# Improvement the Performance of R.C. Beams Under Torsion Using Various Systems – A review

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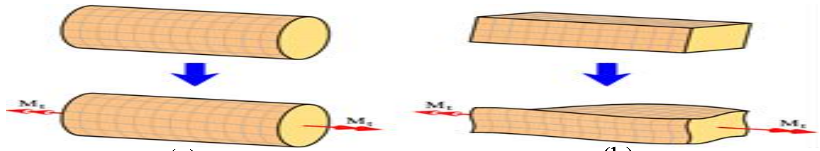
**Abstract**. Due to the human needs to increase the loads of structures such as residential buildings, bridges, ports and other structures, and also the emergence of so-called strengthening and restoration, there must be different methods to implement the needs of every structure that is standing and used normally. Therefore, we will present below the most prominent methods used in strengthening concrete beams. To resist the torsional moments occurring on it, such as using fibre bars, glass fibre reinforced plastic (GFRP), and steel fibres, and finding the most appropriate methods in terms of ease of implementation and low cost, and also presenting some of the methods used during implementation. This research also gave a qualitative division of the reinforcement methods and classified them according to their implementation methods and method, as it there are methods of reinforcement before pouring reinforced concrete, that is, during the implementation of the concrete element, and also methods of reinforcement during the work of the concrete element in the building, and this case is called restoration. This research dealt with a compilation of many methods of reinforcement to resist torsional loads, and the most prominent of these materials are the materials based in their manufacture on glass fibre, as well as additions during the making of the concrete mixture, such as steel fibres.

**Keywords:**
Torsion; Strengthening; RC Beams; Steel fibre; FRP; GFRP.

## 1. Introduction

Concrete is considered a widely used material due to its low cost, strength, tolerance to different weather conditions, and durability. However, like any other material, it has its drawbacks. One of the limitations of concrete is that it twists easily as shown in **Figure 2.** Torsional force is a force that tries to twist an object. If an object is not stationary, it will rotate. However, when the body is immobilized or supported, this force causes the body to bend about its axis. Twisting due to bumps or irregularities. Torsion is a loading condition that occurs when an object is subjected to a torque about its longitudinal axis. Various reinforced concrete members such as beams, columns, slabs and walls can undergo torsion.[5]
The behavior of concrete members under torsion is affected by a various element, including the math of the part, the material properties of the substantial and the concrete and the distribution of reinforcement. There are many factors affecting torsional resistance such as: the geometry of the component as shown in **Figure 1.** Material properties of concrete. (strength, elasticity, ductility, etc.), and the type of reinforcement (steel – GFRP), distribution of reinforcement. (larger distance), the shape of the element cross-section can significantly affect its impact torsion resistant, unusual shape provides higher resistance. (circular cross-sections provide more torsional resistance than rectangular cross-sections),

number and spacing of reinforcement bars. Due to the presence of many causes and factors affecting the occurrence of torsion, techniques have been conceived to work on the exhibition of concrete sleeves to resist torsion moments. Each of the researches that will be presented will address the shortcomings in the factor causing the torsion.[16]



(a) (b)

**Figure 1.** Shap elements effects on torsional resistance of concrete; (a) circular and (b) rectangular.[5]

## 2. Methods of calculating torsional moments

The torsional resistance (T) could compute through several methods [5], as shown in **Table 1**.

**Table 1.** Methods of calculating torsion.

| No | The method | Equation | Variables |
|---|---|---|---|
| 1 | Saint Venant's theory | T= (G*J*θ)/L | (G) shear modulus- (J) torsional constant- (θ) angle of twist- (L) element length- (τ) shear stress- (W) warping function- (A) cross section area |
| 2 | Torsion Constant method | T=τ*J | |
| 3 | the warping function method | T=∫τ*w*dA | |

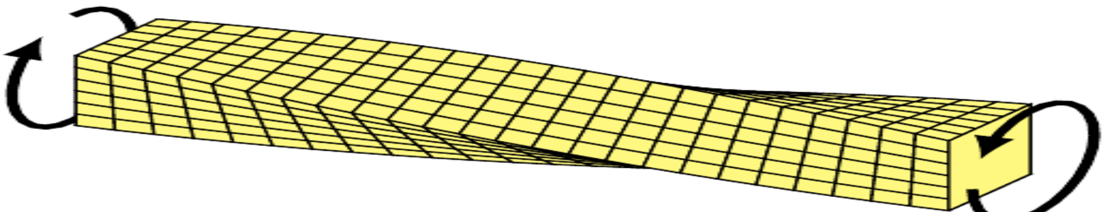
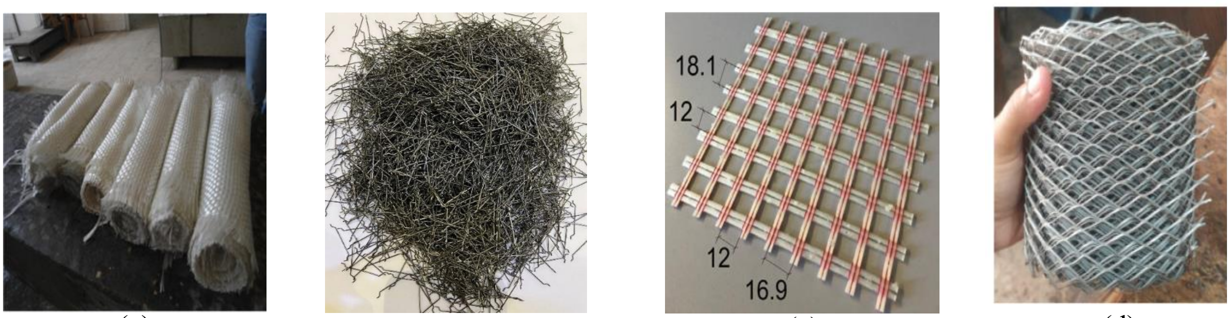


**Figure 2.** Mechanism of torsion.[5]

## 3. Different systems of strengthening

There are many systems of improvement as shown in **Figure 3.** That have been used to resist twisting, including reinforcement before casting (fresh concrete), such as reinforcement using metallic materials like cross rod steel[8], steel fiber ratio[6], number of stirrups[4], and non-metallic materials like glass textile[1], GFRP bars[9], and there are strengthening systems after casting (hardened concrete), metallic material like wrapped stainless steel strips, wrapped aluminum strips, wrapped steel meshes[3], near-surface mounted steel wire rope[12], and non-metallic materials like GFRP bars[13], CFRP sheets[7], and aramid fiber strips[2], we will explain some support systems as shown in **Figure 4.**




(a) (b) (c) (d)

**Figure 3.** Materials of strengthen, (a) fiberglass strips aramid, (b) steel fiber, (c) glass textile, (d) Steel Meshes.[1-4]

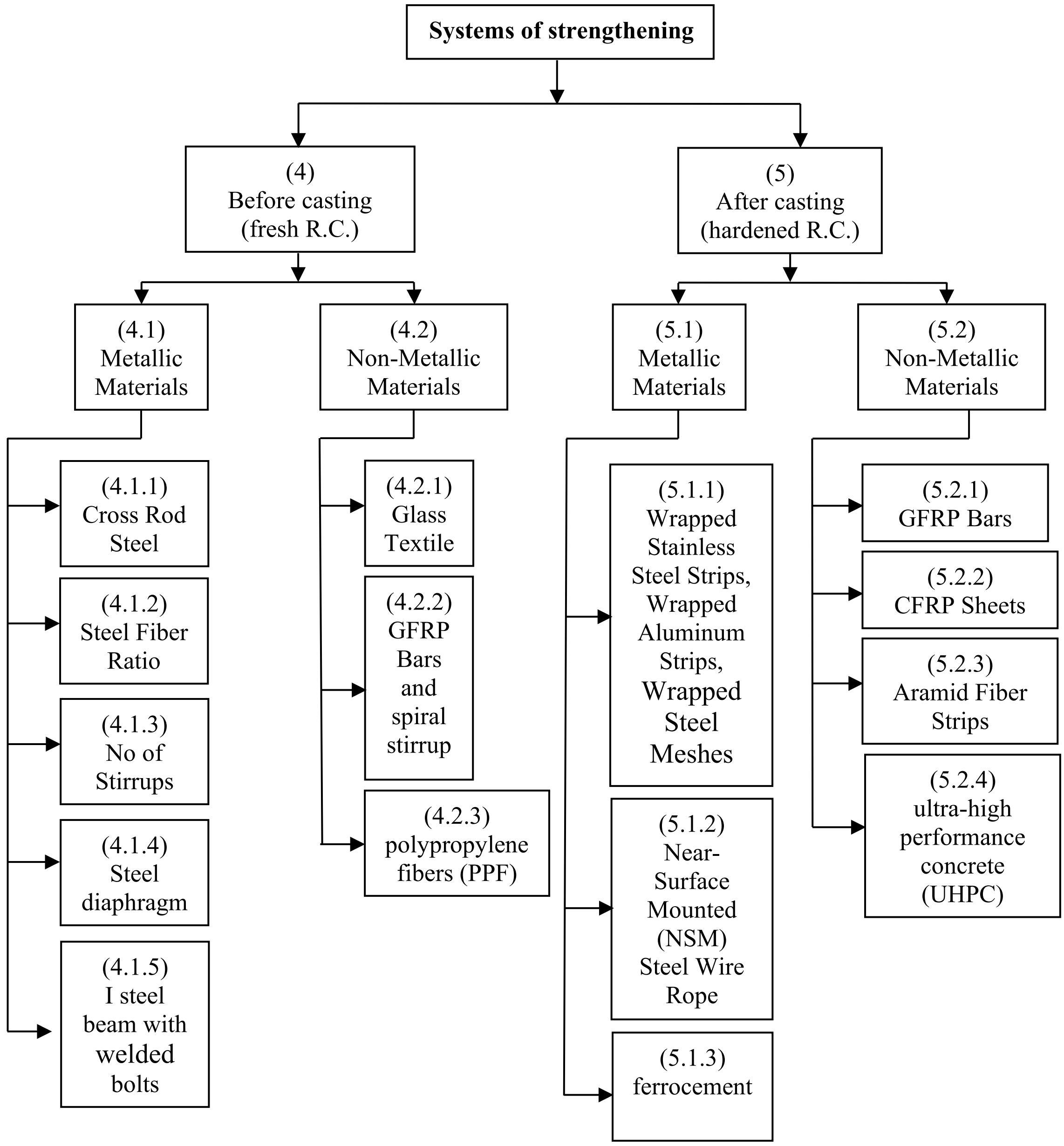



**Figure 4.** Systems of strengthening

## 4. System of strengthening before casting (fresh R.C.)

### *4.1. Metallic materials*

#### *4.1.1. Cross Rod Steel*

Abdullah, et.al discussed the effect of steel bars attached to reinforced concrete beams and the degree of their impact on the resilience of concrete beams under torsion, the significant test is picking a fitting reinforcing methodology to beat its low twist quality. Subsequently, the most unbiased of this examine is to find that it is so liable to suggest or get a specific inner in-plane way to deal with increment the torsional strength, it was presumed that insides cross-rods **Figure 5.** Would upgrade the torsional quality capacity of the strengthened concrete beams. The degree of upgrade depended primarily on the number of inside cross rods (CR) conveyed.[8]

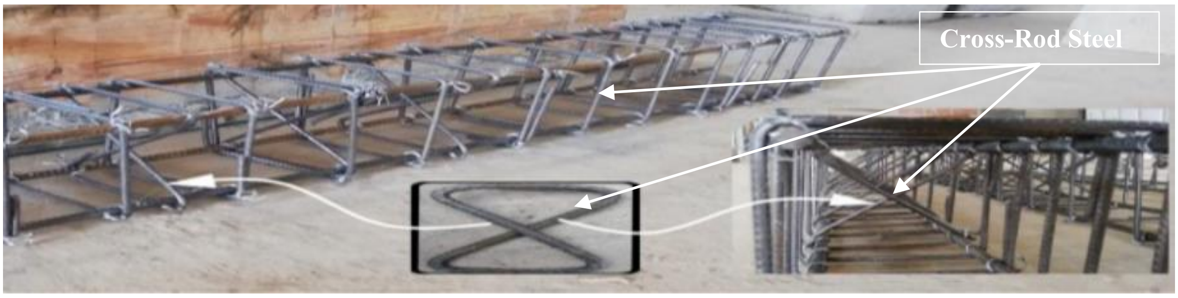



**Figure 5.** Internal Cross-Rod Steel Reinforcement Details.[8]

*4.1.2. Steel Fiber Ratio*

Oettel, et.al discussed the use of steel fibers in reinforced concrete showed a positive effect in terms of results, and therefore its application to resist torsional loads was not limited to one form. Accordingly, a space truss model was invented with the addition of steel fibres so that we can clearly determine the results, and this research showed the results from the use of steel fibres. The steel is formed longitudinally and transversely and collected in a database by taking into account that the torsional load causes tensile and compressive forces, as shown in **Figure 6.** Accordingly, the steel fibres work as reinforcement that resists tension through its random distribution within the concrete sector, and also works to reduce shear forces by reducing the friction forces resulting between the two concrete sectors, which cause repulsion between them in the direction of the impact of the forces resulting from the bending of the concrete sector.[6, 17]

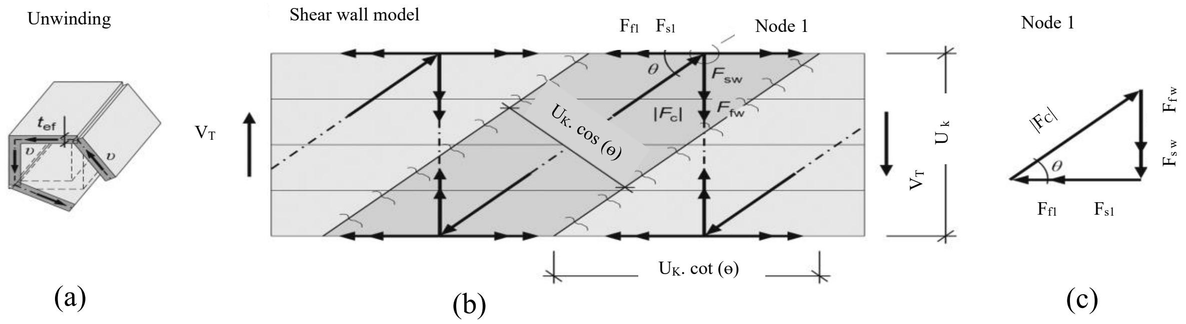


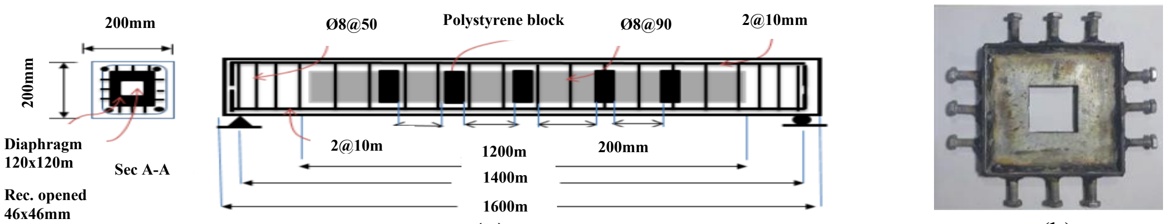

**Figure 6.** (a), plane shear wall model (b), and force polygon for node I (c) of steel fiber reinforced RC beams.[6]

*4.1.3. No of stirrups and longitudinal reinforcement*

Abdullah, et.al showed the change in the main reinforcement (longitudinal reinforcement and stirrups) of the reinforced beams in terms of increase gives clear results in terms of the beams' tolerance to twisting, as is clear in this research by changing the longitudinal reinforcement, increasing the number of beams, and placing steel fibers in concrete mix, the fibers work to increase the resistance strength of the concrete, the results appear the behavior of concrete changing from delicate to ductile when expanding the proportion of the steel fiber enlisting the greatest torsional ductility record (3.98).increasing the rate of stirrups to 2.5%, whereas the rate of longitudinal reinforcement and steel fiber was settled, which driven to increase the torque which come to 130.4%.[4]

*4.1.4. Steel diaphragm*

Jasem, et.al studied a method of internal strengthening of hollow concrete beams from the inside, by adding steel diaphragm as shown in **Figure 7.** The number of steel diaphragm supporting the beams in the entire solid part of the concrete beam was changed with the placement of a number of nails. Affixed to the steel diaphragm according to the effect of the stresses resulting from the torsion load, which are highest in value at the outer border of the concrete section. The results showed high values in the bearing of concrete beams to the torsional loads affecting them.[14]




(a) (b)

**Figure 7.** (a) Reinforcement and details of tested beam, (b) Steel diaphragm with rectangular opening.[14]

### *4.1.5. I-shape steel beam with welded bolts*

Zhou, et.al presented the results of eight pure torsion tests on steel reinforced concrete (SRC) beams and a pure torsion test on heterogeneous reinforced concrete beams as shown in **Figure 8**. Test variables included position, spacing, length, diameter, and design of the screw. The test results indicated that the failure mode of all SRC beams is ductile failure with the characteristics of multiple 45° diagonal cracks and concrete crushing, but for RC beams, it is brittle failure with a single 45° diagonal crack. Arranging the nails at the end can improve the torsional behaviour of SRC beams, and increasing diameter and length of the nails can have an enhanced effect, but the effect of fixing the nails at the edge was not significant. Compared with the specimen with symmetrical welded studs, the specimen with staggered welded studs has better torsional properties.[11]

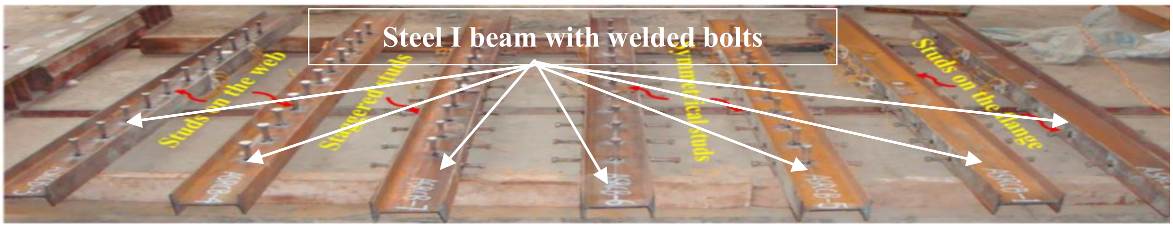



**Figure 8.** Steel beams with different nail layout.[11]

## *4.2. Non-metallic materials*

### *4.2.1. Glass textile*

Le, D.D., et.al discussed the alternative method for using fiber, and so-called fiber bars were used, as they have many advantages, such as their ability to withstand high tensile forces and being stainless. This research discussed the use of fiber bars instead of longitudinal rebar, and fiberglass mesh instead of reinforcement. The transverse (stirrups) **Figure 9.** Effect was studied on the fiber bars and mesh in the tested beams by changing the number of layers of fiberglass mesh and their position in terms of placing them vertically or diagonally at an angle of 45°. The comparison shows that the current rules are risky in evaluating the least transverse torsional reinforcements. For concrete beams reinforced with glass fabric.[1]


**Figure 9.** Failures of beams in the FRP.[1]

*4.2.2. FRP Bars and spiral stirrup*

Hadhood, et.al discussed the effectiveness of fiber bars in withstanding torsion, as there is no confirmed reference on the extent to which bars can withstand torsional moments. The experiment was carried out by replacing the steel bars with fiber bars and the steel stirrups with fiber stirrups formed in a rectangular shape and the other in a spiral shape as shown in **Figure 10.** And with different distances in terms of expansion and narrowing in the interspaces between the stirrup poles to form a spiral shape over the entire length of the beam. The results appeared that the spiral stirrup tolerated the necessary twisting better than the rectangular stirrup, as after failure occurred in the concrete, the spiral stirrup withstood the full forces, while the rectangular stirrup expanded. It became completely ineffective, and therefore, through this experiment, it becomes clear that the use of fiber bars in a helical form greatly contributes to strengthening concrete beams in their ability to withstand torsion.[9]

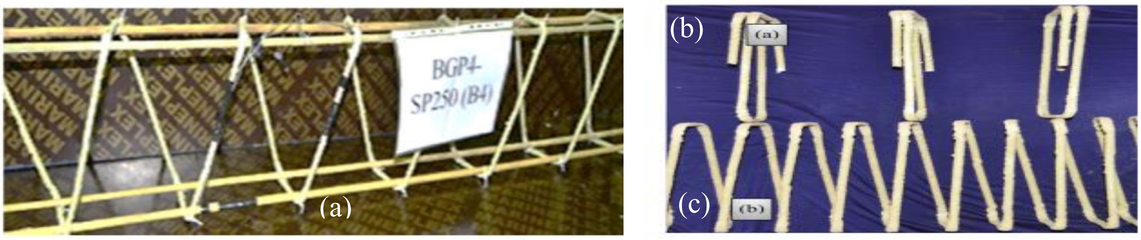



**Figure 10.** (a) GFRP reinforcement (b) individual rectangular GFRP(c) spiral stirrup GFRP.[9]

*4.2.3. Polypropylene fibres (PPF)*

Karimipour, et.al discussed using polypropylene fibers and steel fibers to resist torsion in reinforced concrete beams was discussed by mixing them in certain proportions. In this research, two sets of beams were made, the first reinforced with polypropylene fibers and the other reinforced with iron fibers. The torsional load was applied to all beams and the failure modes were studied. Torsional torque and torsion angle. By comparing them with control beams, it was found that using of PPF and steel fibers led to an improvement in both torsional torque and torsion angle, while the torsional performance of HPC beams strengthened with PPF was higher than those strengthened with steel fibers. On the contrary, the positive effect of steel fibers on torsional stiffness was HPC beams have a greater influence than PPF.[18]

## 5. System of strengthening after casting (hardened R.C.)

*5.1. Metallic materials*

*5.1.1. Wrapped stainless steel strips, wrapped aluminium strips and wrapped steel meshes*

El-Mandouh, et.al discussed multiple systems for the external strengthening of reinforced concrete beams to resist effects of torsion on them were discussed. The strengthening was done by

- Wrapped stainless steel strips
- Wrapped aluminum strips
- Wrapped steel meshes

The results indicated that the resistance of beams supported by aluminum strips and stainless-steel strips was greater than other beams, but it turns out to us that the cost is high for aluminum, steel and stainless-steel strips. The results also appeared that using two layers of steel mesh increases the beams' tolerance to torsional moments to a greater extent than beams supported by a single layer.[3]

*5.1.2. Near-Surface Mounted (NSM) Steel Wire Rope*

Askandar, et.al discussed the external reinforcement using a steel wire wound spirally over the entire external section of the beam, into grooves and fixed using epoxy materials, as shown in **Figure 11.** Were compared with those of reinforced beams. Torsional strengthening of RC beams was mainly carried out using NSM steel wire rope in different NSM setups.[12]

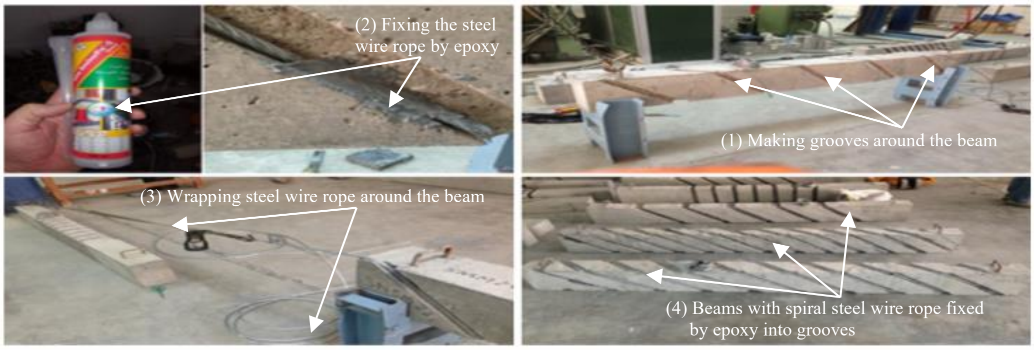



**Figure 11.** Installation method of NSN continuous spiral steel wire rope.[12]

*5.1.3. ferrocement*

Alzabidi, et.al presented a new reinforcement system, which is reinforcement using ferrocement (reinforced cement) as shown in **Figure 12**. Which is the use of steel mesh on the outer surface of the beams and fixing it using screws. This research studied the possibility of reinforcement with one layer and with more than one layer to resist torsion, the results showed that increasing the number of layers increases the beams' tolerance to torsion. Reinforced concrete beams can withstand twisting and prevent cracks on the sides of the beams, but when they collapse, damage occurs to the system used due to the layer's cohesion with each other as a single mass.[10, 19]


**Figure 12.** Details of the repair techniques.[10]

*5.2. Non-metallic materials*

*5.2.1. GFRP Bars*

Al-Ziady, et.al used the near-surface mounted (NSM) method to strength reinforced concrete beams under torsion, the effect of beams was studied by using reinforcement of fiber bars in the shape of the letter u and another in the same shape, but in an overlapping manner in the form of a cane. The installation was done by making grooves and placing epoxy materials as shown in **Figure 13**. And the results showed an improvement in the bearing capacity of beams supported by interlocking beams and their ability to withstand twisting is better than others that are not supported, as well as the u-shaped support.[13]


(a) (b) (c)

**Figure 13.** (a) Near-surface mounted NSM GFRP bar installation, (b) U- shape GFRP bar, (c)rectangular shape GFRP bar.[13]

### *5.2.2. CFRP Sheets*

S. K. Mohaisen experimentally studied the use of carbon fiber strips to reinforce reinforced concrete beams to resist pure torsion using two sets of beams as shown in **Figure 14**. The factors that were taken into account in the test included the effect of concrete compressive strength and the angle of torsion. The angle of twisting at each level of force application, the torque at the first crack, and the final torque should be compared with the control and reinforcement of the beams. Test results indicated that all CFRP-wrapped sills resulted in an improvement in tensile strength compared to the reference specimens.[7, 20]

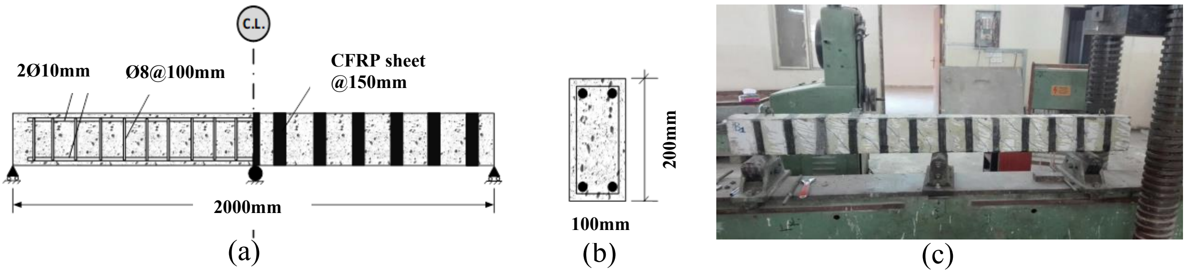



**Figure 14.** (a) The reinforcement layout and scheme CFRP that used in the study (b) RC beams depth dimensions, (c) The shape of the tested samples with CFRP sheets under torsion.[7]

### *5.2.3. Aramid fibre strips*

Elwakkad, et.al studied numerically and practically the effect of aramid strips when used to reinforce reinforced concrete beams from the outside under the influence of torsion by studying the effect of the distance and closeness of the strips and also the width of the slice **Figure 15**. The results were analyzed numerically using the abacus program and the results showed a strong convergence between the practical and numerical results.[2]

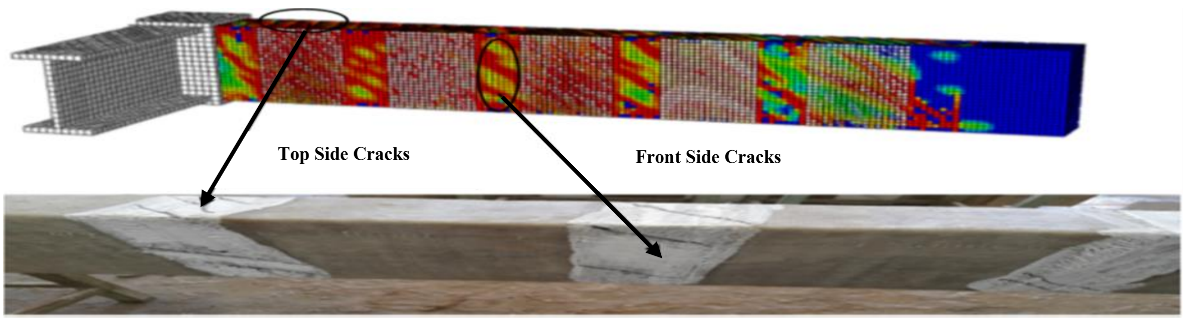



**Figure 15.** Beam with aramid strips and finite element model.[2]

### *5.2.4. Ultra-high-performance concrete (UHPC)*

Zhou, et.al studied high-performance concrete to strength reinforced concrete beams and to study the extent of its effect on the bending tolerance of concrete beams. To experiment with this reinforcement, several models were made to simulate the beams on the ground, as this reinforcement is external. Accordingly, several models were made, divided into placing concrete on two sides. Facing the beam, one group was reinforced on three sides, and the other was reinforced on all faces of the beam. It is necessary to roughen the surface of beam before starting to make the concrete layer in order to ensure its cohesion with the body of the beam as shown in **Figure 16**. The results appeared that high-performance concrete played a prominent role in bearing the concrete beams. It has higher torsional moments than its unsupported counterpart. Some frp fibers were also added and studied, and the results appeared that the fiber increases the strength of reinforcement.[15]


**Figure 16.** (a) RC beam after roughening, (b) casting UHPC layers.[15]

## 6. Conclusions

According to the various reinforcement systems discussed to strengthen concrete beams to resist torsional moments, some of which are permeable during concrete pouring and the other after the concrete hardens, the following could be drawn as follows:

- Reinforcement systems implemented before pouring concrete are easier and less expensive than those implemented after pouring.
- The use of steel fibers in reinforcement gave high results for concrete beams to withstand large torsional moments.
- Using iron mesh for reinforcement is better than fiber mesh.
- Using a metal frame equipped with screws on the sides showed high results in resisting twisting in hollow beams and increasing their number.
- The use of I-shaped steel beams equipped with side bolts gave a distinctive result under the influence of torsion, as it transformed the collapse of the beam from a brittle collapse to an elongated collapse.
- Using fiber bars as longitudinal reinforcement and spiral stirrups from fiber bars gave a better result than rectangular stirrups.

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