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Effect of Fiber Stacking Sequence on Mechanical Property of Polymeric Composite through VARTIM Method and Metallographic Examination

Yusuf Sahin
OSTIM Technical University
Nisantası University

Abstract: Because of higher specific modulus/strength, lower weight, good corrosion resistance with design flexibility and easy production, carbon fiber reinforced epoxy composites are widely used for many structural applications. Glass woven (plain) and carbon fabric (plain) were studied. Thus, glass fabric-reinforced epoxy composites (GFRCs) and carbon fabric-reinforced composites (CFRCs) were fabricated throughVacuum Assisted Resin Transfer moulding (VARTM) methodology. Firstly, manufacturing unit/control system, preparation stages and some elements used in manufacturing the epoxy based composites are reviewed. Then, effects of stacking sequence of fibers on mechanical properties were investigated and a comparison was made on two types of fabrics on hardness/deformation depth through Stereo Microscope (SM). The experimental results exhibited that the hardnesses measured were around 40.6 HB and 52.4 HRB for GFRP and CFRP, respectively. Improvements in carbon fiber were about 29% in comparison to glass fiber. Further, both hybrid composites made from glass and carbon fiber, the hardnesses values were reduced. In case of C2/G2/C2 hybrid composites, reduction rate was about 9.3% in comparison to C6 fiber reinforced laminate composite. Moreover, it is clearly revealed that there were extensive deformation regions reflecting the white areas because top layer was in G2/C2/G2 samples, but there was no such a white area in C2/G2/C2 composite.

Keywords: Carbon fiber, Epoxy, VARTM, Hardness, Deformation region

Introduction

Carbon fibers are commonly preferred reinforcement elements because they have higher strength/modulus associated with lower weight and good flame resistance. This makes carbon fibers to be increased usage in automobile, aircraft, ships, construction, and sport industries (Paiva et al.,2009;Taketa et al.,2010). Whereas they have some disadvantages like lower strain to failure, poor impact resistance, very high electrical conductivity and costly produced (Rosa Garcia et al.2013). In order to improve the weakness of CFRP composite is to design and fabricate the hybrid composites, which are produced by combining two or more different fibers in common matrix (Dong et al., 2012). In this way, new materials are created by improvement of mechanical and physical properties associated with lower cost. This can be ductile fibers/fabrics like glass, basalt or kevlar by forming various layers.

Basalt/carbon fibers, glass/carbon fiber or glass/kevlar fiber are used to provide excellent mechanical behaviour in the fiber axis direction. Therefore, it is possible to incorporate high elongation fibers (glass) into low elongation fibers (carbon) for increasing the failure strain. There are many parametres affecting on mechanical property of epoxy composites including matrix/fiber types and fracture mechanics (Hashim et al., 2017; Zhang et al.,2019; Ma et al.,2017; Ma et al.,2016; Agarwal et al.,2014), nano addition (Xu & Hoa, 2008; Sanchez et al., 2013; Phong et al., 2013; Bora & Kirtania, 2020), interface bonding (Liu et al., 2014; Li et al., 2013), applied methods (Sahin et al., 2021; Bodaghi et al.,2016), stacking sequence effect on hybrid including carbon/glass, carbon/basalt, glass/carbon (Turla et al., 2014; Ary Subagia et al., 2014; Zhang et al., 2012), carbon epoxy, carbon/kenaf and carbon/basalt/epoxy (Artemenko&Kadykova, 2008; Yusuff et al.2021; Reis et al.2012); characterization (Çecen & Sarıkanat, 2008; Ozsoy et al., 2015; Shokriech & Omidi, 2009; Pandya et al., 2011) and effect of orientation (Yokozeki et al.2005; Rahmani et al.2014; Mohamed Kaleemulla& Sideswarappa, 2010; Agrawal&Bhattacharya, 2021; GuruRaja&HariRao,2013) for manufacturing the composites. The purpose of this study is to see the effects of stacking sequence of fibers on mechanical properties of composites and a comparison was made on two types of fabrics on hardness/deformation depth through Stereo Microscope (SM).

Materials/Composite Preparation

GFRP & CFRC epoxy composites were manufactured through Vacuum Assisted Resin Infusion Transfer Molding (VARTIM) method. Carbon and glass fibers with plain-weave type, which are supplied from Kompozitsan Inc. İzmir/Turkey. Thermosetting bisphenol-A epoxy resin (F-1564) and its hardener like F-3487 were mixed in 100:35 ratio. Areal weights for both fibers wemulla as 200 g/m^2, selected as reinforcement, average diameter is about 10/20 µm, respectively. The properties of carbon fabrics used for VARTIM approach were indicated in Table 1. In production of composites, total of three plies of plain carbon fabrics were stacked on release film of aluminum mold. VARTIM is commonly adopted to manufacture large and high quality components. VARTIM production unit is shown in Fig.1, compose of aluminum alloy as a main table, temperature and vacuum are provided through this table, electrical heating system to heat up the table, close-loop temperature control and thermo couple fixed under the table, PLC controller and touch screen unit, temperature can be controlled to 200 ^{o}C, A vacuum pomp, which can be open loop control.

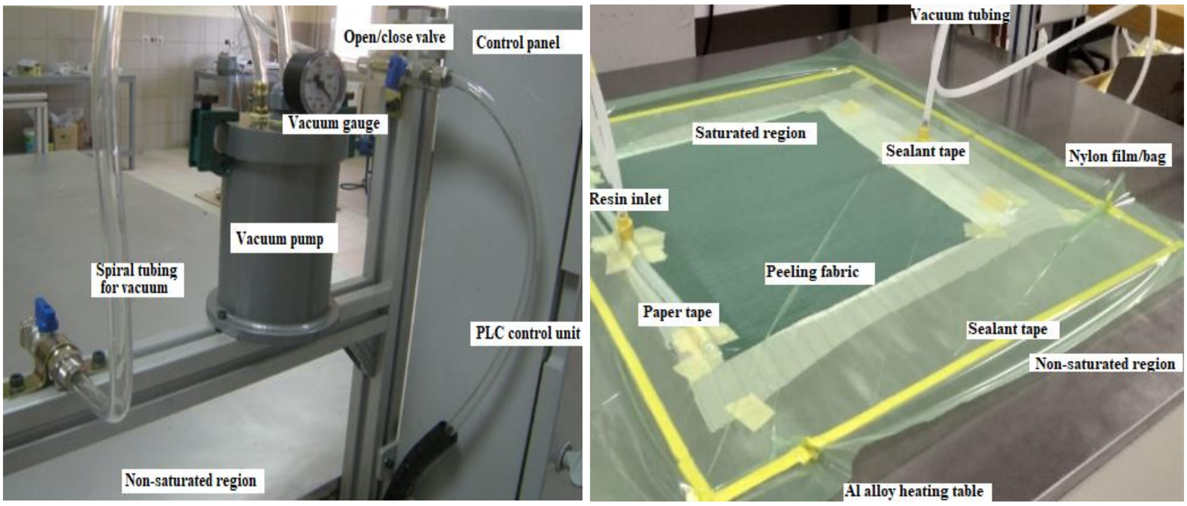

Figure 1. VARTIM unit and preparation stages of VARTIM with some basic elements

The machine can be set up using control panel for three temperatures for curing cycle of the composites. In first step, machine set at ambient temperature to 95°C for 50 min, then moved to second step, materials are cured and fibers started to get fixed with each other. It is kept at 95°C for 45 min to absorb the epoxy resin. At last step, the temperature downs to 50°C for 45 min duration. Then, the machine will be automatically stopped to return back about room temperature. The laminate composites produced by VARTIM was a dimension of 500 x 500 x 2.5 mm.

Hardness

Table 1. The properties of glass/carbon fabrics, epoxy used for VARTIM [43].

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

Hardness's were measured with Rockwell B hardness method by applying 60 Kgf load, and at least, the mean of five readings was taken.

Stereo Microscopy

After hardness testing results, samples were photographed and failure modes were analyzed by Stereo microscope (SM).

Results & Discussion

Hardness Results

Table 3 exhibites the hardness values obtained for epoxy reinforced with carbon and glass fibers. The hardnesses measured were about 40.6 HB and 52.4 HRB for glass and carbon fiber reinforced composite, respectively. This is due to used reinforcement effect. The hardness increased from 40.6 to 52.4 HRB, as shown in Fig. 3. The improvements in carbon in comparison to glass were about 29%. In other words, the hardness increased more significantly with increasing the carbon fibers.

In the case of hybrid composites, lower hardnesses were obtained. For G2/C2/G2 epoxy laminate composites, the hardness was meassured as 37.6 HRB, the reductions in hybrid composites was about 5% in comparison to G6 composites. The strengthening effect was not achieved by forming an enough interface bonding between the matrix and fibers, especially for the G2/C2/G2 hybrid composites. As for the case of C2/G2/C2 hybrid composites, reduction rate was around 9.3% in comparison to C6 fiber reinforced laminate composites because its measured value was about 47.5 HRB. During hardness testing, the indentation on the specimen's surface under the effect of load resulted in localised plastic deformation of the material. For the hybrid composite samples, the indenter caused a slightly higher degree of localised plastic deformation because of containing G2 fiber in the matrix. However, during hardness testing of C6 composites, there was decreases in localised plastic deformations due to presence of hard C6 fibers on the top layer. Further, for a given plain composite, the increase in hardness values was observed with using G6 or C6 reinforced composite. On the other hand, for hardness testing, compressive force allows the material to flow in a vertical direction. This vertical flow of material causes the reinforced material to concentrate beneath the indenter. The pattern of plastic deformation in the G6/C6 is more uniform. The changes in fibers below the indenter leads to transfer of load from matrix to reinforcement.

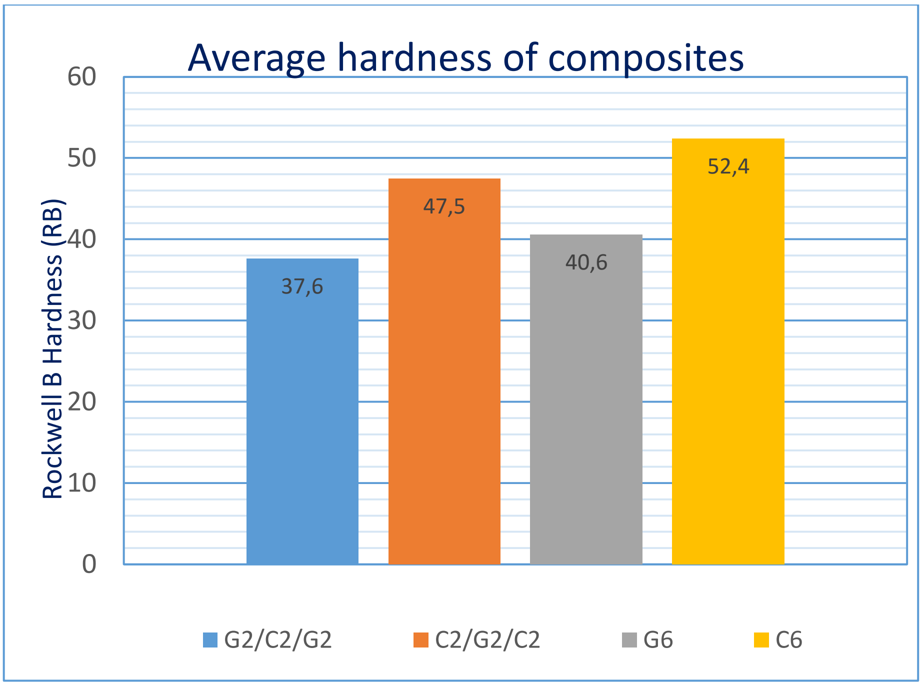

Figure 3. Hardness of the laminate composites.

Also, plastic deformation of epoxy matrix increases with decrease in hardness of fibers. Thus, hardness of normal composites rose with the type of reinforcements. For that reason, at given reinforcement types, C6 fiber reinforced composites showed higher hardness than G6 fiber reinforced composites. The lowest hardness was achieved for the G2/C2/G2 type hybrid composites, followed by C2/G2/C2 type hybrid composites.

Deformation Region/Depth

Stereo microscope was used the measure and determine the deformation region/size after the hardness testing of the composites. The micrographs in these figures show compressive damages. These can be in the forms fiber micro-buckling, kinking, shear, fiber fracturing/splitting or kinking-splitting mode. Fig. 4 shows the depth and deformation regions of G6 composites by stereo micoscope. Green color represents the glass reinforcement material in polymeric matrix. It is taken from two different local areas,showing the low distortion and localized buckling area at the left side reached to about 500 µm, but not heavily deformation formed in Fig.4a because the hardness measured was around 40.6 HB for these samples while similar case was observed at the left-upper side of the sample in Fig.4b even indicating slightly less amount of edge distortion. Evidence of microbuckling at the compressive side is the predominant features found in shear failure (Sudarisman & Davies, 2009). Fig. 5a indicates the compressive failure regions at three locations for C6 composites. It is taken with SM from different regions again. It is oberved that fiber fracturing/splitting and size of the splitted region was about 430 µm due to hardness of these composite reached at 52.4HB. Other sample shown in Fig.5b measured from two localizations and indicated more clear deformation like a hole. When you compared to these two samples in Figs. 4 and 5, improvements in carbon fiber reinforced composites were about 29% compared to glass fiber reinforced composites based on the hardnesses values and micro-scale size.

Let's see the hybrid composites that are made using glass and carbon fibers in epoxy matrix. Fig. 6 shows the deformation regions for G2/C2/G2 hybrid composites. Top/bottom layers consists of glasses while medium one is carbon fiber in composites. White area in these SM views reflects the localized kinking types of failure regions, as shown in Fig.6a. It is clearly revealed that there were extensive distortion regions were observed which is reached to 800 µm size for both samples because top layer was glass. Similar observation was also shown in Fig.6b for other samples tested at two different locations and in terms of the deformation area, which is close to other one. On the other hand, hardness of the composites measured at about 37.6HB. The reduction in hardness was found to be estimated as 7.3% in comparison to G6 reinforced epoxy composites. The compressive damage in the form of fibre buckling-modes was reported (Chen et al., 1993). However, delamination occurred at the carbon–glass interface work carried out with the previous study (Davies & Hamada, 2001). In another words, the hybrid composite increased the toughness of these samples. Moreover, Fig.7a,b exhibites the deformation/fracture regions for C2/G2/C2 hybrid composites. It is exhibited clear deformed region due to top layer carbon fibers, whereas, there are no white areas in these micrographs. Size of the deformations for these samples which is lower than 500 µm reduced significantly designing carbon layers and their brittleness, as indicated in Fig.7b. Other reason might be due to changing from kinking to splitting failure mode for these samples. The reduction in hardness was calculated 9.35% in comparison to C6 reinforced epoxy composites due to using 2 glass layers at the medium interface.

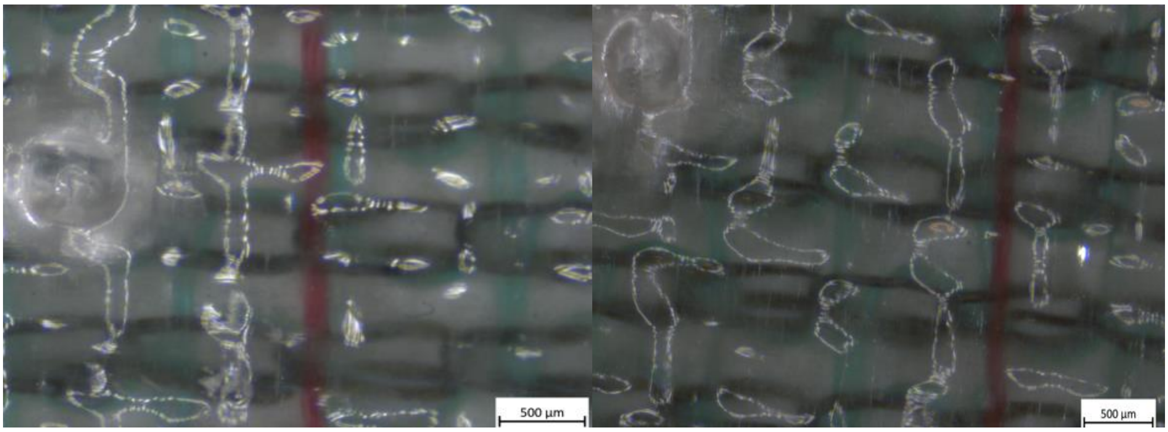

Figure 4. Depth and deformation regions for G6 composites (40.6 HB), indicating very slight distortion and not clear.

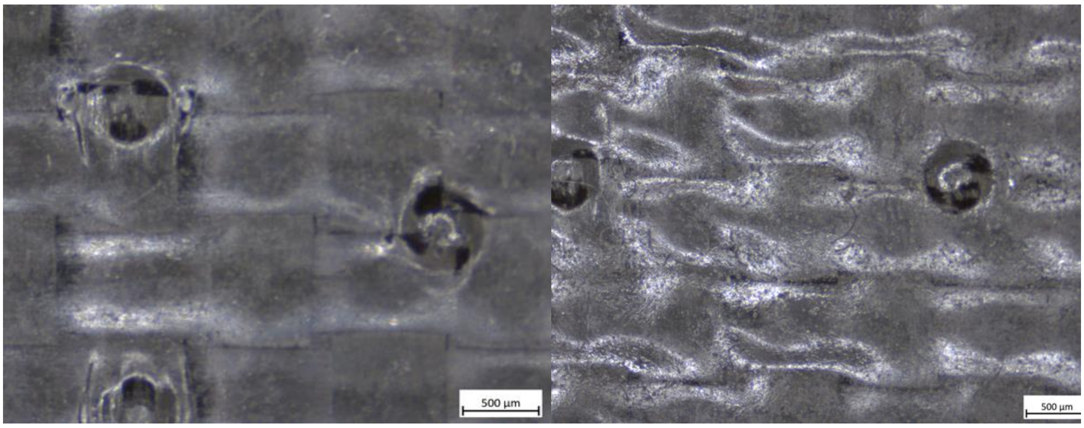

Figure 5. Depth and deformation regions for C6 composites (52.4HB), showing the deformed zone and like a hole.

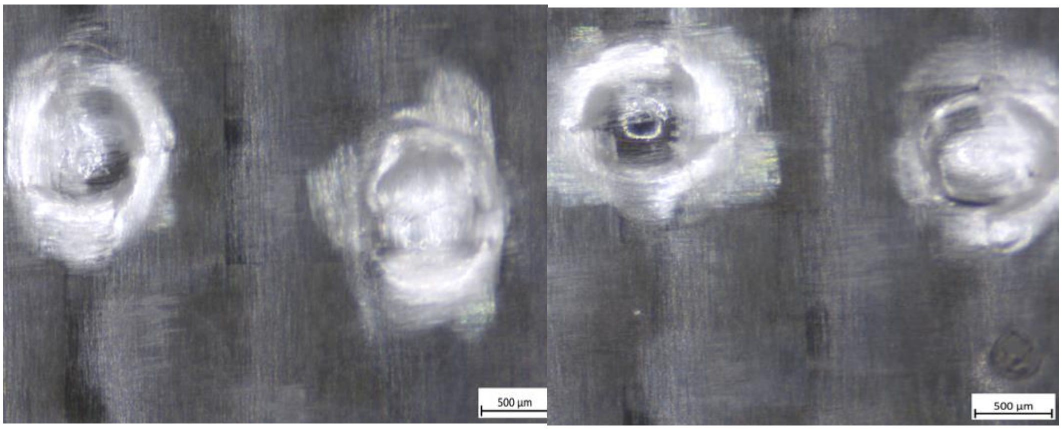

Figure 6. Depth and deformation regions for G2/C2/G2 hybrid composites (37.6HB), revealing kinking regions from all applied depth.

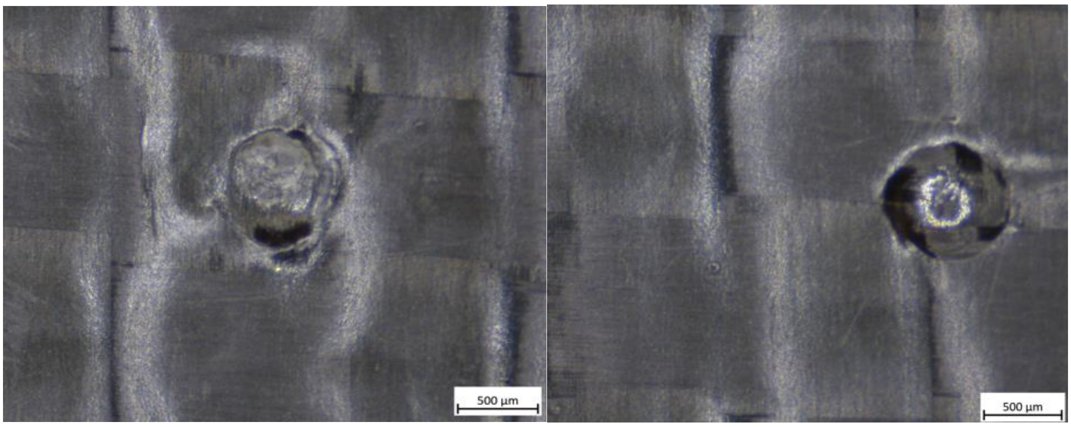

Figure 7. Depth and deformation region for C2/G2/C2 hybrid composites (47.5HB), exhibiting clear deformed and fractured region due to brittleness of top layer of carbon fibers.

Conclusions

The following conclusions were drawn from the current study on carbon reinforced epoxy composites (CFRCs) and its hybrid composites produced by glass fibers using VARTIM method. Mechanical properties such as hardness, depth of deformatin zone were investigated with Streeo microscope (SM), comparison was made for both composites.

1. Experimentally obtained results indicated that hardness of the composites changed with fabric types. The hardness increased from 40.6 to 52.4 HRB and improvements in carbon in comparison to glass fibers were about 29%.

2. In the case of hybrid composites, lower hardness was obtained. The hardness of G2/C2/G2 epoxy laminate composites was meassured as 37.6 HRB, the reductions in hybrid composites was about 5% in comparison to G6 composites. For the case of C2/G2/C2 hybrid composites, reduction rate was around 9.3% in comparison to C6 fiber reinforced laminate composites because for the hybrid composite samples indicating split-mode, the indenter caused a slightly high degree of localised plastic deformation because of containing G2 fiber in the matrix for dominating kink-mode.

3. For G6 composites, the size of deformation areas reached to about 500 µm while the deformed region was about 430 µm for C6 composites due to increased the hardness of these composites.

4. There were extensive deformation regions for hybrid composites. Their deformation depth were reached to around 800 µm for both samples when the top layer was glass fibers. Whereas, the plastic deformations for C2/G2/C2 samples reduced considerably due to using carbon layer on the top.

Scientific Ethics Declaration

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

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Author Information

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

Department of Mechanical Engineering Faculty of Engineering&Architecture of Nişantaşı University1453 Neotech Kampus, Maslak, Sarıyer, İstanbul, Turkey

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