Revue des Composites et des Matériaux Avancés-Journal of Composite and Advanced Materials
Vol. 34, No. 1, February, 2024, pp. 117-124
Journal homepage: http://iieta.org/journals/rcma

Static Load Behavior of Ferrocement Slabs Reinforced with Recycled Tire Steel Wire

Ahmed S. Ahmed[1*], Ahmed S. Al-Fahal[1], Naeem M. Al-Hantoosh[2], Mazin A. Hussein[2]

[1] Environmental Engineering Department, College of Engineering, Tikrit University, Tikrit 34001, Iraq
[2] Civil Engineering Department, College of Engineering, Tikrit University, Tikrit 34001, Iraq

Corresponding Author Email: ahmed.s.mahmood@tu.edu.iq

https://doi.org/10.18280/rcma.340115

Received: 13 November 2023
Revised: 22 January 2024
Accepted: 3 February 2024
Available online: 29 February 2024

Keywords:
ferrocement, slabs, wire mesh, tire steel wire, failure

ABSTRACT

Ferrocement is extensively utilized in construction as a structural material, given its exceptional mechanical properties and impact strength. This study aimed to analyze the performance of ferrocement that is reinforced with recycled steel wire tires under static loads. This current study a comparative investigation of behavior of compressive strength of ferrocement cubes and flexural behavior of ferrocement panels and behavior of ferrocement panels reinforced with tire Steel wire tires under static loads. Ferrocement slabs sample was (L 500×W 500× t 50mm) in size, and 15 slabs were subjected to static point load. The number of wire mesh layers, which was replaced by recycling tire steel wire as a ratio of the volume of wire mesh, was the main parameter in the current study. The percentage of recycle steel wire tires are 33% and 66% and 99% from of steel wire mesh for reinforcements of ferrocement panels. The results presented, the behavior of panels under static load at ultimate failure and first crack. It showed that ferrocement have 99.0% steel wire tires gave a good performance under static loading which were required to increase the load value to make the first crack and ultimate failure, and causing late of the failure and less deflection.

1. INTRODUCTION

The consumption of hundreds of tons of tires annually is a result of a wide spread of cars, which calls for efficient disposal of these used tires, recycling the of these used tires, and extracting the wires that are used to strengthen the structural properties of ferrocement, which are characterized by high tensile resistance, this study has emphasized the creation of environmentally friendly (green) ferrocement slabs [1-3]. So that it is cheap, environmentally friendly and, available, which will contribute to reducing the cost of strengthening and rehabilitating concrete structures [4, 5]. Reinforcement is an important in reinforced concrete structures, which resists the impact of different loads and gives the structures durability and sustainability. Ferrocement is a captivating, material for manufacture of different construction member as walls, floors system, and different types of slabs for substructure, underground water vessels, water control equipment, vessel coating and retaining walls [6]. Ferrocement composite was generally used in different structural construction which includes in storage towers, tanks, shell panels, and load-bearing walls and to protect some riverbanks [7, 8]. Ferrocement panels without fibers was used as reference panels for the behavior of ferrocement panels reinforced with straight strips of jute fibers and reinforced ferrocement panels with carbon fiber [9, 10]. Six cases were examined in the study to analyze the reinforcement patterns of jute fibers. The study involved using jute fiber strips from the same area but with varying lengths and shapes. Reinforcement is an important part of reinforced concrete, as it gives it support to resist the impact of various loads and gives it durability and sustainability [11]. The high cost of reinforced concrete in implementing concrete structures, as traditional concrete has a high weight, leads to additional loads, especially in large structures. For this reason, we may need to improve the properties of concrete, and this leads to more efforts by researchers to study and improve the properties of ferrocement, which is the best in terms of cost and weight [12]. Hence, many studies were conducted on iron technology, and engineers improved alternatives to iron and its properties. Ferrocement is a type of concrete cement mortar in which the cement mortar is reinforced with layers of small diameter wire mesh. The epoxy underwent testing and was applied to enhance the flexural properties of reinforced concrete beams, demonstrating substantial improvement .Other types of reinforced cement mortar can be used to achieve the same functional purposes while maintaining the structural properties within the required design specifications and specifications [13].

One of the most important achievements in the design of concrete structures is reducing dead loads (By reducing weight) as a result of using cement mortar without high density (not using coarse aggregate), and this is the working principle in ferrocement. Moreover, reinforcement with Steel wire tires has many advantages such as increased resistance of the section to tensile stresses, and faster implementation [14]. The tires steel wire decreases production and installation expenses. Many of methods were used to reinforce of elements made of ferrocement, such as reinforced by polymer fiber (Ferrocement has a satisfied RPF) for three types are (carbon, glass and aramid) [15].

The fiber was used to support ferrocement samples due to its high tensile strength and light weight. The toughness is that characterizes these materials. From this standpoint, researchers use and work on this technology to improve the properties of ferrocement. Ferrocement reinforce by natural fibers can be deliberate existence an efficient system to achieve the global request for ecological development [16]. The study showed that toughness, ultimate flexural strength, and load carrying value of reinforced concrete (RC) beams strengthened with jute fiber reinforced polymer (JFRP) were improved with the increase of the strip width and thickness. Due to a good physical properties of tire steel wire, it is used for bending, shear and support reinforcement of wire mesh and can be used to modify damaged structural elements such as beams, columns, walls, slabs, tunnels and other structural elements [17]. It also has other advantages, which are ease of work and use, speed of implementation and installation, cheap price, and does not require special equipment to work. The study presented that addition of porcelain and glass powder improved epoxy properties and cost reduce. The results showed that the addition reduced the interaction temperature by 11.37%, epoxy flow by 10.41%, and improved the compressive strength by 7.61% [18].

Therefore, there is a demand to find a cheap alternative to overcome the high cost of reinforced polymer fiber (RPF) through use other cheap alternatives. In this regard, Steel wire tires used to strengthen and qualify ferrocement elements. due to have a good property such as high tensile resistance, in addition to being recycled materials.

In this research, layered wire was used as an alternative to reinforced polymer fiber (RPF) in strengthening ferrocement. Moreover, the behavior of these slabs under static load with several different conditions Investigation. According to the results and advantages of tire steel wire, it is a good alternative technology to RPF synthetic fiber and is considered a recycled material as it can be recycled by obtaining it from old tires.

Several numbers of wire mesh layers were used in the current study to test the reinforced flat ferrocement slab by utilizing the recycled steel wires from tires. To reach this goal, five models of ferrocement slabs will be subjected to different static point loads. Thus, the main objective of the experimental work is to address the impacts on the flexural strength of ferrocement slabs due to the replacement of the regular wire mesh layers by a volume percentage of recycled steel wires from tires. Further, the number of wire mesh layers would be inspected to figure out the optimal amount of strength of toughness for this kind of structure built by ferrocement.

2. EXPERIMENTAL WORK

There are many methods that have been developed and used in strengthening the structural members and we will refer here to one of the modern methods used in strengthening and supporting the structural members, which is the addition of wires extracted from spent tires with good characteristics and advantages of use, high tensile strength, light weight, speed of implementation, low costs, great availability and being environmentally friendly which will be used in the study to reinforce ferrocement slabs. These ferrocement can be used to concrete structures, such as buildings, walkways and the banks of rivers, the sea and many types of cement concrete structures. The concrete mix was designed according to the flow test (compressive insulation of the cement mortar (compressive strength)) [19]. The best water to cement ratio was (0.4%), which gave the best flow rate of (110%) according to (ASTM C1437), which is obtained from the following mathematical relationship:

$$Flow = \frac{D - 100}{100} \times 100\% \quad (1)$$

where,

D: Average diameter of cement mortar after testing it.

2.1 Methods and material

Ordinary Portland Cement used in the present study. The Tables 1 and 2, are illustrated the chemical composition and physical properties of the used cement, respectively. After conducting a sieve analysis, it was found that it conformed to (Iraqi Standard Specifications No. 45 of 1984) and Amendment No. 2 of 2010.

Table 1. Physical analysis of cement

Physical Properties	Test Result	Limit of I.Q.S NO. (45/1984,2/2010)
Specific of Blaine method (m2/kg)	325	230 (Min)
Setting time Initial (Min) Final (hr)	 120 6.00	 00:45 (Min) 10:00 (Max)
Soundness Autoclave Method	0.24%	0.8%(Max)
Compressive Strength 3 days (Mpa) 7 days (Mpa)	 1.5 31	 15 (Min) 23 (Max)

Table 2. Chemical analysis of cement

Compound Composition	Chemical Composition	Weight %	Limit of I.Q.S NO. (5/1984,2/2010)
Lime	CaO	64.2	-
Silica	SiO_2	18.1	<21%
Alumina	Al_2O_3	5.2	<8%
Iron Oxide	Fe_2O_3	3.5	<6%
Magnesia	MgO	3.15	<5%
Sulphate	SO_3	2.1	<2.8%
Loss on ignition	L. O. I	2.7	<4%
Insoluble residue	I. R	0.9	<1.5%
Lime saturation factor	L.S. F	0.75	%0.66_1.02
Tricalci Aluminate	C3A	7.82	_
Tri-calcium silicate	C3S	68.25	_
Di-calcium silicate	C2S	18.52	_
Tetra-calcium Alumina Ferrite	C4AF	10.96	_

The fine aggregate used in the current study is river sand from the Al-Alam area, its smoothness coefficient (3), and the analysis results. Sieve analysis, physical and chemical properties clarified in Tables 3 and 4, respectively.

Tab water used in mixing of all ng for all specimens. Reinforcement wire mesh with 0.68mm diameter, yielding strength (fy)=389.4MPa, ultimate tensile strength (fu)=412.2MPa and modulus of elasticity of wire mesh (E)=61981MPa. All reinforced layers upper, lowest and middle RCM layers are also fixed. The reinforcement wire mesh designed to proper sizes and forms at multi layers. The layers of wire mesh linked to all sides of frame, and made holes in the frame wall to ensure that fixative distance between layers [2]. In the current study, the used wire mesh with dimensions (450×450) mm, and three layers bound together as one layer. Table 5 shows the results of the wire mesh tests and Figure 1 shows the frame with reinforcement wire mesh.

Table 3. Sieve analysis results of sand used

Size of Sieve	Cumulative Passing (%)	Limit of I.Q.S NO. (5/1984, 4/2010) (ZONE3)
4.75mm (No. 4)	100	90-100
2.36mm (No. 8)	100	85-100
1.18mm (No. 16)	98	75-100
600µm (No. 30)	75	60-79
300µm (No. 50)	37.52	12-40
150µm (No. 100)	2.75	0-10

Table 4. Chemical and physical properties of fine aggregates

Properties	Results	Limit of I. Q. S
Specific gravity	2.69	
Absorption (%)	1%	
Finess modulus	2.17	
Dry unit weight (kg/m^3)	1565	
Sulfate (%)	0.026%	0.5 (Max. value)
Gypsum (%)	0.05%	<0.5
Soluble salts (%)	0.12%	<0.5
Material finer than 0.075mm (%)	1.2	5(Max. value)

Table 5. Wire mesh test results

Type	Diameter (mm)	Yield Stress (f_y) (MPa)	Ultimate Strength (f_u) (MPa)	Modulus of Elasticity (E) (MPa)
Wire mesh	0.68	389.4	412.8	61981

Figure 1. The frame with reinforcement wire mesh

Figure 2. Tire steel wire

Table 6. Steel wire tirestest results

Type	Diameter (mm)	High-Tensile (MPa)
Tire steel wire	1.35	1340

The tire steel wire has good characteristics and features with good use, high tensile strength, light weight, speed of execution, great resistance for stress, and being friendly to environmental. The wires cut into the pieces, the length of piece of the wire is 45cm, and the tire steel wires connected as a network such as a wire mesh, and each layer replaced by a layer of wire mesh. and as shown in Figure 2 and Table 6 shows the results of the wire mesh tests.

2.2 Testing program

The main object at this stage is to study the possibility of improving the tension (tensile strength) by strengthening the ferrocement slabs with tire wires.

Mechanical properties of cement mortar, compressive strength the compressive strength at the age of 7 days and 28 days with dimensions (50×50×50mm) and examined them in the compression test apparatus shown in Figure 3, where the ratio given (0.4)%. The best compressive strength, at age of 7 days and 28 days, at a rate of 3 cubes, and identical to (ASTM C 109-87).

All slabs tested by using universal testing machine. Each slab exposed a static load throughout a central concentrated load with the average speed 1.2kN/min and diameter of cylindrical steel shaft is 5cm. The dial gauge fixing on frame for recording the deflections under point load. All loads recorded by using a digital data logger fixed with a load cell.

3. RESULTS AND DISCUSSIONS

Tensile strength calculated by tensile testing machine with a unit (kg) and then converted to Newton units and divide it into the area of one thread to extract the strength of the tensile (Mpa), The results of high tensile strength tests is (1340 Mpa).

All slabs that have been identified by symbols as in the table below Table 7 examined under the influence of static load and the result as the Table 7.

Table 7. Definition of the symbols

ID	Description
A	Reference slabs without reinforcement
B	Reference slabs with wire mesh reinforcement
C	Slabs with 33.0% steel wire of tires reinforcement
D	Slabs with 66.0% steel wire of tires reinforcement
E	Slabs with 99.0% steel wire of tires reinforcement

The Figure 3 shown for the reference slab samples without reinforcement, behavior of the slabs under static load:

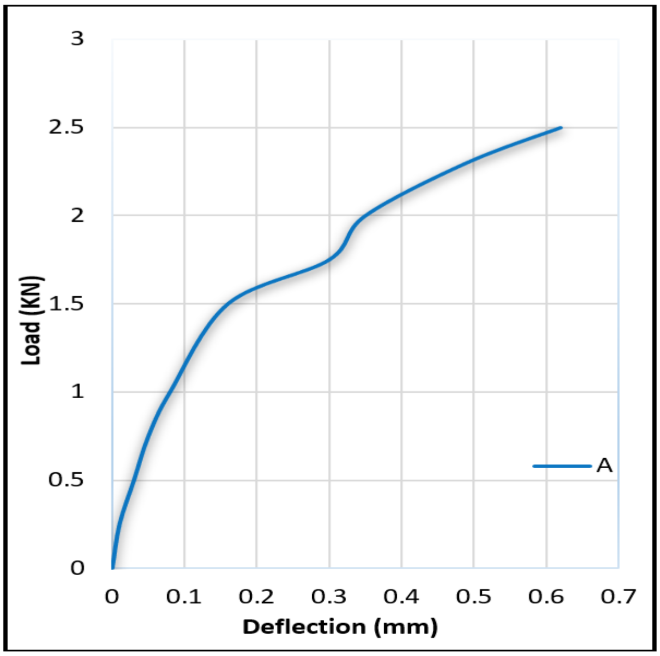

Figure 3. Reference slabs without reinf behavior under static load

The Figure 4 shown below for the reference slab samples with reinforcement, behavior of the slabs under static load:

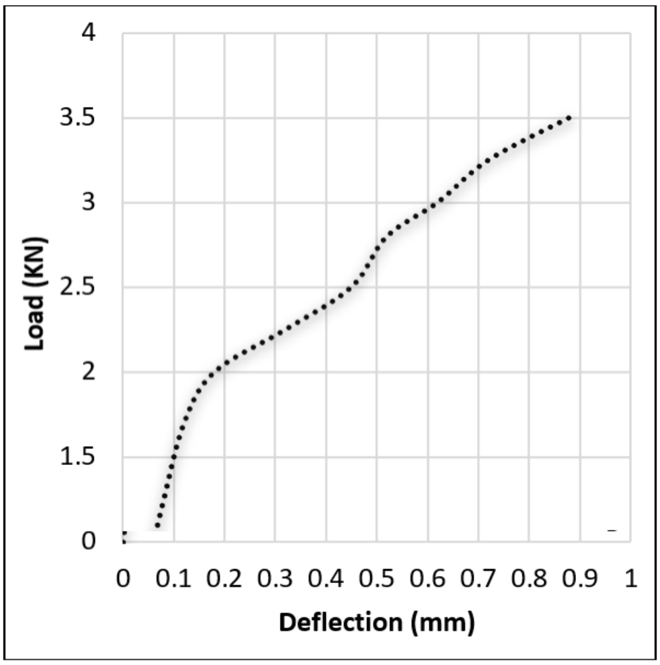

Figure 4. Reference slabs with wire mesh reinf behavior under static load

The Figure 5 shown below for the reinforcement slab samples with 33.0% steel wire of tires, behavior of slabs under static load:

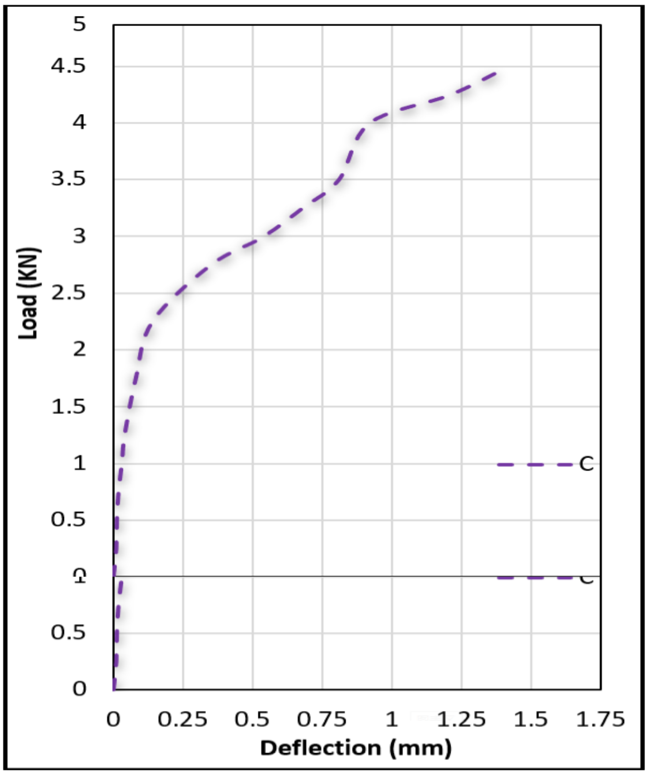

Figure 5. Slabs with 33.0% steel wire of tires reinforcement behavior under static load

The Figure 6 shown below for the reinforcement slab samples with 66.0% steel wire of tires, behavior of slabs under static load:

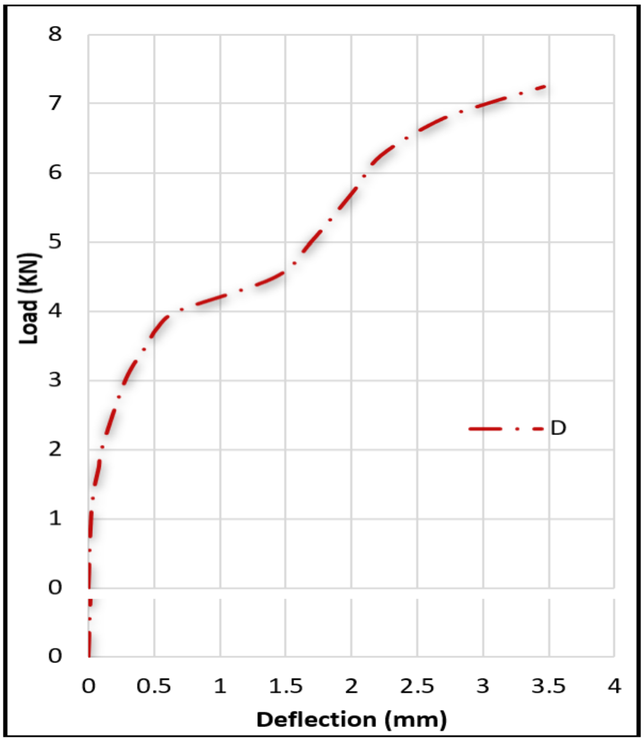

Figure 6. Slabs with 66.0% steel wire of tires reinf behavior under static load

The Figure 7 shown below for the reinforcement slab samples with 99.0% steel wire of tires, behavior of slabs under static load:

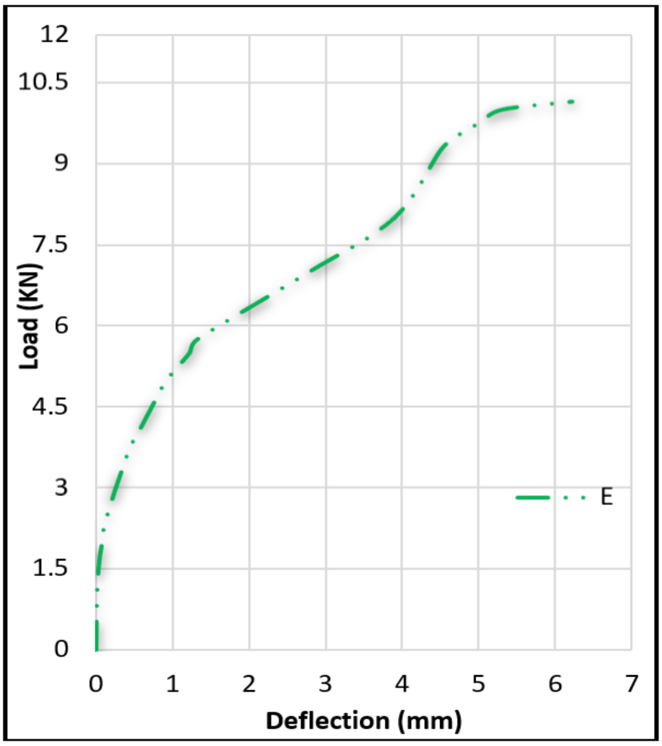

Figure 7. Slabs with 99.0% steel wire of tires reinf behavior under static load

The Figure 8 shown below is the load-deflection relationship between samples of 33.0% steel wire tires supported reinforced slabs with the reference slabs.

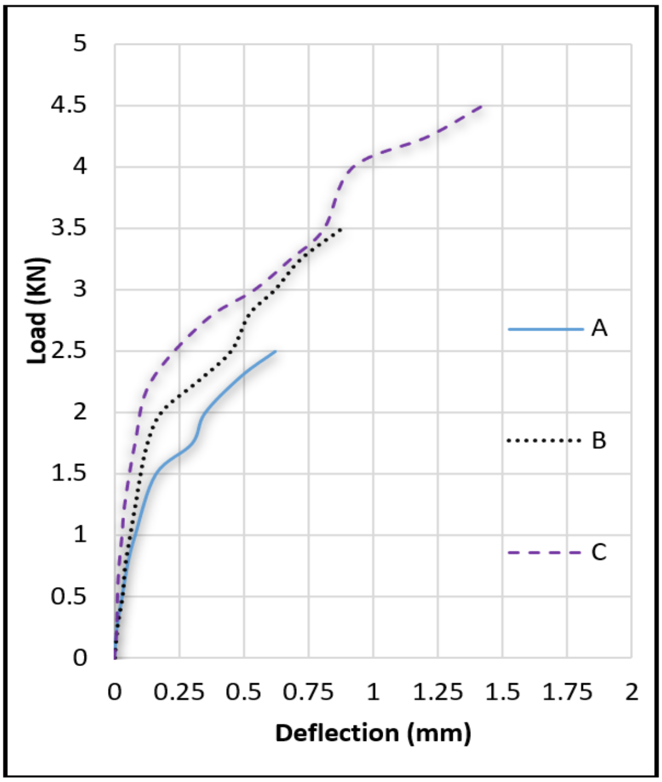

Figure 8. Slabs with 33.0% steel wire of tires reinf with refrenceces slabs behavior under static load

The Figure 9 shown below is the load-deflection relationship between samples of 66.0% steel wire tires supported reinforced slabs with the reference slabs, and the behavior it under static load. There is an improvement in the resistance of the slabs to load with strengthening compared to the reference slabs:

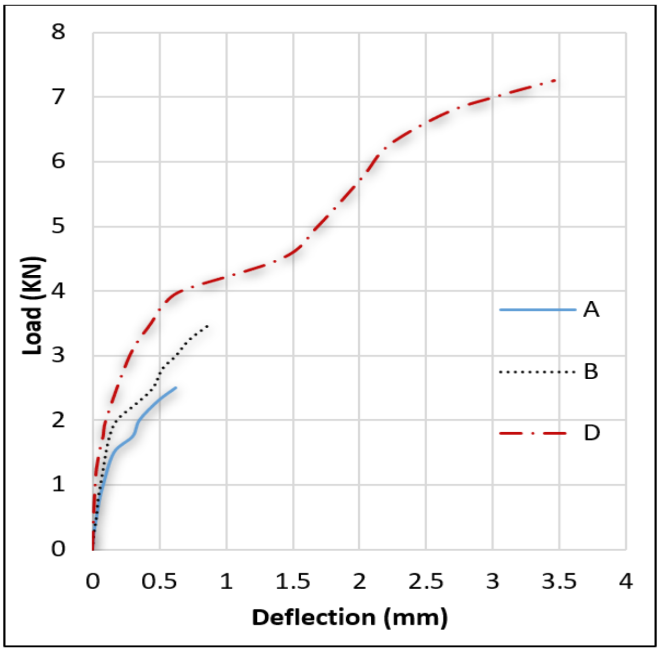

Figure 9. Slabs with 66.0% steel wire of tires reinf with refrenceces slabs behavior under static load

The Figure 10 shown below is the load-deflection relationship between samples of 99.0% steel wire tires supported reinforced slabs with the reference slabs, and the behavior it under static load. Notice more improvement in the resistance of the slabs to load with strengthening compared to the reference slabs:

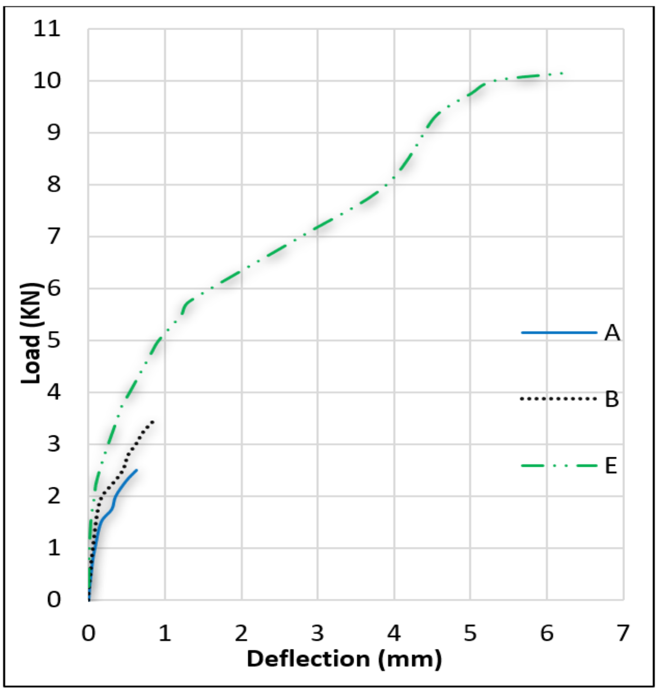

Figure 10. Slabs with 99.0% steel wire of tires reinf with refrenceces slabs behavior under static load

The Figure 11 shown below is the load-deflection relationship between all samples of 33.0% ,66.0% and 99.0% steel wire tires supported reinforced slabs with the reference slabs, and the behavior it under static load. Notice more improvement in the resistance of the all slabs to load with strengthening compared to the reference slabs:

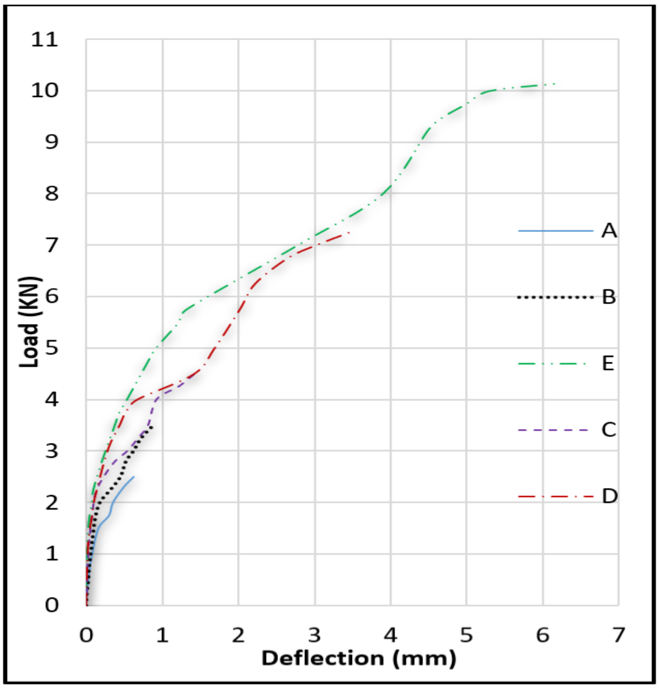

Figure 11. All Slabs behavior under static load

The behavior it under static load. Notice an improvement in the resistance of the slabs to load with strengthening compared to the reference slabs. From (load-deflection) relationship can the result as the Table 8 below:

Table 8. Static load results

S	fy (N)	fu (N)	Δy (mm)	Δu (mm)	Ductility	Stiffness (N/mm)	Toughness (N.mm)
A	1750	2500	0.16	0.62	3.88	10938	1465.75
B	2500	3500	0.32	0.88	2.75	7813	920.5
C	3000	4500	0.54	1.42	2.63	5556	1707.5
D	4500	7250	1.42	3.46	2.44	3169	7190.5
E	5750	1015	2.78	6.22	2.24	2068	17828

where,

Ductility: Proportion of the ultimate deflection (Δu) to the deflection at yield point, and the following relationship used to calculate the ductility ($\Delta\mu$):

$$\Delta\mu = \frac{\Delta u}{\Delta y} \tag{2}$$

Stiffness: Slope of the load-deflection curve before yield point, and the following relationship used to calculate the stiffness (N/mm):

$$\text{Stiffness}=\frac{fy}{\Delta y} \tag{3}$$

Toughness: Area under the curve of (load-deflection) relationship (N.mm).

4. CONCLUSIONS

(1) The results of the tests carried out on the ferrocement wire-reinforced models of slabs showed that use of Steel wire tires in strengthening ferrocement slabs is very effective in resistance of increasing the bearing static.

(2) It is possible to use Steel wire tires in the treatment and strengthening of ferrocement slabs, as it is environmentally friendly and possesses good tensile strength as it is economically cheap as it is a recycled material from tires.

(3) The best type of wire ratios used is the 99% ratio, as the ferrocement slabs reinforced in this way showed an increase in the maximum load of four times compared to the reference models.

(4) The reinforcement of ferrocement slabs with using tire steel wire increases the durability, which mean an increase in the resistant to static loads, therefore, the use of treated steel tire may open up the scope for developing other types of strengthening methods.

(5) The type of failure at reference slabs (without reinforced), due to fragility, as for failure in the reinforced slabs with wires, assumed that due to the bonding process as well as to the wire, it is withdrawn from the concrete due to its smooth surface.

(6) Tire steel wire reinforcement can be used as a substitute or partially for ferrocement slabs reinforcement with steel wire mesh.

ACKNOWLEDGMENT

The authors would like to acknowledge the support provided by Dr. Wesam Sameer Mohammed-Ali, from the Environmental Engineering Department, College of Engineering, Tikrit University, in terms of help and guidance during the preparation of this research.

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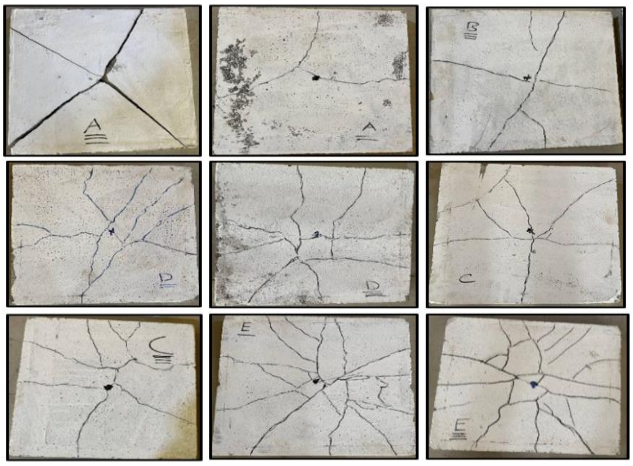
NOMENCLATURE

fu	The ultimate load of ferrocement slabs, N.
fy	The load at the yield point of ferrocement slabs, N.
Δu	The ultimate deflection, mm.
Δy	The deflection at yield point, mm.

APPENDIX



Failure Modes

Static Point Load Machine