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Damping and Vibration Behavior of Adhesively Bonded Glass Fiber Reinforced Composite Laminates

Ömer Yavuz BOZKURT*[1], Özkan ÖZBEK[1], Mehmet BULUT[1]

[1]*Gaziantep University, Engineering Faculty, Mechanical Engineering Department, Gaziantep*

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Abstract

Recently, the fiber-reinforced composite materials have been widely used for structural applications due to their superior mechanical properties. The structural applications require a method to join the components of the system. Due to the ease of fabrication and installation, adhesively bonded joint receives particular attention in recent years. In the current study, damping and vibration characteristics of glass fiber-reinforced composite laminated materials have been investigated with respect to the bonded length of adhesively single strap joint type. The experimental studies were performed using six symmetric laminates having $[(0/90)_6]_s$ fiber orientation angle at four different bonded length. The vibration characteristics of the composite laminates were determined by dynamic modal analysis. The damping properties were obtained using half power bandwidth method from the results taken vibration response curves. The obtained results were compared with original laminates.

Keywords: Single strap joint, Composite laminates, Damping, Vibration

Yapıştırma ile Birleştirilmiş Cam Elyaf Takviyeli Kompozit Tabakaların Sönümleme ve Titreşim Davranışları

Öz

Son zamanlarda, elyaf takviyeli kompozit malzemeler üstün mekanik özelliklerinden dolayı yapısal uygulamalarda yaygın olarak kullanılmaktadır. Yapı bileşenlerinin sisteme dahil olması için bir yöntem gerekmektedir. Son yıllarda yapıştırma ile birleştirme yöntemi üretim ve kurulum kolaylığından dolayı dikkat çekmektedir. Bu çalışmada cam elyaf takviyeli kompozit tabakalı plakaların sönümleme ve titreşim davranışları tek takviyeli bindirme bağlantısı kullanılarak birleşim uzunluğuna göre araştırılmıştır. $[(0/90)_6]_s$ fiber yönelimlerine sahip altı simetrik tabakadan oluşan plakalar dört farklı birleşim uzunluğunda deneysel olarak incelenmişlerdir. Kompozit plakaların titreşim özellikleri dinamik model analizi yapılarak belirlenmiştir. Sönümleme özellikleri titreşim tepkisi eğrilerinden alınan sonuçların yarım bant genişlik yöntemini kullanmak sureti ile elde edilmiştir. Elde edilen sonuçlar birleştirme yapılmamış kompozit tabaka ile karşılaştırılmıştır.

Anahtar Kelimeler: Tek takviyeli bindirme, Kompozit tabakalar, Sönümleme, Titreşim

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* Sorumlu yazar (Corresponding author) : Ömer Yavuz BOZKURT, *Engineering Faculty, Mechanical Engineering Department, Gaziantep. oybozkurt@gantep.edu.tr*

1. INTRODUCTION

Nowadays, the fiber-reinforced composite material have been widely used in many engineering applications because of their superior mechanical properties. The determination and investigation of their behaviors at various parameters have become so important. The structural composite applications require a connection type to join the components of the system. Many joint types for composite materials are examined by researchers, but adhesively bonded joints such as single/double lap, single/double strap, tongue/groove etc [1] receive particular attention in recent years. Quaresimin and Ricotta [2] performed an experimental study about the behavior of single lap joints of composite materials under static and fatigue loading. They found the nominal tensile stress on the adherends increases with the overlap length. Lee et al. [3] compared to adhesively single lap and double strap joints for pultruded glass fiber-reinforced polymer composites. Dvorak et al. [4] examined the tongue and groove joint type for the thick composite laminates. They performed experimental studies such as tension tests on steel and composite material and discussed the obtained results.

Damping is an important parameter that effects the reducing or preventing oscillations on the structures. Also, it measures the ability of vibration energy absorption of the materials. Several studies related to damping and vibration properties of the composite laminates can be found in the literature. He and Rao [5] studied a theoretical study about the vibration analysis of adhesively bonded lap joint. They derived the equations of motion under distributed loads using energy method and Hamilton’s principle. Botelho et al. [6-7] investigated the damping behavior of fiber/metal hybrid composite materials by the free vibration method. They also researched hygrothermal effects on damping behavior of metal/glass fiber hybrid composite materials. Khan et al. [8] damping and vibration characteristics of carbon fiber-reinforced composite laminates having nanoparticles.

According to literature review, some studies are present about dynamic properties of the adhesively bonded fiber-reinforced composite laminates. However, none of them have been considered the single strap joints. The current study presents an investigation on damping and vibration behaviors of adhesively bonded single strap joint by experimentally. The obtained results were compared with those of the results obtained from original unbonded-one piece specimen.

2. MATERIALS AND METHODS

Plain weave glass fiber having six symmetrical laminate with $[(0/90)_6]_s$ orientation is used as reinforcement. Polyester resin (Polipol 3401-TAB) and hardener (methyl-ethyl-ketone-peroxide, MEKP) were mixed in the ratio of 99:1as common matrix. Adhesively bonded specimens, shown Figure 1, were prepared at the different bonded lengths, L of 40 mm, 50 mm, 60 mm and 70 mm as shown in Table 1. The fiber-reinforced glass laminate was fabricated using hand layup technique under 0,3 MPa pressure with 80C^{o} temperature. Afterward, curing of composite laminate was performed at room temperature. Epoxy resin (MOMENTIVE-MGS L285) with hardener (MOMENTIVE-MGS H285) in the ratio of 100:40 were used as adhesive to bond each lamina. Thicknesses, t and 2t on the midpoints of the original and bonded specimens were measured as 2.0 mm and 4.0 mm, respectively.

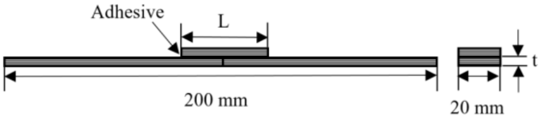


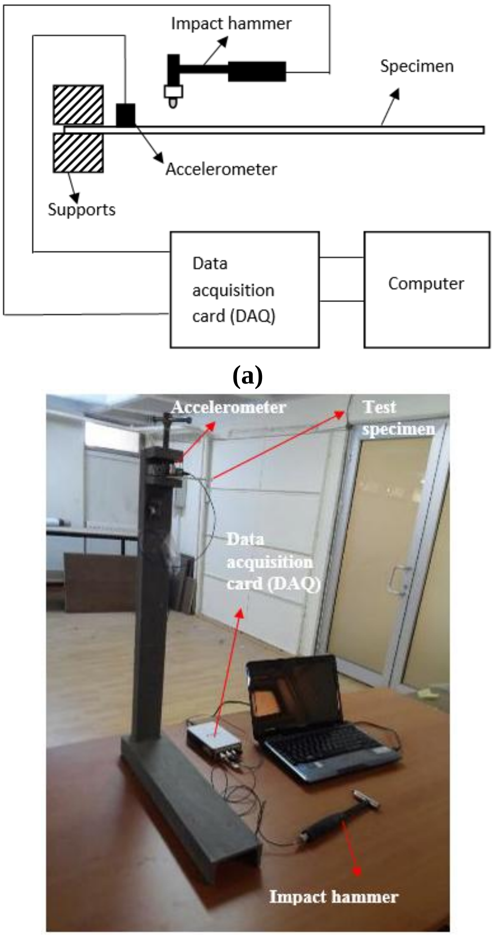
Figure 1. Illustration of adhesively bonded specimen with single strap joint

Table 1. Produced specimens according to adhesively bonded lengths

Bonded Length, L (mm)	Naming
0	$(A_{12})^{0}$
40	$(A_{12})^{40}$
50	$(A_{12})^{50}$
60	$(A_{12})^{60}$
70	$(A_{12})^{70}$

2.1. Vibration Tests

Experimental studies on dynamic behavior of specimens were performed using test device, shown in Figure 2, according to ASTM E756 standard [9]. A National Instrument product NI 9234 data acquisition device with LABVIEW program was used as software. PCB 352C03 ceramic shear ICP ® accelerometer and PCB 086C03 modal impact hammer were employed for output and stimulus force signal, respectively.



(a)

(b)

Figure 2. Vibration test set-up. **(a)** Sketch of vibration test mechanism and unbonded-one piece specimen, **(b)** Overall view of vibration set-up

Time dependent acceleration response of the specimens was measured by the usage of impact hammer. Afterwards, determination of the magnitude versus frequency due to responses was performed using the Fast Fourier Transforms (FFTs). The results belong to frequency responses were extracted within the constant frequency range from 0 to 500 Hz. Five specimens were prepared for each bonded length and three vibration tests were recorded for each specimens.

2.2. Damping Ratios

Half-power bandwidth method was used to measure first mode natural frequencies as shown in Figure 3. Then, damping ratios of the specimens were calculated using Eq. (1).

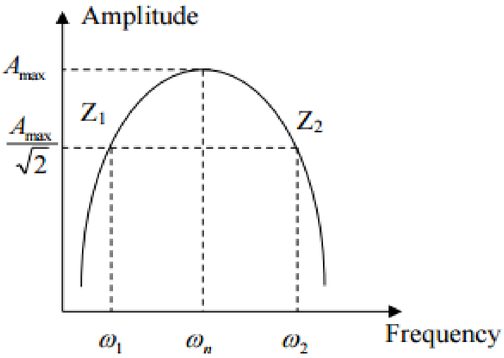


Figure 3. Half-power bandwidth method

$$\xi = \frac{\omega_2 - \omega_1}{2 \times \omega_n} \qquad (1)$$

where w_1, w_2 are the bandwidth, w_n is the natural frequency of first mode, and ξ is the damping ratio.

The storage and loss modulus of the adhesively bonded specimens cannot be calculated since their discontinuous structures. This two modulus was obtained for only unbonded-one piece specimen. The storage modulus (E') of the beam specimen was obtained using Eq. (2).

$$\omega_1 = \frac{1.875^2}{2\pi L^2}\sqrt{\frac{E'I}{\rho A}} \qquad (2)$$

where ρ is density of the beam, A is the cross-section of the beam, I is the moment of inertia of the given cross-section of beam, E' is the storage modulus, L is the free length of the beam and $w_1$is the natural frequency of first mode.

Similarly, loss modulus (E'') of the beam specimen can be found using the following relationship between loss and storage modulus.

$$E'' = E'(\omega)\, tan(\delta) = 2E'(\omega)\xi(\omega) \qquad (3)$$

3. RESULT AND DISCUSSION

The frequency response curve versus amplitude were recorded as shown in Figure 4 after the vibration experiments. The values of first, second natural frequencies and maximum amplitudes that is given in Table 3 was obtained from the frequency response curve. It is observed that first natural frequency value has maximum value on the bonded length is 50 mm. However, frequency value in the second mode has higher than others at the bonded length is 60 mm. Also, it is observed that there is an increase up to 50 mm, after this value it takes a decreasing trend for the damping ratio results. According to below results, the bonded length having 50 mm looks like the most suitable length for stability of the system when comparing to other ones. Also, storage and loss modulus of the unbonded- one piece specimen was calculated as 18.8 GPa and 5.33 GPa from the Eq. (2) and (3).

Table 2. Damping and natural frequency values

Bonded Length, L (mm)	First mode (Hz)	A_1 (g/N)	Second mode (Hz)	A_2 (g/N)	Damping ratio
0	37,99	107,10	234,53	122,64	0,142
40	41,29	93,80	241,14	116,32	0,593
50	46,25	70,68	257,65	109,40	0,646
60	44,6	93,97	265,91	109,42	0,332
70	26,62	100,43	163,84	116,53	0,188

A1: Maximum Amplitude of First Mode; A2: Maximum Amplitude of Second Mode

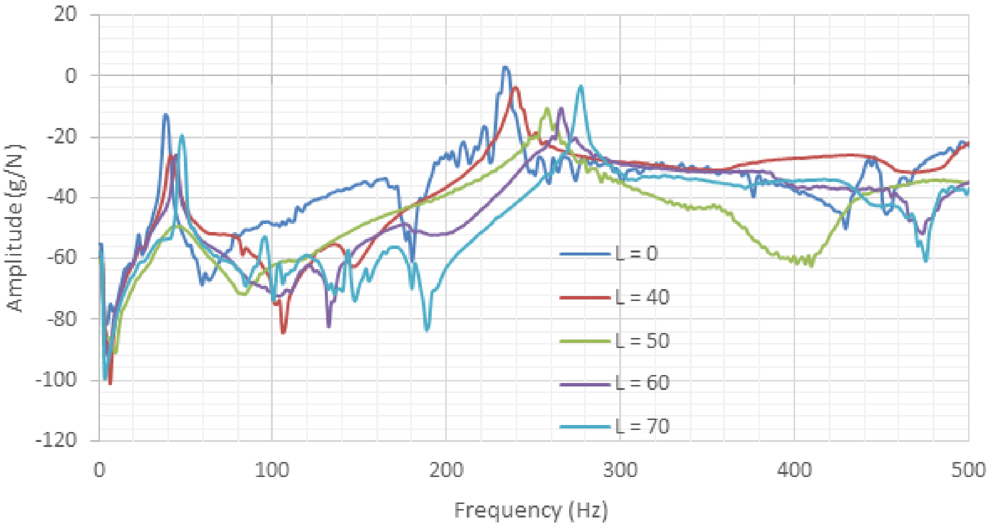


Figure 4. Frequency responses of specimens

Figure 5 presents the effects of bonded lengths resulting from the time versus acceleration records. Amplitude-time decaying curves were recorded within the same time intervals (a second) to compare damping properties of the specimens. The unbonded-one piece specimen has the worst value because of the thickness is half of the others. Among the adhesively bonded specimens, 40 mm seems the best one, but all of them diverge the stability with a close intervals.

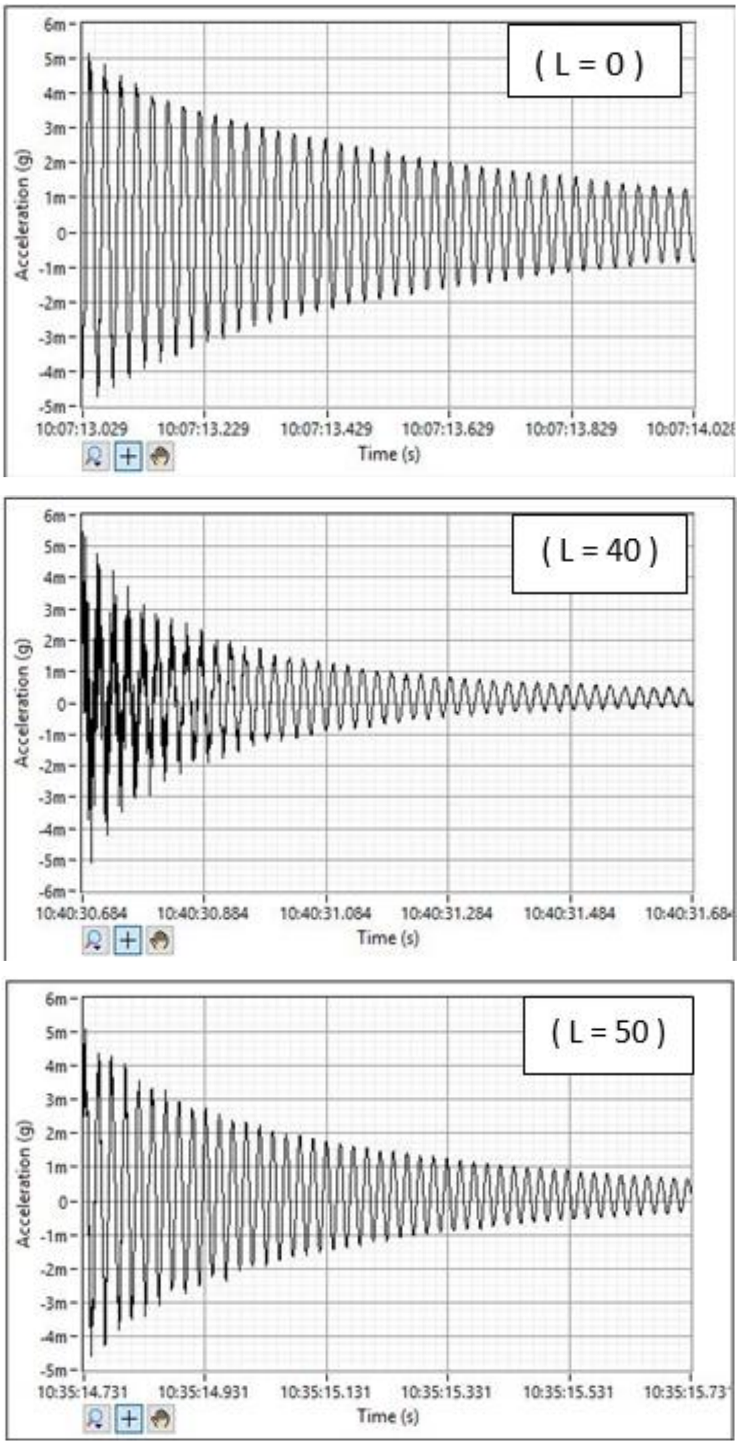


Figure 5. Time dependent acceleration responses of specimens

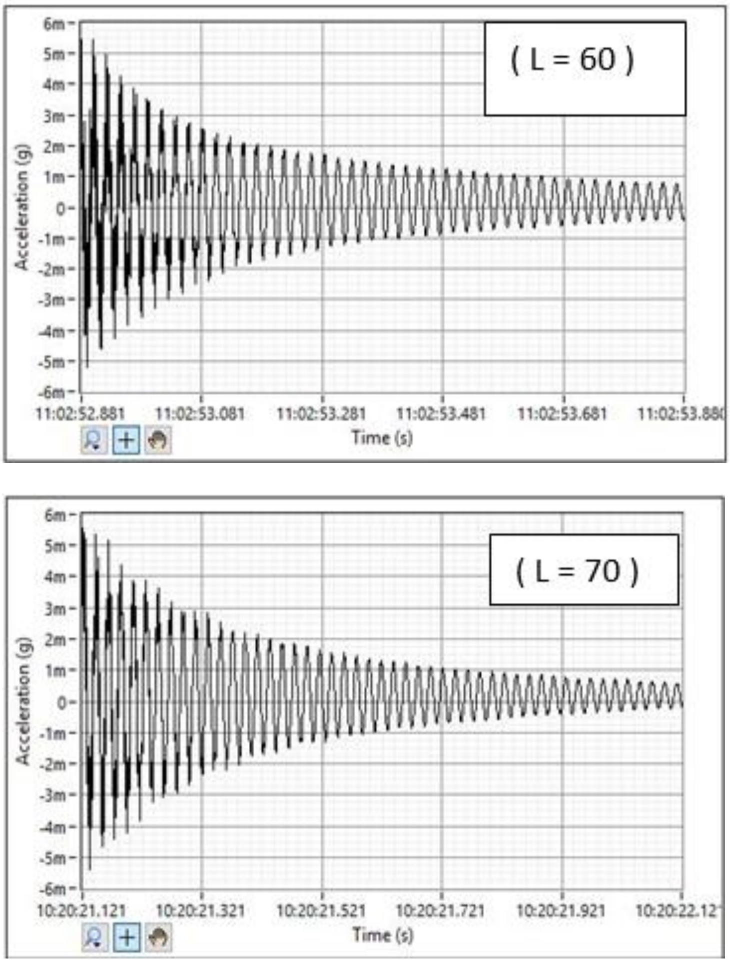


Figure 5. Time dependent acceleration responses of specimens (Continue)

4. CONCLUSIONS

In this work, damping and vibration characteristics of adhesively bonded glass/polyester fiber-reinforced composite laminates were experimentally determined. The effect of bonded lengths applying epoxy resin as adhesive was performed. Using half-power bandwidth method and FFTs, the damping properties were measured from vibration response envelope curve. The main conclusions from this study can be summarized as follows;

- Damping and vibration characteristics of the composite specimens are strongly affected by the adhesively bonded lengths,

- Damping ratio of the specimens is increasing up to certain bonded length (50 mm) and after that decreasing happens.

Finally, the results recommend that the application of adhesively bonded length will be appropriate up to certain length for stability of the structures. It should be determined before performing in structures during the service

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