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Tensile Property of Carbon Reinforced Epoxy Composites for Different Directions

Selahattin Selek
OSTIM Technical University

Yusuf Sahin
OSTIM Technical University

Abstract: Due to higher chemical stability, higher strength/stiffness, lower density, and good corrosion resistance, carbon fiber-reinforced polymeric composites (CFRPs) have been increased numbers of areas such as aircraft industry, automotive industry, ship making and packing industry, turbines, compressors, wind blades besides implant applications. Epoxy based composites are developed using carbon fiber reinforcements by vacuum controlled resin transfer (VARTM) molding method by Twill carbon fiber [K3T] with 200 gr and Plain carbon fiber [K3P] with 200 gr. Composite plates are produced in the dimension of 500 mm x 500 mm with 0.8 mm thickness. According to the ASTM D3039, standard test samples are cut with CNC machine. Tensile tests are conducted at three different fiber directions like 0^0-45^0- 90^o, respectively. Their mechanical properties are determined. Experimental results indicated that fiber direction significantly affected the tensile behavior of tested samples. Average tensile strength of CFRPs was obtained around 470 MPa for 0 degree to x-axis, and testing lasted about 44 s. For 90^o direction, tensile strength of carbon fiber composites reached to 520 MPa, which is slightly higher than the previous one while trial period was around 50 s. For 45^o tested samples, a completely different behavior was observed because stress-strain curve showed the elastic-plastic behavior. Its tensile strength measured was about 120 MPa average value while the trial lasted about 145 s.

Keywords: Carbon fiber, Plain fiber, Twill fiber, Fiber direction, Tensile strength

Introduction

Since fiber reinforced polymeric composites (FRPCs) have higher strength/rigidity, higher corrosion, lightweight, fire retardant associated with dimensional stability, lower cost, easy production when compared with steel structures, concretes and other building materials, FRPCs have been found many applications such as airplane, sport, marine and automotive industries (Soutis et al., 2005; Sahin, 2022; Sahin&Patrick, 2018). In general, FRPCs consists of the matrix like epoxy, polyester, vinyl ester while fibers such as glass, carbon, basalt fiber, and kevlar used as reinforcements. The development of composite materials design and manufacturing technology is one of the most important tasks in the history of materials. Researcher and scientific engineering people interested in new method to provide larger and quality components like Vacuum Assisted Resin Transfer Method (VARTIM) approach, particularly for fiber-reinforced polymeric materials (Mallick, 2007; Sahin, 2022; Sanchez, 2012; Bodaghi et al., 2016). For metals and composites, tensile tests have been used as a standard testing to evaluate the mechanical properties like tensile and Young's modulus and compare qualitatively with different materials. The mechanical property of composites show different characteristics based on types of fiber/matrix (Ma et al., 2017; Ma et al., 2018; Turla et al.,2014), Nano-addition (Agarwal et al., 2014; Zhang et al., 2019; Xu & Hoa, 2008), interface bonding (Liu et al., 2014; Li et al.,2013), applied methods (Sahin, 2021; Cecen &Sarıkant, 2008), stacking sequence (Ary Subagia et al., 2014; Zhang et al., 2012; Yusuff et al., 2021), orientation effect (Rahmani et al., 2012; Kaleemulla & Siddeswarappa,2010; Agrawal & Bhattacharya, 2021;

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GuruRaja & HariRao,2013) and characterization (Shokrieh &Omidi, 2009; Paive et al., 2006; Cecen & Sarıkanat, 2008; Pandy et al., 2011) in making composites.

For the case of fiber orientation, it also affects the properties of composites (Agarwal et al.2014; Rahmani et al.2014; Kaleemulla &Siddeswarappa, 2010). The highest mechanical properties were obtained for longitudinal direction of the fibers (Ozsoy, 2015). Shokrieh and Omidi (2009) indicated significant increases in strength as strain rate increased for glass fiber reinforced epoxy. Paive et al. (2006) showed that the highest strength was provided for F584/PW samples with reinforced with Plain Weave (PW) and Eight Harness Satin (8HS) fabrics while the highest elastic modulus was obtained for F584/8HS samples. Agarwal et al. (2021) revealed that higher property for tensile and flexural test were achieved with first [(0/0/0/0)] and fifth [0/+90/-90/0)] configurations in CFRPs. GuruRaja et al. (2013) indicated that the 0/90^o samples indicated the considerable increase in elasticity modulus of composites, followed by 60/30^o oriented samples for carbon/glass hybrid composites. Çecen and Sarıkanat (2008) showed that longitudinal direction (0^o) was about 54% larger than that of 45^o directed for glass-fabric based polyester composites. Pandy et al. (2011) indicated that higher tensile stress was provided for satin weave T300 carbon reinforced composite while lower strength was provided for hybrid composite. In hybrid epoxy composite, plain carbon fabrics, 8H satin weave in addition to glass fabrics were used.

From the above literature review, large numbers of studies carried out over mechanical behaviorof FRPCs using different fillers and factors. There are some other works conducted to determinethe effects of fiber directions, but limited numbers of investigations for tensile properties of composites produced through VARTM were studied (sahin 2021, 2022; Sanchez et al., 2013; Bodaghi et al., 2016; Cecen&Sarıkanat, 2008). Therefore, the purpose of the study is tocharacterize tensile property for CFRP composites fabricated using VARTIM with different orientations such as 0^o, 45^o, 0/90^o subjected to tensile loading in accordance with ASTM standard.

Experimental Details

Materials

CFRC composites were produced through Vacuum Assisted Resin Infusion Transfer Molding (VARTIM) method. Carbon dry fabric with plain-weave type (K3P), Twill carbon (K3T), plainbasalt fiber (K3P). Areal weight of woven carbon is 200 g/m^2, selected as reinforcement, average diameter is about 10 μm. Thermosetting bisphenol-A epoxy resin (F-1564) andhardener (F-3487) were mixed in 3:1 ratio. The properties of carbon fabrics used for VARTIMapproach were indicated in Table 1. In manufacturing the composites, total of three plies of plain carbon fabrics were stacked on release film of aluminum mold.

The composite specimen size was about 500 mm × 500 mm × 0.8 mm fabricated with a squarelaminate. A releasing agent was applied on mold for providing quality surface roughness and removing the laminate easily. Sealant tape, peel ply, vacuum bag was used for completing process. Preform was prepared using fabrics like carbon. Vacuum will be continued until the resin has run out. 1 at pressure was applied at inlet port to remove the resin-rich layer. Flow direction should be along flow media.

Table 1. The properties of glass/carbon fabrics, epoxy used for VARTIM approach

Materials	Plain Carbon Fabric (CF)	Glass fiber (GF)	Epoxy resin (EP)
Fabric weight (g/m^2)	200	220	-
Fabric thickness (mm)	0.32	0.15	-
Warp construction/fill	12/13	22/26	-
Monofilament diameter (μm)	7-10	10-18	-
Density (g/cm^3)	1.78	2.60	1.15
Modulus of elasticity (GPa)	230	80-90	30-50
Tensile strength (MPa)	4900	1380-3200	73

Fig.1 shows some basic elements used in preparing of composite in VARTIM technique. Theseare mostly release film, infusion mesh (a), peel ply, (b) vacuum bag or nylon film, (c) vacuumsealant tape (yellow), infusion vacuum hose and spiral house, T-connector and finally carbon fibers or any other fibers.

The mechanical tests like tensile test according to ASTM D3039 were performed using the composites using universal mechanical testing machine with 100 kN load cell capacity.Specimens were prepared for mechanical testing by cutting from the epoxy laminate panels with a CNC-machining. Samples were cut from the plate according to 0-45-0/90^o direction withrectangle shape. The specimen was measured about 18 mm in width, 179 mm in length, 1.0 mmin thickness. Head speed rate was 10 mm/min.


(a) (b)

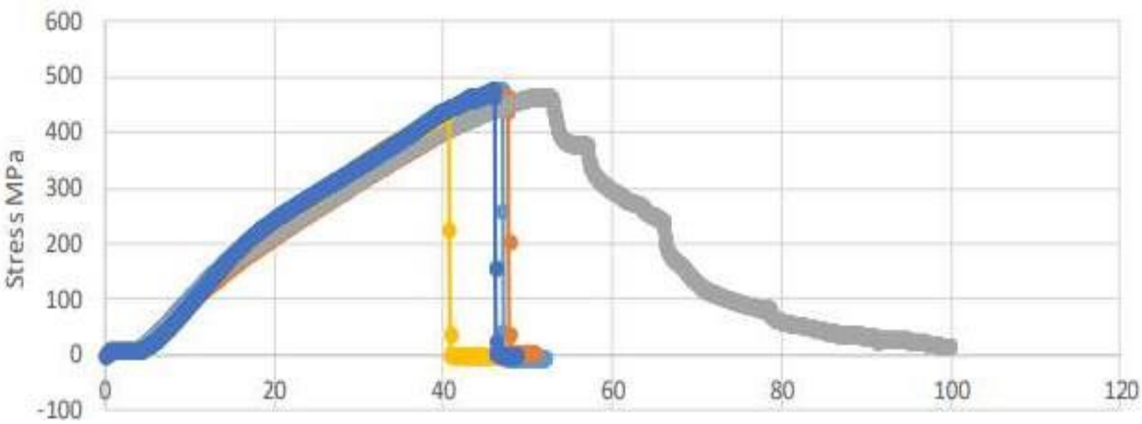

(c) (d)

Figure 1. Some elements used in preparing of composite in VARTIM technique.
(a) Infusionmesh, (b) Peel ply, (c) Sealant tape, (d) Carbon fiber.Mechanical testing

Results and Discussion

Tensile Strength of Composites

Typical stress versus time curves for the carbon fiber reinforced epoxy composites when loaded in tension load was indicated in Fig. 2, 3 and Fig. 4 for 0^o orientation (longitudinal), 30^o (angle-ply) orientation of composite and 90^o design, respectively. The tensile stress was provided by getting maximum load as a failure for all tested samples.

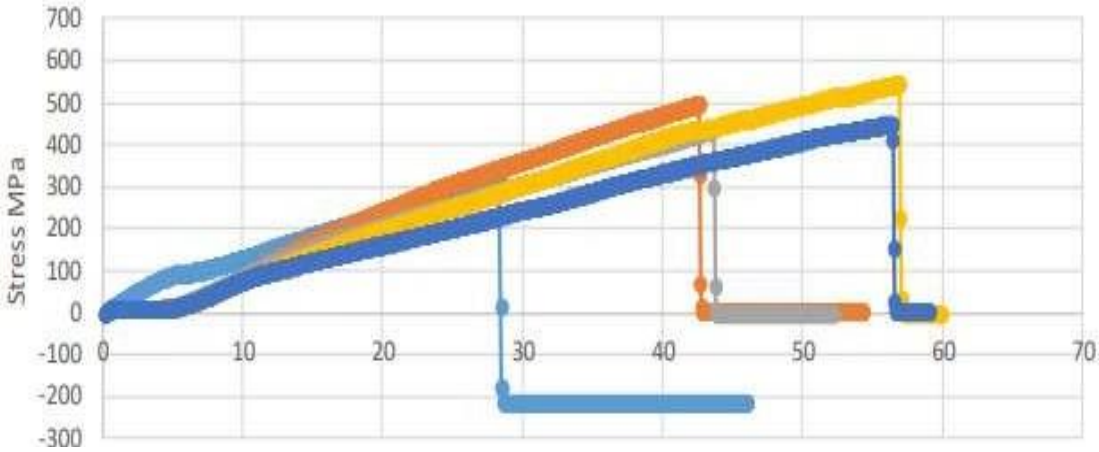


Strain Time (s)

Figure 2. Stress vs. Time curves for CFRCs with plain carbon tested along 0^o orientation.

Let's look at each one separately. Fig. 2 shows the experimental results of stress vs. time graphwhen tested at 10 mm/min head speed in 0^o orientation. It is observed that this figure exhibited almost linear behavior to failure before the load reached its maximum level due to having higher mechanical properties. The fiber reinforced composite samples indicated an around maximumstress of 460 - 480 MPa but for trial 3, average strain to failure is found to be increased a little bit more due to not achievement enough interface bonding between fiber and resin. It is observed that there was a decreasing trend in testing time or strain rate for trial 4 samples and test was lasted about 45 s.

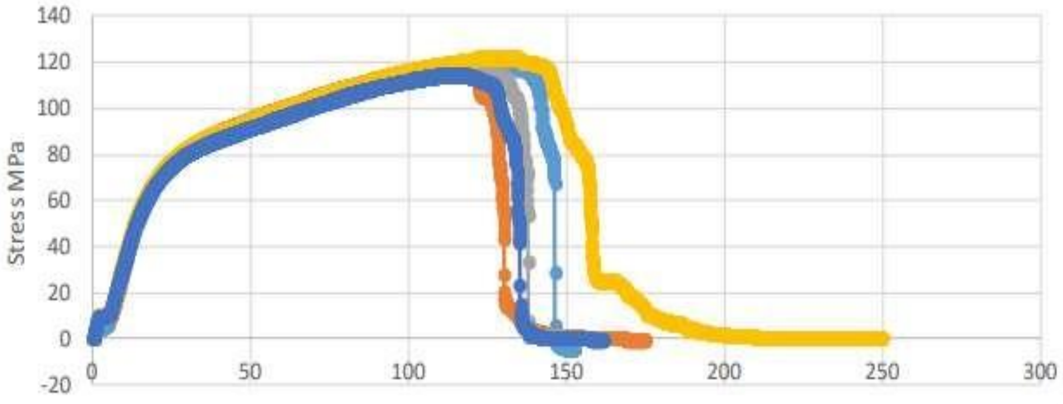
Fig. 3 showed a typical tensile stress - time behavior of woven CFRPs subjected to tensile testsat 10 mm/min speed. This is obviously indicated more linear behavior to failure before the loadreached its maximum level. The results showed that maximum strength achieved was around 480 – 520 MPa and average failure time was 45s for these tested samples. The tensile strengthincreased slightly more when fibers orientated in 0/90^o. This might be related to formation of enough interface bonding between the fiber/resin due to production method, its process parameters. The test duration was about 50s. The composite laminates using epoxy matrix reinforced with carbon fabrics showed the highest tensile strength/highest elastic modulus were obtained for F584/PW sample and for F584/8HS sample, respectively (Paive et al., 2006).



Strain Time (s)

Figure 3. Stress vs. Time curves for CFRCs tested along 90^o orientation.

Fig. 4 revealed stress vs. time curves for CFRCs when tested along 30^o orientation. The mechanical behavior of composite was fully different way when compared to the previous two composites because in first indication, non-linear behavior was observed with gradual increase by forming concave curve, (elastic-plastic) after reaching to peak point around 110 MPa, and then dropped to about 60 - 80 MPa in tensile stress and average strain time to failure is around 140s. Second indication was that the layers were subjected to change angle in aligning their selves in application of load direction. As the load applied, it was limited with bending and shear force, and finally this resulted in debonding of adhesion and fracture of the specimens (Korkmaz et al., 2016).



Strain Time (s)

Figure 4. Stress vs. Strain times curves for CFRCs tested along 45^o orientation.

Other reason is that the transfer of load is achieved through the resin instead of fibers. Final one was to obtain higher strain time, which is about 140-145 s that are very higher than those of other composites. The higher strain time to failure was because of subjecting the fibers distortion along the warp and weft direction. This also another indication that elastic modulus seems to be smaller than other samples. On the other hand, due to generating more energy, this composite is supposed to be tougher than those of others.

Conclusion

The following conclusions were drawn out from present study on tensile strength and fracture behavior of FRPC composites.

- Among the orientation effects for three types of CFRPs, the 90^o oriented samples indicated higher tensile stresses (485 MPa), followed by 0^o oriented samples (460 MPa) and 45^o oriented samples (115 MPa), respectively. There was no significant difference between first and second oriented samples.

- Based on tensile stress obtained here, the improvements in 90^o and 0^o orientation in CFRP composite were about 321%, 300% compared to 45^o orientation, respectively.

However, strain time of the 0^o samples was found to be around 40s while the toughness energy of samples of 45^o were the highest about 140s. The improvements in angle ply orientation is about 250%. The reason was that fibers propagated through zigzag way along the 45^o fibers/matrix interface that resulted in higher crack propagation energies. A similarrate was provided for other composite samples.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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Author Information

Selahettin Selek
Ostim Technical University
Department of Mechanical Engineering
Ostim, Yeni Mahalle, Ankara, Turkey

Yusuf Sahin
Ostim Technical University
Department of Mechanical Engineering
100 Yıl Blv.55/F, Ostim, Yeni Mahalle, Ankara, Turkey
Contact e-mail: *yusuf.sahin@ostimteknik.edu.tr*

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