



EXPERIMENTAL INVESTIGATION AND VALIDATION OF NATURAL FREQUENCY OF RECTANGULAR PLATES AND LAP JOINTS

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Abstract: This paper deals with experimental investigation and validation of rectangular plates and lap joint using modal analysis. The purpose of the study is to analyze the dynamic behavior of structures like a rectangular plate, bolted lap joint, and single lap epoxy adhesive joint subjected to impact or shock loads using Finite Element Analysis (FEA) and experimental modal analysis. The various factors that affect the response of single rectangular plate, bolted and adhesive joint structures are studied, such as, mode shapes, damping ratio, natural frequencies etc. The purpose of this paper is to deliver effective techniques using software analysis for the calculation of the vibrant reply of single rectangular plate with rectangular plate lap joints and to validate the predictions by experimental modal analysis and FEA. The FEA method is used to validate the mode shapes, natural frequencies, and frequency response roles of the beams. The three different specimens are used which consist of aluminum material. The initial case study is focused on a simple rectangular plate of cantilever beam subjected to impact force. The second case study is focused on bolted lap joint and single lap adhesive joint. The core objective of this work is to determine the natural frequency and mode shape of all three specimens at cantilever beam condition and first to compare the result of all joints with the single rectangular plate and then compare it with experimental modal analysis. In practical application this kind of modal analysis can be used to analyze various structures to find natural frequency & mode shapes such as cantilever bridge, frame of bicycle, automobile product, Industrial robots (manipulator), building structures, heavy machineries and aircraft industry etc.

Keywords -Finite element analysis, Lap Joints, Modal Analysis, Mode Shapes.

I. INTRODUCTION

Vibration problems are mostly often occurred in mechanical structure. So that is important to prevent such a problems because it can be cause structural fatigue and damages. The structure itself has a certain properties so it is necessary to understand its characteristics. For this there are different methods. In this work a modal analysis by finite element method is used. The focus or main purpose of modal analysis is to predict the dynamic properties of configurations like natural frequency, damping and mode shapes. This can also be used for some purposes such as, troubleshooting. The adhesive bonding must importance in the structural bonding in aircraft, marine industry. The latest trends are to use visco-elastic type material in the joining for vibration control in structures relevant to dynamic loading [1]. So it is important to determine dynamic properties of a cantilever beam rectangular plate, bolted lap Joint and single lap adhesive joints of aluminium material to study the structural response of these joints after loading or impact. The main aim is to find natural frequency and mode shapes of rectangular cross sectioned cantilever plat, rectangular cross sectioned cantilever plates with bolted lap joint and rectangular cross sectioned cantilever plates with adhesive bonded lap joint. To analyse the effect of natural frequencies and mode shapes on rectangular cross sectioned cantilever plates with bolted lap joint & adhesive bonded lap joint and to find the error between them [2]. Then the finite element analysis results of these three components are compared with each other and then with experimental modal analysis to find the error between software and experimental

results. To avoid the stress concentration in the joints by using epoxy adhesive bonded material i.e. araldite for joining the two plates each other as an alternative joining process.

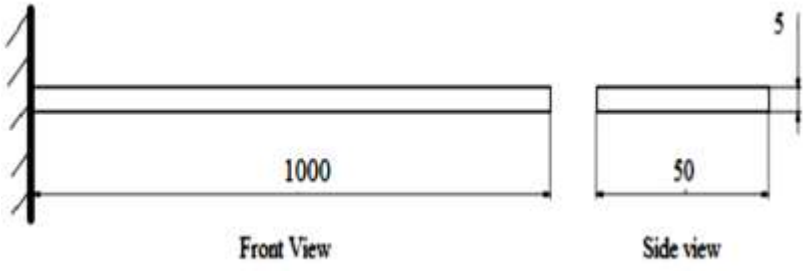
II. LITERATURE REVIEW

Xiao Cong He [1]. Investigated the dynamic response of adhesively bonded beams with a single lap adhesive joint numerically using ABAQUS software & experimentally and compared both the results with each other. The ABAQUS FEA software was used to predict the mode shapes, dynamic response and natural frequencies. Y.B.Patil, R.B.Barjibhe [2]. Investigated modal analysis of bonded beam with single lap adhesive joint of two plates. The three different specimens are used like Al-Al plates, Ms-Ms plates and Cu-Cu plates. The araldite epoxies type material is used which is consist of hardener and strainer. The results shows the mode shapes and natural frequencies gives an idea how design will respond to the different types of dynamic loads and this allows designer to change the specific design to avoiding vibrations or to vibrate at a specific frequency. Xiao Cong He, [4]. Investigated that the adhesive material used was a acrylic cement. In these paper the FEA of adhesively bonded joints the thickness of adhesion layer in much smaller than that of the adherents. The specific result is that the finite element meshing several orders of magnitude in a very small area. The adherents used in lap joint is 0.2 mm thick used. Yu Du*, Lu Shi, [5]. Prepared the FEA model for the SLJ apparatus are used in this paper. The structural model of the single cantilever rectangular plate only takes into transvers deflection and it is similar to Euler's – Bernoulli beam theory. Xiaocong He, [7]. In this paper the author investigate research and progress in FEA modal analysis of adhesively bonded lap joints are critically reviewed and latest trends in the application of FEA are specific mentioned. It is concluded that the finite element analysis of adhesively bonded lap joints will more help in future applications of adhesive bonding either that other conventional methods by allowing system parameters to successful joint manufacture. Melih Eriten, Mehmet Kurt, Guanyang Luo, D.Michael McFarland [8]. Author applied a new nonlinear system identification methodology to the validation and modeling of the nonlinear damping effects induced in cantilever beam. I. Ullah and M. Yasin, [9] this paper deals results of dynamic response of bolted lap joints under a shear loading using finite element models. The reduced models are withstand to measure both slip and energy dissipation. Bhagat Singh, Bijoy Kumar Nanda, [10] In this paper work, a dynamic response has been continued to carried out the investigation of the mechanism of slip damping in lap and welded with a single interference. In this paper it was also mentioned that analyze the dynamic behavior of two layered it mat welded or lap adhesive bonded are undergoing slip. The main aim of this paper is to determine the natural frequency and mode shape of a single rectangular plate, bolted lap joint and single lap adhesive joint at cantilever beam condition. The modal analysis is used to understand the dynamic response of structure such as resonant frequency, damping ratio and mode shape. The finite element analysis results are equated with the obtained investigational effects to verify the modal analysis.

With FEA modal analysis, we can dynamic properties of a structure. In this the modal parameters including the damping ratio, mode shape, and the natural frequency. The adhesive bonding come to be importance in structural closeness in aircraft, automotive industry. The subject of adhesives come to be even more interesting when the use of synthetic resins as adhesives such as wood, elastic, crystal and metals were discovered. Epoxy resin bonding as an substitute method of joining materials composed over the conventional assembly methods such as welding, locking, riveting and much. X.Hea, Y. Zhang [11]. The goal of this paper is to deliver an experimental dimension method for the investigation of the forced vibration performance of clinched joints. The dynamic examination software and the data attainment hardware were used in the experimental dimension of the dynamic reply of the clinched joints. Adhesive attachment is in advance more and more attention due to the rising request for assembly related or unrelated structural elements, regularly inside the framework of scheming light weight structures. Ramu I, Moahanty, [12]. The present trends are to practice viscoelastic material in the intersections for inert vibration control in

the assemblies subjected to vibrant loading. Jeong kim, Joocheol [13]. These mechanisms are frequently subjected to dynamic loading, which may origin start and propagation of disappointment in the joint. In demand to safeguard that all the consistency of these structures, their dynamic reply and its deviation in the bonded space. In epoxy resin lap combined the most important purpose of epoxy resin is to spread loads from one member of joint to an additional member. It permits a additional uniform tension delivery than it is attained by additional mechanical joining process such as welding, locking, riveting, holding etc.[14] Thus, adhesive over and over again permit the fabrication of structures that are mechanical corresponding or greater to conservative assemblies and moreover cost and weight profits. The conventional assembly procedure increase the weight of the structure by addition extra material such as fasten, screws, extra filler material which are increases costing. [15] If we want to combined two plate by fastening then hole is produced in the plate which outcome in stress concentration or if you combined by weld then there is limited to a small area means localized heating of the element take place which change its mechanical properties and this may take much more time. In epoxy resin joining procedure you do not essential to create the hole in the plate or there is no limited to a small area heating take place. Thus adhesive bonding in advance more importance in fitting together process where you have to avoid stress concentration and avoid localized heating.[16] In adding adhesive be able to produce joints with high strength, rigidity, dimensional, precision in the light metals, such as aluminum and magnesium, which may be debilitated or inaccurate by welding.

It was observed that the modal analysis of rectangular cross sectioned cantilever plate, rectangular cross sectioned plate with bolted joint and rectangular cross sectioned cantilever plate with lap joint are to be done individually with different diameters and different parameters, so that the results are not comparable with each other to find out any conclusion. Authors had only concentrated on the separate individual methods either it may software finite element method or experimental method. Some of authors used adhesive material bonding thickness minimum 0.3 mm to 0.15 mm. It is a very big task or critical to find out vibration behavior and to perform a modal analysis of rectangular cross sectioned cantilever plate, rectangular cross sectioned cantilever plates with bolted lap joint and rectangular cross sectioned cantilever plates with adhesive bonded lap joint together in one project and to analyze the results by taking the same geometric parameter specimens and to be find out natural frequencies and mode shapes. The dynamic response is needed for vibration analysis. Araldite is a two constituent paste, it has room temperature curative capability, it has a great strength and great toughness. It is thixotropic with decent ecofriendly and chemical resistance. Even though it is designed as a metal bonding epoxy resin, it is also suitable for closeness other materials such as ceramic ware, crystal, rubbers, rigid plastics and most other materials in common use. It is very big job to achieve modal examination of rectangular cross sectioned cantilever plate, rectangular cross sectioned cantilever plates with bolted lap joint and rectangular cross sectioned cantilever plates with adhesive bonded lap joint composed in one project and to investigate the results by taking the same geometric parameter samplings.

Sr. no	Specimens Specifications	Specifications
1	 <p>Front View Side view</p>	<p>$L = 1000\text{mm}$ $b = 50\text{mm}$ $h = 5\text{mm}$</p>
2		$L1 = 500\text{mm}$

steps are usually embodied in commercial finite element software packages. There are three main steps, namely: preprocessing, solution and post processing. (Model definition) step is critical. This step includes; define the symmetrical area of the problem, the component types to be used, the material properties of the components, the symmetrical properties of the components (like length, area), the component connectivity (meshing model), the physical restrictions (means boundary conditions) and the loadings. The next phase is solution, in this step the leading algebraic equations in matrix form and computes the unidentified value of the prime field variables is assembled. 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 predicted results of finite element analysis. This gives a decent agreement between the investigational and FEA results.

IV. EXPERIMENTATION

A. Validation of FEA Techniques by Experimentation

In demand to validate the efficiency of the finite element analysis results used with experimental analysis results in the study of the forced vibration analysis and characteristics of the material used. The adhesive used for single lap adhesive joint is very common there two components araldite which is commercially obtainable. The mechanical belongings of the specimen and adhesive are given in the table 1 & 2. For receiving expected adhesive level thinness, the combined is bonded under continuous pressure by means of the clips and preserved at room temperature for at least 3 hours. The specimens which are used for this analysis are given in fig.1. So by using the finite element analysis techniques the natural frequencies and mode shapes are calculated with the help of parameters also properties given in table 1 & 2. For measuring the natural frequencies also mode shapes of the single plate, bolted lap joint and adhesive bonded lap joint. Single end of the joint is clamped in a heavy support with the help of c-clamp. 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 PC or Laptop loaded with NI-Lab View software as shown in fig. 2. 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 we apply impacts 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 predicted results of finite element analysis. This gives a decent agreement between the investigational and FEA results.

V. RESULTS AND DISCUSSIONS

A. Evaluation between measured and predicted frequencies of the beams.

In this analysis, the modal belongings of the single plate and both the lap joints are first predicted using FEA software and measured by experimental test rig are evaluated. The natural frequencies obtained by FEA and Experimental tests are almost close to each other and shown in table 3. Although only the first 10 natural frequencies are takeout. First five natural frequencies are more vital for all the specimens. Thus, that one can be believed that the table 3 and figure 3 shows good agreement between the predicted and measured natural frequencies of the joined beams. The

table 3 and figures as well show that the natural frequencies from experimentation are lesser than those predicted using FEA. In FEA, however, the beams are fastened with unlimited rigidity and no any extra masses involved on Kind of joint is only different but then also the natural frequencies and mode shapes are nearby same which is shown by table 3. In table 3 we also compared the experimental and software analysis solution with each other and found that the natural frequencies at first 10 modes are nearby same that means the results are satisfactory as per the expectation.

B. Evaluation between measured and predicted modal shapes

Mode shapes are very significant in the dynamic reply examination of single plate, bolted and adhesive lap joint. If they are identified at the design step, the nodes be able to be place in the correct area of the structures. The FEA and experimental quantities are passed out of single plate and both the lap joints. There are total 10 natural frequencies and 10 mode forms are extracted in this analysis. First 4 mode shapes of the experimental as well as FEA are compared with each other.

Table 3 Comparison of FEA and Experimental Natural Frequencies

MODE	Natural Frequency (Hz)					
	Single Rectangular Plate		Bolted Lap Joint		Single Lap Adhesive Joint	
	FEA	Experimental	FEA	Experimental	FEA	Experimental
1	0.29774	0.67	0.28115	0.44	0.20229	0.385
2	1.3296	1.705	1.445	1.132	1.382	1.45
3	1.8632	2.98	1.7527	1.66	1.4432	1.86
4	5.2034	3.92	4.9879	4.375	4.1426	3.845
5	8.2374	8.32	8.6378	8.74	7.9265	7.56
6	10.172	9.36	9.5469	9.29	8.7888	8.368
7	12.254	11.67	11.582	11.31	9.5233	8.939
8	16.817	15.013	15.808	14.779	13.16	12.913
9	22.658	23.617	23.753	23.475	19.779	19.032
10	24.999	23.944	24.929	23.794	24.726	23.67

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 the single rectangular plate are compared with each other and other mode shapes of the joints will remain the same.

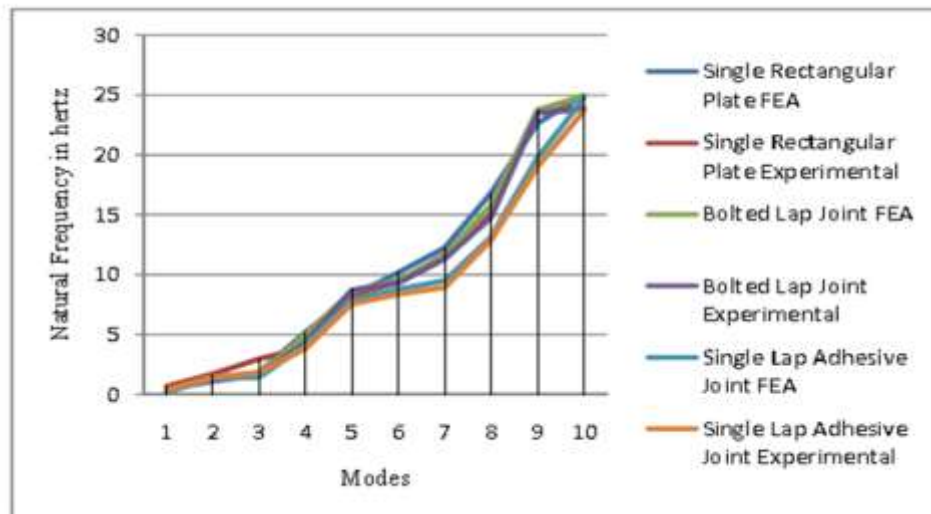
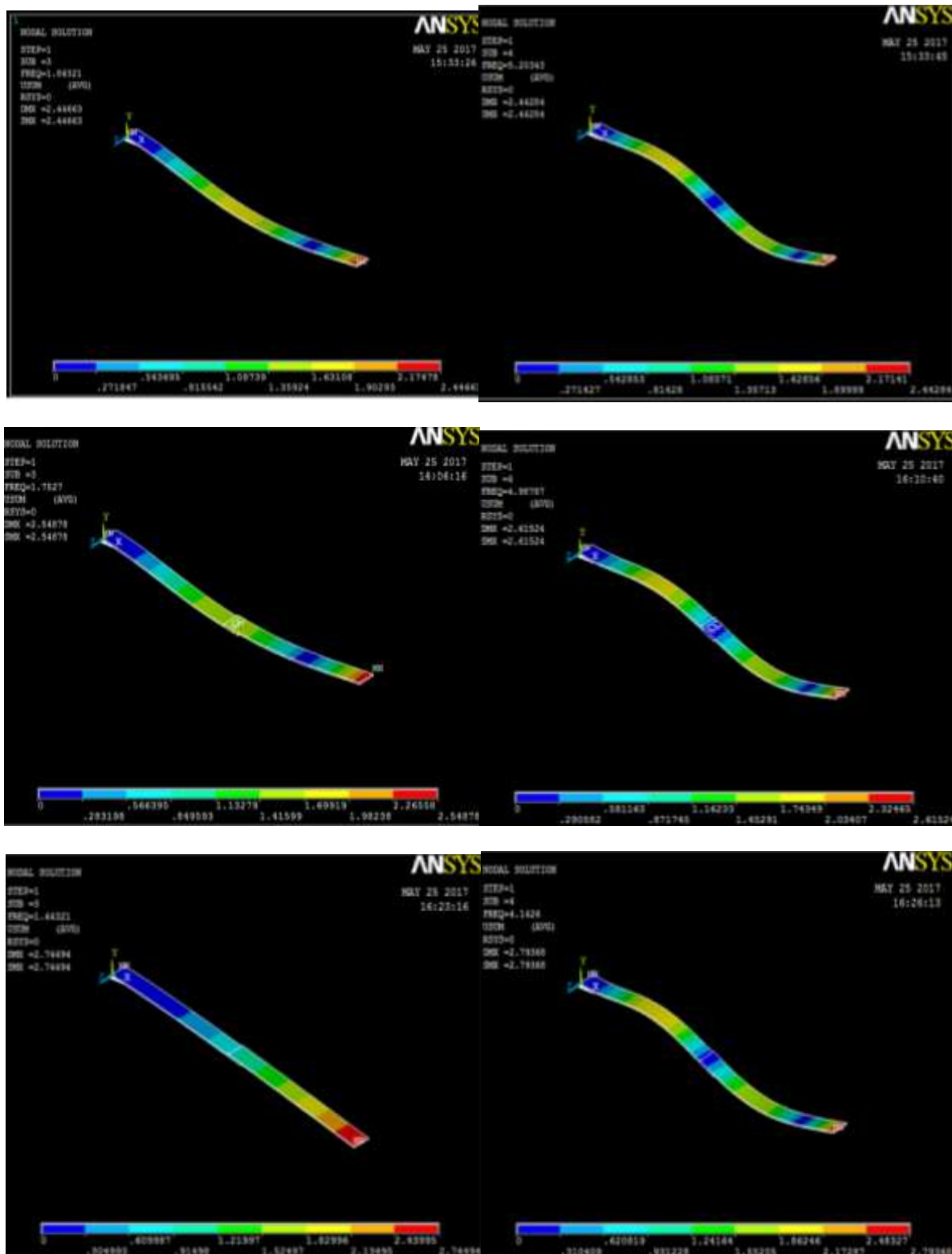


Figure.3 Comparison of natural frequencies with respect to modes



VI. CONCLUSION

The natural frequencies and mode shapes are obtained by FEA and experimental method for rectangular cross sectioned cantilever plate. From the table 3 it is observed that the FEA results have close agreement with experimental results. The dynamic response of all the specimens are investigated numerically (FEA) and experimentally and compared both the results with other. The Ansys 13.0 software is used for finite element analysis to predict the natural frequencies and mode shapes of the entire 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. It can also be concluded that the bonding of adhesive joints is an alternative method of joining materials together, which has many advantages over the other conventional joining methods such as riveting, welding, and bolting. The natural frequencies and mode shapes obtained by the both methods are compared and shown in table 3 and fig. 3. It is observed from the FEA and experimental analysis of rectangular cross sectioned cantilever plate, with bolted joint and with adhesive bonded lap joint have close agreement with each other and obtained results are acceptable. From this big task it can be also concluded 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, riveting and much also. Hence adhesive bonded lap joint can replace the bolted lap joint for the considered cases.

REFERENCES

- [1] Xiaocong He, Numerical and Experimental Investigations of Dynamic Response of Bonded Beams with a Single Lap Joint, *International Journal of Adhesion and Adhesives* 37 (2012) 79-85.
- [2] Y.B. Patil, R.B. Barjibhe, Modal analysis of adhesively bonded Joints of different Materials, *International Journal of Modern Engineering Research*, Vol.3, Issue.2, March-April.(2013) pp-633-636.
- [3] X.He, S.O. Oyadiji, Influence of adhesive characteristics on the transverse free vibration of single lap-jointed cantilevered beams, *Journal of material processing technology* 119 (2001) 366-373.
- [4] Xiaocong He, Finite element analysis of torsional free vibration of adhesively bonded single lap joints, *International journal of adhesion and adhesives* 48 (2014) 59-66.
- [5] Yu Du*, Lu Shi, Effect of vibration fatigue on modal properties of single lap adhesive joints, *International Journal of adhesion and adhesives* 53 (2014) 72-79.
- [6] A. Boudjemaia*, R. Amria,1, A. Mankoura,1, H. Salema,1, Modal analysis and testing of hexagonal honeycomb plates used for satellite structural design, *Materials and design* 35 (2012) 266-275.
- [7] Xiaocong He, A review of finite element analysis of adhesively bonded joints, *International journal of adhesion and adhesives* 31 (2011) 248-264.
- [8] Melih Eriten^{a,*}, Mehmet Kurt^b, Guanyang Luo^b, D. Michael McFarland^c, Nonlinear system identification of frictional effects in a beam with a bolted joint connection, *mechanical system and signal processing* 39 (2013) 245-264.
- [9] I. Ullah^a and M. Yasin, Reduced order modeling for dynamic response of bolted joints subjected to multi harmonic loading, *Procedia Engineering* 14 (2011) 1326-1333.
- [10] Bhagat Singh*, Bijoy Kumar Nanda, Dynamic analysis of damping in layered and welded beams, *Engineering structures* 48 (2013) 10-20.
- [11] X. He^{a,*}, Y. Zhang^a, H. Cun^b, S. Yuan^b, Y. Ding^a, K. Zeng^a, Vibration Measurements of Clinched Joints, *Procedia CIRP* 26 (2015) 208-211.
- [12] Ramu I and Mohanty S. C. Modal Analysis of functionally graded plates using finite element method, *Procedia Materials Science* 6 (2014) 460 – 467,
- [13] Jeong Kim, Joo-Cheol Yoon, Beom-Sookang, Finite element analysis and modeling of structure with bolted joints, *Applied mathematical modeling* 31 (2007) 895-911
- [14] Serife Tol, H. Nevzat Ozguven, Dynamic characterization of bolted joints using FRF decoupling and optimization, *Mechanical systems and signal processing* 54-55 (2015) 124-138.
- [15] H.K. Harsha, R.P. Rokade, A. Sivakumar, Studies of stress concentration at bolt hole location in lap joints using.
- [16] H. Ouyang, M.J. Oldfield, J.E. Mottershead, Experimental and theoretical studies of a bolted joint excited by a torsional dynamic load, *International Journal of Mechanical Science* 48 (2006) 1447-1455.
- [17] Hans Irschik, Johannes Kepler, Efficient modal formulation for vibration analysis of solid structures with bolted joints, *ActaMechanica*, Vol.62, pp 155-167