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Vibration Characteristics Analysis of Adhesively Bonded Different Joints

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ABSTRACT Joining components is a critical concern in material science and construction. Adhesively bonded joints have been used extensively in engineering applications. This issue draws the attention of researchers. This paper investigates the vibration properties of adhesively bonded different joints with double-sided adhesive tape, experimentally. Single lap joint, single strap joint, and double strap joint were taken into consideration as joint types. Vibration tests were conducted on constructed joints and results were evaluated based on natural frequencies and their corresponding damping ratios which were obtained from experimental data. The influences of adhesive tape thickness, aluminium plate thickness, and overlap length on vibration behaviour were also studied. In brief, growing overlap length increases both the natural frequencies and damping ratios of the system for single lap joints. For both single strap and double strap joints, overlap length does not play an important role in the natural frequencies but it has an essential effect on the damping ratios. Based on the results, double strap joint construction attained the best damping capability, which proves different joint constructions are another effective parameter affecting the damping ratio. Last but not least, it was noted that the adhesive tape thickness had a more significant effect over the damping ratio than the effect of overlap length.

Keywords: Natural frequency, Damping ratio, Single lap joint, Single strap joint, Double strap joint

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1. INTRODUCTION

Assembling the structural parts and their connection techniques are of main concerns in engineering applications. Traditional repair and bonding techniques such as welding, bolds, soldering, rivets have some constraints that can be difficult to apply in engineering materials where lightness, fuel-saving, sealing, aerodynamic, and vibration damping are important. These constraints make adhesively bonded techniques an attractive option which provides ease of manufacturing, reduction in stress concentrations, reduced weight [1], cost-effective, and ecological reasons [2], reduced corrosion, minimal shape change, improved fatigue behaviour and reduction of the maintenance costs [3]. Due to these advantages, adhesive bonding is a widely used assembly technique for connection parts in structural engineering. Besides, adhesive bonding is an effective method of becoming similar and dissimilar components together without damage to the adherent.

Despite these positive aspects, adhesively bonded joints can be exposed to dynamic loadings such as impact, crash, and vibration while those are in service which may results in fatigue and eventually the failure of the system. There has been an increasing interest in analysing of the dynamic behaviour of the adhesively bonded joints. Analysing is necessary to ensure the durability, safety, reliability, and integrity of adhesively bonded joints. Dynamic behaviours can be analysed analytically [4, 5], experimentally [6-9], and also numerically [10-16].

The dynamic loading of the adhesively bonded joint is a fundamental concern in engineering applications. Adhesively bonded joints must be investigated and well understood to ensure safety, durability, and customer satisfaction. Vibration outputs such as natural frequencies, damping ratios, and mode shapes give knowledge for interpreting the dynamic behaviour of adhesively bonded joints [17-21].

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The main objective of this study is to experimentally investigate the vibration behaviour of bonded different joints with double-sided adhesive tape. The influence of aluminium plate thickness, plate length, overlap length, and double-sided adhesive tape thickness have been characterized by the vibration parameters of the natural frequency and damping ratio of the fabricated test specimens.

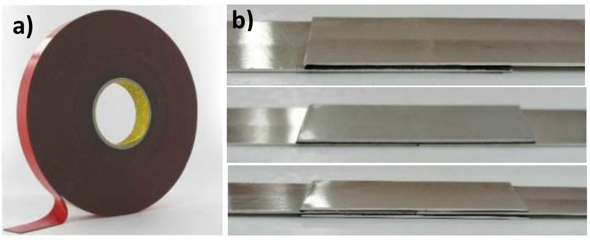


Fig. 1. a) Double-sided tape b) Test specimens of adhesively bonded different joints

2. EXPERIMENTAL

The adherent material used for this study was chosen as aluminum in plate form, and its physical and mechanical properties of it is provided in Table 1. Aluminum plates had 25 mm in width, and in different thicknesses (0.8, 1.0, 1.2, 1.6 mm) and in different lengths but the overall length of the testing specimens was fixed to be constant as 300 mm. Double-sided adhesive tape also known as VHB 3M 4646F (Egebant Sandpaper and Buffing Materials Co., Kocaeli, Turkey) was used as an adhesive and its properties given in Table 2. The dimensions for double-sided tape were 0.6 mm in thickness, 25 mm in width. However, tape lengths were chosen and cut depending on the bonding length shown in Figure 1(a).

Table 1. Properties of adherents

Adherent Type	Aluminium 2024
Density	2780 [kg/m^3]
Young's Modulus, E	73.1 [GPa]
Shear Modulus, G	28.0 [GPa]
Poison's Raito, ν	0.33

Three types of adhesively bonded joints; single lap joint, single strap joint and double strap joint, were constructed to determine the vibration behaviour of joints. Prior to the bonding, surfaces of all aluminum plates were cleaned with alcohol to achieve a well-bonded joint. Then, the bonding process was applied to the materials at room temperature with a subjected load to have a better bond.

Table 2. Properties of adhesive tape used in current study

Adhesive Type	Acrylic
Foam Core	Acrylic
Thickness (ASTM D-3652) Tape	0.6 mm ± 0.1 mm
Release Liner	White Filmic
Tape Colour	Dark Grey
Foam Density	840 kg/m^3

2.1. Experimental

Vibration tests were conducted on fabricated specimens shown in Figure 1(b). Specimens were tested under the free-free boundary condition. Pulse, a vibration test measurement system shown in Figure 2, was used to obtain vibration data. The test system consists of a modal impact hammer (B&K 2302–5), a Fast Fourier Transform (FFT) analyser (B&K 3560), a laser vibrometer, and a computer. The bonded specimens were excited at any point with the help of impact hammer, and the responses of specimens were recorded by the laser vibrometer. The natural frequencies and their corresponding damping ratios were calculated with the pulse vibration test measurement system. Eventually, the influences of adhesive tape thickness, aluminium plate thickness, and overlap length on natural frequency and damping ratio were determined.

The geometrical properties shown in Figure 3-5 were chosen as the experimental parameters, which their values unless stated otherwise, are ℓ_{ol}=20 mm, 30 mm, 40 mm and 50 mm; ℓ =300 mm; t_1=0.8 mm, 1 mm, 1.2 mm and 1.6 mm; t_2=0.6 mm, 1.8 mm, 3.6 mm and 5.4 mm; t_3=0.8 mm, 1 mm, 1.2 mm and 1.6 mm.

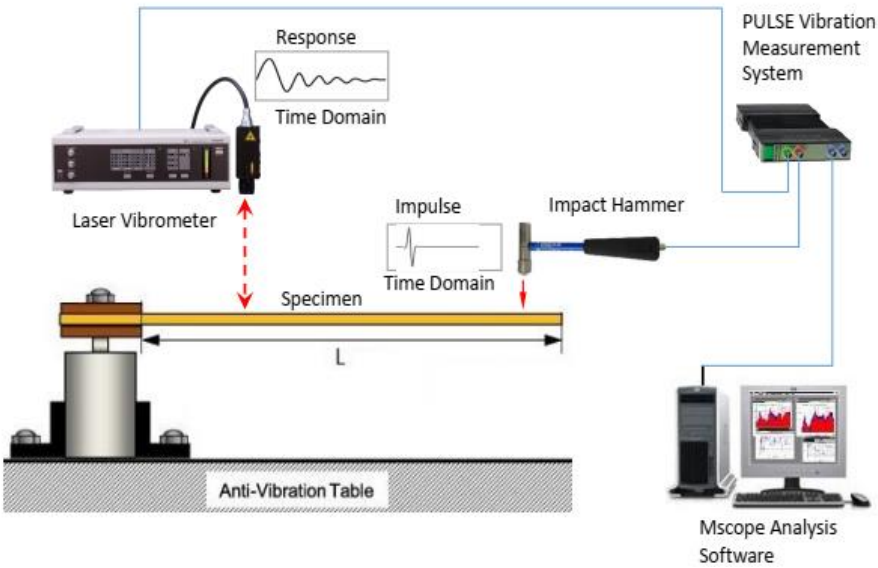


Fig. 2. The schematic of the experimental test set-up

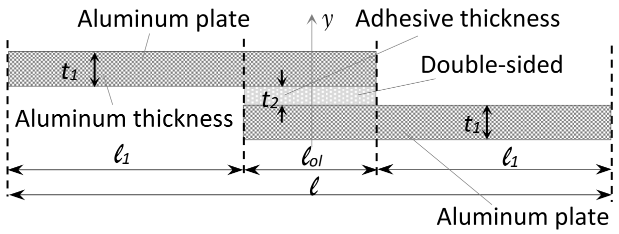


Fig. 3. The configuration of the single-lap joint

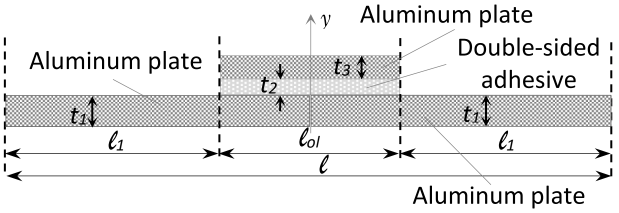


Fig. 4. The configuration of the single strap joint

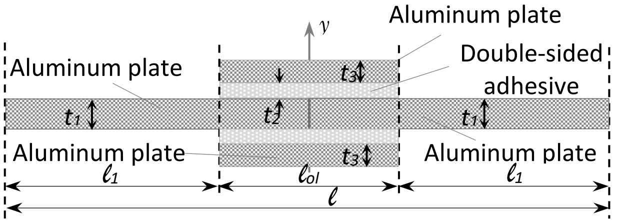
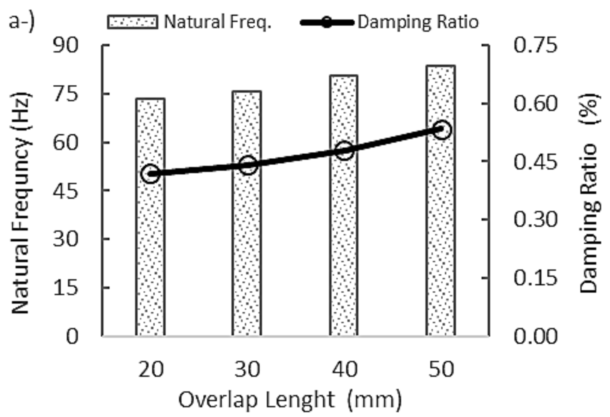


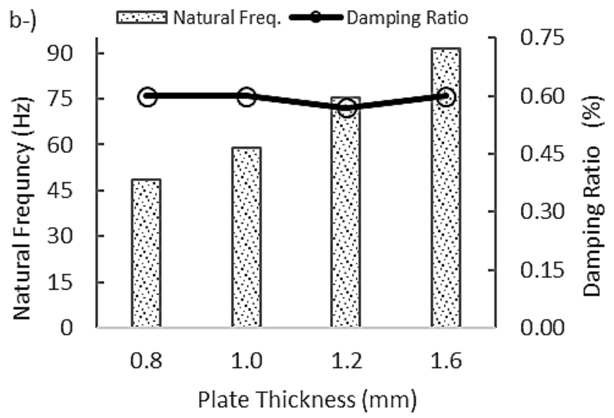
Fig. 5. The configuration of the double strap joint

3. RESULTS and DISCUSSION

In this paper, the experimental test technique was used to investigate the vibration and damping characteristic of an adhesively bonded single lap, single strap, and double strap joint shown in Figure 1(b), and the obtained results are given in Figures 6 - 10.

For the single lap joint shown in Figure 3, the effect of the double-sided adhesive tape thickness, overlap length, and aluminium plate thickness of the resonant frequency ratio and damping ratio are graphically shown in Figure 6(a-c). Only the fundamental natural frequency and its corresponding damping ratio were determined, but higher natural frequencies and their damping ratios were ignored.





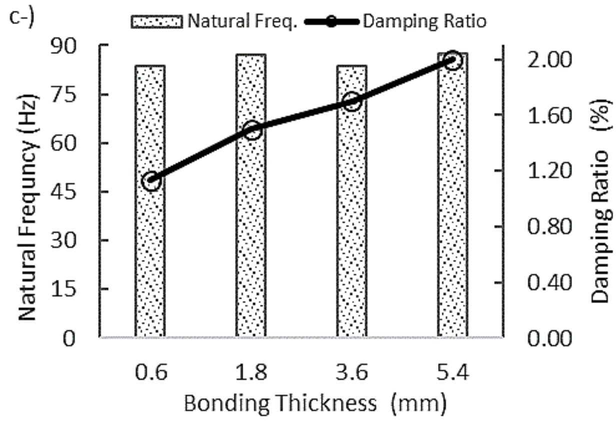
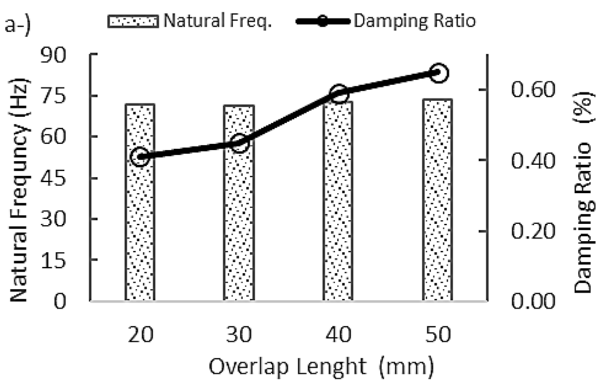


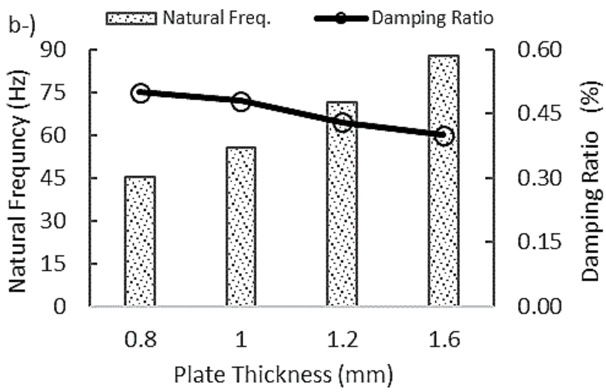
Fig. 6. Variation of natural frequency and damping ratio values of single lap joint; a) overlap length b) aluminium plate thickness, c) adhesive tape thickness

Figure 6(a) shows the lowest resonant frequency and the damping ratio of single lap joints versus the overlap length for t_1 = 1.2 mm and t_2 = 0.6 mm. It is seen that the rise in the overlap length increases both the lowest resonant frequency and damping ratio of the system. This state can be interpreted that the effective beam length is shortened since the tip of the overlap moves towards both ends of the beam. This situation increases both the total mass and rigidity of the system at the same time. It may be seen also that the increase of rigidity which is more dominant than the rise in the total mass of the beam, and the damping coverage will increase the resonant frequency and damping ratio. Besides, when the overlap length was increased by 2.5 times, the damping ratio increased by 27.58%.

Figure 6(b) demonstrates the lowest resonant frequency, and the damping ratio of single lap joints according to aluminium plate thickness. The natural frequency of the system increases apparently. The reason for this increase can be attributed to the fact that increasing thickness rise the moment of inertia of the area. On the other hand, the damping ratio is not affected by increasing aluminium plate thickness. The effect of bonding thickness is represented in Figure 6(c). This figure exhibits that the damping ratio of the system increases remarkably with increasing bonding thickness. Nevertheless, the bonding thickness, which does not change the amount of mass, did not significantly affect the natural frequency.

Figure 7(a) depicts the lowest resonant frequency and the damping ratio of single strap joints shown in Figure 4 versus the overlap length for t_1 = 1.2 mm and t_2 = 0.6 mm. It can be seen that the increase in the overlap length does not affect the lowest resonant frequency of the system. This can be explained with patching a strap, the rigidity and the total mass of the system changed at the same amount; hence the natural frequency did not change. Also, from Figure 7(a), when the overlap length was increased by 2.5 times, the damping ratio remarkably increased by 59%. Figure 7(b) presents the lowest resonant frequency and the damping ratio of single strap joints versus aluminum plate thickness. As it can be noted, the natural frequency of the system increases with increasing plate thickness. The reason for this can be explained with that the increasing thickness gives rise to the moment of inertia of the area. In contrast to the natural frequency, it can be noticed that the damping ratio decreases with increasing aluminium plate thickness. The effect of bonding thickness which is another parameter of the joint as illustrated in Figure 7(c). It is observed from the figure that the damping ratio of the beam increases significantly with increasing bonding thickness. It shows the dominance of effective bonding thickness is on the damping ratio. On the contrary, the natural frequency of the beam has slightly changing tendency. This condition can be explained by the fact that the mass of the system has increased due to the increasing bonding thickness.





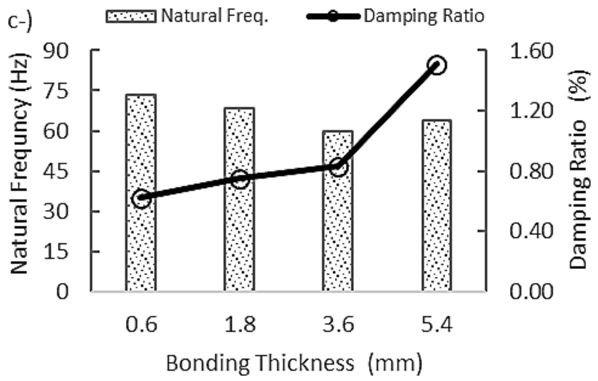
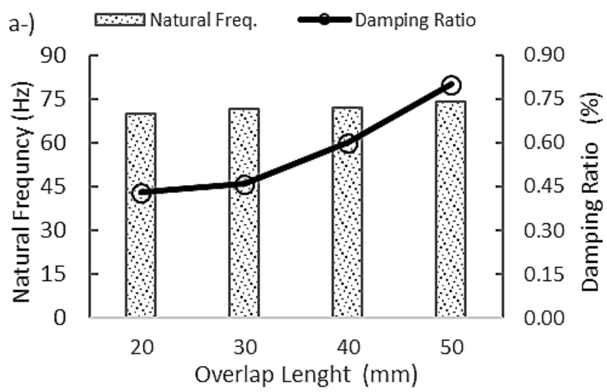


Fig. 7. Variation of natural frequency and damping ratio values of single strap joint; a) overlap length, b) aluminium plate thickness, c) adhesive tape thickness

As one can notice from the above figures for the single strap joint, similar changes have been observed for the double strap joint shown in Figure 5 depending on the same parameters. Figure 8(a) indicates the lowest resonant frequency and the damping ratio of double strap joints versus the overlap length for t_1 = 1.2 mm and t_2 = 0.6 mm. It can be seen that the increase in the overlap length has a slight effect on the lowest resonant frequency of the system, but this cannot be regarded as an increase trend.

As it was concluded before, with patching a strap, the rigidity and the total mass of the system change at the same time; hence nothing changed the natural frequency. Also, from Figure 8(a), when the overlap length was increased by 2.5 times, the damping ratio importantly increased by 86%. Figure 8(b) presents the lowest resonant frequency and the damping ratio of double strap joints versus aluminium plate thickness. With increasing plate thickness, the natural frequency increased with the effect of growing the moment of inertia for the area. On the contrary, it can be seen that the damping ratio decreases with increasing aluminium plate thickness. The effect of bonding thickness which is another parameter of the joint is illustrated in Figure 8(c). It is observed from this figure; the damping ratio of the beam increases with increasing bonding thickness. It is evident that how effective bonding thickness is on the damping ratio. Whereas, the natural frequency of the beam displays a decreasing trend with increasing bonding thickness. This case can be explained by the fact that the mass of the system has increased due to the increasing bonding thickness.



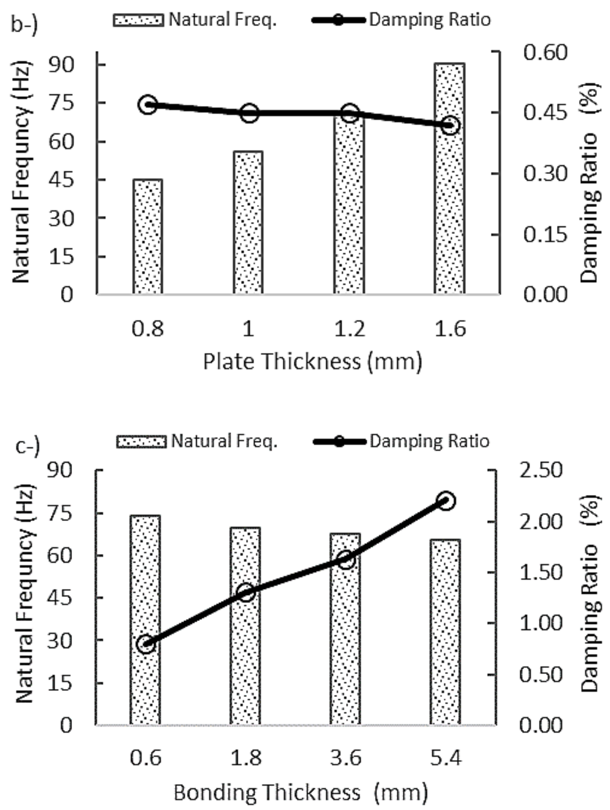


Fig. 8. Variation of natural frequency and damping ratio values of double strap joint with a) overlap length, b) aluminium plate thickness, and c) adhesive tape thickness

In Figure 9, the damping ratios of the samples are plotted as a function of the overlap length for three different joint constructions. It may be deduced from the figure that an increase in adhesive tape coverage increases the system damping ratio that is related to energy dissipation. As more damping material covers the beam, more energy is dissipated, thus increasing the system damping ratio.

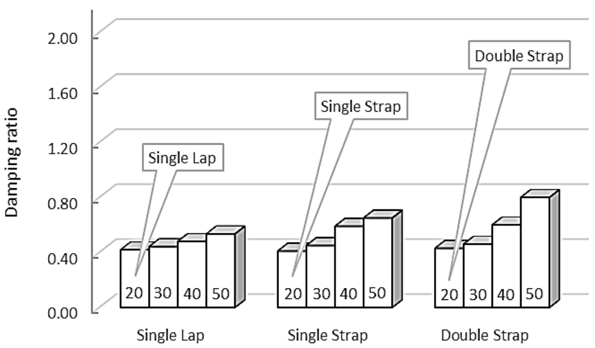


Fig. 9. Comparison of damping ratios of different joint constructions depending on overlap length (20, 30, 40, 50 mm)

The different joint construction is another parameter affecting the damping ratio. It can be seen that double strap joint construction has the best energy absorption capability. Therefore, the joint construction types may take into account in terms of engineering requirements.

Figure 10 reveals the significance of the variation of the damping ratio concerning the adhesive tape thickness for different joint construction. It can be seen from Figure 9; similarly, the same changes have been observed for the adhesive tape thickness depending on different joint construction. However, in addition to the observations of Figure 10, adhesive tape thickness has a more significant effect over the damping ratio than the effect of overlap length.

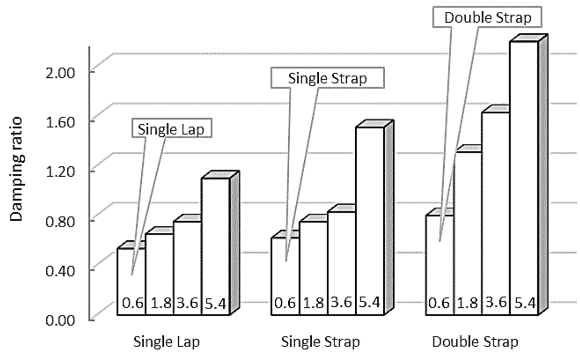


Fig. 10. Comparison of damping ratios of different joint constructions depending on adhesive tape thickness (0.6, 1.8, 3.6, 5.4 mm)

4. CONCLUSION

In this paper, the vibration behaviour of adhesively bonded different joint constructions with double-sided adhesive tape was investigated experimentally. Double-sided tape as an adhesive and aluminium plates as adherents were used to construct different types of joints. The vibration tests have been carried out to analyse the effect of the overlap length, aluminium plate thickness, and bonding thickness on the natural frequencies and corresponding damping ratios of the beam. The following conclusions can be made:

- ✓ For single lap joint construction, the growing overlap length increases both the natural frequencies and damping ratios of the system. Besides, the natural frequency of the system visibly increased, but the damping ratio was not affected by increasing aluminium plate thickness. Moreover, the damping ratio of the system increased remarkably with increasing bonding thickness, yet bonding thickness did not significantly affect the natural frequency.
- ✓ In single strap joints, the increase in the overlap length did not affect the natural frequency of the system. It can be seen that while the overlap length was increased, the damping ratio was also increased remarkably. Furthermore, as aluminium plate thickness was increased natural frequency increased as well yet the damping ratio decreased with increasing aluminum plate thickness. Moreover, the damping ratio of the beam increased significantly with increasing bonding thickness; however, the natural frequency of the beam had a slight change.
- ✓ The increase in the overlap length had a slight increasing effect on the natural frequency of the system for double strap joint constructions. The damping ratio importantly increased by increasing overlap length. Additionally, by increasing plate

thickness, the natural frequency increased due to the increased moment of inertia of the area. Nevertheless, the damping ratio decreased with increasing aluminium plate thickness. Besides, the damping ratio of the beam significantly increased depending on the increasing bonding thickness. On the contrary, natural frequency showed a decreasing tendency with the increasing bonding thickness.

- ✓ Joint construction was found as another effective parameter on the damping ratio. Double strap joint construction had attained the best damping capability.
- ✓ Adhesive tape thickness had more significant effect than the effect of overlap length on the damping ratio.

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Biographies

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