Flexural Behavior of Square Ferrocement Panels Enhanced with Recycled Tires Sim Strengthened by CFRP

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Abstract

This paper presents an algorithm with the results of using steel fibers in ferrocement panels, which were recovered from tires scrap. Waste steel fibers were cut with the same geometrical characteristics of normal steel fibers and were used in the panels at different layers. To have a reference ferrocement specimen, a plain mixture without fibers and mixtures containing a ratio of recycled steel fiber were also prepared. Some mechanical tests, such as compressive strength, splitting tensile strength and flexural strength were determined. Furthermore, load deflection behaviors for 24 panels specimens were carried out under patch load. Test results show that the recycled steel fibers layers recovered from scrap tires affected the mechanical behavior of ferrocement panels that are similar to the number of wire mesh layers. Depending on the distribution of R.S.F layers and wire mesh layers, the load-deflection curves were found. A comparison between these curves indicates that the R.S.F can reduce the deflection of panels, and increasing the number of wire mesh layers can increase the ability to bear stresses for panels. Rehabilitation with carbon fiber strips CFRP carried out with three forms (box network, inclined with diagonal, parallel to the diagonal and mix of diagonal and box network). The curves show that the rehabilitation with a parallel form to the diameter of the sample is a better treatment, which is characterized by resistance to stresses rather than other forms. We estimate that the recycled steel fibers increase the flexural strength and tensile strength, and 10\% is the optimal ratio for increasing the flexural strength and tensile, increasing the number of wire mesh layers increases the ability to bear stresses of the panels. Recycled steel fibers can cause reduction in the deflection of ferrocement panels and can give the same bearing strength proximity (or less) to the panel containing the same number of wire mesh layers.

Key Words: - Ferrocement panel, Recycled steel fiber (R.S.F), Waste tiers, Rehabilitation, Carbon fibers (CFRP).

1. Introduction and Literature Review

Ferrocement is a composite material contains of a cement mortar strengthened with light steel fabric-mesh used to form thin segments (Ferrocement must not be confused with ‘Ferro-concrete’, which a name is given to primary strengthened concrete). The construction process involves forming the shape of the required structure with a mesh of fine strengthening, such as chicken wire or expanded metal. Multiple layers can be used to reach the required density of steel, and the whole amount may be stiffened with a few standard strengthening bars. A stiff mortar is consequently applied to both sides of the layer of reinforcement (known as the ‘armature’) and ended to the required thickness.

The technique is very intensive labor, as the mortar is normally hand-applied (though can be spray applied). Therefore, it is mostly used in rising countries, where labor costs are low. In the western countries, the main application of ferrocement has been for the building of boat hulls that include competing ships. It has further been used for roof shells and in ornamental uses. Ferrocement
is additional widely utilized in Asia and the Pacific. Furthermore, the material is used for water containers and storage structures [1]. In addition, sixteen reinforced concrete beams that have cross-sectional dimensions of (100 × 200 × 2000) mm. The clear span of 1800 mm were cast and verified until failure under a single mid-span focused load. In this research, Ferrocement beams involved either an Autoclaved Aerated lightweight brick Core (AAC), an Extruded Foam Core (EFC) or a Lightweight Concrete Core (LWC). They were strengthened with whichever Expanded Metal Mesh (EMM), Welded Wire Mesh (WWM) or Fiber Glass Mesh (FGM). Structural behavior of investigated beams, including first crack, ultimate load, deflection, ductility index, strain characteristics, crack pattern and failure mode were explored [2]. Other researchers investigated a Sixteen full-scale simply supported composite beams of the same dimensions (breath of 100 mm, thickness of 200 mm, and length of 2000 mm), exposed to flexural stacking, were experimentally tested and their structural parameters, specifically, pre-crack toughness, serviceability loads, post-cracking loads, energy captivation, eventual load-to weight ratio, and compressive pressures were investigated. Moreover, theoretic expectation of eventual loads was carried out to adopt a theoretic method as a plan methodology for ferrocement elements. Experimental results depicted that pre-crack toughness, ultimate service loads, ultimate values of energy absorption and maximum loads to load fractions of ferrocement beams are higher than that of lightweight governor (control) beam by about 46%, 32%, 64.4% and 32.8%, respectively [3].

Recent research shows that adding Recycled Steel Fibers (RSF) from wasted tires can significantly reduce the brittle behavior of cement-founded materials by improving its stiffness and post-cracking opposition. In such logic, Recycled Steel Fiber Reinforced Concrete (RSFRC) appears to have the prospective to constitute a sustainable material for structural and non-structural tenders. To evaluate this prospective, experimental and arithmetical research was carried out on the use of RSFRC in components failing in twisting and in beams failing in shear [4]. Another paper presents the results of an experimental algorithm, in which steel fibers improved from scrap tires used to produce fiber strengthened concretes. Waste fibers that have dissimilar geometrical features were used in the mixtures at dissimilar fractions. To obtain reference concrete, a plain combination without fibers and one combination involving a profitable steel fiber were also prepared. Certain mechanical merits, such as compressive strength, piercing strength and flexural strength were computed. Load-deflection performances that include the post-peak reactions were observed by means of a closed-loop twisting test set-up [5].

In our paper, the flexural behavior of using recycled steel fiber from waste tires as an economical reinforcing material in ferrocement panels and, further, strengthening the panels with carbon polymer fiber in different shapes after failure were investigated.

2. Experimental Program

2.1 Materials

2.1.1 Cement

A normal Portland cement (CEM I 42.5 according to EN 197-1) Turkesh type was used in all combinations. Cement examinations was consistent with the Iraqi qualifications (IQS No.5/1984) [6]. Table (1) and Table (2) show the chemical and physical properties of cement respectively.

| Cement Composition | Content Content | Limits of Iraqi Specification No. 5/1984 | 8 |
|--------------------|-----------------|------------------------------------------|---|
| SiO₂               | 13.60%          | 21% Max                                  |   |
| SO                 | 1.10%           | 2.5% Max                                 |   |
| Loss on Ignition (L.O.I) | 0.92% | 4% Max                                   |   |
| Insoluble material | 0.88%           | 1.5% Max                                 |   |
Table 2. Physical properties of cement

| Physical Properties                      | Test results | Limit of Iraqi specification No. 5/1984 [8]                      |
|-----------------------------------------|--------------|-----------------------------------------------------------------|
| Fineness Of cement (m²/kg) [9]           | 301.5        | (230 m²/kg) lower limit                                         |
| Setting time (Vicat Needle) [10]         |              |                                                                |
| Initial setting, (hrs. : min)            | 55 min       | Not less than 45min                                             |
| Final setting, (hrs. : min)              | 7 hrs. .55 min| Not more than 10 hrs.                                           |
| Compressive strength (kg/cm²) [11]       |              |                                                                |
| For 3-day                                | 230.47       | Not less than 150 kg/cm²                                        |
| For 7-day                                | 343.6        | Not less than 230 kg/cm²                                        |

2.1.2 Fine Aggregate

Fine aggregate (sand) was river sand from Tuz region in Saladin governorate. Sieving was performed on fine sand and was confirmed to American specification (ASTM) [7]. Table (3) shows the used sand gradient, while Table (4) shows the sand specifications according to ASTM. In addition, Table 5. shows the chemical properties of fine aggregate according to the Iraqi specifications [IQS No. 45/1984] [8].

Table 3. Fine aggregate gradient

| Sieve Size   | Cumulative passing % | Limit of ASTM C33 [12] |
|--------------|-----------------------|-------------------------|
| 4.75-mm (No.4) | 99.85                 | 95-100                  |
| 2.36-mm (No.8) | 91.85                 | 80-100                  |
| 1.18-mm (No.16) | 80.35                 | 50-85                   |
| 600-µm (No.30)  | 58.35                 | 25-60                   |
| 300-µm (No.50)  | 15.35                 | 10-30                   |
| 150-µm (No.100) | 3.85                  | 2-10                    |

Table 4. Sand specifications according to ASTM

| Item                                      | Mass Percent, of Total Sample Max | Used Sand |
|-------------------------------------------|----------------------------------|-----------|
| Clay lumps and friable particles          | 3.0                              | 2.0       |

Material finer than 75-µm (No. 200) sieve:

| Concrete subject to abrasion              | 3.0A                             |
| All other concrete                        | 5.0 A                            |

Coal and lignite:

| Where surface appearance of concrete is of importance | 0.5                               |

| All other concrete                         | 1.0                               |

| 0.0                                       |

Table 5. Chemical properties for fine aggregate

| Properties                          | Specification                | Test Results | Limits of Specification |
|-------------------------------------|-----------------------------|--------------|-------------------------|
| Sulfate content (as SO3) (%)        | (I.Q.S.) No. 45/1984        | 0.17         | 0.5 (max. value)        |
| Material finer than 0.075 mm (%)    | (I.Q.S.) No. 45/1984        | 1.03         | 5 (max. value)          |
2.1.3 Wire Mesh

Welded square wire mesh was used in this study as shown in Figure (1), the wire diameter was 0.5 mm, length of square side 12.5 mm, yielding stress 440 MPa, max. strength was 490 MPa and modulus of elasticity 20000 Mpa.

![Wire mesh](image)

Figure 1. Wire mesh used

2.1.4 Recycled Steel Fiber

The steel fibers extracted from waste tires were used after cutting them into different lengths, so that the maximum length is not more than 5 cm, and the diameter is 1 mm, according to the specification of the standards related to steel fibers.

2.1.5 Epoxy

A chemical material, which is a type of thermoplastic with two compounds (epoxy or epoxy resin or cruciferous) was utilized. It is highly adhesive and resistant to friction and chemicals, whether acids, bases or solvents used as a coating, mortar or adhesive. Moreover, it forms an insulating layer after drying. Most types of epoxy production are the results of the interaction between the Epichlorohydrin and Bisphenol chemicals. The density was 1.31 kg/L, viscosity pasty with no flow enabled and tensile strength was 30 N/mm².

3. Mixtures, Mixing, Casting and Curing

Thirty main mixtures were used with panel dimensions (500*500*30) mm. The molds were formed prior to casting and mixing process by cleaning them with a steel brush, wiping them with a cloth, making sure that there were no suspended materials and, then, moistening them with a bit of water. Then, an oil layer lubricated the mold. Besides, the layers of wire mesh or the recycled steel fiber layers were placed with specific distances in the mold. The mixing ratio was 1:2 with W/C 0.45 for all mixture. The number of wire mesh was (2, 4, 6, and 8) layers with replacing layers by recycled steel fiber by (0, 2, and 4) layers on condition that at least two layers of wire mesh remain.

The mixing process of all mixtures was performed in the laboratory of the Civil Engineering Department according to ASTM C192 [9]. After completing the formation of the molds and the laying of wire mesh layers, the process of casting the models and compacting them was achieved using the electric vibrator table according to the standard ASTM C192 [9] for all mixtures. The mortar was placed in the molds containing wire mesh in a form of layers. The thickness is one between two wire mesh layers or between two recycled steel fibers. Further, layers are equal and each layer was compacted to ensure the penetration of the mortar between the layers of the wire mesh. Furthermore, the compacting process continued for 3 seconds after applying a final layer of mortar, which was about 3 mm thickness. This process was for panels within wire mesh layers. On the other hand, for panels with recycled steel fiber layers, the previous process was carried out again with replacing wire mesh layer with equal weight of steel fiber.
Opening the molds and curing of the samples were carried out by leaving it after casting and compacting for 24 hours at the laboratory temperature, which varied from one season to another (34°C in summer and 18°C in winter. Then, the molds were opened and submerged in water within the basin for 28 days.

4. Modes of Panels Rehabilitation by CFRP

Rehabilitation must be within certain modes that give the best strength and protection for the structure, so three modes of rehabilitation were studied, the first one was rehabilitation by placing carbon fiber in the form of a box network consisting of 3 strips in each direction as shown in Figure (2.1). The second form was rehabilitation by placing fiber parallel to the diameter of the sample, where 3 strips are placed parallel to each diameter as shown in Figure (2.2), the last one was rehabilitation that is a mixture between the first and the second method, where the strips are placed towards the length of the sample and 3 strips towards the diameter of the sample as shown in Figure (2.3).

![Figure 2](image)

*(Figure 2. The forms of rehabilitation)*

5. Methodology of Rehabilitation for Panels

Samples were processed on a flat and clean surface, and the cleaning panels surfaces were treated well from dust and dirt by a clean cloth or a brush. After cleaning the panels, the cracks that formed as a result of the failure were filled with epoxy and hardener materials by an injection of the stomach for this purpose. The hardener and the epoxy mixing were in a ratio of 4:1. The prepared strips of carbon fiber were in 2.5 cm width, and were put on the surface of the samples (the amounts of used carbon fiber were the same for all samples).

6. Laboratory Tests

The compressive strength (f_{cu}) of the standard mortar cubes was tested according to ASTM C109 [10]. The compressive strength of the three cubes was at 28 days. In accordance to ASTM C78-02 [11] with the dimensions (40 × 40 × 160) mm and by the Third-Point Loading method, the bending resistance of the cement mortar (f_r) of the mixture types was computed. The results were at the age of 28 days from the time of adding water to the mixture. The test was performed on cylindrical models according to (B.S. 1881:part3:1970) [14] at 28 days.

7. Flexural Strength Capacity of Panels Specimens

The flexural strength of the panels was tested under a punched load. The frame structure consists of a steel frame that supports the panels during the test in a simple support system. It has a spiral spring moving to the top during deflection, enabling the dial gage to read the deflection. The
reference panel (non-container on fibers) as well as the panels containing recycled steel fiber were tested at 28-day and under a central punch load on the panel center.

The deflection was measured under each loaded case, and the panels were considered to be fail after the recorded strength was decreased with continuous deflection and appearing the sound of the wire cut. The panels that failed were tested again after rehabilitation with carbon fibers strips and epoxy fibers. Figure (3) shows the panels model in the tests apparatus.

Figure 3. Shows a panel specimen during flexural strength testing.

8. Results and Discussion

8.1 Compressive Strength

The compressive resistance test carried out for cubes with 150 mm length, 3 cubes tested at 7 days and 3 cubes tested at 28 days used in the casting of panels, the compressive strength was recorded at failure. Arithmetic mean of three cubes is considered to be compressive strength of the mixture. Table (10) illustrates the compression resistance of the mixture at the age of 7 and compressive strength was 35.33 kN/m$^2$ and compressive strength at 28 days was 49kN/m$^2$.

8.2 Flexural Strength

Flexural strength was carried out on 24 samples. They were 6 samples of mortar only, without additions, and 6 samples with the addition of recycled steel fiber, 5% of cement weight. Further, 6 samples were by adding recycled steel fiber, 10% of the weight of cement and 6 models with 15% recycled steel fiber addition of cement weight. Tests were at 7days and 28 days, as shown in figure (4) and figure (5).

Addition of recycled fiber 5% of cement weight increases in the flexural strength of the prisms about 5.13% with respect to the flexure strength of the prisms, which have no fibers. The addition of recycled steel fiber by 10% of the cement weight leads to an increase in the flexure strength about 20.52% from the flexure of the prisms, which do not contain recycled fibers, and about 16.22% from the flexural strength of the prisms containing 5% of the cement weight. Adding 15% of the recycled steel fiber of cement weight leads to a decrease in the flexural strength by 8.6% of the prisms containing the ratio of 10%. However, the flexural strength of this ratio is higher than of prisms that do not contain fiber, which contains 5% of cement weight.

The reason of the increase in the flexural strength was due to the recycled steel fiber properties in increasing the flexural force that it is highly flexible, as well as it contributes in linking the molecules of the mortar with each other. This turns it a very coherent and, thus, slows down the speed failure. In the meanwhile, the strength of 15% recycled steel fiber had a reduction of 10%. The reason was due to the increase in fiber ratio to a greater amount than 10%, which leads to a lack of mixing and air voids
formed in the model. When the load was placed on the model, it would bump with the mortar and fibers, which would, consequently, exhibit high resistance and, then, the load would collide with the formed spaces. The load, in turn, would withstand any resistance to the load direction because they were free of any material and, thus, they weakened the model.

![Graph](image)

**Figure 4.** The Load-Deflection relationship of the prisms at 7 days

![Graph](image)

**Figure 5.** The Load-Deflection relationship of the prisms at 28 days

### 8.3 Splitting Tensile Strength

The tests were conducted for cylinders of 150 mm diameter and 300 mm height. There were 6 cylinders were tested for mortar, 6 cylinders with 5% recycled steel fibers, 6 cylinders with 10% recycled steel fibers and 6 cylinders with 15% recycled steel fibers. The increase in the recycled steel fiber ratio leads to an improvement in tensile strength through known properties, which increase the tensile strength of the structural elements. The addition of the recycled steel fibers by 5% leads to an increase in the tensile strength by 8.8%. In addition, adding the recycled steel fibers by 10%, this increases the tensile strength by 22.6% because of the ability of the recycled steel fibers to resist the high tensile strength as well as being high in flexibility. Recycled steel fibers by 15% lead to a decrease in the resistance by 6.5% for those containing 10% fibers, but the resistance of this ratio is greater than the resistance of cylinders without containing fiber, the reason is due to the increase in the recycled steel fiber that leads to the formation of spaces between the particles of the mortar.

### 8.4 Flexural Strength for Panels

Tests were carried out on the ferrocement panels containing the layers or ratios of the wire mesh. An increasing in wire mesh was observed that caused an increase in strength as well as a decrease in the value of the deflection occurring in the panels. Moreover, the addition of 4 layers wire mesh led to a bearing load of 4 kN, adding 6 layers of wire mesh led to a bearing load capacity of 4.5 kN, and adding 8 layers of wire mesh led to a bearing load of 6 kN, as shown in figures (6-9). This is
due to the efficiency of the wire mesh in the endurance of the loads, thus, it showed a positive resistance to the force, which increased the bearing of the panels and links the mortar particles between layers as a block that was working to reduce the deflection of panels.

In panels, the wire mesh was replaced with layers of recycled steel fiber (while maintaining at least two layers of wire mesh to stay within the ferrocement type). It was observed that the replacement of wire mesh with layers of recycled steel fiber reduced the deflection. Further, the strength of panels were somewhat similar to the panels that had wire mesh compared to those containing steel fibers and same number of layers. In addition, the resistance of the panels, which contained 4 layers of the wire mesh, was somewhat similar to the resistance of the panels that contained 2 layer wire mesh and 2 layers of recycled steel fibers (grossing 4 layers). The reason for this was the presence of the recycled steel fiber with the wire mesh that worked together to show resistance against the load and to prevent deflection by loading.

**Figure 6.** The load-deflection relationship for ferrocement panels with 6 layers of wire mesh

**Figure 7.** The load-deflection relationship for ferrocement panels with 6 layers wire mesh
Figure 8. Panels the load-deflection relationship for ferrocement panels with 4 layers wire mesh

Figure 9. Panels the load-deflection relationship for ferrocement panels with 4 layers wire mesh

Panels after the forms of rehabilitation were mentioned previously. All forms of repair demonstrated a clear contribution of carbon fiber in increasing the resistance of the panels and improving the behavior of these panels in varying proportions depending on the form of treatment. The rehabilitation was developed to be in parallel to the diameter of the sample that showed more bearing strength than the remaining shapes. The reason is that the stresses formed in the sample were vertical and horizontal with respect to the four sides. Consequently, these forces would decompose in the middle of the sample and, thus, would consist of cracks towards the diameter of the panels. On the other side, these cracks would face high resistance by the carbon fiber, which was characterized by high flexibility and resistance against stresses working to repel. As a result, this led to strengthening the resistance of the panel more than the other forms. The other forms of repairing were also resistant to the stresses, but due to the lack of carbon fiber in the full diameter, they would provide the panels a greater motive for landing and cracking due to stress. However, the failure of the sample was because of the dislocation (or deboning) of the carbon fibers; hence, the fibers were resistant to high strength. Finally, the failure occurred because of the deboning between the fiber and the bonding material.

9. Conclusion

1- Recycled steel fibers increase the flexural strength, and 10% is the optimal ratio for increasing the flexural strength, increasing the number of wire mesh layers increases the ability to bear stresses of the panels.
2- Recycled steel fibers increase the tensile strength of the mortar, and the ratio of 10% is the ideal ratio. Cylinders containing the fibers do not break down completely even after failure.

3- Recycled steel fibers can cause reduction in the deflection of ferrocement panels and can give the same bearing strength proximity (or less) to the panel containing the same number of wire mesh layers.

4- Recycled steel fiber can be used with two layers in the panels, which represent the best addition compared to the rest kinds of additions.

5- Using of recycled steel fiber is economic as the tire of a normal car contains 300 grams of steel wire. For example, if we had 1000000 tires, the resulting quantity is estimated to be 300 thousands kilogram of steel wire, which can be cut and used as steel fibers.

6- Rehabilitation with carbon fiber, which takes the parallel form to the diameter of the sample, is the best treatment that is characterized by the resistance to the stresses more than the other forms.

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