INVESTIGATION OF DYNAMIC RESPONSE OF A SINGLE LAP ADHESIVE BONDED JOINT

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ABSTRACT

The aim of this paper is to study the modal analysis to analyze the dynamic behavior of single lap adhesive joint subjected to impact or shock loads using Finite Element Analysis (FEA) and experimental analysis. In this paper modal analysis of bonded beams with a single lap adhesive joint is investigated. The various factors that affect the response of adhesive joint structures are studied, such as natural frequencies, mode shapes, damping ratio etc.. The finite element analysis software ANSYS 13.0 is used for modal analysis of a specimen. The material used for the specimen is aluminum and adhesive used for lap joint is araldite epoxy adhesive. The initial case study is focused on software modal analysis of cantilever beam subjected to impact load. The main objective of this paper is to determine the natural frequency and mode shape of a single lap adhesive joint at cantilever beam condition and to compare the results obtained by finite element analysis with experimental results and to find the error between them. NI Lab-View 13.0 software is used for experimental modal analysis along with data acquisition hardware. The results obtained by both the methods are found to be satisfactory.

Keyword: - *Adhesive bonding, Finite element analysis, Modal analysis, Experimental modal analysis, Natural frequency, Mode shape etc.*

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1. INTRODUCTION

The aim of this paper is to provide an efficient numerical techniques for the prediction of the dynamic response of bonded beams with a single-lap joint and to validate the predictions via experimental tests. As a result of the trend towards lightweight construction in manufacturing, there has been a significant increase in the use of adhesively bonded joints in engineering structures and components. In the design of mechanical systems, which consist of adhesively bonded joints, for minimum vibration response, a specific knowledge of damping capacity of the joints is important. As adhesive bonding become importance in structural bonding in aircraft industry. The subject of adhesives became even more interesting to scientists when the application of synthetic resins as adhesives for wood, rubber, glass and metals were discovered. Adhesive bonding as an alternative method of joining materials together has many advantages over the more conventional joining methods such as fusion and spot welding, bolting and riveting. Adhesive bonding is gaining more and more interest due to the increasing demand for joining similar or dissimilar structural components, mostly within the framework of designing light weight structures. The current trends are to use visco-elastic material in the joints for passive vibration control in the structures subjected to dynamic loading. These components are often subjected to dynamic loading, which may cause initiation and propagation of failure in the joint. In order to ensure the reliability of these structures, their dynamic response and its variation in the bonded area must be understood. In adhesive joint the major function of adhesive is to transmit loads from one member of joint to another. It allows a more uniform stress distribution than is obtained by another mechanical joining process such as welding, bolting, riveting, etc. Thus, adhesive often permit the fabrication of structures that are mechanical equivalent or superior to conventional assembles and furthermore cost and weight benefits.

The conventional joining process increase the weight of the structure by adding extra material such as bolt, screws, extra filler material. If you want to joint two plate by bolting then hole is created in the plate which result in stress concentration or if you joint by weld then there is localized heating of the component take place which alter its mechanical properties. In adhesive joining process you do not need to create the hole in the plate or there is no localized heating take place. Thus adhesive bonding gaining more importance in joining process where you have to avoid stress concentration and avoid localized heating. In addition adhesive can produce joints with high strength, rigidity, dimensional precision in the light metals, such as aluminum and magnesium, which may be weakened or distorted by welding. Adhesive can also prevent electrochemical corrosion between dissimilar metals.

Adhesive bonded lap joint Fig.1 is made up of the aluminum material of dimensions 550 mm long x 50 mm wide and 5 mm thickness and lapping dimensions will be 50 mm x 50 mm. Adhesive bonding is a material joining process in which an adhesive, placed between the adhered surfaces, solidifies to produce an adhesive bond. When we bond components together the adhesive first thoroughly wets the surface and fills the gap between, then it solidifies. When solidification is completed the bond can withstand the stresses of use. The strongest adhesives solidify through chemical reaction and have a pronounced affinity for the joint surfaces. Adhesives come in several forms thin liquids, thick pastes, films, powders, pre-applied on tapes, or solids that must be melted. Adhesive can be designed with a wide range of strengths, all the way from weak temporary adhesives for holding papers in place to high strength structural systems that bond cars and airplanes. Now a day's adhesive compete with mechanical fastening systems such as nuts, bolts, and rivets, or welding and soldering. In the practical application this kind of modal analysis can be used to analyze some structure such as cantilever bridge, frame of bicycle, automobile product, Industrial robots (manipulator), building structures, heavy machineries etc. that can be simplified as beam and so on.

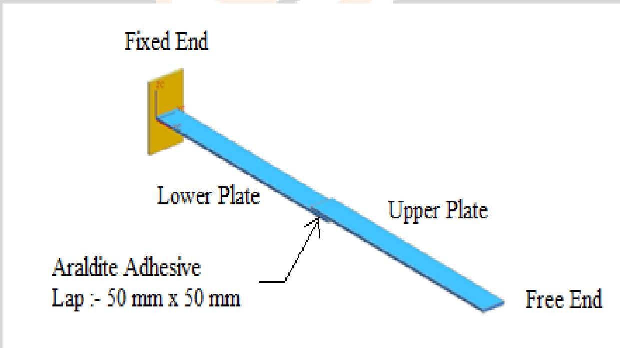


Fig.1: 3D view of single lap adhesive joint

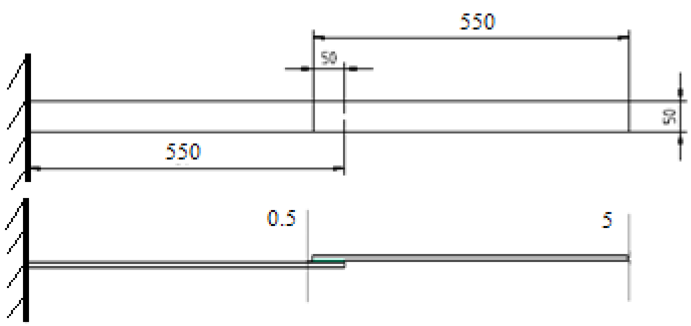


Fig.2: Single lap adhesive bonded joint (All dimensions in mm)

1.1 Araldite Adhesive

The adhesive used for experimental modal analysis is araldite. Araldite is a two component paste, room temperature curing adhesive, adhesive paste of high strength and toughness. It is thixotropic with good environmental and chemical resistance. Although it is designed as a metal bonding adhesive it is also suitable for bonding other materials such as, ceramics, glass, rubbers, rigid plastics and most other materials in common use. Metal colored paste, Suitable for vertical applications, Low shrinkage, Good environmental and chemical resistance, Bonds a wide variety of materials. Araldite is a two component, room temperature curing, paste adhesive of high strength and toughness. It is thixotropic with good environmental and chemical resistance. Although it is designed as a metal bonding adhesive it is also suitable for bonding other materials such as, ceramics, glass, rubbers, rigid plastics and most other materials in common use.

2. FINITE ELEMENT ANALYSIS (FEA)

The finite element analysis (FEA) is a computational technique used to obtain approximate solution of boundary value problems in engineering. Simply stated, a boundary value problem is mathematical problem in which one or more dependent variables must satisfy a differential equation everywhere within a known domain of independent variables and satisfy specific conditions on the boundary of the domain.

The modal analysis of aluminum material single lap adhesive bonded joint is done by finite element analysis method using ANSYS 13.0 software. ANSYS software is a comprehensive FEA analysis (finite element analysis) tool for structural analysis in the mechanical engineering, including linear, nonlinear and dynamic studies. The engineering simulation product provides a complete set of elements behavior, material models and equation solvers for a wide range of mechanical design problems. The properties of aluminum material used are given in Table 1. The analysis is done for 3D element and the type of element used in this analysis is solid 185 and the type of meshing used is tetrahedral meshing by considering mesh size as 5 mm. The required properties of the aluminum material as well as adhesive used for the finite element analysis are given in Table 1 & 2. The properties of aluminum material also includes: low-density and therefore low weight, high strength, superior malleability, easy machining, excellent corrosion resistance and good thermal and electrical conductivity are amongst aluminum's most important properties. Aluminum is also very easy to recycle.

The properties of the araldite adhesive are given in Table 2.2 & 2.3. It is a metal colored paste, Suitable for vertical applications, Low shrinkage, Good environmental and chemical resistance, Bonds a wide variety of materials. Araldite is a two component paste, room temperature curing, adhesive paste of high strength and toughness. It is thixotropic with good environmental and chemical resistance. Although it is designed as a metal bonding adhesive it is also suitable for bonding other materials such as, ceramics, glass, rubbers, rigid plastics and most other materials in common use.

There are certain common steps in formulating a finite element analysis of a physical problem, whether structural, fluid flow, heat transfer, vibration and some other problem. These steps are usually embodied in commercial finite element software packages. There are three main steps, namely: preprocessing, solution and post processing. The preprocessing (model definition) step is critical. This step includes; define the geometric domain of the problem, the element types to be used, the material properties of the elements, the geometric properties of the elements (length, area) the element connectivity (mesh the model), the physical constraints (boundary conditions) and the loadings. The next step is solution, in this step the governing algebraic equations in matrix form and computes the unknown values of the primary field variables are assembled. Actually the features in this step such as matrix manipulation, numerical integration and equation solving are carried out automatically by commercial software. The final step is post processing, the analysis and evaluation of the result is conducted in this step [1] & [4]. . So by using the finite element analysis techniques the natural frequencies and mode shapes are calculated with the help of parameters and properties. Fig.1 & 2 shows the configuration of the specimen which being used in this analysis.

Table 1: Material Properties of Aluminum Material

Material Properties	Notation	Aluminum	Unit
Modulus of elasticity	E	7.00E+10	N/m^2
Poisson's Ratio	v	0.3	-
Density	ρ	2700	Kg/m^3

Table 2: Properties of epoxy adhesive material

Material Properties	Notation	Adhesive	Unit
Modulus of elasticity	E	4.00E+04	N/mm^2
Poisson's Ratio	v	0.33	-
Length	l	50	mm
Width	b	50	mm
Thickness	h	50	mm

Table 3: Properties of two paste araldite adhesive

Property	2013/A	2013/B	2013 (mixed)
Colour (visual)	grey soft paste	beige soft paste	grey paste
Specific gravity	ca. 1.4	ca. 0.9	ca. 1.2
Viscosity at 25°C (Pas)	380 - 720	thixotropic	thixotropic
Pot Life (100 gm at 25°C)	-	-	50 - 80 minutes
Shelf life (2-40°C)	3 years	3 years	-

3. EXPERIMENTAL MODAL ANALYSIS

The experimental set up for adhesive bonded lap joint is shown in Fig.3. The two plates of dimensions 550 mm long x 50 mm wide and 5 mm thick is formed into lap joints using araldite adhesive, Adhesive is placed between the two plates at the cross section 50 mm x 50 mm and kept for 3 hours for curing and then it is formed into the bonded lap joint. This adhesive bonded lap joint is clamped at one end during experimental modal analysis with the help of c-clamp & pressure plates and formed as a cantilever beam. The experimental test rig set up is prepared by arranging all the equipments in the defined manner. There are total 10 natural frequencies and five mode shapes are extracted with the help of NI-Lab View software and data acquisition hardware. It is observed from this modal analysis that the natural frequencies are increases according to each nodes and also the mode shapes shows the dynamic behavior of adhesive lap joint at each node it is different. The produced mode shapes are shown in Fig. 3.

In order to validate the effectiveness of the finite element analysis results or techniques used with experimental analysis results in the study of the forced vibration analysis and characteristics of the material used. Experimental tests are carried out by NI-Lab View software for measuring the natural frequencies and mode shapes of a single lap joints. NI Lab view software is used for a wide variety of applications and industries, which can make it challenging to answer the question: Mostly it is used for experimental modal analysis to find natural frequencies and mode shapes to study the dynamic behavior and response of the structure when it is in dynamic condition. The adhesive used for adhesive bonded lap joint is very common and it is a two components araldite adhesive which is commercially available. The mechanical properties of the specimen and adhesive are given in the Table 1 & 2. The adhesive is applied on the degreased surfaces of the both the specimen and the two sheets or specimen pressed together in order to squeeze sufficient adhesive out to avoid undue quilting of the finished joint which probably affects the natural frequencies of the joint. For getting expected adhesive layer thickness, the joint is bonded under constant pressure by using the clips and cured at room temperature for at least 3 hours.

The experimental set ups used for vibration measurements of the all three specimen is shown in the Fig. 3. The NI-Lab View software is used in conjunction with the data acquisition hardware of four channel (QDAC) i.e. vibration analyzer for the dynamic tests. For measuring the natural frequencies and mode shapes of adhesive bonded lap joint. One end of the plate and plate with joint is clamped in a heavy support with the help of c-clamp & pressure plates by applying uniform pressure on the plate as shown in Fig.3. The accelerometer is fixed at 20 % of the length of the beam from its clamped end or from its free end. Connection of all the wires and cables are done with the data acquisition hardware, accelerometer, and Impact hammer and with a computer loaded with NI-Lab View software as shown in Fig.3. The power supply is given to the system and software is opened and given all necessary inputs and make all required settings in the software to perform experimental tests. Now the impact load is applied by the impact hammer on the nodes marked on the cantilever beam one by one. Total six nodes are marked on each cantilever beam for accurate readings. Signals from the accelerometer and impact hammer are received by the data acquisition hardware for each impact provided one after the other and that compared and analyzed by the software. After this with the help of Ni-Lab View software the natural frequencies and mode shapes at required nodes are computed by performing some operations in the software. Then obtained results i.e. natural frequencies and mode shapes are compared with the finite element analysis results. This shows a good agreement between the experimental and FEA outputs.

The equipments which are used to perform the real experiments are as follows.

1. Impact Hammer
2. Accelerometer
3. Data Acquisition Hardware (At least 2-Channel.)
4. A PC or a Laptop loaded with NI-Lab View software for modal analysis.
5. Test-specimens.
6. Power supply for the PC and vibration analyzer, connecting cables for the impact hammer and accelerometer and adhesive/wax to fix the accelerometer.

Experimental modal analysis procedure :-

1. Prepare the cantilever: Measure the length on the fixture that holds the aluminum plate and leave a margin of that length on the plate. Fix the accelerometer to the aluminum plate at one node but on the face of the plate opposite to the markings. Ensuring that face of plate with markings and node numbers up, fix the plate into the slot on the fixture so that a cantilever is formed.
2. Connect the wires and cables: Make connections of the data acquisition hardware, PC or laptop, accelerometer and the impact hammer as given in the manuals or under guidance of experts.
3. Switch on the power supply Open the software of vibration analysis and experimental modal analysis installed on the PC/laptop. Provide necessary inputs and make necessary settings in the software. Ensure that there is proper supply and communication between the devices connected.
4. Impact hammer: Now, provide impacts by the impact hammer on the nodes marked on the cantilever one by one. Impacts will be given on nodes. Accelerometer is connected at one node. Signals from the impact hammer and the accelerometer will be received by the data acquisition hardware /vibration analyzer for each impact provided one by one and will be compared and analyzed by the software. Curve known as Frequency Response Function (FRF) will be generated by the software that is used to find the natural frequencies of the cantilever.
5. Natural frequency: After that put the nodes how much you required in required frequency range. so that at each peak we will get corresponding natural frequency.
6. Mode shapes: Now determine mode shapes for each natural frequency.

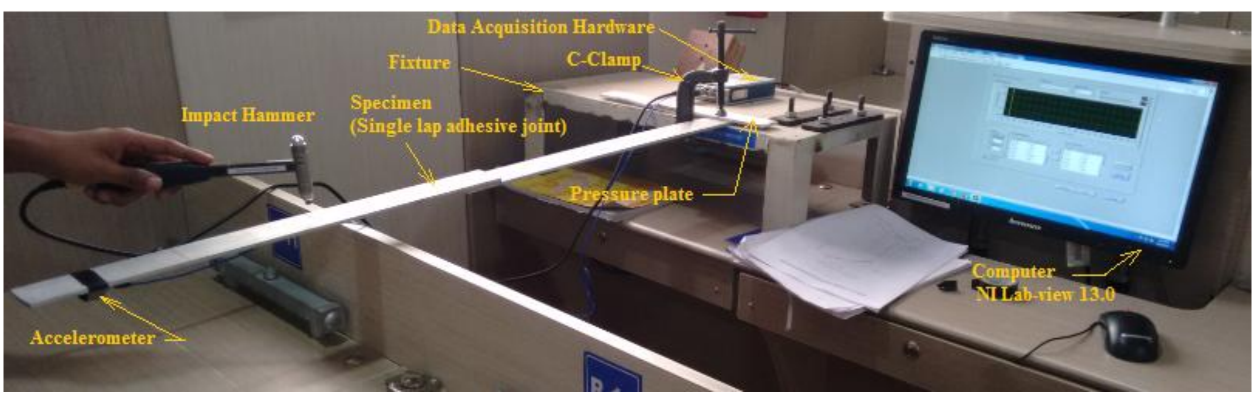


Fig.3: An experimental set up of a single lap adhesive bonded joint.

4. RESULT AND DISCUSSION

4.1 Comparison of FEA and Experimental Frequencies of Adhesive Bonded Lap Joint.

The modal properties of the adhesive bonded lap joint are obtained using FEA software and then measured using the experimental test rig. The natural frequencies from FEA and experimental measurements are shown in Table 4 and Fig.4. Although total 10 natural frequencies are extracted, the first three natural frequencies are more important. Thus, it can be said that the Table 4 and Fig.4 shows good agreements between the experimentally measured and FEA natural frequencies of the bonded beam. Table 4 and Fig.4 also show that the natural frequencies from experiment are lower than those obtained using FEA. This is because the support, which clamps the beam, is not infinitely rigid, causing a finite stiffness of the support on the measured modal characteristics. In addition, the variation in the natural frequencies is attributed to force transducer mass and accelerometer mass contributions to the overall system mass. In FEA, however, the beams are clamped with infinite rigidity and no any additional masses attached on. Therefore, the experimental results will be lower than the FEA results obtained under the assumption of infinite support stiffness. As seen in Table 4 that the natural frequencies are decreasing in the finite element analysis and in experimental also. It is because of the software error as discussed earlier, while doing the software analysis we need to convert infinite degrees of freedom into finite degrees of freedom and while doing this activity by software, there are some errors in the software methods and because of this only the errors are occurred in the final results but they are acceptable because they are within the range

Table 4: FEA and Experimental results of adhesive lap joint.

Modes	Natural Frequencies in Hertz		
	FEA	Experimental	Error %
1	0.20229	0.195	3.603737
2	1.382	1.230	10.99855
3	1.4432	1.351	6.388581
4	4.1426	3.845	7.183894
5	7.9265	7.56	4.623731
6	8.7888	8.368	4.787912
7	9.5233	8.939	6.135478
8	13.16	12.913	1.8769
9	19.779	19.032	3.776733
10	24.726	23.67	4.270808

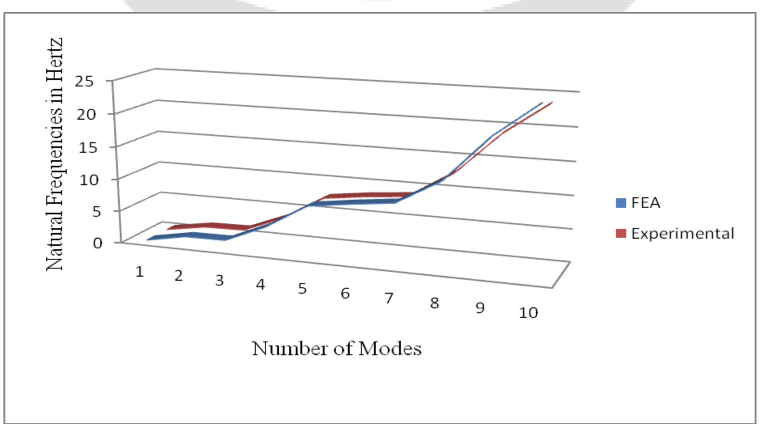


Fig.4: 3D View of Natural frequencies Vs Number of modes

4.2 Comparison of FEA and Experimental Modal Shapes

Mode shapes are very important in the dynamic response analysis of adhesive bonded lap joint. If they are known at the design stage, the nodes can be place in the proper region of the structures. In this study, the FEA and experimental measurements are carried out adhesive bonded lap joint. There are total 10 natural frequencies and 10 mode shapes are extracted in this analysis. First 4 mode shapes of the experimental as well as FEA of all the specimens are compared with each other and shown Fig.5. In this, it is seen that all corresponding mode shapes are similar. The dynamic response of the beams depends on the transducer or accelerometer and impact of hammer on the specimen locations. Some complexity in the mode shapes can be attributed to accelerometer mass contribution to the overall system mass. In Fig. 4 only first 4 FEA and experimental mode shapes of adhesive bonded lap joint are compared with each other and found to be satisfactory as per the expectation

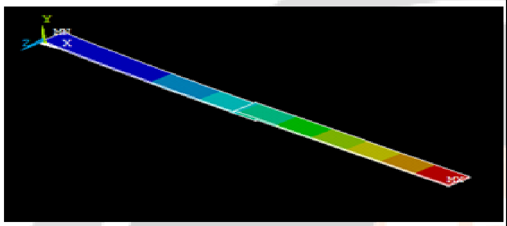
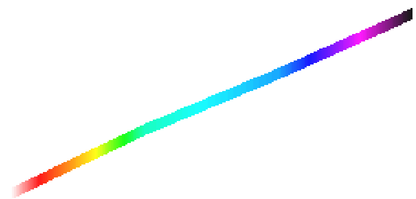
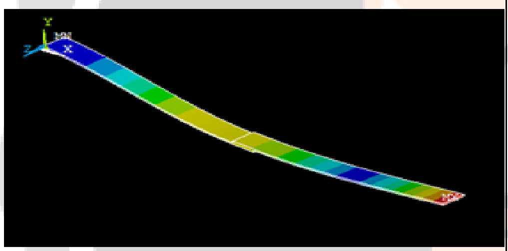
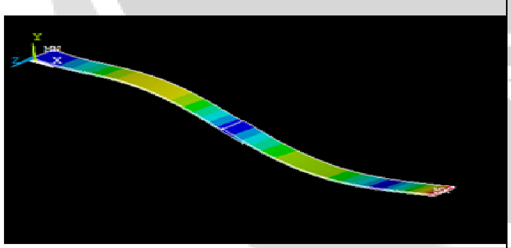
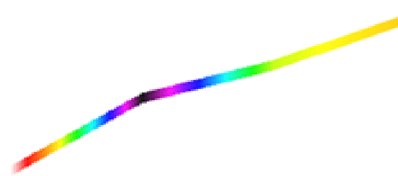
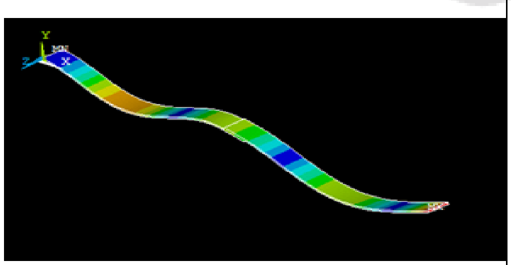
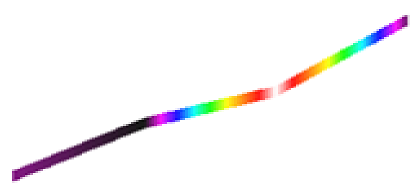
FEA Mode shapes	Experimental Mode Shapes
 Mode 1(0.202 Hz	 Mode 1 (0.195 Hz)
 Mode 2 (1.382 Hz)	 Mode 2 (1.23 Hz)
 Mode 3 (1.443 Hz)	 Mode 3 (1.351 Hz)
 Mode 4 (4.142 Hz)	 Mode 4 (3.845 Hz)

Fig.5: Comparison of modal shapes of FEA and experimental modal analysis of adhesive bonded lap joint.

5. CONCLUSIONS

Modal analysis of adhesively bonded lap joint is done using numerical and experimental methods. The dynamic response of specimen is investigated numerically (FEA) and experimentally and compared both the results with each other. The ANSYS 13.0 software is used to perform numerical method i.e. Finite element analysis to predict the natural frequencies and mode shapes of the specimen at cantilever beam condition. The NI-Lab View Software and data acquisition hardware is used for the experimental modal analysis to find natural frequencies and mode shapes. Then, the finite element analysis predicted results are compared with the experimental results and found to be satisfactory. These are almost close to each other. The natural frequencies and mode shapes obtained by both methods are compared and shown in Table 4.1 and Fig. 4.1 It is seen that the natural frequencies obtained experimentally are lower than the predicted (FEA); it is because of the accelerometer or transducer mass and impact of the hammer on the specimen. It is concluded that the FEA of dynamic response of the bonded beams with a single lap joint will help future applications of adhesive bonding by allowing different parameters to be selected to give as large a process window as possible for bonded beams vibration analysis. It can also be conclude that the adhesive bonding of joints is an alternative method of joining materials together, which has many advantages over the conventional joining methods such as welding, bolting and riveting. The corrosion and vibration stresses associated with mechanical fasteners and welds can be reduced or eliminated by forming adhesive joint. It is important to study modal analysis of single lap adhesive joints to understand the dynamic nature of the systems and also in design control.

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