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Vibration Response of Thermoplastic Veil Interleaved Carbon Fiber Reinforced Epoxy Composites

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Abstract: This study investigated the vibration responses of carbon/epoxy composites interleaved with polyether ether ketone (PEEK) and poliamid (PA) thermoplastic veils. The composite manufacturing was carried out using the vacuum-assisted resin transfer molding (VARTM) technique utilizing veils interleaved carbon fabrics, and the test specimens were prepared according to the ASTM E756-05 standard. The vibration tests showed that the thermoplastic veil reinforcement increased the natural frequencies of the composites but decreased the damping ratios. In this context, approximately a 29% increase was recorded in the natural frequencies of PA interleaved composites, and it was observed that the thermoplastic veil reinforcement significantly affected the dynamic properties.

Termoplastik Keçe İlaveli Karbon Fiber Takviyeli Epoksi Kompozitlerinin Titreşim Cevabı

Anahtar Kelimeler
Doğal frekans,
Sönüm,
Termoplastik keçe,
PEEK,
PA,

Öz: Bu çalışmada, polieter eter keton (PEEK) ve poliamid (PA) termoplastik keçe ilave edilmiş karbon/epoksi kompozitlerinin titreşim cevapları incelenmiştir. Karbon elyaflar arasına ilave edilen keçeler ile VARTM tekniği kullanılarak kompozit üretimleri gerçekleştirilmiş ve ASTM E756-05 standardı kullanılarak test numuneleri hazırlanmıştır. Yapılan titreşim testleri, termoplastik keçe ilavelerinin, kompozitlerin doğal frekanslarını arttırdığı fakat sönüm oranlarını azalttığı anlaşılmıştır. Bu kapsamda, PA takviyeli kompozitlerin doğal frekanslarında yaklaşık %29'luk artışlar meydana gelmiş ve termoplastik keçe takviyesinin dinamik özellikleri önemli ölçüde etkilediği görülmüştür.

1. INTRODUCTION

Carbon fiber-reinforced polymer composites are widely used in many sectors, such as aviation, wind turbines, energy, etc., because of their superior mechanical properties [1]. However, laminated composite structures are susceptible to delamination damage [2]. Delaminations resulting from micro-cracks, voids formed during manufacturing, and damage occurs under loads reduce the composite's rigidity, strength, and service life [3]. The presence of damages, such as delamination and matrix cracks, cause composites to have low interlaminar properties which negatively affect the mechanical performance of the composite [4]. Various studies, such as hybridization, stitching, etc., are available to improve interlaminar properties [5]. One of them is nanostructure reinforcement. The primary purpose of this process is to strengthen the fiber/matrix interface or toughening the resin. However, the difficulties of dispersion of nanostructures in the resin stands out as a problem that needs to be overcome [6]. A promising method for improving the interlaminar properties is the interleaving process.

The interleaving process is a method that increases the fracture toughness of the composite interface. Nanofiber veils, short fibers, and thermoplastic films are frequently used in interleaving processes. [6]. In one of these studies, the interface of the laminated composite consisting of carbon fiber prepregs was reinforced with ultra-thin short aramid fiber veils. A toughened interface was created by strengthening the resin-rich regions between the layers with the veil [7]. In another study, carbon and glass nonwoven veils with different arial densities were interleaved to unidirectional glass fiber-reinforced composites and the mode I and mode II fracture toughness of these composites were determined. In all veil-interleaved composites, fracture toughness increased by 5-25% compared to non-veil-interleaved composites during propagation [8].

The meltability of some veils has also been the topic of study. In a study, meltable/non-meltable hybrid veils were interleaved to carbon composites. It was reported that the meltable veil strengthened the matrix, while the non-meltable veil created a bridging effect and significantly improved the fracture toughness of the composites [9]. Veil interleaving for fatigue-based delaminations has also been the topic of investigation. In a study conducted on this topic, significant increases were recorded in the fatigue life of composite manufacturing by interleaving processes using meltable (PA) and non-meltable polyphenylene-sulphide (PPS) resins [10]. Also, studies on the surface treatment of thermoplastic veils are available to ensure a better bonding with epoxy. For example, by applying the UV-irradiation technique to the PPS veil surface, the veil/epoxy interface improved, and the fracture toughness of the composites increased [11]. In another study in this context, nickel-coated carbon fiber veils were interleaved between carbon prepregs and increased the impact contact force [12].

Another process in the veil interleaving is nanostructure/veil interaction. It was observed that PPS veil reinforcement increases the fracture toughness, and composites interleaved with multi-walled carbon nanotube (MWCNT) reinforced PPS veils exhibit additional advantages with the bridging effect occurring at the interface between the epoxy/veil interface with the presence of MWCNTs [13]. In another study, partially cured, functionalized graphene-reinforced epoxy veils were interleaved to the carbon/epoxy composite, and significant increases were observed in the mode I test compared to control specimens [14].

Studies have also been carried out on the vibration response behavior of composites interleaved with veils. For example, a study utilizing four different thermoplastic-elastomer veil reinforcements exhibited that the veil reinforcement significantly affected the damping ratios of carbon fiber prepregs [15]. In a study regarding carbon composites interleaved with poly (ethylene-co-acrylic acid) (PEAA), the veil reinforcement significantly increased the damping ratio of the composite [16]. In another study in which the hybridization of basalt fibers between carbon layers can be considered an interleaving process, it was observed that basalt fiber reinforcement improved the damping ratios of hybrid composites [17]. In a previous study conducted by our research group, the vibration responses after the impact of carbon and glass fiber composites interleaved with five different thermoplastic veils were examined, and significant improvements were noted, especially in the natural frequencies of the carbon composites [18].

In this study, the vibration response behaviors of PEEK and PA veil interleaved carbon composites were investigated. In the previous study carried out by our research group [18], the vibration response of specimens prepared for impact testing was discussed. This study investigated the natural frequency and damping ratio performances of vibration specimens prepared per the ASTM E756-05 standard [19].

2. MATERIAL AND METHOD

2.1. Materials

Carbon fabric in plain weaving with a nominal weight of 500 g/m^2 utilized in the study was supplied from Carbomid Co. (Istanbul/Turkey). Duratek DTE 1120 epoxy and DTS 1151 hardener were used as epoxy system (Duratek Co. Kocaeli/Turkey). Thermoplastic veils (PA and PEEK) with 10 g/m^2 areal weight were purchased from Technical Fiber Products Ltd. (Cumbria/England).

2.2. Composite Manufacturing

Vacuum-assisted resin transfer molding (VARTM) was used in laminated composite manufacturing [20]. A schematic view of the VARTM technique is given in Figure 1. This technique is based on the principle of vacuuming the release film, fabric, peel ply and flow mesh stacked on the mold with a vacuum bag and the resin infusion. The resin system was prepared by mixing the resin with a mechanical mixer at 500 rpm for five minutes, with an epoxy/hardener ratio of 100/27 by weight according to the recommendation of the resin system's manufacturer [21]. The prepared resin system was subjected to a degassing process in a vacuum chamber.

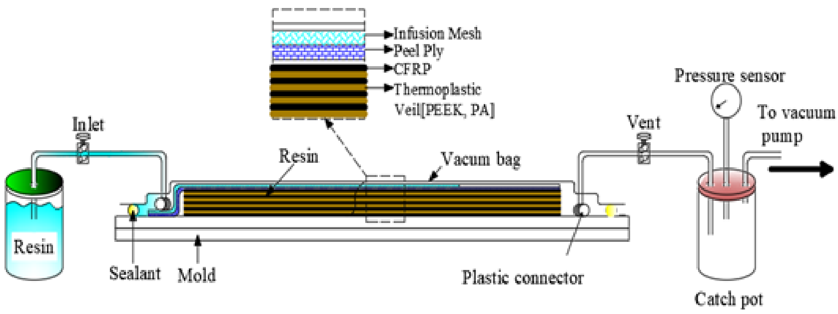

Figure 1. The VARTM technique, adapted from [18, 20]

The interleaving of thermoplastic veils in composite manufacturing is based on the principle of interply hybridization. Accordingly, the manufacturing details given in Table 1 are presented for the interleaving process performed by placing veils between the eight-layer carbon composite layers. Figure 2 shows the schematic of thermoplastic veil-reinforced and unreinforced products.

Table 1. Manufactured composites in the study.

Staking Sequence	Designation
[C/C/C/C/C/C/C/C]	Carbon-8
[C/PEEK/C/PEEK/C/PEEK/C/PEEK/C/PEEK/ C/PEEK/C/PEEK/C]	Carbon-8/7-PEEK
[C/PA/C/PA/C/PA/C/PA/C/PA/C/PA/C/PA/C]	Carbon-8/7-PA

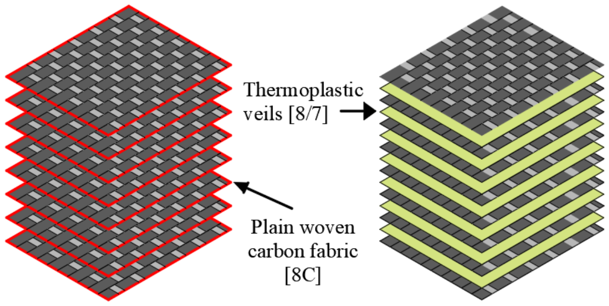

Figure 2. Composites interleaved with/without veils, adapted from [18]

2.3. Vibration Tests

Vibration tests were performed according to the ASTM E756-05 standard [19]. In this context, specimens with a dimension of 25x250 mm^2 were prepared (Figure 3), and vibration responses were obtained using the PULSE vibration test measurement setup (Brüel & KjærSound & Vibration Measurement A/S, Denmark), (Figure 4). The impact of creating a vibration response in the test specimens was applied using an impact hammer. Vibration responses of the specimens were achieved with a laser vibrometer. Natural frequency and damping datas were obtained with the ME'scopeVES software [22-24]. The tests were carried out under clamped-free boundary conditions.

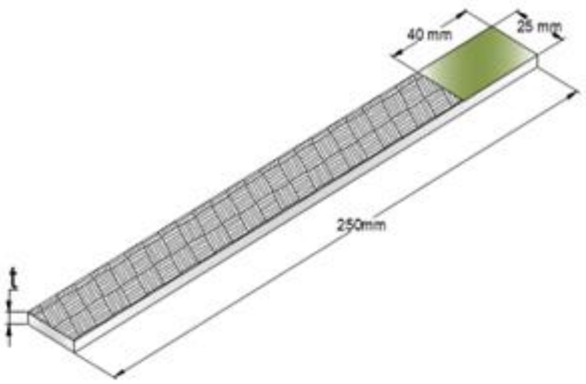

Figure 3. Dimensions of a vibration test specimen [20].

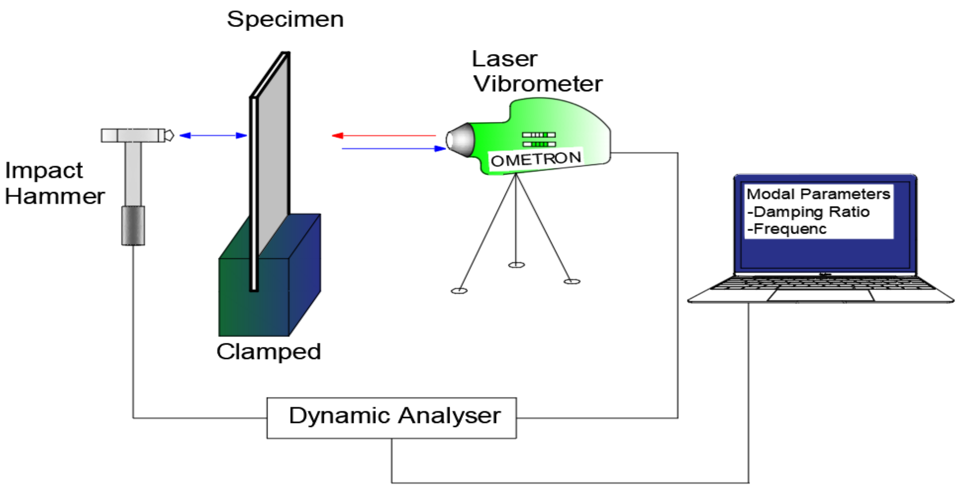

Figure 4. Schematic representation of the vibration measurement system, adapted from [18, 20]

3. RESULTS AND DİSCUSSİONS

Six specimens from each composite group were used in the clamped-free condition in the vibration tests. The average of the values obtained with at least three hammer strikes for each specimen was taken. The results were analyzed by calculating the final average values and standard deviations for the average vibration results of the composite group. In this context, the first natural frequency values and damping ratios were determined. Table 2 shows the first natural frequency and damping ratio values obtained. Figure 5 shows the graphs of the vibration test results.

Tablo 2. First natural frequency and damping ratio values [20].

Designation	Stacking Sequence	1stNatural Frequency (Hz)	Damping Ratio (%)
Carbon-8	8	54.6 ± 1.71	0.574±0.141
Carbon-8/7-PEEK	8/7	59.7 ± 2.76	0.541±0.166
Carbon-8/7-PA	8/7	70.4 ± 1.05	0.476±0.126

It was understood that thermoplastic veil interleaving increases the first natural frequency of carbon composites. Accordingly, the average natural frequencies of Carbon-8/7-PEEK and Carbon-8/7-PA specimens increased by approximately 9% and 29%, respectively, compared to the control specimen. On the other hand, decreases in the damping ratios of carbon composites with veil reinforcement were observed. In this context, approximately 6% and 17% decreases occurred in Carbon-8/7-PEEK and Carbon-8/7-PA composites, respectively.

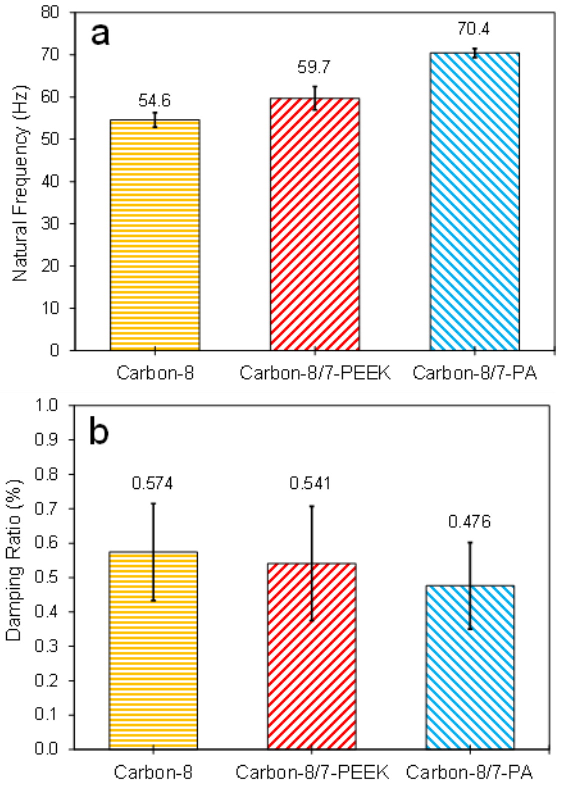

Figure 5. Vibration test results, a) 1st natural frequency, b) damping ratio.

In the study, it is thought that the veils interleaved between the layers provide enhanced adhesion with epoxy. Therefore, it is assumed that veils that create a new interface with epoxy increase the interlaminar toughness, and this improvement increases the rigidity of the composites. As the stiffness of the composites increased, the natural frequency values also increased. On the other hand, increasing stiffness had adverse effects on damping, and decreases in damping ratios were recorded. The inverse relationship between stiffness and damping is a phenomenon. In a study, it was noted that basalt fiber hybridization increased the damping ratios of carbon composites, and this was due to the low stiffness of the basalt fiber composites [17]. A similar trend is observed in our study.

On the other hand, in the study conducted by our research group [18], vibration responses of specimens with similar composites used in this study were investigated according to the condition of pre/post impact testing. In the motioned research [18], natural frequencies of the pre-impact specimens with dimensions of 100x150 mm^2 were significantly higher than those prepared according to ASTM E756-05 standard in this study. In addition, it was noted that the damping ratio of PEEK interleaving was slightly lower compared to the similar specimen used in this study. However, the damping ratios of other composites were found to be higher than their equivalents in this study. In this context, it has been understood that dimensional difference is an effective parameter for vibration response. Moreover, it is thought that the mechanical properties of composites with increased natural frequency enhance as their stiffness increases.

4. CONCLUSION

In this study, the effect of two different thermoplastic veils interleaved between the layers of carbon fiber-reinforced composites on the vibration response behavior of the composite was experimentally investigated. The results are summarized below.

- It was observed that both veil interleaving had enhanced adhesion with epoxy and toughened the interface. Therefore, the stiffness and natural frequencies of the modified composites were increased.
- Decreases were observed in damping ratios.
- While PA veil interleaving exhibited high performance in terms of natural frequency, PEEK veil interleaved composites show similar damping behavior with non-interleaved composites.

For future studies, it is necessary to interleave these veils in different stacking squences within the composite by an interply hybridization and to perform more comprehensive vibration analyses.

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