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BENDING STRENGTH AND STRUCTURAL HEALING PROPERTIES OF CARBON/PP(POLYPROPYLENE)/EPOXY COMPOSITES

KARBON/PP(POLİPROPİLEN)/EPOKSİ KOMPOZİTLERİN EĞİLME DAYANIMI VE YAPISAL İYİLEŞME ÖZELLİKLERİ

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ÖZET

Bu çalışmada, karbon/PP(Polipropilen)/epoksi hibrid kompozitlerin eğilme dayanımı ve yapısal iyileştirme özellikleri incelenmiştir. Karbon ve PP lifleri, manuel bir dokuma tezgâhında dokunmuştur. Burada, karbon lifleri yapıya yüksek dayanım kazandırırken, PP lifleri ise tokluk özelliği sağlamaktadır. İki farklı yapısal iyileşme prosesi kullanılmıştır. Önerilen iyileşme proseslerinin etkinliği, hem mekanik hem de mikroskobik olarak değerlendirilmiştir. Sonuçlar, iyileşmiş kompozitlerin eğilme dayanımlarının, hem 0° hem de 90° doğrultuda oldukça azaldığını göstermiştir. Presle iyileştirilmiş kompozitlerin artık eğilme dayanımları, etüvde iyileştirilen kompozitlere kıyasla daha yüksektir. Bunun nedeni, erimiş PP liflerinin boşlukları basınç altında daha etkili bir şekilde doldurmasıdır.

Keywords: Karbon/PP/epoksi kompozitler, karbon lifi, yapısal iyileşme, eğilme dayanımı.

ABSTRACT

In this study, bending strength and structural healing properties of carbon/PP(Polypropylene)/epoxy hybrid composites are investigated. Carbon and PP fibres were woven in a manual loom in which the carbon fibres provide high strength while the PP fibres contribute with their high strain in hybridization. Two different structural healing processes were used. Effectiveness of the proposed healing processes was evaluated by both mechanically and microscopically. The results showed that bending strengths of healed composites incredibly decreased at both 0° and 90° directions. Residual bending strengths of press-healed composites were higher than that of oven-healed composites since the molten PP filled the gaps more influentially under pressure.

Keywords: Carbon/PP/epoxy composites, carbon fibre, structural healing, bending strength.

INTRODUCTION

Carbon fibre reinforced polymeric (CFRP) composites have begun to replace materials such as aluminium and titanium in aerospace applications, with the increase in usage and developments in fibre and matrix. The most important advantages of CFRP composites are to be suitable for mass production in complex geometric shapes, reducing the amount of scrap, improved fatigue strength, design flexibility and improved corrosion resistance. Restrictive aspects are generally material and process costs, low damage tolerance and repair difficulties (Soutis, 2005).

Structural healing and self-healing have an increasing interest in reducing the damage effect on composite materials (Williams et al., 2007). Structural healing aims to re-use of damaged composites which expects to recover the functional properties of the undamaged structures (Gibson, 2010). Use of glass tubes or microcapsules containing healing agents during the production of composite materials is among the methods used. Polymerization of the healing agents in the damaged area increases the mechanical performance of the composite materials (Bleay et al., 2001; Kessler et. al., 2003). Recently, graphene based self-healing materials are used in composites which also contributes to composite performance with their high mechanical, electrical, and thermal properties (Li et. al., 2019). Williams et al. (2007) studied the self-healing properties of resin filled hollow glass fibre implanted carbon/epoxy composites. Flexural strengths of undamaged, damaged and healed composites are investigated. It is stated that the healed samples achieved almost 80% of their undamaged strengths. Ladani et al. (2018) investigated the healing performances Z-fibre reinforced hybrid 3D composites. An incredibly high mode-I fracture toughness up to 2000% is achieved by carbon Z-fibre while EMAA (polyethylene-comethacrylic acid) provides a partial repair of crack of delaminated regions. Mode-II interlaminar fracture toughness of composites increased almost 75% (Ladani et. al., 2019). Dutra et al. (2000) stated that the hybridization of carbon fibre based composites with modified polypropylene fibres increases the impact resistance and thermal properties. Selver et. al., (2015) improved the damage resistance and damage tolerance by hybridisation of glass fibres with thermoplastic fibres and provided healing properties to composite structures.

In recent study, hybridization method is used to provide structural healing on composite structures. Bending properties of carbon/PP/epoxy hybrid composites are investigated before and after healing processes. Carbon and PP fibres were woven in a manual loom in which the carbon fibres provide high strength while the PP fibres contribute with their high strain in hybridization. Different structural healing processes were used to heal damaged composites where the molten PP fibres are expected to heal the damages of composites. Effectiveness of the proposed healing processes was evaluated by both mechanically and microscopically.

MATERIALS AND METHODS

Hybrid fabric and composite production

Carbon/PP hybrid fabric is manufactured by using a manual weaving loom (GARM-55, Gülas Makine, Turkey) in plain weave. Bulk Continuous Filament (BCF) PP fibres (Eruslu Textile, Turkey) are used as warp(90°) while carbon fibres (Aksa, Turkey) are used as weft(0°). Hybrid fabric is layered as $[(0°/90°)]_3$ and consolidated with an epoxy resin system (Hexion MGS L160 resin/Hexion MGS H160 hardener, 100/25 wt.) in vacuum bagging. Curing process is occurred at 80°C for 2h on a hot vacuum table. Hybrid fabric and composite properties are given in Table 1. Thickness of carbon/PP hybrid fabric was measured using portable thickness gauge (SDL Atlas, J200) according to ISO 5084. The thickness of composites was measured by using a digital calliper. The fibre fractions composites were determined as weight based according to ASTM D3171-15. Cross-sectional view of composite is illustrated in Figure 1.

Table 1. Hybrid Fabric and Composite Properties.

Properties		**Fabric**	**Composite**
Yarn sets	**Warp (0°)**	PP (150 tex)	-
	Weft (90°)	Carbon (3K)	-
Fabric density (ends/cm)	**Warp (0°)**	4	-
	Weft (90°)	4	-
Crimp ratio (%)	**Warp (0°)**	4.75	-
	Weft (90°)	1.8	-
Weight (g/m^2)		768	-
Thickness (mm)		1.29	3.44
Fibre fraction (wt., %)		-	Carbon: 45 PP: 10 Total: 55
Composite density (g/cm^3)		-	1.23

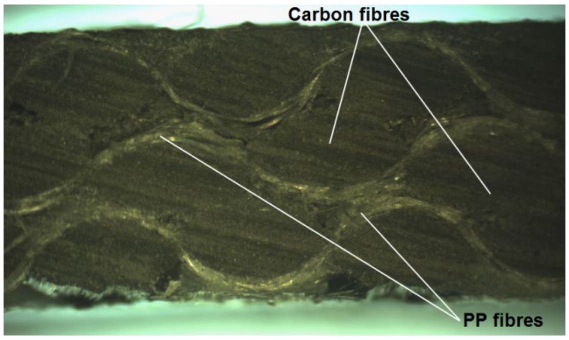

Figure 1. Cross-Sectional View of Composite (x2 Magnification).

Tests

Bending tests are provided on both normal to 0° (PP) and 90° (carbon) directions. Support span length is used as 50 mm on 25×80 mm sample dimension at 1.3 mm/min testing speed. Bending test is performed to undamaged and healed samples. Figure 2 shows the views of composite samples during bending test.

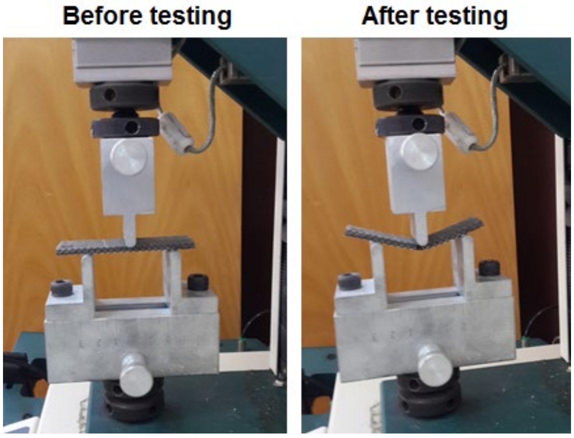

Figure 2. Views of Composite Samples During Bending Test.

Bending strength (1), modulus (2) and strain (3) of composites are calculated according to the formulations of ASTM D790-17.

$$\sigma = 3PL / 2bd^2 \quad (1)$$

$$E = L^3 m / 4bd^3 \quad (2)$$

$$\varepsilon = 6Dd / L^2 \quad (3)$$

where σ is stress in the outer fibres at midpoint (MPa), P is load at a given point on the load-deflection curve (N), L is support span (mm), b is width of beam tested (mm), d is depth of beam tested (mm), E is modulus of elasticity in bending (MPa), m is slope of the tangent to the initial straight-line portion of the load-deflection curve (N/mm) of deflection; ε is strain in the outer surface (mm/mm), D is maximum deflection of the centre of the beam (mm).

2.3. Healing process

Healing of composites after bending test is performed by using hot-press and oven methods. The process diagram of healing is given in Figure 3. In both hot-press and oven methods, healing process is started at 100°C. Temperature raised to 215°C in 20 min. Samples are subjected to this temperature for 20 min. Process is completed at 50°C. 2 bars pressure is used in hot-press (Wermac®-H501, Turkey).

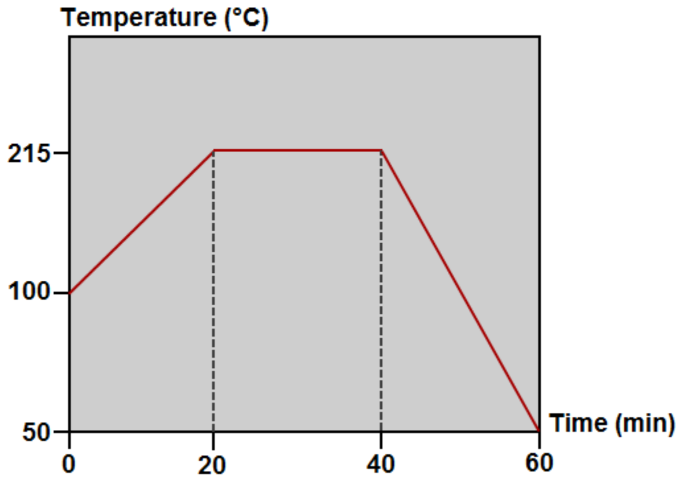

Figure 3. Process Diagram of Healing.

RESULTS AND DISCUSSIONS

Bending test results of undamaged and healed composites are given in Table 2. As seen in Figure 4, stiffness of composites in both healing methods decreased. Bending strength of undamaged composite is 37.77 MPa at 0° direction while the bending strength of undamaged composite is 283.00 MPa at 90° direction. The bending strength at 90° is almost 7.5 times higher than that of 0° since the stiffer carbon fibres are placed at 90° direction. Bending strain of undamaged composite is 7.37% at 0° direction while the bending strain of undamaged composite is 2.39% at 90° direction. This is due to PP fibres which have high strain to failure are placed at 0° and increased the ductility of composite.

Table 2. Bending Test Results of Composite Samples.

Samples	Flexural strength (MPa)			Flexural strain (%)		
	Undamaged	Healed		Undamaged	Healed	
		Press	Oven		Press	Oven
0°	37.77 ±2.62	13.04 ±2.03	10.17 ±1.07	7.37 ±0.98	3.79 ±1.50	1.52 ±0.30
90°	283.00 ±15.46	24.67 ±2.40	5.96 ±1.45	2.39 ±0.20	5.78 ±0.89	0.82 ±0.33

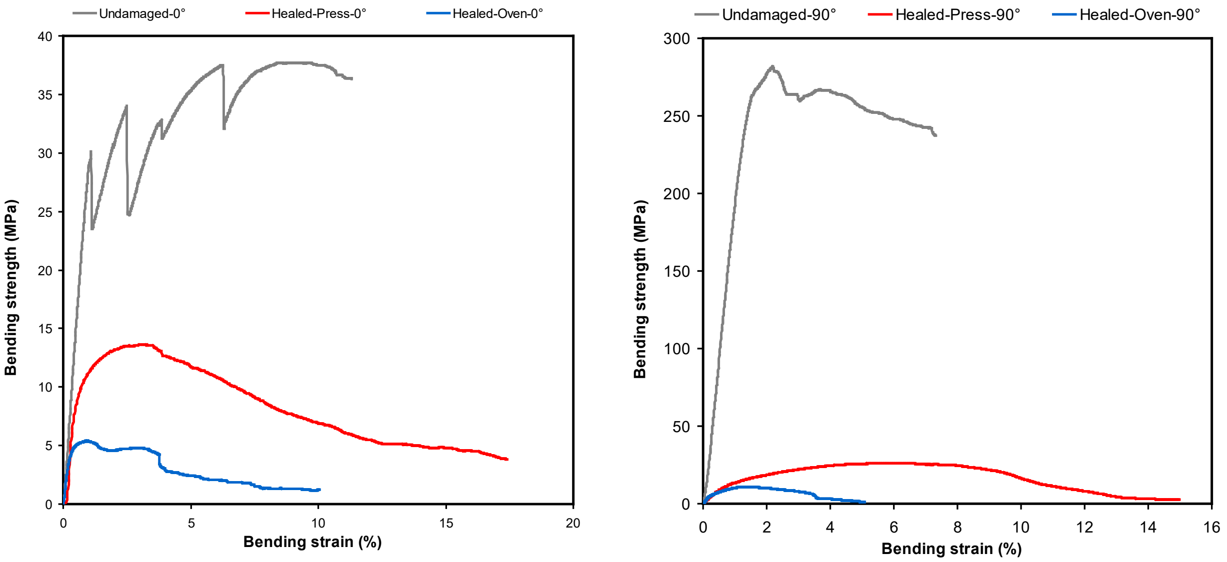

Figure 4. Bending Strength-Strain Curves of Composites.

Thickness results of undamaged and healed composites are also given in Table 3 to compare the effects of oven or press healing process on the thickness values of composites. It can be seen that the healing process has not any effect on the thickness values of composites. Therefore, it can be concluded that the pressure and/or temperature applied during the healing process did not change the fibre volumetric ratio. The pressure and temperature healed composites have better bending properties than the only oven-healed composites. In oven healed composite, PP fibres showed shrinkage under heat without pressure and this caused more gaps within the composite which decreased the bending strength.

Table 3. Thickness Results of Composite Samples.

Samples	**Thickness (mm)**		
	Undamaged	**Healed**	
		Press	**Oven**
0°	3.44 ± 0.10	3.43 ± 0.12	3.44 ± 0.11
90°	3.44 ± 0.04	3.43 ± 0.06	3.43 ± 0.01

Bending strengths of healed composites incredibly decreased at both 0° and 90° directions. However, the decrement at 0° is somehow reasonable. At both directions, the residual bending strengths (Figure 5) of press-healed composites are higher than that of oven-healed composites. This is due to the molten PP filled the gaps more influentially under pressure. Residual flexural strength of press-healed 0° composite is 34.5% while the residual bending strength of oven-healed 90° composite is 28.3%. It can be stated that the healing process is not effective at the bending strength of 90° composites. The bending strains of press-healed and oven-healed 0° composites are lower compare to undamaged composites. These results showed that the molten PP acts more brittle than PP fibres.

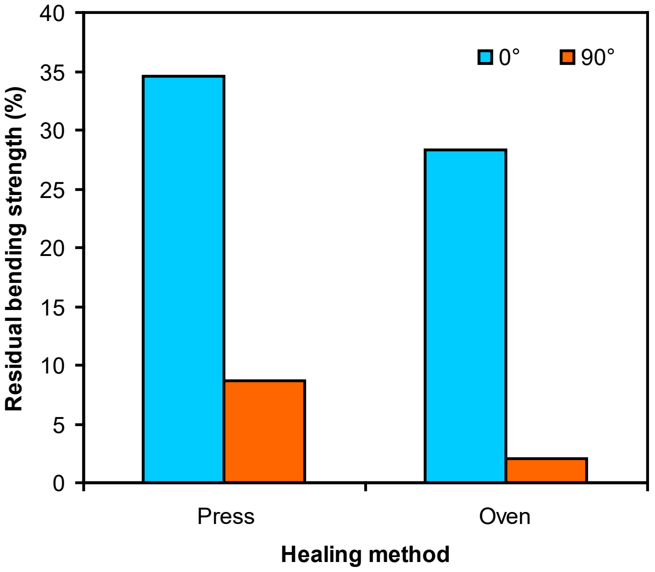

Figure 5. Residual Bending Strengths.

The cross-sectional failure views of composites (Figure 6) showed that both 0° and 90° samples have fibre breakages, fibre-matrix delamination and molten PP fibres. In oven-healing process, there are a lot of gaps are observed between PP and carbon fibres. It can be concluded that the PP fibres showed shrinkage under heat without pressure. Therefore, unpressured samples have more gaps which confirm the lower bending strengths of oven-healed samples.

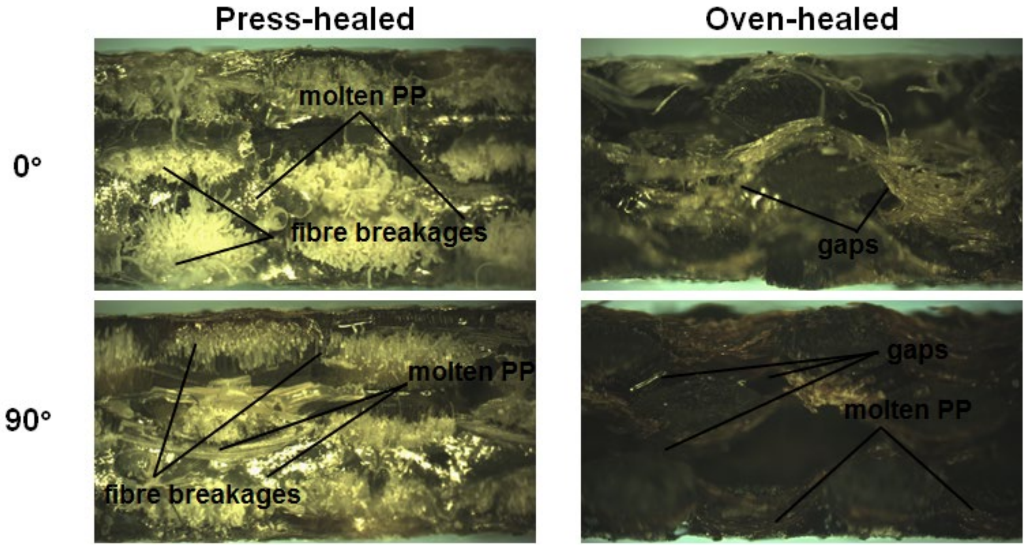

Figure 6. The cross-sectional failure views of composites (x2 magnification).

CONCLUSIONS

Bending strength and structural healing properties of carbon/PP/epoxy hybrid composites are investigated. For this purpose, two different structural healing processes are used. Effectiveness of the proposed healing processes is evaluated by both mechanically and microscopically. The conclusions are:

- The bending strength at 90° is almost 7.5 times higher than that of 0° since stiffer carbon fibres are placed at 90° direction.
- PP fibres increased the ductility of compositesat 0° because of theirhigh strain to failure.
- Bending strengths of healed composites incredibly decreased at both 0° and 90° directions in where the decrement at 0° is somehow reasonable.
- Residual bending strengths of press-healed composites are higher than that of oven-healed composites since the molten PP filled the gaps more influentially under pressure.
- Bending strains of press-healed and oven-healed 0° composites are lower compare to undamaged composites because of more brittle behaviour of molten PP than PP fibres.
- Cross-sectional views of composite samples confirm the lower bending strengths of oven healed samples in which PP fibres showed shrinkage under heat without pressure.

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