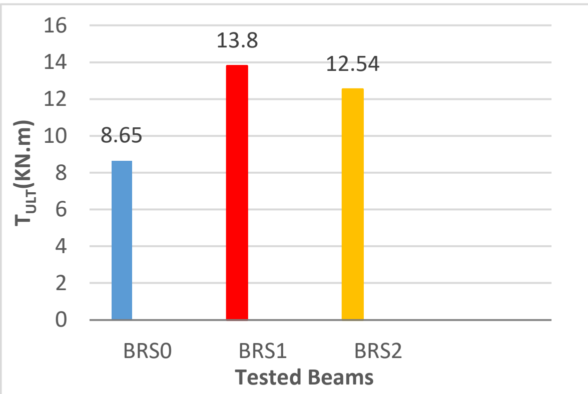

Figure (4): The average value of ultimate torque of tested beams

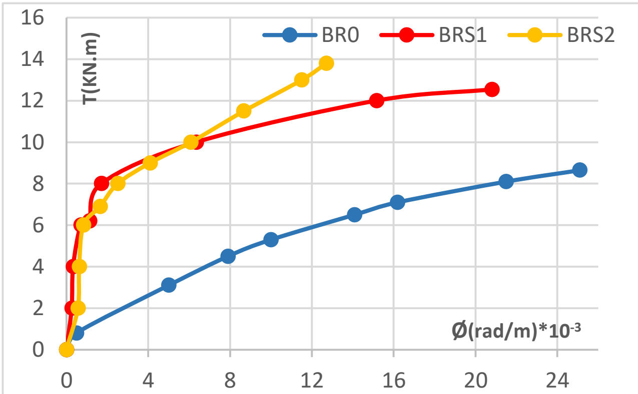

Figure (5): The relationship between the torque and the twist of tested beams

The chart in Fig.5 depicts this relationship which shows that while the behaviour of the control beams was nearly linear, there was a sharp rise in the value of torque accompanied with a relatively small value of twist in both two-side wrapping and three-side wrapping. However, the trend of the control beam shows a rapid increase which steadily continues to reach its point of failure at 25 rad/m when the applied torque value was only 8.7 kN.m. The general behaviour of two-side wrapping beams was nearly the same as that of beams of three-side wrapping, where at nearly 6.5 kN.m the crack torque value reached the turning point that caused a change in the behaviour of the beams. At this point, the values of the twist dramatically increased from nearly 1rad/m to slightly more than 10 rad/m for BR1 and to about 20 rad/m for BR2. While the behaviour of the control beam was almost reaching the collapse point, the strengthened beams started to change their behaviour to show more resistance and to move from brittle behaviour to ductile behaviour. This movement makes it crystal clear that an adequate inelastic stress redistribution ensued to cause the torgue-twist curves to bend over slightly just before failure. Clearly, three-side wrapping showed best resistance, where the failure point occurred approximately at 14kN.m and that consequently indicates that adding only one side to the two-side wrapping caused a good and disproportionate increase in the ultimate torque, as shown in Fig. 5.

From visual observation along with the gathered results mentioned-above, we noticed that the ferrocement laminates of two-side wrapping that used SBR to connect with the beam, to a great extent, has partially been sloughed off with a semi-deep cracking, as shown in Fig.6, while three-side wrapping kept its connection with the RC beams with only a few minor hairlines, cracking as shown in Fig.7. The control beam after the appearance of the first crack showed a brittle behaviour which developed numbers of cracks that increased in an accelerated pace in comparison with the strengthened beams. After failure, these beams showed a stability value of torque between (12-14.6) kN.m.

Figure (6): The partial separations of the ferrocement laminates in BRS2

Figure (7): The ineffective separations of the ferrocement laminates in BRS1

The continuity of the wire mesh, when the wrapping is from three sides, provides additional strength in the longitudinal and transverse directions, which reflects on the torsion behaviour. It also increases the interconnectedness between the three faces of ferrocement laminates, which explains why there is no separation noticed after failure.

Because of torsion, diagonal cracks separate the concrete and ferrocement into a series of diagonal struts, where wire meshes with steel reinforcement acting as a tension link in the ferrocement faces. Consequently, the propagation and growth of cracks are diminished in the ferrocement faces in comparison to the unwrapped concrete face due to the presence of the ferrocement, as the ferrocement has a better crack-arresting ability. That can explain the better torsion behavior of 3-side wrapped beams in comparison with 2-side wrapped beams.

CONCLUSION

From the above-mentioned discussion, the following conclusions are drawn:

- The strengthened beams with ferrocement satisfiedly improves the torsional behaviour regardless of the wrapping type.
- The results of the ultimate torque showed that strengthening from three-side improved the torsion behaviour more than strengthening from two sides by 15%.
- While two-side wrapping caused a little increase in stability, U-wrapping developed a substantial increase in stability through a marked decrease in cracks and in the ultimate twist.
- Using an SBR- cement ratio of 20% as an ingredient of the used mortar thoroughly enhanced the adhesion between the R-C beams and ferrocement whether from three-sides or from two sides and kept the connection without complete collapse.
- Similar to the results of using SBR as a slurry, mixing SBR within the mortar showed a highly effective performance, but with more workability.

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