TENSILE STRENGTH AND IMPACT RESISTANCE OF CARBON, GLASS, KEVLAR, AND STEEL REINFORCED PLAIN AND HYBRID COMPOSITES

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The present study experimentally investigates tensile strength and impact toughness of plain composites made of carbon, glass, Kevlar, and steel wire mesh fabric; and hybrid composites of carbon-Kevlar reinforcement with polyethylene matrix. Composites are prepared by employing a hot press technique, where reinforcement fabrics, as well as polyethylene film are stacked in varying number of layers. Samples were cut from the composite plates for uniaxial tensile loading and low-velocity Charpy impact tests, as well as for resin burn-off process. It is shown that number of layers affects tensile and impact characteristics, as in general, tensile strength of composites increases with number of layers. Also, impact energy absorbed by the specimens is also proportional to number of layers.

Keywords: *Plain composites, hybrid composites, hot press, tensile test, Charpy impact test*

1. Introduction

Composite materials are widely used due to their good mechanical properties, in many fields such as automotive, aerospace, military applications, construction, health, and sports. The reason why they are preferred is their relatively superior strength, light weight, anti-corrosive properties and resistance to heat.

A low-speed impact test was applied to PMC materials of equal thickness produced under the same conditions as Kevlar reinforced polymer matrix composites using the hot press technique. It has been observed that the amount of energy absorbed by the composite material decreases with the increase of the impact energy [1]. Composites were produced using three different resins (polyester, epoxy, polypropylene) to produce three-layer carbon-Kevlar. Carbon-Kevlar/polyester and Carbon-Kevlar/epoxy were produced by hand lay-up method and Carbon-Kevlar/Polypropylene was produced by hot press technique. When tests are carried out to determine the mechanical properties of the produced materials; It has been observed that the tensile and impact strength of CK/epoxy material is higher than the others [2]. Non-hybrid and hybrid (Glass, Aramid and Carbon) fabric epoxy composites were produced with different stacking sequences by hand lay-up method and then by hot press technique. In the experiments to determine the mechanical properties; It was observed that the stacking arrangement did not significantly affect the hardness and tensile strength of the material but affected the bending strength. Non-hybrid composites showed higher stiffness and fracture behavior than the others [3]. Carbon fiber reinforced metal matrix composites (Cu, Ni, Ti, Al, and their alloys) were produced by three types of solid, liquid and deposition (ion plating and plasma spray) methods, and carbon fibers were produced by hot press technique and the wear resistance and morphological properties of the materials produced were experimental. was scrutinized. [4] In order to reveal the effective properties of the composite material, the effect of pressing temperature on the physical properties of the matrix, the mesoscopic structure of the fabric and the macroscopic mechanical properties were experimentally investigated [5]. Polyamide 6 (PA6) based single polymer laminate composites produced by nylon reactive injection molding and press molding techniques were examined mechanically and morphologically by reactive processing techniques, and it was seen that the composite material produced by press molding technique had good mechanical and thermal properties [6].Unidirectional composites of jute spun yarn/polylactic acid were produced by press molding technique and the effect of mold temperature on the mechanical properties of the composite material, as well as production quality and cross-section observation were examined [7]. Mechanical and physical examination of date/bamboo fiber reinforced epoxy hybrid composites produced by hot press technique [8]. Ramie fabric/epoxy composite laminates are produced by vacuum assisted resin infusion molding and hot press technique. As a result of examining the mechanical and morphological properties, it was observed that the tensile strength decreased at high temperature and pressure [9]. Aramid fiber reinforced polypropylene-based fiber metal laminate composites were produced by hot press technique by stacking and the results were observed by performing a tensile test [10]. The physical and mechanical behaviors of thermoplastic molding of wood polymer composites under the hot press

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technique were investigated. It has been observed that it increases the impact strength, surface hardness and tensile strength of the fasteners [11]. He investigated the optimization of hot press parameters related to the tensile strength of unidirectional long kenaf fiber reinforced polylactic acid composites. The optimization method was examined rather than the parameters affecting the tensile strength, and as a result, the strength of the composites was determined in the light of the data obtained according to the variability of factors such as temperature, pressure, and heating time [12]. The effect of fillers on the mechanical behavior of carbon fiber/vinyl ester hybrid composites was investigated. Hybrid composites were produced by hand lay-up, stacking and hot press methods, and because of the experiment, it was observed that the tensile and flexural strength of the filling materials increased as well as the hardness value [13]. The mechanical and tribological properties of compression mold parameters of multi-wall carbon nanotube/glass/Kevlar/epoxy composites were experimentally investigated, and their optimization was discussed. It has been observed that the tensile strength and wear resistance of nano-reinforced hybrid composites give better results than plain composites [14]. A multi-layered carbon-fabric/polycarbonate laminate thermoplastic composite was fabricated in two steps using the hot press technique. Uniaxial tensile test was subjected to impact test and morphological tests, optimal values of press temperature parameters were selected, and results were examined [15].

In this study, plain composites reinforced with carbon, glass, Kevlar (aramid), steel fabric and hybrid carbon-Kevlar fabric with polyethylene matrix were prepared in the form of laminates with the help of a hot hydraulic press machine, while all of which were formed in different layers and by stacking. Test samples of the prepared composite materials were obtained in accordance with the standards and the mechanical properties of the composite materials were examined by subjecting the samples to tensile test and low-velocity Charpy impact tests.

2.Material and method

2.1.Preparation of Composites

Mechanical properties of polyethylene (PE) and reinforcement materials (glass, carbon, Kevlar, and steel fabrics) are presented in Table 1. The fabrics were obtained from the company METYX located in Istanbul, whereas Polyethylene was supplied from a local supplier.

Composites prepared in the present study and their stacking configuration are presented in Table 2. The samples were prepared by using a hot hydraulic press technique, which provides a better fiber-to-resin bonding. Fabrics and polyethylene (PE) films were cut into 250 mm by 250 mm sheets, which were stacked in alternating sequence and enclosed with acetate sheets of 300 mm x 300 mm to prevent the hot press from being contaminated by molten PE when heated. Then, the stackings were centered between two stainless-steel plates and hot plates of the compression molding press, while stacking order for a two-layer composite is shown in Fig. 1, for instance. Subsequently, the platens were closed, the hot press plates were heated to temperatures between 150 and 180 °C for 40-120 mins depending on the fabric and number of layers, under a compression pressure of 470 kPa. After this compression cycle, plate temperature was reduced to room temperature (25 °C) and maintained for 30-40 minutes, to prevent thermal shock and provide better bonding, while the pressure was maintained at 470 kPa until the temperature reached 25 °C. Once plate temperature reached 25 °C, the composites were taken out of the compression molding frame. Eighteen specimens were fabricated for each type of composite, and three samples of each specimen were considered.

3.Experimental

3.1.Tensile Loading Test

Tensile tests were carried out using a universal tensile test equipment, Instron 3382. Each tensile test was repeated three times and average of the collected data are presented herein, therefore, three specimens were cut out from each type of composite with dimensions of 20 mm x 250 mm, complied with ASTM A-3039 standards. To connect the specimens to the test equipment, copper plates were affixed to both ends, for the specimens to be kept steadily by the jaws during the tensile loading process. Tensile tests were conducted under 5 kN force at a rate of 5 mm/min. Thus, the tensile tests can conveniently be assumed to be quasi-static.

Table 1

Reported mechanical properties of the components of the composites

Material	**Density (g/cm^3)**	**Ultimate tensile strength (MPa)**	**Ultimate tensile strain (%)**	**Tensile modulus (GPa)**
Glass fabric (plain woven)	1,80	8,27	0,176	46,97
Carbon fabric (unidirectional)	1.76	3950	-	238
Carbon fabric (twill woven)		12,66	0,162	78,04
Kevlar fabric	1,44	12,89	1,801	7,158
Hybrid carbon-Kevlar fabric		9,96	0,445	22,51
Steel fabric		5,52	0,104	52,86
Polyethylene		-	-	-

Table 2

Stacking configuration of the composites (C: carbon, G: glass, K: Kevlar, ST: Steel, UD: Uni-directional, W: Woven)

Composite	Definition	Stacking sequence	Thickness [mm]
G-2L	Two-layer glass fabric	$[0^{G}]_2$	0.79
G-4L	Four-layer glass fabric	$[0^{G}]_4$	1.53
G-6L	Six-layer glass fabric	$[0^{G}]_6$	2.37
K-1L	One-layer Kevlar fabric	$[0^{K}]_1$	0.62
K-2L	Two-layer Kevlar fabric	$[0^{K}]_2$	1.52
K-3L	Three-layer Kevlar fabric	$[0^{K}]_3$	1.90
CK-1L	One-layer carbon-Kevlar hybrid fabric	$[0^{CK}]_1$	0.90
CK-2L	Two-layer carbon-Kevlar hybrid fabric	$[0^{CK}]_2$	1.23
CK-3L	Three-layer carbon-Kevlar hybrid fabric	$[0^{CK}]_3$	2.05
CUD-2L	Two-layer unidirectional carbon fabric	$[0^{CUD}]_2$	1.33
CUD-4L	Four-layer unidirectional carbon fabric	$[0^{CUD}]_4$	2.16
CUD-6L	Six-layer unidirectional carbon fabric	$[0^{CUD}]_6$	3.16
CW-2L	Two-layer woven carbon fabric	$[0^{CW}]_2$	1.14
CW-4L	Four-layer woven carbon fabric	$[0^{CW}]_4$	1.99
CW-6L	Six-layer woven carbon fabric	$[0^{CW}]_6$	3.29
ST-2L	Two-layer steel fabric	$[0^{ST}]_2$	0.79
ST-4L	Four-layer steel fabric	$[0^{ST}]_4$	1.50
ST-6L	Six-layer steel fabric	$[0^{ST}]_6$	2.31

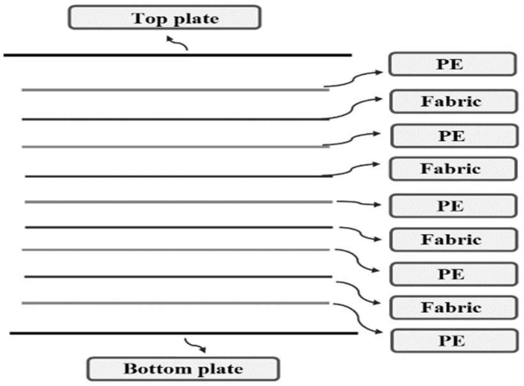

Fig. 1 - Schematic illustration of the stacking order for the composites

While the maximum tensile strength of six-layer composite is 8 MPa, the maximum tensile strength of four-layer composite is 6 MPa.

Stress-strain curves are presented for Kevlar-fabric composite materials as K-1L, K-2L and K-3L in Fig. 3. When K-1L and K-2L are compared, it is seen that there is a little difference between maximum tensile strengths of one-layer and two-layer composites. The curves progressed linearly up to the maximum tensile strength. It is also determined that the difference between K-2L and K-3L is more than two-fold, and the maximum tensile strength of K-3L exceeds 12MPa.

Stress-strain curves are presented for carbon-Kevlar hybrid composites as CK-1L, CK-2L and CK-3L in Fig. 4. It is seen that 2-layer carbon-Kevlar hybrid composite has maximum tensile strength. When extension amounts are compared, maximum extension is occurred in 3-layer carbon-Kevlar composite.

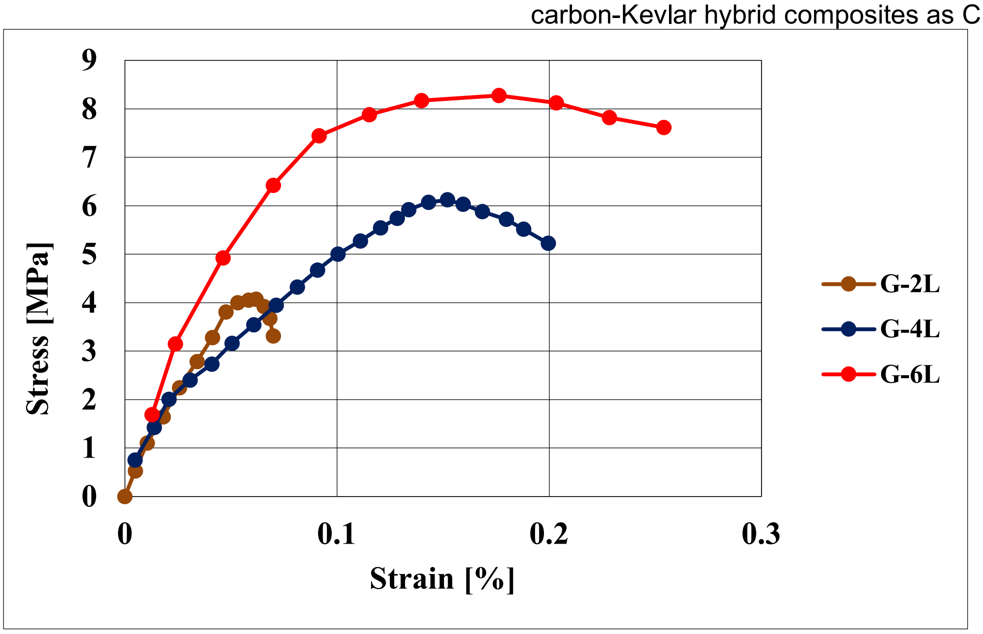

Fig. 2 **-** Stress-strain curve for G-2L, G-4L and G-6L

Stress-strain curves are presented for glass-fabric composite materials as G-2L, G-4L and G-6L in Fig. 2. In two- and four-layer composites, the curves progressed linearly up to the maximum tensile strength. As the number of layers increased, the tensile strength of the composite also increased.

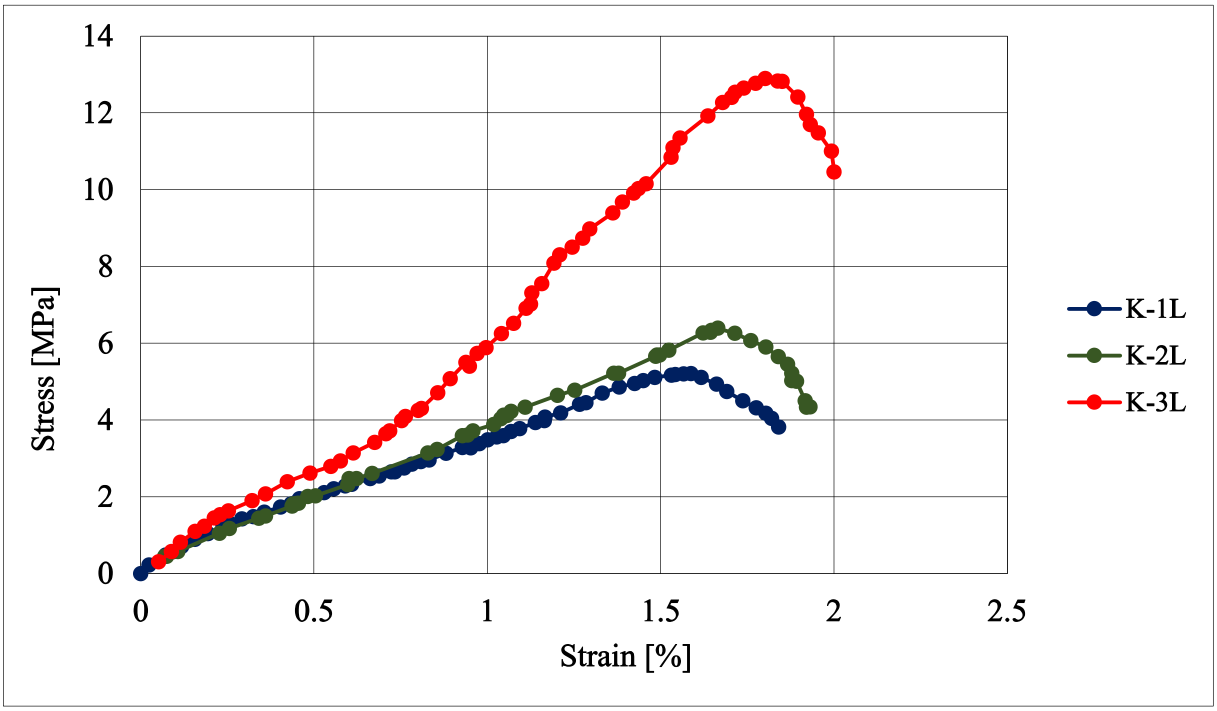

Fig.3 - Stress-strain curve for K-1L, K-2L and K-3L

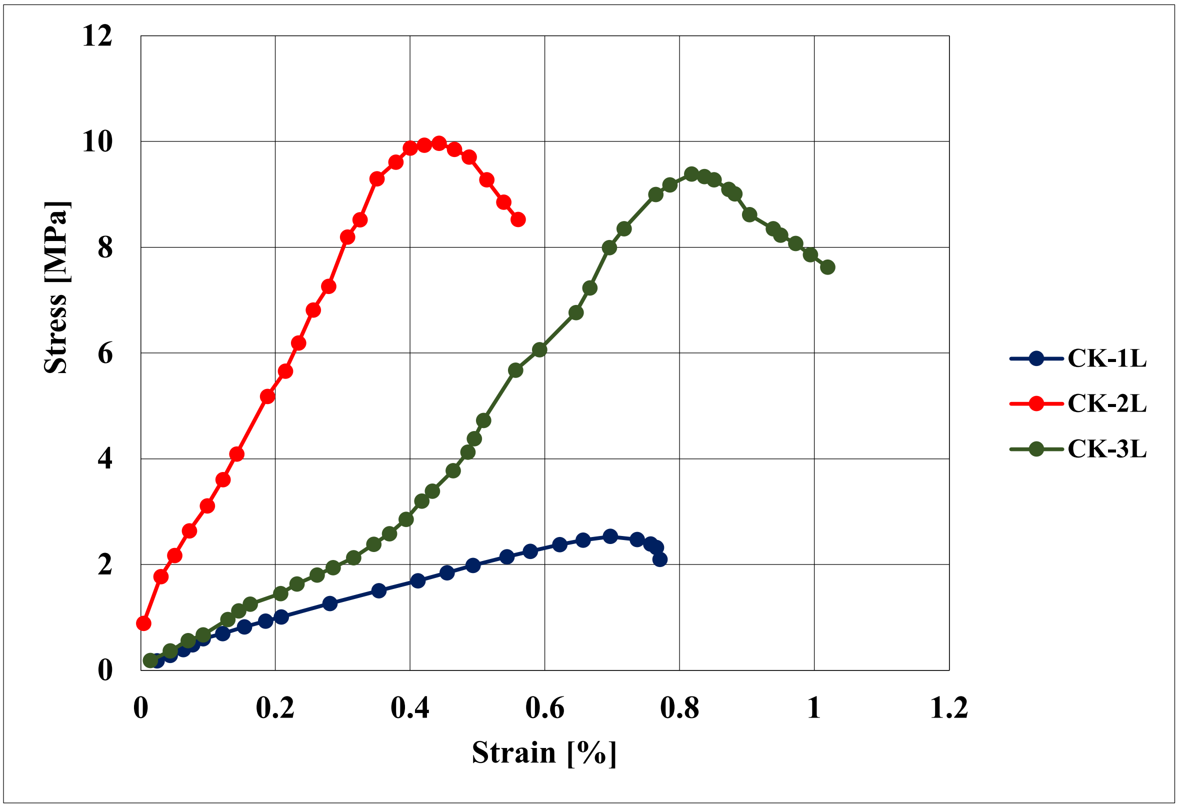

Fig. 4 - Stress-strain curve for CK-1L, CK-2L and CK-3L

Stress-strain curves are presented for unidirectional carbon-fiber composites as CUD-2L, CUD-4L and CUD-6L in Fig. 5. The maximum tensile strength of CUD-2L and CUD-4L are very close to each other. However, extension amount of CUD-2L is more than CUD-4L. The tensile strength of CUD-6L is not increased much and the breaking point is close to CUD-4L.

Stress-strain curves are presented for bi-directional carbon-fiber composite materials as CW-2L, CW-6L in Fig. 6. When considering layer number, it is observed that CW-6L composite material is better in terms of extension amount and tensile strength.

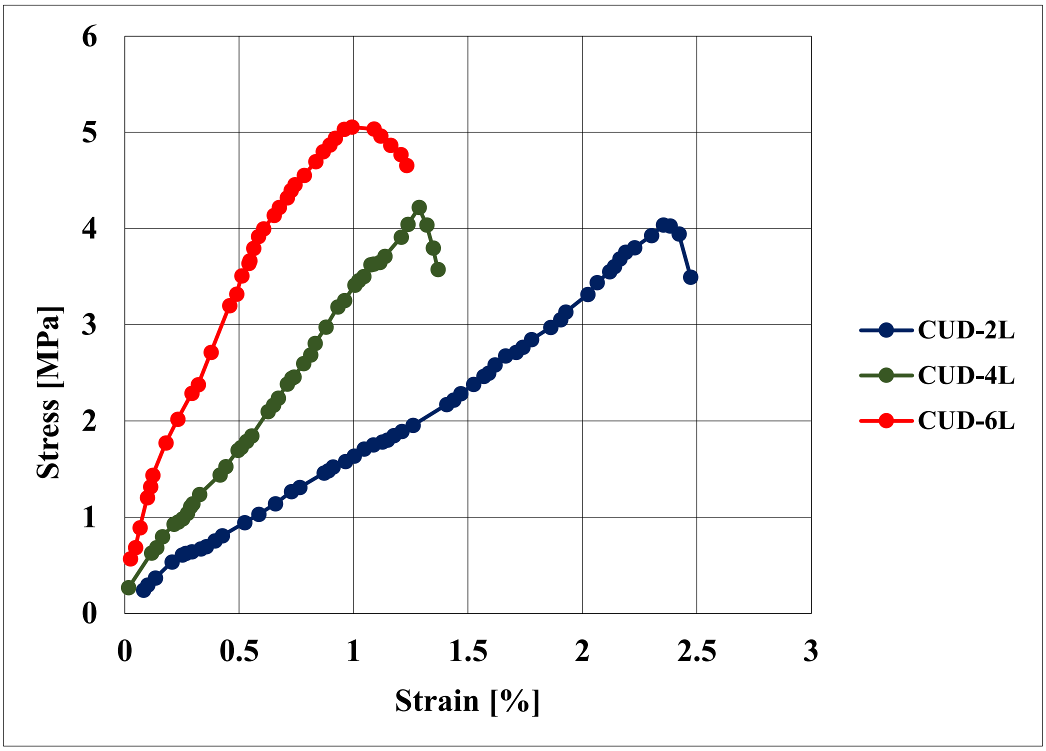

Fig. 5 - Stress-strain curve for CUD-2L, CUD-4L and CUD-6L

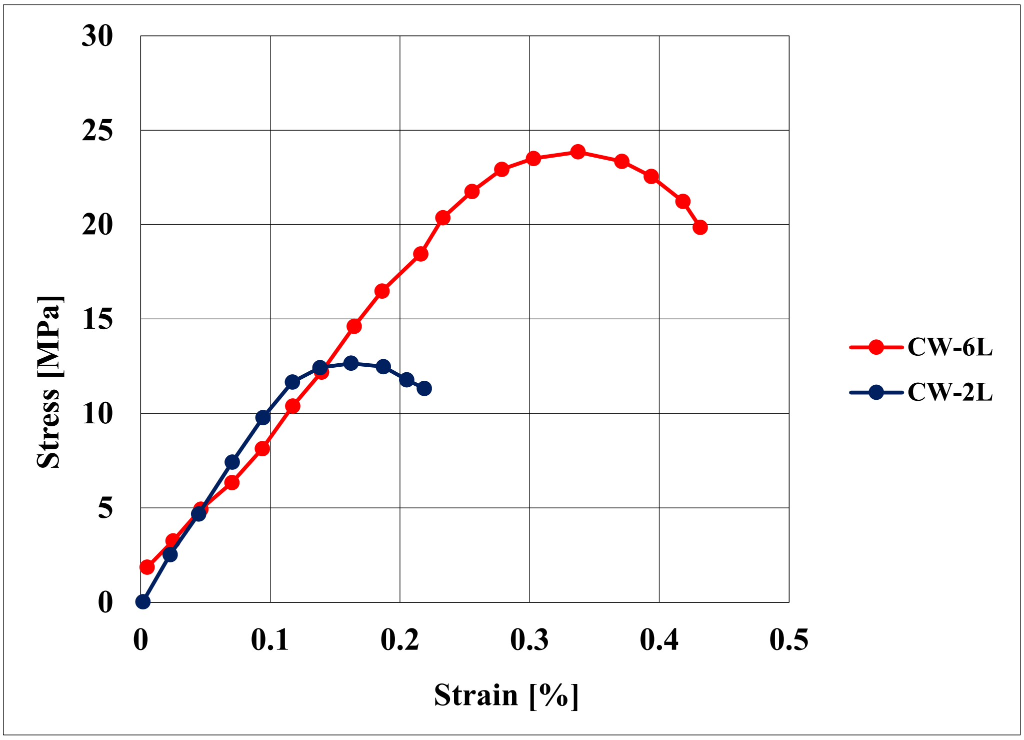

Fig. 6 - Stress-strain curve for CW-2L, CW-6L

Stress-strain curves are presented for steel wire mesh composite materials as ST-2L, ST-4L and ST-6L in Fig. 7. When stress-strain curves are investigated, tensile strength for ST-6L is reached to maximum value progressing linearly up to 5 MPa. ST-6L has maximum ultimate strain compared to others as well.

3.2.Charpy Impact Test

Impact toughness (E_t) of the composites considered in the present study were determined by Charpy impact tests at room temperature using the pendulum impact system, Devotrans CDC. For this purpose, specimens were cut to 10x80 mm pieces in accordance with ASTM E23 standards. A notch with 45° angle and with 2 mm indentation was

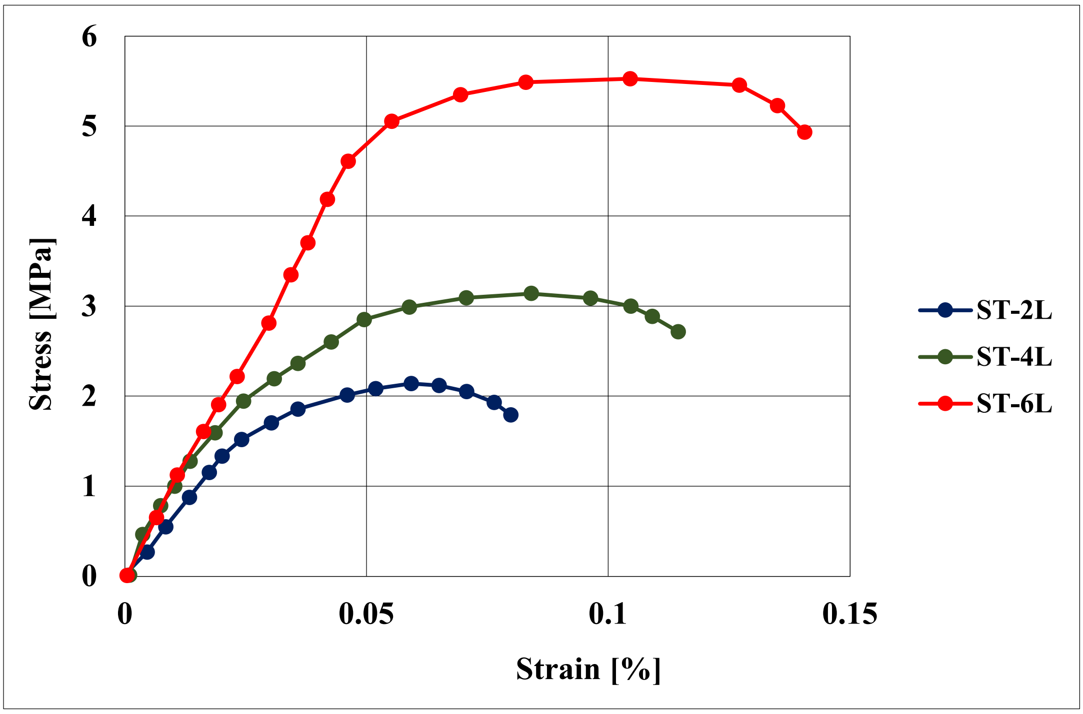

Fig. 7- Stress-strain curve for ST-2L, ST-4L and ST-6L

Table3

Results of the Charpy impact tests

Composite	No. of layers	Thickness, t (mm)	Average absorbed impact energy (J)	E_t (kj/m²)
CW	2L	1.07	2.57	30.02
	4L	2.05	4.53	27.62
	6L	3.39	8	29.50
CUD	2L	1.25	1.53	15.30
	4L	2.35	1.73	9.20
	6L	3.07	2.73	11.12
G	2L	0.8	2.13	33.28
	4L	1.76	4.77	33.88
	6L	2.18	8.13	46.62
K	1L	0.71	1.73	30.46
	2L	1.13	1.83	20.24
	3L	1.75	2.1	15.00
CK	1L	0.85	1.13	16.62
	2L	1.38	2.07	18.75
	3L	2	2.5	15.63
ST	2L	0.69	3.5	63.41
	4L	1.3	7.13	68.56
	6L	1.71	10.1	73.83

created on all the specimens. Three specimens were cut from each type of composites, corresponding to fifty-four specimens in total. All the specimens were subjected to an impact energy of 12 Joules. Total energy required to fracture the specimen can be determined from vertical position of the pendulum before and after impact. Values of energy absorbed by specimens (*E*) were directly read from the dial gauge in joules. Impact toughness, E_t, was obtained using Eq. (1):

$$E_t = E/(Wt) \qquad (1)$$

where *W* and *t* are width and thickness of the specimens, respectively,

When Table 3 is examined; For composites, it was observed that the absorbed impact energy increased with the increase in the number of layers. In particular, the amount of absorbed energy reached the maximum in ST composite.

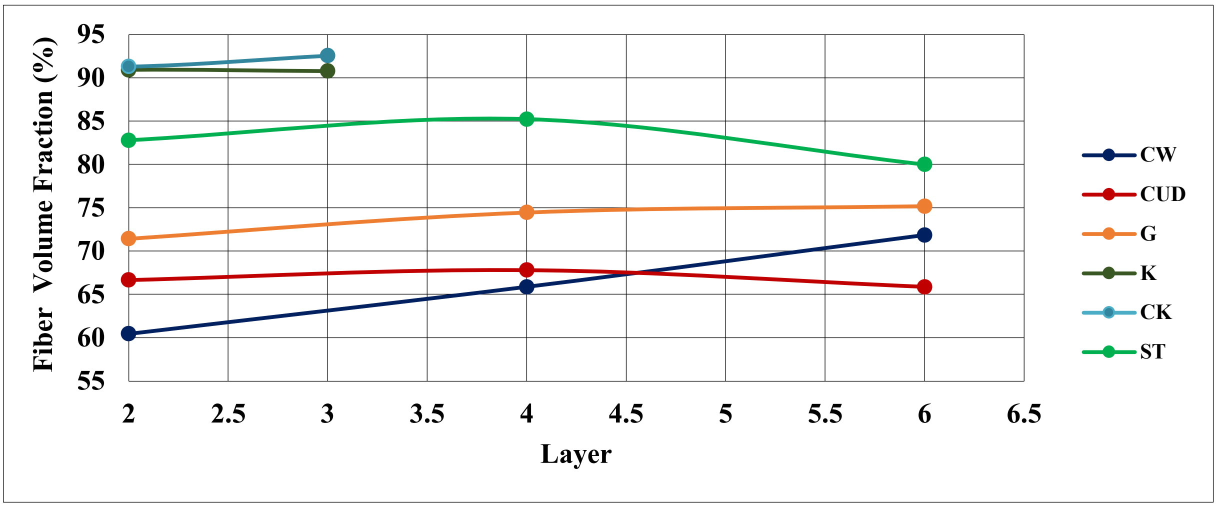

Fig. 8 - Fiber volume fraction for composites

3.3.Resin Burn-off Test

One of the most important values of fiber reinforced composite materials is the volume fraction of fiber and resin. There are two methods for determining these fractions. These are the determination of the density of the composite and the combustion test. Data obtained from the experiments are given in the formula below. The fiber volume fraction is calculated by replacing it. It is calculated from the following formula $V_f = (W_f/\rho_f) / (W_k/\rho_k)$ Respectively, W_f refers to fiber weight, ρ_f fiber density, W_k composite weight and ρ_k composite density.

In Figure 8, fiber volume fraction graphs are shown as a result of the combustion test of composites. It was determined that CW and G' fiber volume fraction increased linearly with increasing layer number, four-layer CUD had maximum fiber volume fraction, bilayer K' had maximum fiber volume fraction and this ratio decreased with increasing layer number. The fiber volume fraction of CK has a certain value, it gradually decreases for the two-layer and this ratio reaches its maximum in the three-layer, the two-layer ST has a smaller fiber volume fraction than the four-layer ST, and it decreases significantly in the six-layer is seen.

4.Conclusion

The present study investigates tensile strength and impact resistance of plain composites made of carbon, glass, Kevlar, steel wire mesh; as well as those of hybrid carbon-Kevlar composites with polyethylene matrix; which are prepared in the form of laminates with the help of a hot hydraulic press machine. All the specimens were prepared in different number of layers and stacking configurations. Mechanical properties are determined by tensile and Charpy-V-notch impact tests.

When we examined the strain stress curves of the composites, it was observed that the tensile strength increased with the number of layers. It is seen that the maximum tensile strength is about 30MPa in CW-6L, followed by K-3L with 12MPa. It has been determined that the minimum tensile strength is in CK-1L.

When the Charpy impact test results are examined; It was observed that the amount of energy absorbed increased as the number of layers increased. The amount of energy absorbed reached the maximum at ST and minimum at K.

When we look at the results of the combustion test, the composites with the highest fiber volume fraction and the minimum decrease in the minimum number of layers are CK and K, respectively. In general, the fiber volume fraction excluding CW increased with the increase in the number of layers.

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