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Studying the bending behavior of polymer-based composites reinforced with wires of different geometric shapes by numerical analysis method

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Abstract The aim of this research is to study the effect of changing the geometric shape of wires which are used to reinforce the composite materials, The composite material consists of polyester as a matrix (87% wt.) and wires (13% wt.) as a reinforced that have different cross-section area shapes used (circular, triangle, and square). A bending test was performed on composite materials and matrix material, the results showed that the composite material reinforced with steel wires with a circular shape has a bending strength higher than composite materials reinforced with wires that has a triangle and square shape in a cross-section area, the results also showed that the lowest bending strength was for the matrix material.

Keywords: Composite Materials; Wires; Polyester; Bending test.

1 Introduction

The mechanical and physical properties of materials may change if they are exposed to external stresses, there for modern technologies require materials with unique properties, therefore, there was a need to discover new materials that bear new qualities and properties that are not available in ordinary alloys or ceramic materials, especially materials that are used in outer space applications, in the seas, and for transportation purposes such as aircraft and cars [1]. The engineers searched for materials to manufacture the structure so that they have high resistance to bending, impact resistance and non-corrosiveness, and these characteristics cannot be combined in one type of material, Therefore, there was a need to invent materials that combine these properties as much as possible, and these materials called composite materials [2]. It is a mixture of two or more substances with different properties, meaning that each substance has properties that differ from the properties of the other substance, which are related to each other without melting one of them with the other in certain proportions sufficient to form a new substance with desirable properties, which are not available in the original constituent substances. One of these substances is called the base substance, and the other substance that is placed inside the matrix substance is called the reinforcing, it is in form of powder or fibers(long, short) [3]. The most common experimental characterization procedure in the industry is bending tests, bending tests are carried out by placing a length of material under load and pushing down along the span to bend the material until failure [4].

2 Theoretical Part

2.1 Composite Materials

The word (composite materials) indicates that two or more materials are united to form a third useful substance. When granules or fibers are added to plastics, the resulting materials are called composite materials. The properties of these composites vary widely, depending on the nature, quantity, quality, distribution, and shape of the reinforcing material (granules or fibers) and on the type of resin used in the base material [5].

2.2 Matrix Materials

The base material binds the elements of the superimposed material and binds the parts together to form a compact system capable of withstanding external

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influences and transferring them to the strengthening phase [6].

2.3 Reinforces Materials

Reinforces are one of the main components of the composite material as they give the necessary strength and hardness to the composite material, as for the most common methods of reinforcement, it is the reinforcement with fibers, due to its great strength compared to resin materials, and the fibers are of different types and shapes, some of which are continuous, intermittent, or in the form of woven braids [7].

The bending strength test for composite materials is one of the important mechanical tests in manufacturing processes due to the increasing demand for high quality materials, The bending strength can be defined it is the resistance of the material to deformation under the influence of the load applied to it, and the maximum bending strength is the maximum load that the sample can bear without any collapse of the composite material. It depends on the most important factor depends on the most important factor:

1. Temperature and humidity.
2. Volumetric fraction of the reinforcing material.
3. The type of reinforcing material used, such as the fibers, in terms of (length, direction, and diameter).
4. Different weather conditions.
5. The presence of gaps in the overlapping material.

The bending strength test is divided into two parts:

1- Three-point bending strength test, It is the most common test, figure (1) shows the method of conducting the three-point bending strength test and this test can be calculated using the following relationship (1).

$$F.S=3PL/2bd^2 \quad (1)$$

Where:

F.S: Bending strength (N/mm^2) , P: Maximum sample load (N), L Distance between two loading points(mm),b Sample width (mm), d Sample thickness (mm).

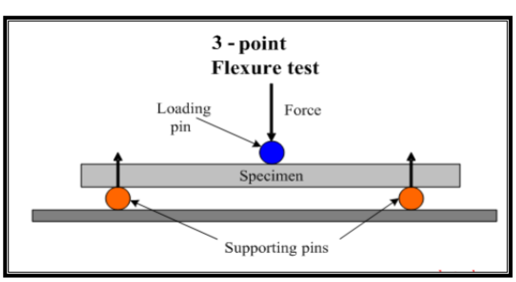

Fig. 1 Method of conducting the three-point bending strength test

Four-point bending strength test, as shown in the figure (2) the method of conducting the four-point bending strength test and this test can be calculated using the following relationship:

$$F.S= 3PL/4bd^2 \quad (2)$$

Where:

F.S: Bending strength (N/mm2) , P: Maximum sample load (N), L Distance between two loading points(mm),b Sample width (mm), d Sample thickness (mm).[8]

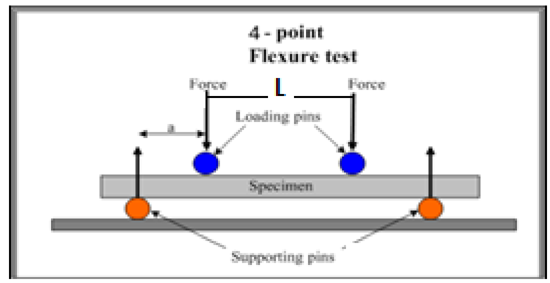

Fig. 2 Method of conducting the four-point bending strength test

Researchers presented many studies in this field, Aseel M.A. [9] study on the role of the interface of a polymer-based composite material (epoxy) reinforced with high-carbon steel wires, as the steel wires were roughened, and their geometry was changed. and studied the effect of roughing and the effect of changing the dimensions of the geometric shape on the binding strength of the interface and the mechanical properties of that material. The researcher noticed from the results of the examination that the binding strength of the interface of the composite material increases by (73.3%) Relative to the composite material reinforced with smooth steel wires of regular shape, as well as an improvement in the bending behavior and bending strength by an amount (11.77%) of the composite material reinforced with roughened steel wire and an increase in the absorbed energy required to break the material by (60%) Compared to the monolithic steel wire reinforced monolithic and smooth .Another study Al-Hassani, Sheelan [10] was conducted on the properties of creep and bending strength of epoxy composites Reinforced with glass fibers, as the tests were carried out at room temperature, the results showed that an increase in the volume fraction of the fiber increases the values of flexural strength and shear stress for all samples, as the results showed. The direction of the fibers within the composite material has a clear effect on the behavior of the material as these values increase for samples reinforced with glass fibers, unidirectional compared to samples reinforced direction . The researchers (Emmad and sheelan) [11] showed the properties of creep and flexural strength of epoxy composite materials reinforced with glass fibers where tests were carried out at room temperature, the results showed that an increase the volumetric fracture of the fibers increases the values of flexural strength and shear stress for all samples, as the results showed, the direction of the fibers within the overlapping material has a clear effect on the behavior of the material as these values increase for samples reinforced with unidirectional glass fibers compared to samples reinforced with random glass fibers. Another study(Alaee, Karihaloo)[12] preparation a composite material consisting of a polymeric base material epoxy reinforced with twisted wires and the possibility of using this superimposed material in the repair of concrete buildings by using two types of steel wires twisted. The first type is high in the number of wires twisted and the second is a small number of twisted wires, the samples were tested for flexural strength.

3 Practical Part

3.1 Sample preparation

In this research use composites materials consist of polymeric material (polyester) as a matrix (87% wt.), the polyester having mechanical properties as shown in Table1 and the reinforced is steel fibers (13% wt.) were used with different geometrical shapes in section area, These wires are distinguished with its high resistance and durability and its low cost, As well as its resistance to weather conditions Figure 3 (circular, square, and triangle) Table 2. Show mechanical properties of steel wires.

Table 1 Mechanical properties of polyester resin

Density	Poisson's ratio	Young's modulus	Thermal conductivity
1350Kg/m3	0.33	1GPa	0.21 w/mc°

Table 2 Mechanical properties of steel fiber.

Density	Poisson's ratio	Young's modulus	shear modulus
7.850Kg/m^3	0.30	210 GPa.	80 GPa.

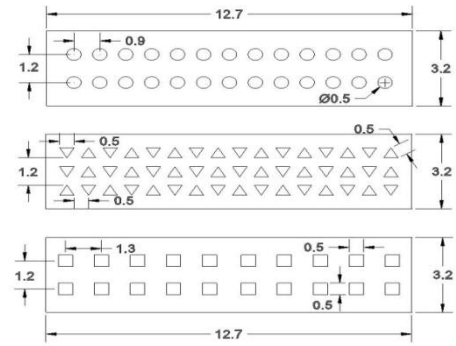

Fig. 3 Fibers with different cross section area shapes for composites materials (All dimensions are in mm)

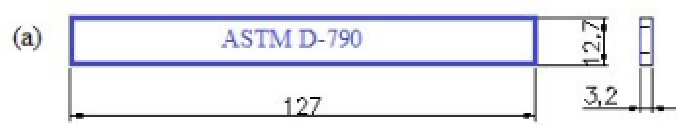

Fig. 4 Bending Test

4 Numerical Analysis

Three-point bending was chosen, finite Element analysis was performed using the Autodesk Inventor program, the sample that were used with dimensions in mm were selected according to international specifications ASTM Standard D-790. Figure 4 represents a schematic diagram of the dimensions of the sample. The first step when using the program was (Model Wizard) to define the drawing and then define the field of work (Solid Mechanics) and finally the field of study (stationary). The second step (Model Builder) involved making the grid (Mesh) in order to bond the steel fibers with the resin for each model to be study [11].

5 Results and Discussions

Figures (5 and 6) show the load applied to the matrix material was 80N without reinforcement (100% polyester) the failure is done at load 90N as shown in Table3

Table 3 Matrix material without reinforcement

Composite metal	Load (N)	Deflection (mm)	Von – Misses stress (Mpa)	Failure Load (N)
100% Polyester	80	11.8	29.19	90

Fig. 5 Load applied to the matrix material 100% polyester

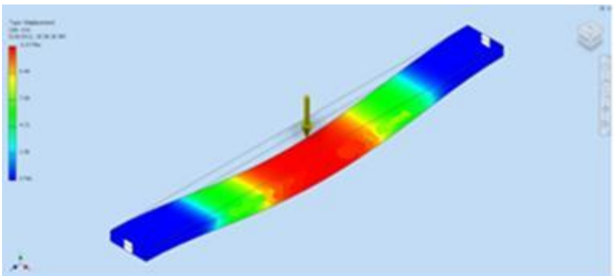

Fig. 6 Load at 80N with deflection 11.8 mm matrix material 100% polyester

The composite material reinforced with steel wires (circular cross-section area), the load applied was started from 80N until the failure done at 1500N, Figures (7, 8, 9, 10) show the load applied until failure. Table 4 shows the loads applied with deflection.

Table 4 Loads applied to composite material reinforced with steel fibers (circular shape)

Load (N)	Deflection (mm)	Von – Misses stress (MPa)
80	0.503	575.7
200	1.258	1439
400	2.517	2879
600	3.775	4318
800	5.033	5757
1000	6.291	7197
1200	7.549	8638
1300	8.179	9356
1400	8.808	10075
1500	9.437	10795

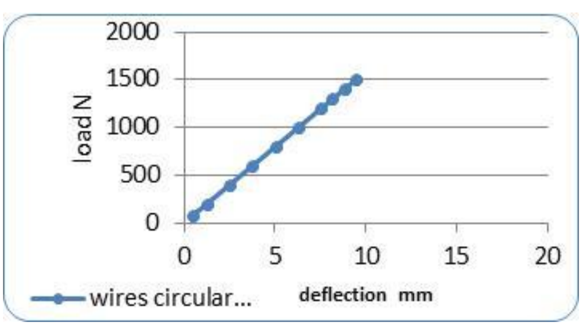

Fig. 7 Relation between load and deflection for composite material reinforced circular wires

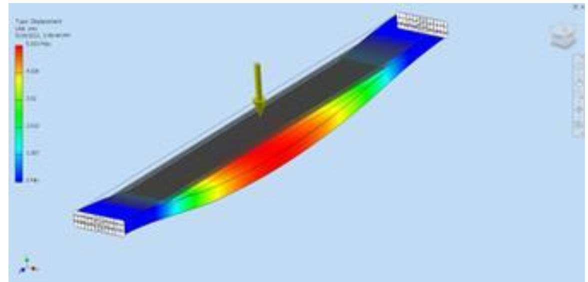

Fig. 8 Load at 200N with deflection 1.258 mm. composite materials

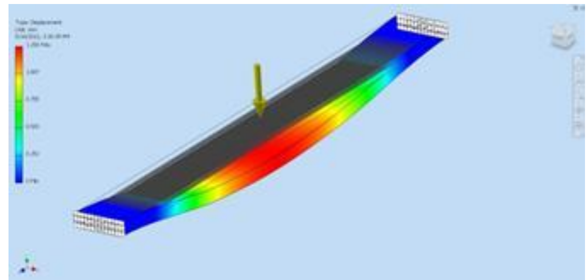

Fig. 9 Load at 800N with deflection 5.033mm.composite materials

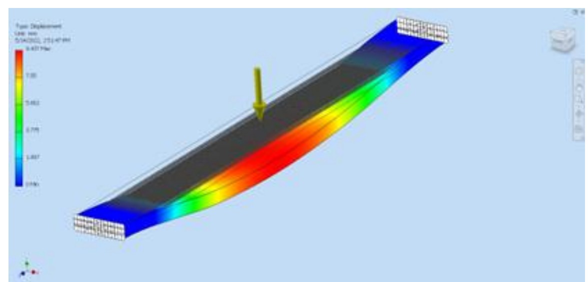

Fig. 10 Load at 1500N with deflection 9.347 mm composite materials

The composite material reinforced with steel fibers (triangle cross-section area), the load applied was started from 80N until the failure done at 1200N, Figures (11, 12, 13, 14) show the load applied until failure. Table 5 shows the loads applied with deflection.

Table 5 Loads applied to composite material reinforced with steel fibers (triangle shape)

Load (N)	Deflection (mm)	Von – Misses stress (MPa)
80	0.912	391.4
200	2.279	978.8
400	4.558	1957
600	6.837	2936
800	9.116	3915
1000	11.40	4896
1200	13.67	5873

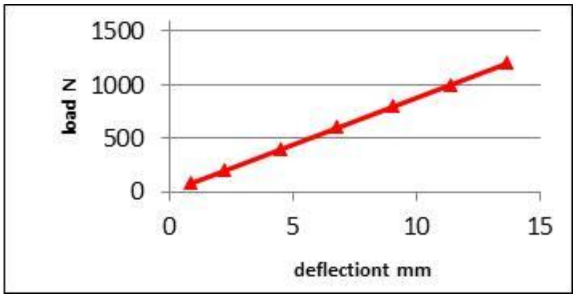

Fig. 11 Relation between load and deflection for composite material reinforced triangle wires shape

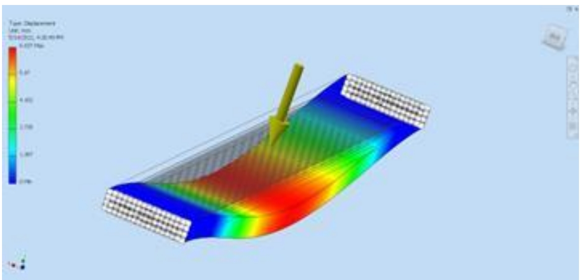

Fig. 12 Load at 200N with deflection. 2.279 mm composite materials

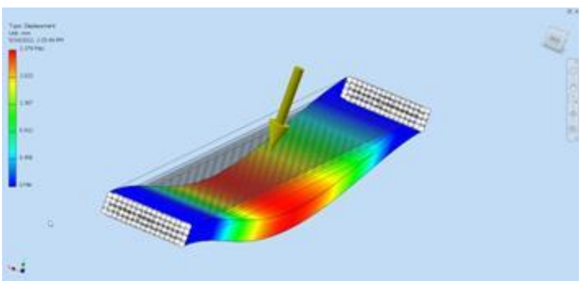

Fig. 13 Load at 600N with deflection 6.837 mm composite materials

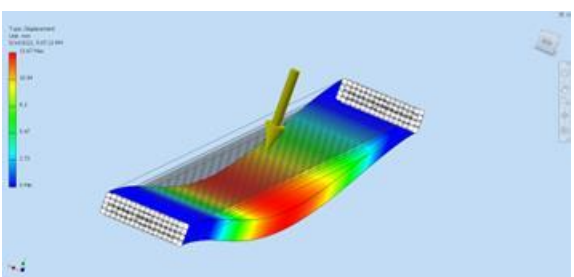

Fig. 14 Load at 1200N with deflection 13.67 mm composite materials

The composite material reinforced with steel wires (square cross-section area), the load applied was started from 80N until the failure done at 1000N, Figures (16,17, 18) show the load applied until failure. While figure 19 shows relation between load and deflection for all types of fibers, and Table 6. shows the loads applied with deflection.

Table 6 Loads applied to composite material reinforced with steel fibers (square shape)

Load (N)	Deflection (mm)	Von – Misses stress (MPa)
80	1.087	399.3
200	2.717	998.3
400	5.433	1997
600	8.15	2995
800	10.87	3993
1000	13.58	4992

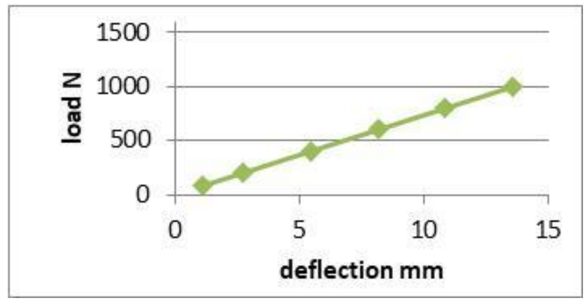

Fig. 15 Relation between load and deflection for composite material reinforced square wires shape

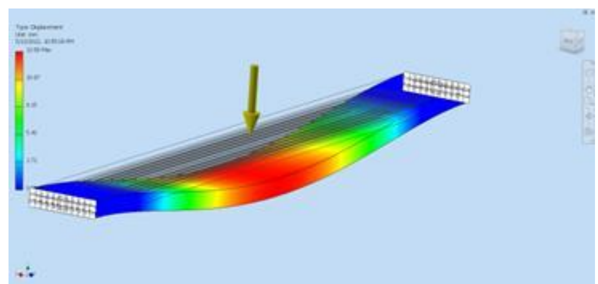

Fig. 16 Load at 200N with deflection 2.717 mm composite materials

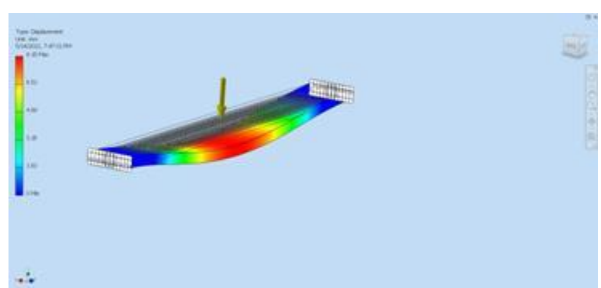

Fig. 17 Load at 600N with deflection 8.15mm composite materials

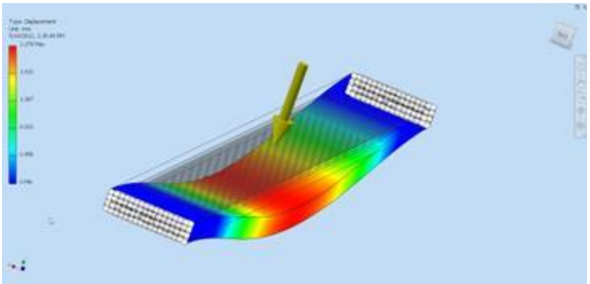

Fig. 18 Load at 1000 with deflection. 13.58 mm composite materials
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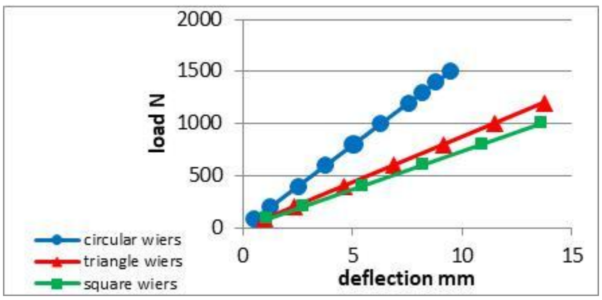

Fig. 19 Relation between load and deflection for composite material for all types of fibers

Figure 19 shows that the composite material reinforced with steel wires with a circular in a cross-section area has a bending strength higher than composite materials that reinforced with triangle and square in a cross-section area steel wires, because of the difference in the geometry of the sectional area of each type This is due to the difference in the bonding strength of the interface between the matrix material and the reinforcing material, where the bonding strength between the matrix material and the reinforcing material in curved surfaces that do not have angles is higher than those that contain angles. The bonding area of the interface between the matrix material and the reinforcing material at the head of the corner is weak, due to the lack of continuity of the bonding force between the matrix material and the reinforcing material, and this leads to early failure due to the formation of a gap that increases the concentration of applied stresses, which causes separation and slippage of the matrix material from the reinforcing material, thus failure occur .Also from figure (6) shows the lowest bending strength was found in the unreinforced composite material.

6 Conclusion

The results showed that the flexural strength values change according to the shape of the reinforcing material in the composite materials.

The bonding strength between the matrix material and it is reinforcing is very important ,to keep the composite material from early failure that is depends on the shape of the wire section area .

The internal stresses are concentrated at the vertex of the angles which is the main cause of failure.

The composite material reinforced with wires is higher in bending strength than non-reinforced composite materials.

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