A Review on Vibration Analysis of Adhesively Bonded Single Lap Joint

Sagar S. Gawade[1] P. D. Darade[2] D. N. Korade[3]
[1,2,3]Department of Mechanical Engineering
[1,2,3]Sinhgad Institute of Technology Science, Pune, India

Abstract— Adhesively bonding is an excessive pace fastening method that's convenient for joining superior lightweight sheet substances which can be varied and tough to weld. This joins is used recently because now a day we are going for lightweight application and it is very important for us to build such joint which will not only decrease its weight as per requirement but will also help in damping the vibrations. In this project we can understand the effect of using neoprene rubber for joining two dissimilar metals, by making use of an industrial adhesive, which is very powerful. Adhesive bonds find a large application in the field of aerospace and automotive industries. There are few aircrafts in the market, which makes use of adhesives for joining the 60% of its body part. This joint ensures a firm structure with a better control over various modes of frequencies while on the other hand welded joints if used in place of elastic joint can add stiffness to the joint. The co-ordination of experimental and analytical techniques will make it possible to find the most efficient tool for studying the dynamic response of single lap joint.

Key words: Adhesive Bond, Neoprene Rubber, Lap Joint, Vibrations

I. Introduction

An adhesively bonded joint has large scale applications in aeronautics, aerospace, automobile, semiconductor, civil structure. Reliability of adhesively bonded joints not only depends on design, material and manufacturing methods but also on effective analysis of the characteristics of the joints. In the last years, adhesives have been largely used to bond dissimilar material members, particularly in aircraft and automobile structures. In many applications adhesively bonded joints are more suitable than existing joining techniques such as mechanical fastening, especially for components made from composite or polymeric materials, because they can supply uniform distribution of load, resulting in better damage tolerance and excellent fatigue life. Because of the implicate of many geometric, material and fabrication variables, and complex failure modes and mechanics present in the joints, a deep understanding of the failure behavior of adhesively bonded joints, particularly under combined loading conditions, is needed in order to fully achieve the benefits of adhesive bonding. Boeing 747 aircraft has 62% of its surface area constructed with adhesive bonding. In many structures such as those for flight and space vehicles, etc. adhesively bonded structures have often been used in these days, because of great advances in adhesive bonding techniques. Many aerospace structures such as a truss system of space telescope space station are constructed using predominantly composites beams, plates & bonded joints. These structures should possess sufficient inherent damping capacity to keep vibration & acoustic response caused by external disturbances within acceptable limits. The current trend is to use viscoelastic material in the joints for passive vibration control in the structures subjected to dynamic loading.

The rapid development of structural adhesives has led to the widespread use of adhesive joining technique in defense, aerospace, rail, ground transportation applications. In these applications the joints are designed to carry in plane roads, although they are also prone to transverse loading from crashes, bullets, fragments, tool drops, or flying debris. The usage of bonded joints in primary load bearing structures, particularly aerospace and military applications, makes it important to understand their failure mechanisms under the transverse and in plane loading.

II. Literature review

Xiaocong He [1] developed an efficient numerical technique for the prediction of the dynamic response of bonded beam. The frequency response functions, natural frequencies, and mode shapes of the joints of different adherent widths and of different adhesive layer thickness were measured.

Yu Du et al. [2] investigated the relationship between modal properties of single lap joints and the cyclic vibration peel loading this study first carries out vibration fatigue tests and subsequent modal response measurements using steel aluminum single lap joint specimens. The relationship between the modal properties and the damage caused by the cyclic-vibration-peel (CVP) loading of SLJs consisting of steel–aluminum adhesive joints was investigated in this paper. Vibration fatigue tests and subsequent modal tests were carried out to study the effects of vibration fatigue on the modal properties, in particular the modal frequencies, of SLJs. A group of steel, aluminum SLJ specimens bonded using AV138/ HV998 adhesive were subjected to a vibration fatigue excitation of 40 Hz harmonic waveforms in the peel direction. In this process, it was experimentally demonstrated that the modal frequencies of the SLJ structure presented a decreasing trend with the increasing vibration fatigue cycles. This is a main contribution of this study. By experimentally comparing the modal frequencies of SLJ specimens and a uniform aluminum beam of identical geometries, it further showed that the dominant reason for the modal frequency decreasing trend is associated with the characteristics of the adhesive layer at various vibration fatigue cycles, but not with the metal substrates.

Xiaocong He [3] shown that torsional natural frequency and torsional natural frequency ratio of adhesively bonded single lap joints increases as Young's modulus of the adhesives increases, but only slight changes are encountered for vibrations of Poisson's ratio. When the adhesive is soft, the torsional mode shapes at the lap joint are slightly distorted. But when the adhesive is relatively very rigid, the torsional mode shapes at the lap joint are fairly smooth and there is a relatively higher local stiffening effect. In these two adherends of aluminum alloy plates are used and common to components, acrylic cement is used as a adhesive. Xiaocong investigated torsional free vibration characteristics of the adhesively bonded single-lap joint theoretically by using the

FE method. The effectiveness of the FE analysis technique used in the study has been validated by experimental tests. Xiaocong analyzed modal frequencies and mode shapes of torsional free vibration of the joints by the using adhesives of various Young's modulus and Poisson's ratio properties.

Xiaocong He [4] worked on finite element analysis of adhesively bonded lap joints in terms of static loading analysis, environmental behaviors, fatigue loading analysis and dynamic characteristics of the adhesively bonded joints. It helps future application of adhesively bonded by allowing system parameter to be selected to give us large a process window as possible for successful joint manufacture.

Saito et al. [5] worked on equations for developing the modal parameters of the coupled longitudinal and flexural vibrations of a system made up of pair of elastic beams lap jointed over a certain length by an adhesive. Numerical results are presented for the case of fixed boundary conditions at the ends. No experimental verification was undertaken in their effort.

Y. B. Patil et al. [6] showed the natural frequencies are directly proportional to the Young's modulus and density ratio. The specimen is used which consist of Al-Al plates, Cu-Cu plates, and Ms-Ms plates. Also Epoxy adhesive is used for analysis.

Shailendra Sakharam Wani [7] worked on adhesively bonded lap joints will be prepared by using aluminum plates. Two aluminum plates, first with dimensions 140 mm length, 25.4 mm width & 3 mm thickness & second 140 mm length, 25.4 mm width & 3 mm thickness are joined together in the single lap with a mixture Araldite resin & hardener. Analysis will be done experimentally by using FFT analyzer & fixture. Natural frequencies will be discovered by hitting the lap joint system with impact hammer, the response at a point of a lap joint will be measured with help of an accelerometer FFT analyzer analyzed the output of an accelerometer. FEM software package is utilized for vibration analysis of adhesively bonded lap joint with different overlap ratios for finding different parameters like Natural frequency, Mode shapes. Thus, experimental & software results obtained will be compared & results will be concluded.

Wani investigated transverse vibration of an adhesively bonded single lap joint has been investigated in this dissertation work. The experimental & finite element methods have been used for free vibration under fixed boundary conditions. A study has been conducted to observe some general trends regarding the variety of natural frequencies with certain structural & geometric parameters of the joint system. Some general conclusions have been drawn from the study. The natural frequency of the system increase with the increase in overlap length of the joint. This trend is logical because of the bearing of joint system to become stiff with increasing the overlap length. This particular fact can be used as a design tool to avoid a particular natural frequency. From the Graph 5.6 displacement is nearly constant for overlap length 30 mm & above & hence for optimum condition 30 mm overlap length can be chosen.

Akhavan Safar [8] showed the effect of bond line thickness on the strength of adhesively bonded single lap joints (SLJs) is still a float issue. According to the analytical methods and also finite element (FE) results, increasing the adhesive thickness causes a more uniform stress and strain classification along the adhesive layer and consequently leads to higher strength of the SLJs, while the experimental data has shown lower strength for joints with thicker bond lines. The FE results showed under a constant tensile load, the values of longitudinal strain along the adhesive mid-plane increase with adhesive thickness. Safar discovered the failure parameter could take into account the reduced in joint strength due to an increase in bondline thickness. Some experiments were carried out on SLJs with different adhesive thicknesses and bonding lengths to consolidate the method. Safar has good co-ordination between the experimental results and the predictions were seen.

Recep Gunesa [9] carried out the three-dimensional free vibration and stress analyses of an adhesively bonded single lap joint. The effects of the adhesive material properties (mechanical inheritance), such as modulus of elasticity, Poisson's ratio and density was found to be contemptible on the first ten natural frequencies and mode shapes of the adhesive joint. The finite element method and the back propagation artificial neural network method was used to discovered the effects of the geometrical parameters, such as overlap length, plate thickness as well as adhesive thickness; and the material composition variation through the plate thickness on the natural frequencies, mode shapes and modal strain energy of the adhesive joint. The optimal joint dimensions and compositional gradient exponent was acquired using genetic algorithm and ANN models so that the maximum natural frequency and the minimum modal strain energy conditions are contented for each natural frequency of the adhesively bonded functionally graded single lap joint.

F. Heidarpour [10] showed the robust design of the joints in the engineering structures, it is necessary to determine the stress and strain under a certain load and predict the failure potential. Adhesive joints are susceptible to defect and separation, especially the joints with high overlap area. Heidarpour showed the experimental investigation on the influences of the size and shape of 2D and 3D defects on the ultimate shear strength of the adhesive single lap joints. So, square, triangular and circular defects with different sizes are artificially embedded into the Araldite 2015 adhesive layer of the Aluminum 2024-T3 joints. The artificially defective samples are examined under the axial tensile tests according to ASTM D1002-01 standard. Heidarpour showed the single lap joints with 3D defects, there is an approximately linear decrease in the joint strength as the defect area increases. However, when 2D defects are applied in adhesive joint, a non-linear decrease in the joint strength is observed. Actually, the joint strength decreases gradually when the defect area/overlap area is smaller than 30%. The decline rate in the joint strength for bigger defect is more sever, indicating that the edges of the overlap area become more important as the local strains exceeding the limiting values in this zone. The survey about the defect shape showed that the least decline in the strength of single lap joints occurs with circular defects. The greatest disparity in reducing the strength compared to the other 2D and 3D defects are approximately 11% and 8%, respectively.

Samia Fida et al. [11] investigated adhesive bonding is preferred joining technique over welding and mechanical fastening method because of its light weight and high strength characteristics. In aerospace applications, adhesive bonding is highly incorporated in FMLs (Fiber Metal Laminate). These FMLs usually fails under peel and shear stresses. Samia Fida worked on, Adhesive lap joint between aluminum and CFRP is optimized through two different joint designs to find out the most effective and suitable joint design to avoid shear and peel stresses and hence to reduce the failure of adhesively bonded parts. Carbon fiber and aluminum are the structural component in most of the aircraft applications. So in this research project adhesive bonding between CFRP and aluminum is optimized by two methods i.e. introduction of fillets and introduction of step configuration in standard lap joint configuration. Samia Fida carried out the modal analysis in Ansys workbench to find out the most effective technique among the two proposed configurations that reduces the shear and peel stresses and hence minimizes the failures.

M. Bhusnar et al. [12] carried out the dynamic behavior of structures like a rectangular plate, bolted lap joint, welded lap joint and single lap epoxy adhesive joint subjected to impact or shock loads using Finite Element Analysis (FEA) and analytical methods. The different factors that affect the response of bolted, welded lap joint and adhesive joint structures was studied by authors, such as natural frequencies, mode shapes, damping ratio etc. In this work the modal analysis of rectangular plates with various lap joints are investigated by authors. The four different specimens are generated of aluminum material. The finite element analysis software was utilized for modal analysis of all joints to find out the mode shapes. The first case study is focused on a rectangular plate of cantilever beam subjected to impact force. The second one case study is focused on bolted lap joint, welded lap joint and single lap adhesive joint. The first objective of this work is to find out the natural frequency and mode shape of all four specimens at cantilever beam condition and to compare the result of all joints with the single rectangular plate and to determine the error between software analysis and analytical solution. In practical application this kind of modal analysis can be utilized to analyze some structures such as cantilever bridge, frame of bicycle, automobile product, Industrial robots (manipulator), building structures, heavy machineries and aircraft industry etc. M. Bhusnar investigated that the analyzed results by above method are compared with finite element analysis and analytical solution.

III. Modal Analysis

Modal analysis determines the vibration characteristics of structure or machine components while it is being designed. The vibration characteristics (natural frequencies and mode shapes) are important in the design of the structure for dynamic loading conditions. The two specimen are used which consist of Al-Al plates, Cu-Cu plates. The Modal analysis had been done by using ANSYS software. The first three natural frequencies corresponding to different materials of single lap adhesive joints are shown in Table I.

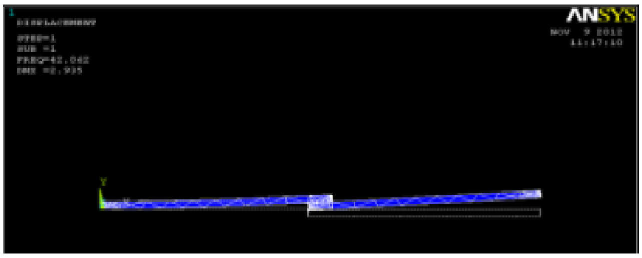

Fig. 1: First Mode Shape Cu-Cu Single Lap Joint [6]

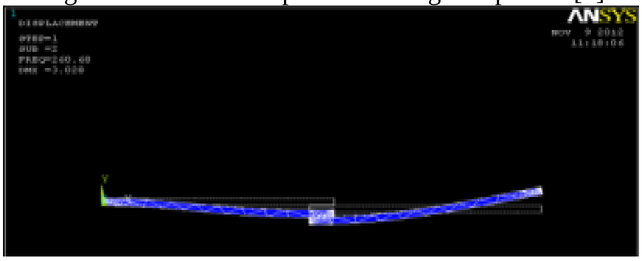

Fig. 2: Second Mode Shape Cu-Cu Single Lap Joint [6]

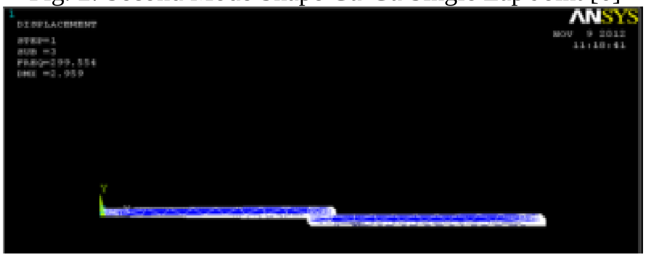

Fig. 3: Third Mode Shape Cu-Cu Single Lap Joint [6]

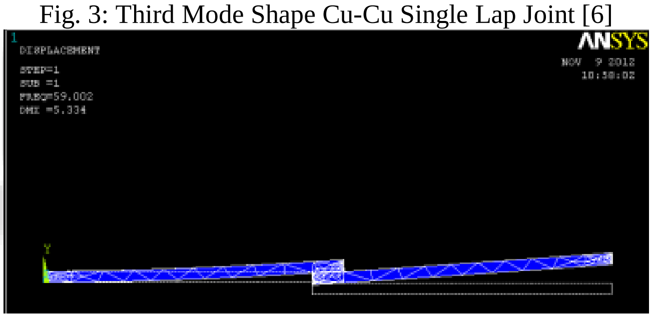

Fig. 4: First Mode Shape Al-Al Single Lap Joint [6]

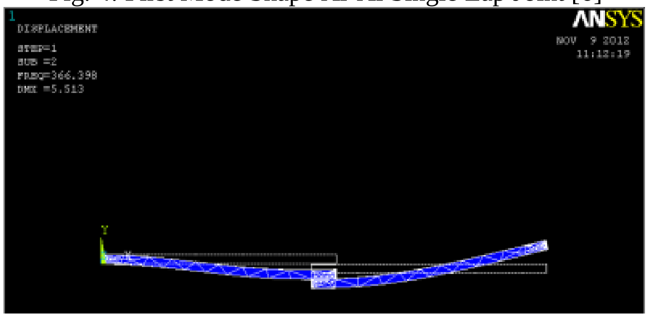

Fig. 5: Second Mode Shape Al-Al Single Lap Joint [6]

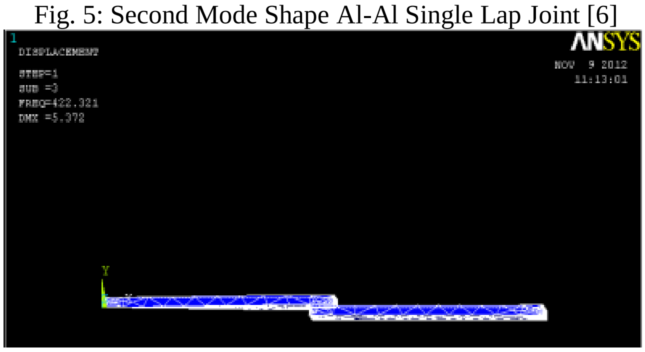

Fig. 6: Third Mode Shape Al-Al Single Lap Joint [6]

Mode Shapes	Cu-Cu (Frequency Hz)	Al-Al (Frequency Hz)
1	42.062	59.002
2	260.68	366.40
3	299.55	422.32

Table 1: Comparison of Single Lap Adhesive Joint [6]

The result showed the natural frequencies are changing as the materials are changing of single lap adhesive joint. The result showed the natural frequencies are depend on Young's modulus (E) and Density ρ ratio. The results showed the natural frequencies are directly proportional to the Young's modulus and Density ratio. If this ratio is increasing the natural frequencies are increasing for respective mode shapes. The Figure 1 to 6 shows the mode shapes for different material of single lap adhesive joint. [6]

IV. SUMMARY

In this paper, the review on vibration analysis of adhesively bonded single lap joint studied. It is observed that due to its low manufacturing cost, low stress concentration and ease of maintenance, adhesive bonding is now one of the most commonly and widely used joining systems in various industrial applications. It is important to study the modal analysis (natural frequency and mode shape) of the single lap adhesive joint to understand the dynamic nature of the systems, and also in design and control. The natural frequencies and mode a shape gives designer or engineers an idea of how the design will respond to different types of dynamic loads. This allows to designer or engineer to change the design to avoid resonant vibrations. The finite element analysis of dynamic response of the bonded beams with a single lap joint will help future applications of adhesive bonding by conceding different parameters to be selected to give as large as a process window as possible for bonded beams vibration analysis.

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