Experimental Study of Mechanical Properties of Unidirectional Woven Carbon Fiber and Fiber Glass - Epoxy Composites

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Abstract

In this study, the mechanical properties of an epoxy, unidirectional woven carbon and fiberglass composite were investigated experimentally. ASTM used for preparing the composite specimen. Different ranges of mixing ratios of woven carbon and fiberglass with epoxy are studied. Tensile, impact and bending test are carried out to investigate the mechanical properties for produced new composites. After testing the mechanical properties of the specimens, it is noted that adding of unidirectional woven carbon layers will leads to strengthens the samples. The mechanical properties of woven carbon composite are far superior to those of woven carbon composite with fiberglass.

Keywords: Unidirectional Woven Carbon, Epoxy, Fiber glass, Composite material.

دراسة تجريبية للخصائص الميكانيكية لألياف الكربون المنسوجة أحادية الاتجاه والألياف الزجاجية - مركبات الإيبوكسي

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الخلاصة:

في هذه الدراسة ، تم فحص الخصائص الميكانيكية لمركب الكربون الإيبوكسي ومركب الألياف الزجاجية المنسوج أحادي الاتجاه بشكل تجريبي. تم استخدام ASTM لتحضير العينة المركبة. تمت دراسة نطاقات مختلفة لنسب مزج الكربون المنسوج والالياف الزجاجية مع الايبوكسي. تم إجراء اختبار الشد والصدمة والانحناء للتحقق من الخواص الميكانيكية للمركبات الجديدة المنتجة. بعد اختبار الخصائص الميكانيكية للمركب الفضائي، لاحظ أن إضافة طبقات الكربون المنسوجة أحادية الاتجاه ستؤدي إلى تقوية العينات. الخصائص الميكانيكية لمركب الكربون المنسوج أعلى بكثير من تلك الخاصة بمركب الكربون المنسوج مع الألياف الزجاجية.

1. Introduction

In recent years, woven fabric reinforced composite materials have gained popularity in structural applications due to advantages such as reasonable manufacturing costs, light weight, ease of handling, and wide adaptability to tape strips and the like engineering materials. Alternative reinforcements to standard systems have become generally considered as an interest in using composite materials for structural purposes [1]. polymer composite materials are lightweight and have a high express modulus; However, only a few types of natural fibers are readily available. Vacuuming reduces the mechanical properties of carbon fiber reinforced composites [2]. To distinguish the properties of the composite materials from those of the constituent components, the compounds contain two or more distinct phases with an amount of a secondary phase greater than 5%. The matrix material, which can be metallic, polymeric or crystalline, is single phase. The consolidation stage, which can be fibrous or particulate, is the other stage. In the manufacture of composite materials, fibrous reinforcement is critical [3].

Due to their light weight, desirable mechanical qualities, and ability to be molded into complex shapes, epoxy resin composite films have seen increasing application in the aerospace industry in recent years. Epoxies have a wide range of uses in composites due to their chemical and thermal resistance, as well as good thermomechanical qualities such as strength, modulus of elasticity and glass transition temperatures, which can be changed by modification chemical composition and kinetic manipulation [4]. Carbon fiber (CF) has been widely adopted as an essential structural and functional material in high performance lightweight structural applications due to its superior mechanical and

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thermal properties [5]. Woven fabric composites have advantages such as good integrity, compatibility and balance properties at the fabric level. Although layers of glass woven fabric are preferred in practice, additional layers are required to achieve the desired design strength. This results in a larger nominal size, which increases the weight of the component/structure, making it more popular in structural applications such as vehicles, aircraft, yachts, and civil structures [5].

Composite materials offer superior mechanical qualities to simple materials, such as high hardness, strength and impact resistance. As a result, they have been widely used in the aerospace, aircraft and automotive industries [6].

1.1 Composite preparation

To process composite materials, several manufacturing techniques are available, including hand molding, distillation, filament winding, vacuum bag forming, and resin transfer molding. The hand position technique is preferred for this work due to its simplicity and robustness [3]. One of the most popular procedures for combining resin and fabric components is the hand position technique [7].

This method involves manually inserting the fiber reinforcement into a one-sided mold, then forcing the resin through the fiber mats using hand rollers. The ability to produce very large and complex parts with shorter manufacturing times is a major advantage of the hand-to-hand approach. Simple equipment and tools, which are much less expensive than other production methods, are also the advantages of the drawing technique. A manual fitting procedure was used to generate all composite samples [8].

The composite is prepared from epoxy as well as strong jute fibers (oriented 0/90) with 760 GSM titanium dioxide and TiO2 filler particles. Woven jute mat, Araldite LY556 epoxy resin and HY951 hardener based on Triethylenetetramine Ltd (TETA). Using hand lay technology and this method was adopted by [9] 10:1 epoxy for curing. For an ASTM D3039-79 tensile test performed on a UTM with a dumbbell-shaped specimen and a crossover speed of 2 mm/min, and for bending testing, ASTM D790 is approved with 1.5mm/min.

S2-glass-woven/reinforced epoxy, woven IM7-graphite/reinforced epoxy, and woven S2-glass-IM7-graphite fiber/epoxy were used by [10] for research purposes. Vacuum Assisted Resin Transfer Molding (VARTM) technology is used to stack pain weave woven warp fabrics and the composite was manufactured and designed by EDO Fiber Innovations in 101.6mm 101.6 mm sheets , the samples were cured at 177 °C. A 0.3 mm thick glass fabric as reinforcement and epoxy with R101 and H101 matrices respectively are used by [8], and also produced a rectangular volume to perform tensile tests using ASTM D638 (165x19x4mm) or tensile testing and ASTM D790 (130x12x4mm) for bending testing.

A WSR618 epoxy resin as matrix with benzene dimethylamine as resin curing agent and butyl phthalate as hardener were used by [11]. The layer-by-layer manual stacking process using room temperature vacuum technology and magic pressure treatment is used to prevent cracks and cracks between layers.

Conductive glass fibers and carbon fibers were used as reinforcements and epoxy as the matrix material by [12]. Epoxy resin and Tri Ethylene Tetra Amine (TETA) hardener were supplied by Atul Ltd. % 15, %30 , 45% and 60% fiberglass and carbon fiber in 40% epoxy matrix. It appears that the mechanical properties of carbon fibers were superior to others.

Aramid twill fiberglass, twill aramid fiber, single-shell carbon fiber, unidirectional glass and unidirectional carbon fiber were used by [2]. An epoxy resin (MGS L285) was mixed with a solid (HGS L285) in a volume ratio of 50/100. The compound was made by a manual laying process. The composites were cured at 75°C in an oven after curing at room temperature for 24 h. Steel plates were stacked on the edges of some samples to prevent failure. The carbon fiber reinforced epoxy compound had much better performance than the glass fiber reinforced epoxy compound, due to the unidirectional fibers reinforcing the epoxy compound.

Another type such as LY556 and HY591 epoxy resin matrix, 0.4mm thick bidirectional jute fiber reinforced and woven S-glass fiber were used by [9]. And the manufacturing technique is to be applied by hand. For mechanical test specimens used in tensile with ASTM-D3039, for impact test, Izod impact test was conducted according to ASTM-D256 and three-point bend test according to ASTM-D790 with sample size (80X8X3mm3). It is observed that in the field of automotive and some components of aerospace applications, high strength, durability and stiffness with the combination of two different levels of fibers play a critical role.

The pilot of this study which is the part two shows all the details on the working procedures and the stages of preparation of the composite materials.

2. Experimental Study

2.1 Materials

In this study, the mechanical properties of unidirectional woven carbon/fiberglass epoxy are investigated in an experimental scientific procedure. The characteristics of each material used is explained below.

2.1.1 Epoxy

For sample preparation, epoxy with its hardeners is used. Master Brace ADH 1406 is a two-part epoxy fixing, fixing and adhesive mortar produced in the correct mixing ratio. The temperature of the material should be between 15 and 25°C before mixing. Part A is a base while B is a reactor A which is a hardener with a mixing ratio of 75:25. It was necessary to mix two components with by Biddle for 3-5 minutes.

2.1.2. Unidirectional woven carbon

The type is used is SikaWrap-230 C is a unidirectional woven carbon fiber fabric with mid-range strengths, designed for installation using the dry application process, see Figure 1.

(a) (b)

Figure (1): (a) Unidirectional carbon fiber (b) fiber glass

2.1.3. Fiber glass

360 Direct Roving is coated with a silane- based compatible with unsaturated polyester, vinyl ester, and epoxy resins. It is designed for filament winding, pultrusion, and weaving applications. By measuring the diameter via Vernier, the dimeters of the fiber glass known, see Figure 1.

2.2. Fabrication of composite layers

For the preparation of the samples, molds were necessary. The molds are built with a 3 mm thick plate with a hole inside 200 mm x 100 mm, see Figure 2, for each test AutoCAD 2022 is used for the design of the mold sample, with different parameters for each test, see Figure 2, and then a CNC machine is used to cut the prepared composite samples.

Figure (2): The plate mold

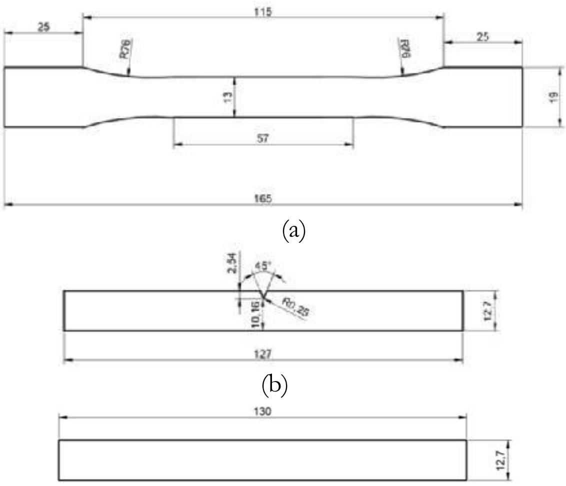

Figure (3): AutoCAD drawing a) tensile test sample b) impact test sample c) flexural test sample

For knowing controlling the mixing ratio of the epoxy for fulfilling the mold and doing the correct percentage of UDWC with fiber glass these calculations was done.
For tensile sample:
Volume=Area x thickness
V = 2509 x 3 = 7.527 cm²
Wight of sample = 1.7 x 527 =12.7957gm
3% of UDWC = 0.3838 gm
5.5% of UDWC = 0.7037
3% of UDWC & 3% fiber glass = 0.3838 + 0.3838 = 0.7676 gm
1.5% of UDWC = 0.1919 gm

For impact and flexural sample all steps repeated the quantities as bellow:
Impact sample
V = 16.1 x 3 = 4.83 cm²
Wight of sample = 8.211 gm
3% of UDWC = 0.2463 gm
5.5% of UDWC = 0.45160 gm
3% of UDWC & 3% OF FIBER GLASS = 0.3838 + 0.3838 = 0.7676 gm
1.5% of UDWC = 0.1231

Flexural sample
V = 16.51 x 3 = 4.953 cm²
Wight of sample = 8.4201 gm
3% of UDWC = 0.22526 gm
5.5% of UDWC = 0.4631 gm
3% of UDWC & 3% of fiber glass = 0.2526 + 0.2526 = 0.5052
1.5% of UDWC = 0.1263 gm

To make the compound, a robotic hand jet was used layer by layer, with each sample having a different layer from the others. To see the strength of the compound and its ability to test time, see the steps in the figures respectively.

Figure (4): Preparing the mold by using on backside a limpid paper and adopting a stick for all sides.

Figure (5): The front pf the mold is cased inside for ease emerging and using sticks for adopting.


Figure (6): First layer epoxy resin

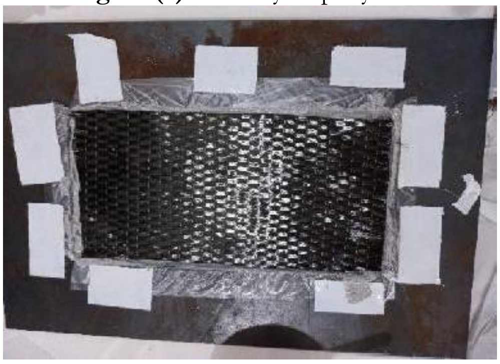
Figure (7): Second layer woven carbon

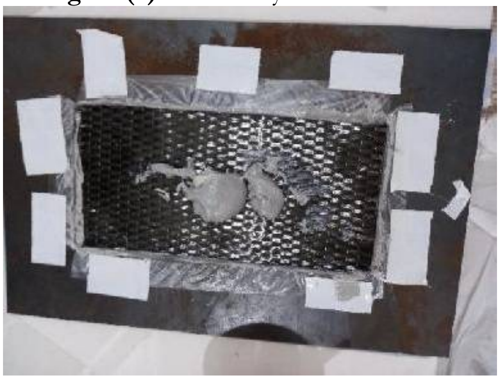
Figure (8): Third layer conducted

These steps are repeated for each composite sample, and in order to verify the mechanical properties of the samples which are composite materials, three tensile, impact and bending tests were carried out. Below are the details of each test.

3. Mechanical tests

Preparing the specimen and coding the samples. For the mechanical tests three group of specimen are prepared group (A2-0, A2-1, A2-2, A2-3, A2-4, A2-5, and A2-6) for tensile experimental tests, group (B2-0, B2-1, B2-2, B2-3, B2-4, B2-5, and B2-6) for impact experimental tests and group (C2-0, C2-1, C2-2, C2-3, C2-4, C2-5, and C2-6) for flexural experimental tests, as indicated in Table 1.

Table (1): Coding each specimen for the experimental tests

Code of composite	*Carbon %*	*Fiber glass %*	*Layers of composite*
A2-0, B2-0, C2-0	*0*	*0*	*Epoxy*
A2-2, B2-1, C2-1	*3*	*0*	*Ep-C-Ep*
A2-2, B2-2, C2-2	*5.5*	*0*	*Ep-C-Ep-C-Ep*
A2-3, B2-3, C2-3	*1.5*	*0*	*Ep-C-Ep*
A2-4, B2-4, C2-4	*3*	*3*	*Ep-C-Ep-F.G-Ep*
A2-5, B2-5, C2-5	*3*	*1.5*	*Ep-C-Ep-F.G-Ep*
A2-6, B2-6, C2-6	*1.5*	*3*	*Ep-C-Ep-F.G-Ep*

3.1. Tensile test

To perform this test use ASTM D638. The XHC-50 Ring Stiffness Tester ran a sample slicer which had software showing all the test details, cross head speed was 5mm/min, operating with a 100 kN load cell with advanced control. The tensile specimen were showed in Figure 9.

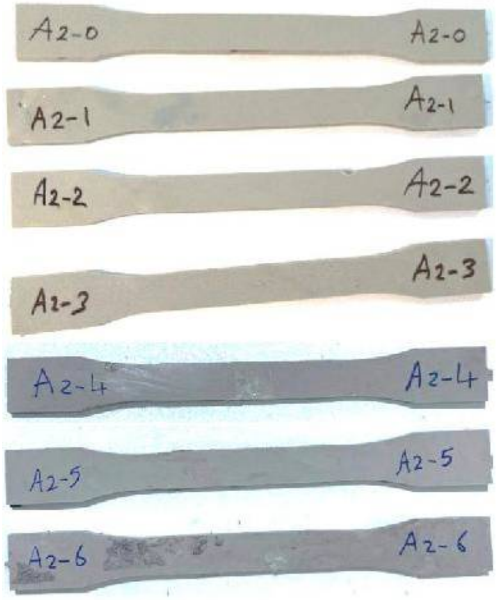

Figure (9): Tensile test samples

3.2 Impact test:

To perform this test, ASTM D256 was used. The machine that performed the test was a special XJJD-50 series for Charpy impact testing on metal and plastic. By smart screen recorder, load and power details are determined. The impact specimen samples were showed in Figure 10.

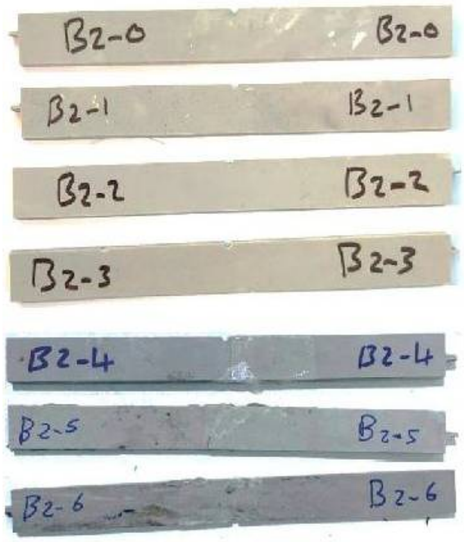

Figure (10): Impact test samples

3.3 Flexural test

This test was performed by ASTM D790 and XWW-5KN by software all details are known. The value of the bending units is determined. Seven samples were generated to perform this test and the average quality, cross head rate of 10 mm/min was calculated for the composite with a span length of 80 mm. The specimen for flexural tests were showed in Figure 11.

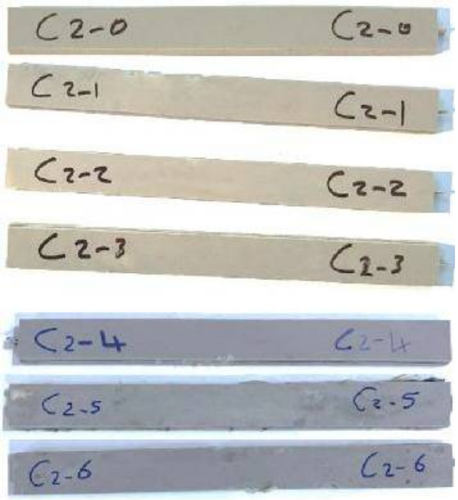

Figure (11): Flexural test samples

4. Experimental Results and Discussion

4.1 Impact test

Table 2 shows results of impact test of epoxy composites reinforced with unidirectional woven carbon fibers, as well as the strength of the glass fibers. As can be seen from the table, as the carbon layers increase, the kinetic energy in the composite samples also increases due to the hard bond between the epoxy fibers and the UDC fibers. On the other hand, by adding 3% glass fiber to the sample and mixing it with the other compound, the energy will be very close to that of UDC fiber, and the results are shown in Fig. 12. The maximum impact force was 5.43 J due to the presence of the largest layer on it. See Figure 13. This test also indicated the rate of hardness and the amount of energy absorbed by the composite sample during fracture, and the ductility would increase with increasing energy. It can be seen that the most flexible sample is B2-2 compared to the others. Also, the B2-4 sample is 4.57 J, which is close to 5,430, but most layers of UDWC are still the highest.

Table (2): Impact test results.

Composite code	*Energy (Joule)*
B2-0	*0.059*
B2-1	*1.059*
B2-2	*5.430*
B2-3	*1.388*
B2-4	*4.573*
B2-5	*3.083*
B2-6	*0.701*

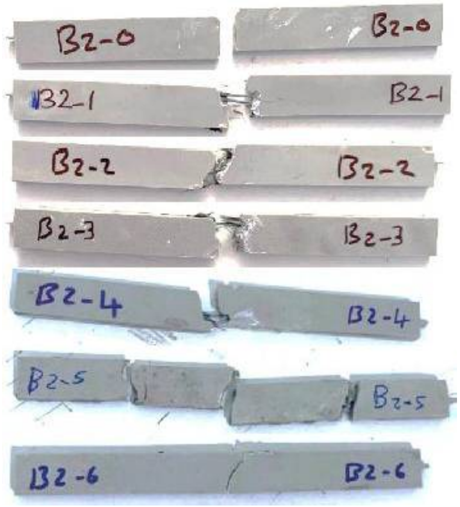

Figure (12): Impact samples

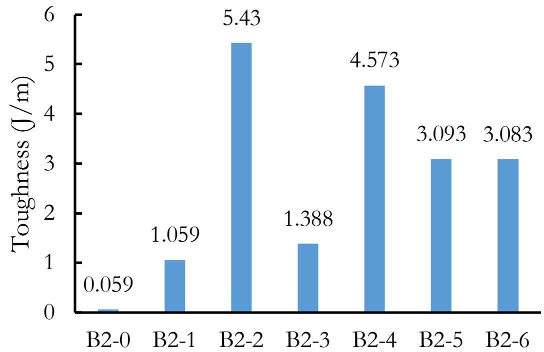

Figure (13): Impact toughness for (B2-0, B2-1, B2-2, B2-3, B2-4, B2-5, and B2-6)

4.2 Tensile test

As can be seen in Table 3 the quantities achieved by this test. The achievement of the maximum pressure distribution in a mixture of UDC and fiber glass is 158 (MPa) due to the maximum resistance to elongation and ductility and the very strong inter-composite bond leads to this. Also, the maximum loading in the bilayer carbon in sample A2-2 is due to the increased strength, which signifies a positive strain rate. Also, the minimum value of the tensile strength is in the A2-0 sample, it is clear for all the reasons that there is no layer of compound on it and the addition of two layers of carbon also has a great value for increasing strength and as can be seen from the graph, the stress value of this sample is higher than that of sample A2 -4 because the sudden deflection of the sample from higher value cannot reach high stress value. The results of the tensile test were explained in Figure 15. The tensile specimen after the experimental tests were illustrated in Figure 14.

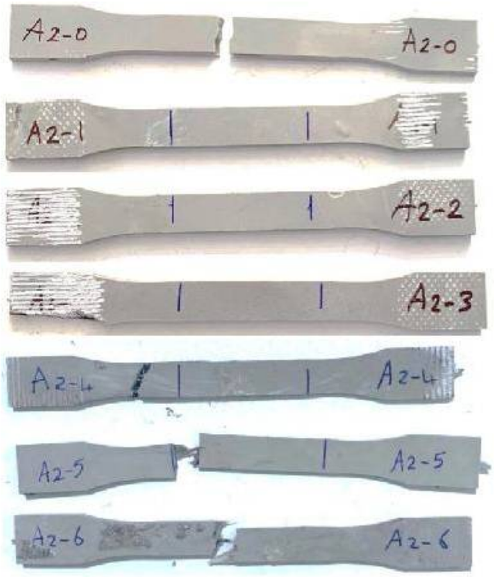

Figure (14): Tensile samples

Table (3): Tensile test results.

Composite code	Load (N)	Stress (MPa)	Strain
A2-0	190	4.25	9.1
A2-1	4050	76	7.3
A2-2	6650	126	9.2
A2-3	709	14	1.34
A2-4	6610	158	4.89
A2-5	2060	135	4.1
A2-6	620	14	1.06

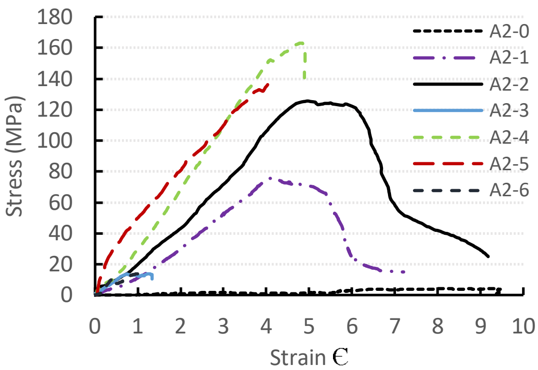

Figure (15): Stress-Strain curves for tensile experimental tests of (A2-0, A2-1, A2-2, A2-3, A2-4, A2-5, and A2-6)

4.3 Flexural test

The variance of flexural strength with the percentage of UDWC and fiberglass is shown in Table 4. The stress increased by this additional percentage, as did the maximum (109 MPa) in the load (226N) containing two coats of UDWC. The flexural behavior of the composite was increased by the interfacial bond between the UDWC and the matrix. The bending extension of each sample depends on the samples resistance to bending because the resistance also increases. Due to the rigid bond between the B2-3 composite sample, it has a maximum value of 13.44 mm, due to there is only one layer of UDWC. The flexural samples after experimental tests were picked in Figure 16. The stress strain curves for all the specimen illustrated in Figure 17.

Figure (16): Flexural samples

Table (4): Flexural test results.

Composite code	Load (N)	Stress (MPa)	Strain	Flexural extension (mm)
C2-0	36	17	0.0059	1.49
C2-1	51	24	0.0081	2.2
C2-2	226	109	0.025	6.1
C2-3	75.18	69	0.06	13.44
C2-4	75	36	0.0071	1.6
C2-5	29.12	26.75	0.055	7.63
C2-6	40	41	0.042	8.14

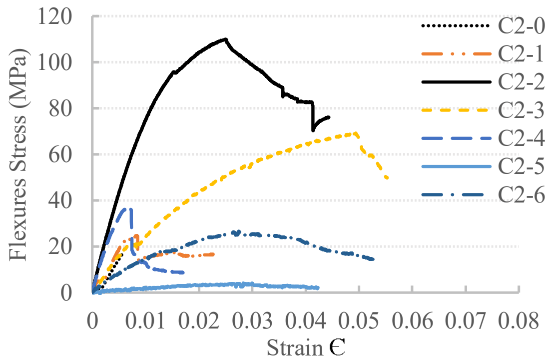

Figure (17): Stress-Strain curves for flexures experimental tests of (C2-0, C2-1, C2-2, C2-3, C2-4, C2-5, and C2-6)

5. Conclusion

An experimental study on unidirectional woven carbon epoxy resin and S-glass fiber for composites has been studied and the following points have been completed.

1. Glass fibers based on epoxy resin with UDWC have been successfully analyzed according to ASTM standards.
2. It is found that the maximum tensile strengths of A1-4 and A2-2 are respectively 158 MPa and 126 MPa of the compounds.
3. The measured flexural modulus with maximum displacement of the sample is 125.728 mm, which shows much better toughness with large deformation in the extension of the material.

4. Due to the presence of two layers of UDWC, a higher fracture work area was observed across the A2-2 sample which was 5.430 J of impact energy 2 compared to the other samples.
5. However, research in the current study of composite materials proves the behavior of mechanical properties, and it has been found that stronger, tougher, and tougher composites have greater strength, stiffness, and toughness.

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