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FREE VIBRATION OF THICK RECTANGULAR DEBONDED METALLIC PLATES: ANALYTICAL AND EXPERIMENTAL APPROACH

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ABSTRACT

In the present investigation, free vibration analysis of thick isotropic materials of debonded metallic plates under various boundary conditions is found using finite element method. In addition experiments are conducted on thick debonded metallic plates to validate FEM with experimental modal analysis also. The finite element models (FEM) which use the elasticity theory for the determination of stiffness matrices are modeled in ANSYS software to evaluate the first natural frequencies of the laminate. The variation of natural frequencies with respect to various debonded isotropic materials like stainless steel and aluminum is presented.

Keywords: Free Vibration, Metallic Plates, Natural Frequencies, Finite Element Method, Modal Analysis.

I. INTRODUCTION

Among all the material types, the metals are the superior ones. These include iron, aluminum, copper etc. The mixture of metals called alloys. These alloys are formed by mixing two or more metals. Metals are more heavy and high temperature resistance when compared with plastics, composites and ceramics. They can be used for applications with higher service temperature requirements, due to their higher temperature resistance than plastics. The following paragraph provides a brief review of various research contributions on free vibration analysis of metallic structures.

Ajay S. Patil (2014) studied the performance of the developed finite element formulation is assessed for free vibration response of thin isotropic rectangular plate with various boundary conditions and different aspect ratios, earlier it is used only for static analysis of plate and no attempt is made to use it for free vibration response. The comparison of natural frequencies of thick and thin rectangular laminates with various boundary conditions is studied by (Chao C.C. and Yeong-chyuan chern, 2000) using 3-D elasticity theory. Cerdem Imrak and Ismail Gerdemeli (2007) discussed an exact solution of the governing equation of an isotropic rectangular plate with four clamped edges. Ehab N. Abbas, Mohammad Qasim Abdullah and Hatem R. Wasmi (2015) studied the static and dynamic analysis of thin isotropic and orthotropic CCCC plates using classical thin plate theory and finite element analysis. Ezeh J. C., Ibearugbulem O.M. and Onyechere C. I. (2013) reported an ordinary Finite Difference method, in free vibration (FB) analysis of thin rectangular flat plate using the proper boundary conditions of SSSS, CCCC and CSCS respectively. Kanak Kalita and Abir Dutta (2013) studied different mode frequencies for free vibration of isotropic plates using the ANSYS computer package. The finite element analysis of thick isotropic rectangular plates is presented by (Kulkarni S.D. and Khandagale N.G., 2011) based on Reddy’s third order theory. Qian L.F., Batra R.C. and Chen L.M. (2003) analyzed three-dimensional infinitesimal elastodynamic deformations of a homogeneous rectangular plate subjected to different edge conditions using a meshless local Petrov-Galerkin method. Neffati M. Werfalli and Abobaker A. Karoud (2012) studied free vibration of thin isotropic rectangular plates with various edge conditions using a Galerkin-based finite element method. Yoshihiro Narita (1979) investigated the free, transverse vibration of thin isotropic plates of various shapes and boundary conditions.

The present investigation intends to apply the finite element techniques for the free vibration analysis of thick isotropic materials. The fundamental natural frequencies are studied by varying the different types of materials.

II. PROBLEM STATEMENT

2.1 Geometric and Finite Element Modeling

The rectangular metal plates are made of stainless-steel and aluminum with length 100mm, width 50mm and thickness 10mm. The element used for the present analysis is SOLID 95 of ANSYS, which is developed, based on three-dimensional elasticity theory and is defined by 20 nodes having three degrees of freedom at each node, translation in the node x, y and z directions. The geometry of the thick rectangular plate is shown in Figure1.

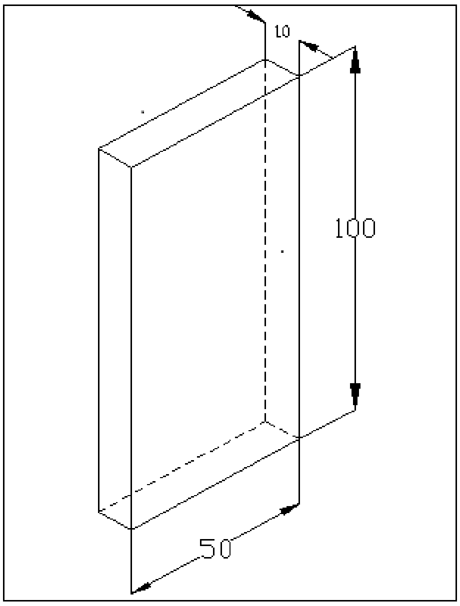


Figure1. Geometry of the plate

2.2 Boundary Conditions

The sides of the plate considered for the analysis are one end clamped and both ends clamped

2.3 Material properties

The following are the material properties of the metallic plates:

1) Stainless-steel: $E = 200 \times 10^9$ N/m^2, $\upsilon = 0.33$, $\rho = 8027$ kg/m^3

2) Aluminum: E = 70 x 10^9 N/m^2, υ =0.34, ρ=2710 kg/m^3

2.4 Validation of finite element model (FEM)

The FEM is validated with the results available in the literature and found good agreement

Table 1: Validation of the 3-D finite element results*

Sliding pin supported edge (S_2)	Isotropic	
Thickness ratio (a/h)	a/h=10	a/h=1000
Present FEM	9.4023	19.9756
Chao (2000)	9.3150	19.7389

*For isotropic: $E_1=E_2$, $\nu_{12}=\nu_{23}=0.3$

Where the normalized frequency, $\Omega_a = 100\omega(\rho_A h/G)^{1/2}$

III. FINITE ELEMENT RESULTS

The following are the obtained finite element results for thick debonded metallic plates [Figures2 -7]. The different debonded metallic plates used are stainlesssteel-stainlesssteel plate, stainless-aluminum plate and aluminum-aluminum plate with one side clamping and two sides clamping.

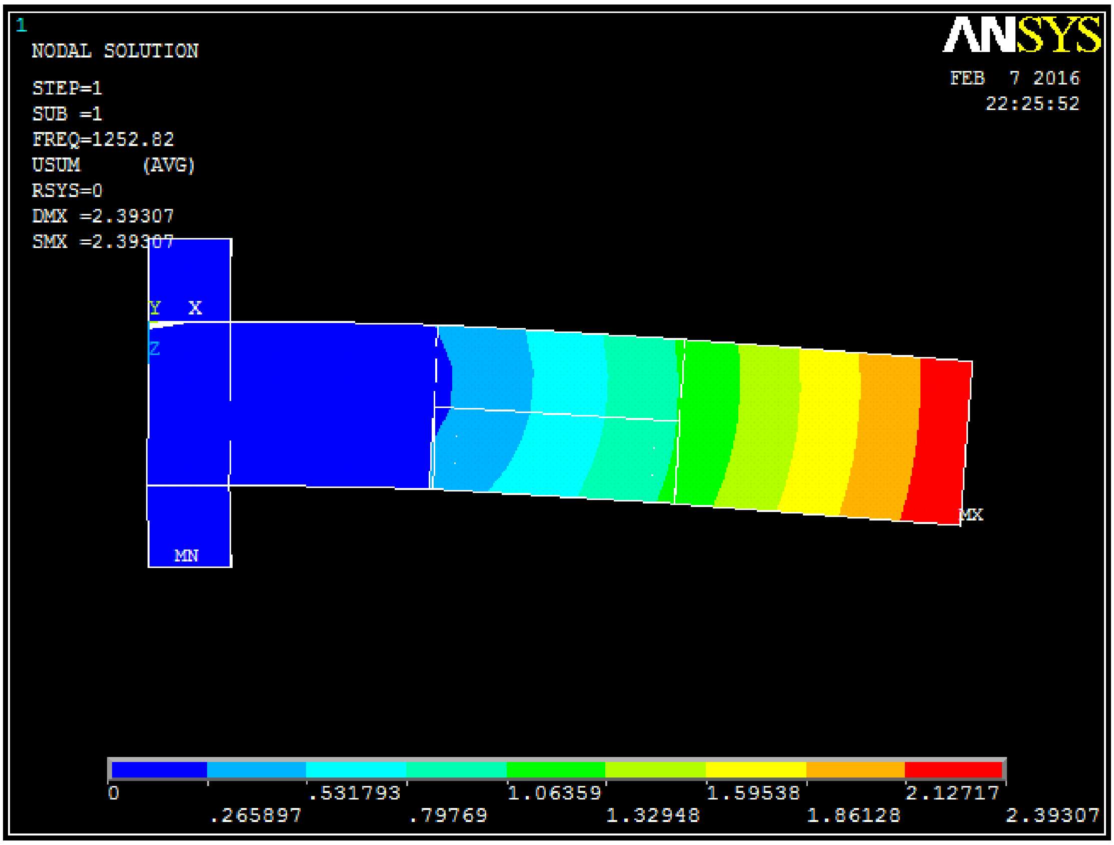
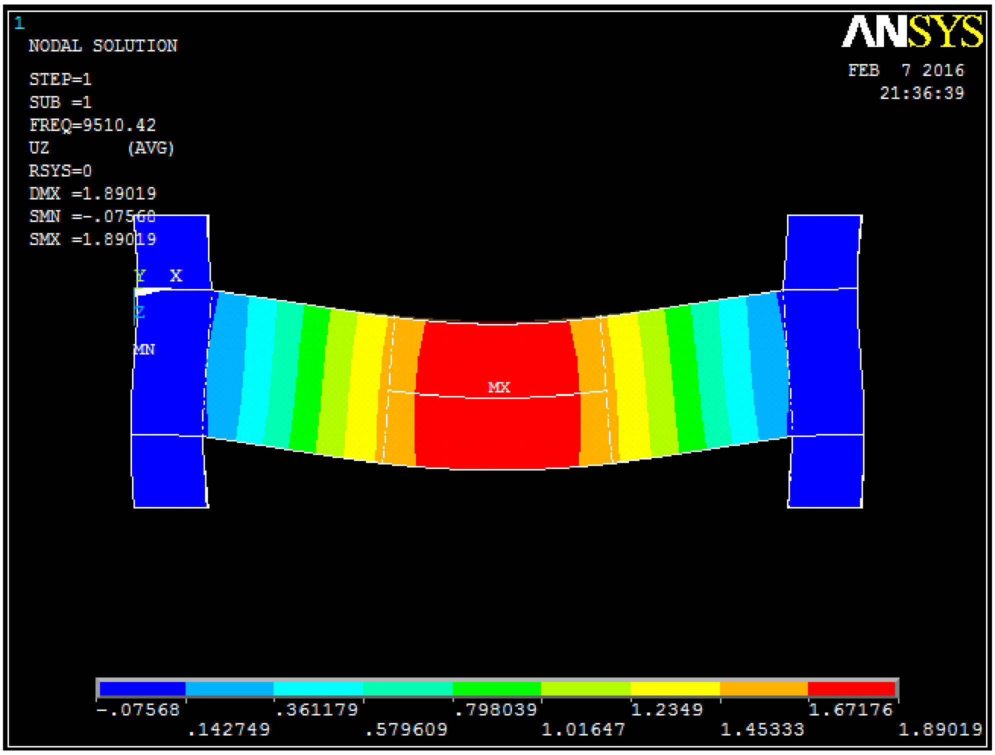


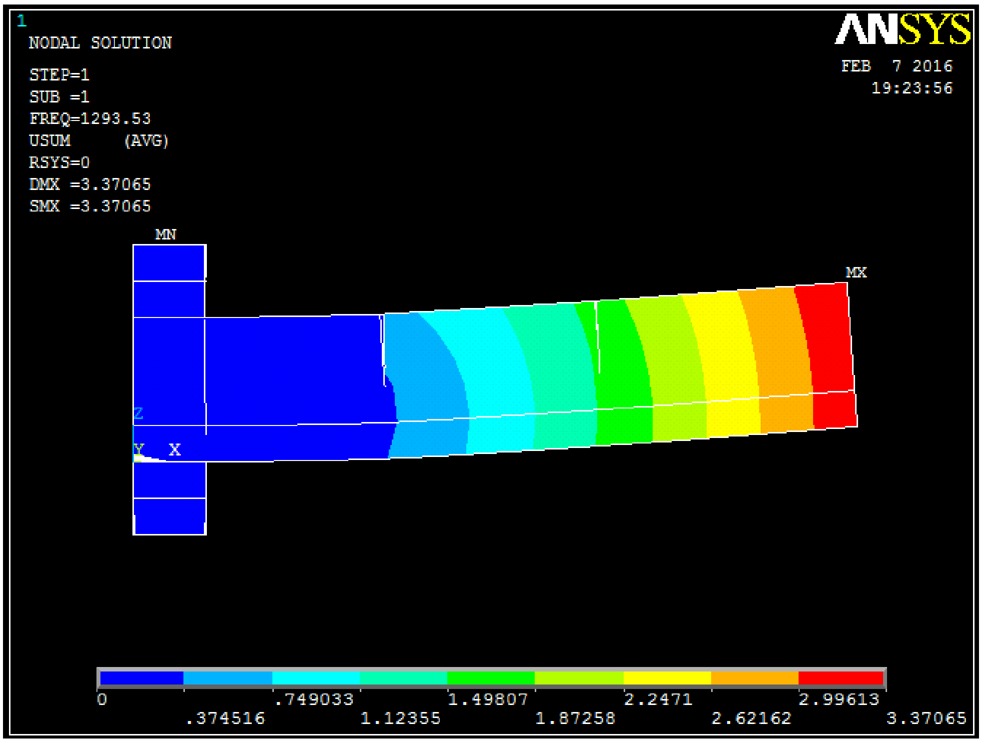
Figure2: First mode shape of one end clamped stainless steel- stainless steel debonded plate (1252.82Hz)



```
1
NODAL SOLUTION

STEP=1
SUB =1
FREQ=9510.42
UZ        (AVG)
RSYS=0
DMX =1.89019
SMN =-.07568
SMX =1.89019
```

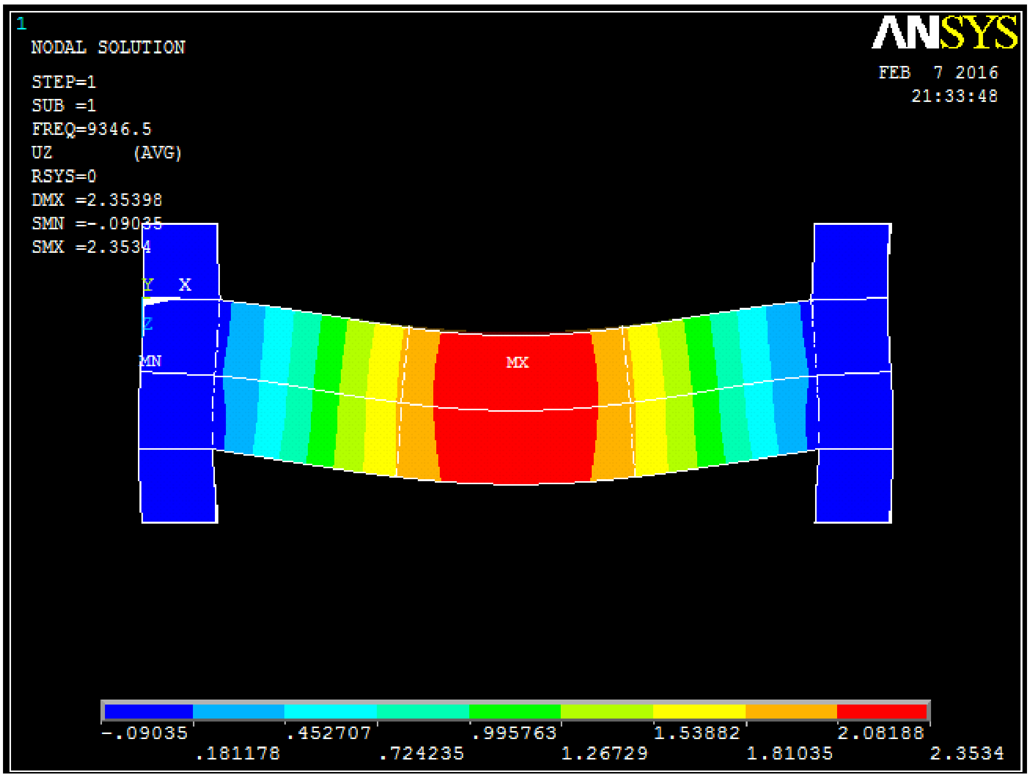
Figure3: First mode shape of both ends clamped stainless steel- stainless steel debonded plate (9510.42Hz)



```
1
NODAL SOLUTION

STEP=1
SUB =1
FREQ=1293.53
USUM      (AVG)
RSYS=0
DMX =3.37065
SMX =3.37065
```

Figure4: First mode shape of one end clamped stainless steel- aluminum debonded plate (1293.53Hz)



```
1
NODAL SOLUTION

STEP=1
SUB =1
FREQ=9346.5
UZ        (AVG)
RSYS=0
DMX =2.35398
SMN =-.09035
SMX =2.3534
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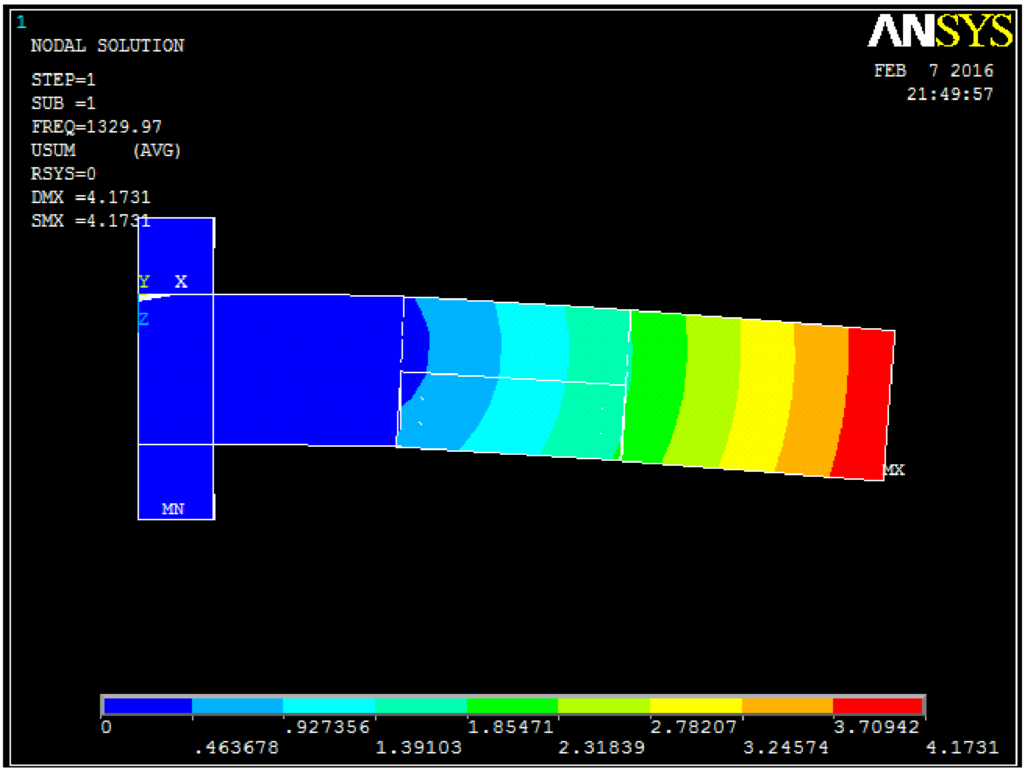
Figure5: First mode shape of both ends clamped stainless steel- aluminum debonded plate (9346.5Hz)



```
1
NODAL SOLUTION

STEP=1
SUB =1
FREQ=1329.97
USUM      (AVG)
RSYS=0
DMX =4.1731
SMX =4.1731
```

Figure6: First mode shape of one end clamped aluminum - aluminum debonded plate (1329.97Hz)

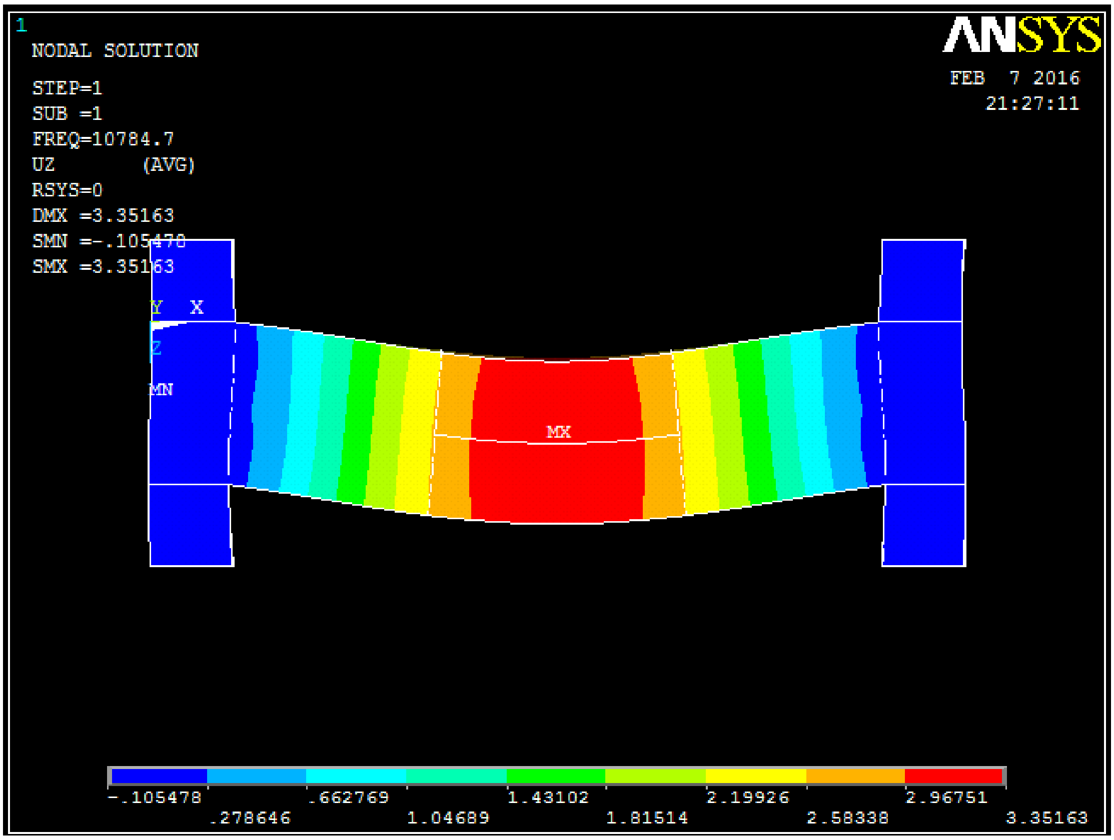


Figure7: First mode shape of both ends clamped aluminum - aluminum debonded plate (10784.7Hz)

IV. EXPERIMENTAL INVESTIGATION

4.1 Experimental set up

In experimental set up, supporting block is initially fixed on a rotating machine edge frame using nut and bolt arrangement. At the end of supporting block, the debonded metallic plates are edge clamped between the stainless steel strips of 10mm thickness, in order to achieve perfect arrangement. Thus, in such an arrangement the stainless steel and aluminum plates do not shatter and accurate readings are obtained. Figure8 and Figure9 show the configurations of the debonded metallic plates.

4.2 Testing procedure

Modal testing has been conducted to determine the frequency response. A piezoelectric strain gauge that senses the vibration signal is placed on the metal plate and impact hammer is used to excite the structure. Finally the output measurements are recorded by the FFT analyzer through the accelerometer.

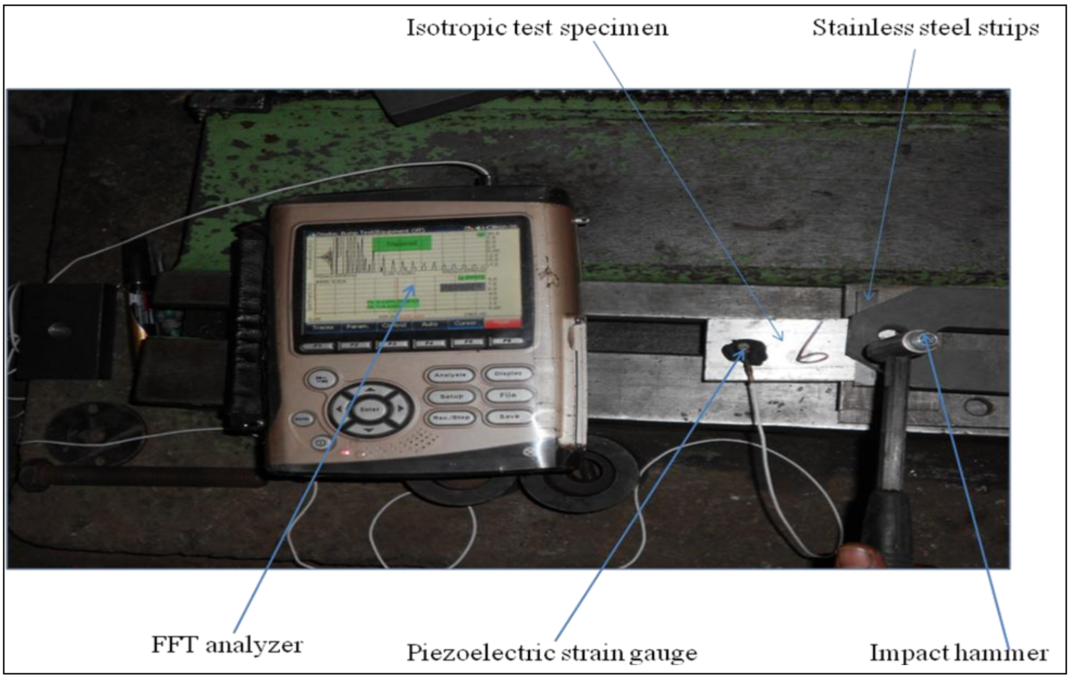


Figure8: Configuration of the one end edge clamped debonded metallic plate

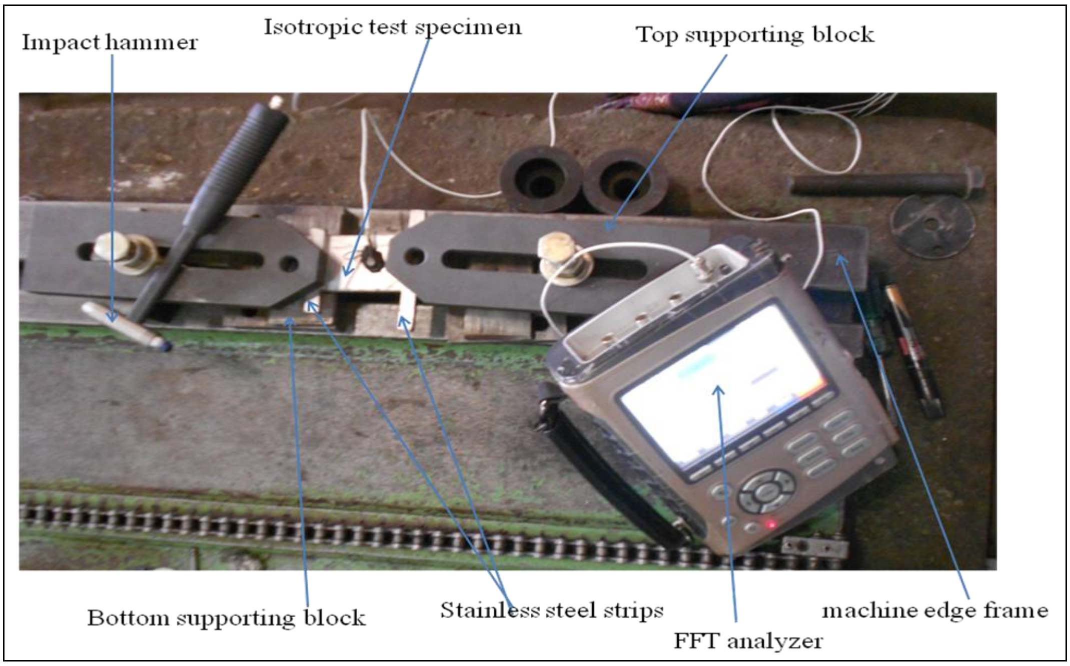


Figure9: Configuration of the both ends edge clamped debonded metallic plate

4.3 Experimental results

The following are the obtained experimental values for thick debonded metallic plates [Figures10-15].

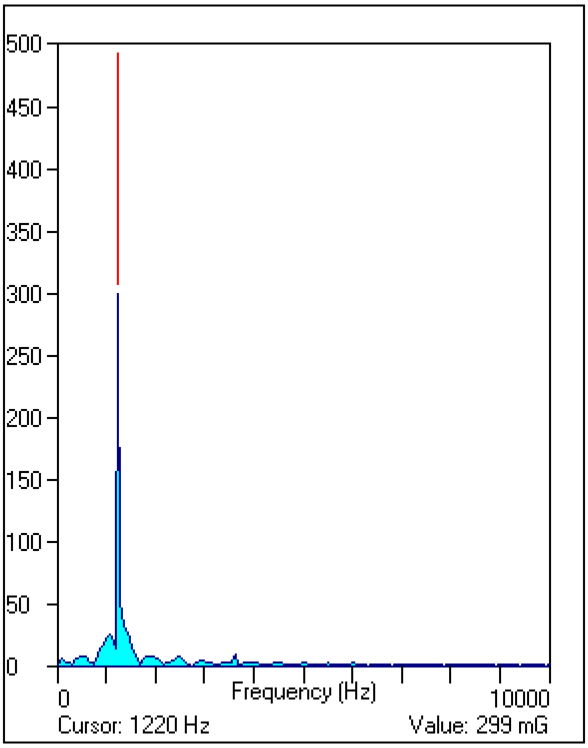


Figure10: First mode shape of one end clamped stainless steel- stainless steel debonded plate (1220Hz)

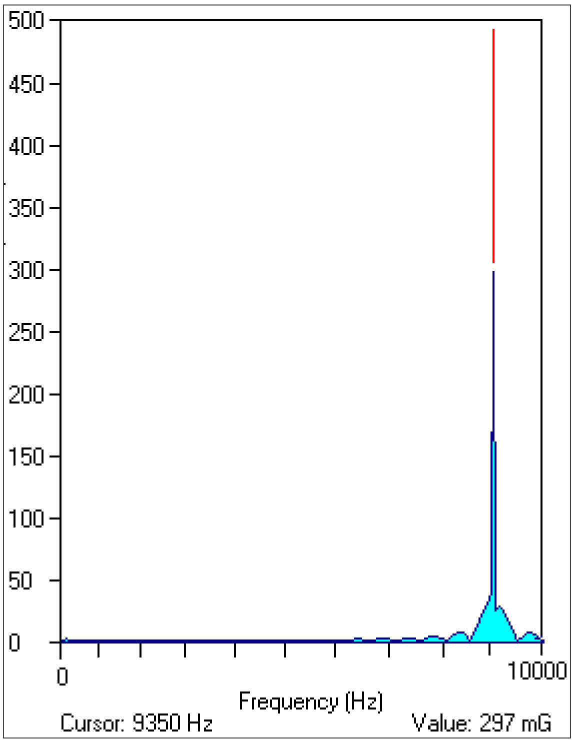


Figure11: First mode shape of both ends clamped stainless steel- stainless steel debonded plate (9350Hz)

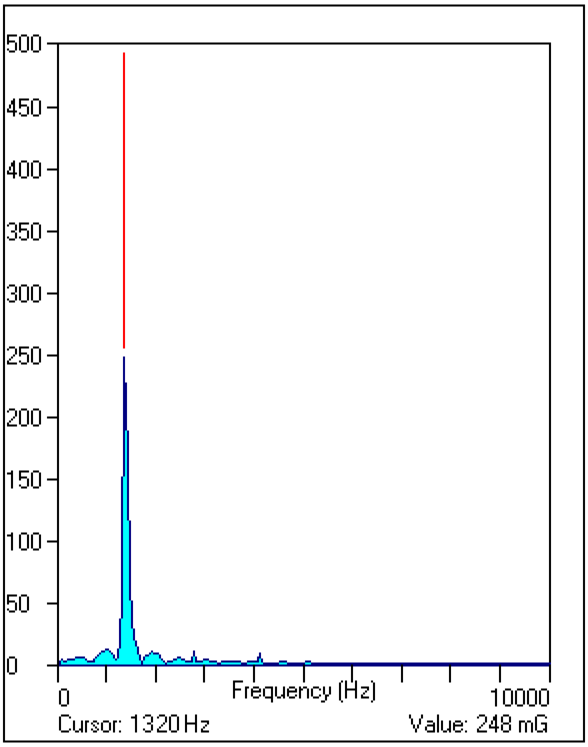


Figure12: First mode shape of one end clamped stainless steel- aluminum debonded plate (1320Hz)

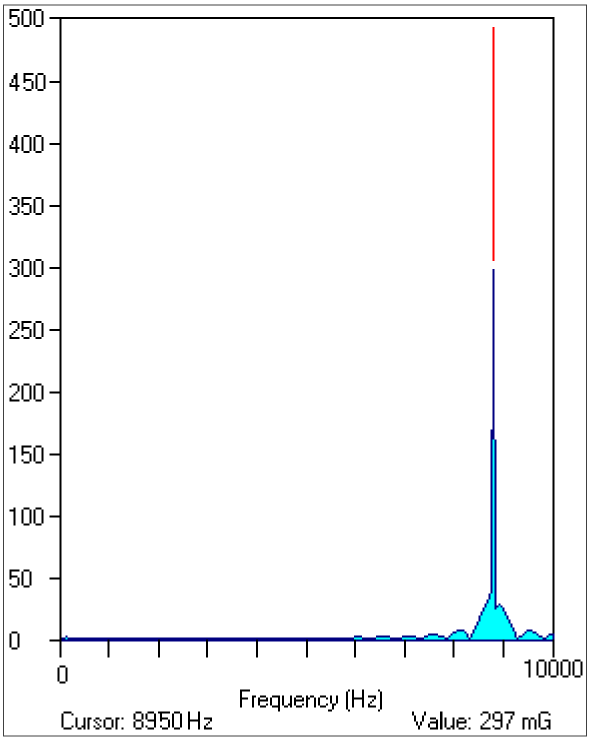


Figure13: First mode shape of both ends clamped stainless steel- aluminum debonded plate (8950Hz)

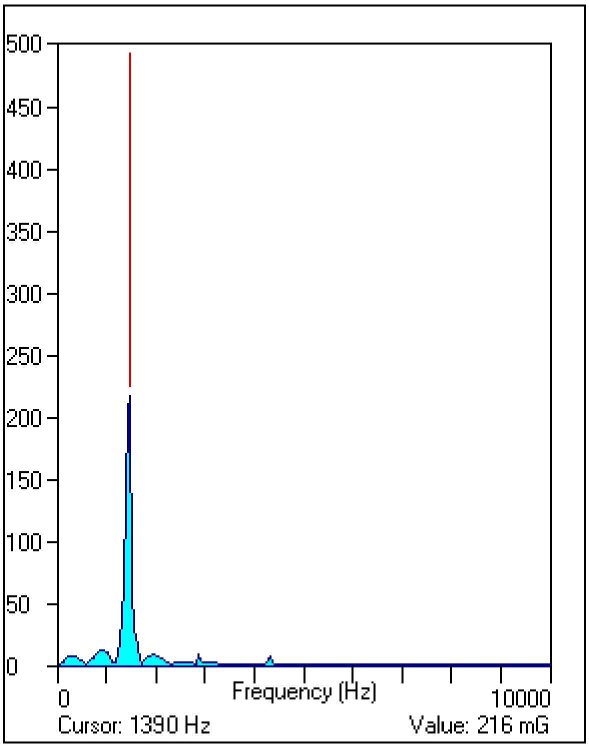


Figure14: First mode shape of one end clamped aluminum- aluminum debonded plate (1390Hz)

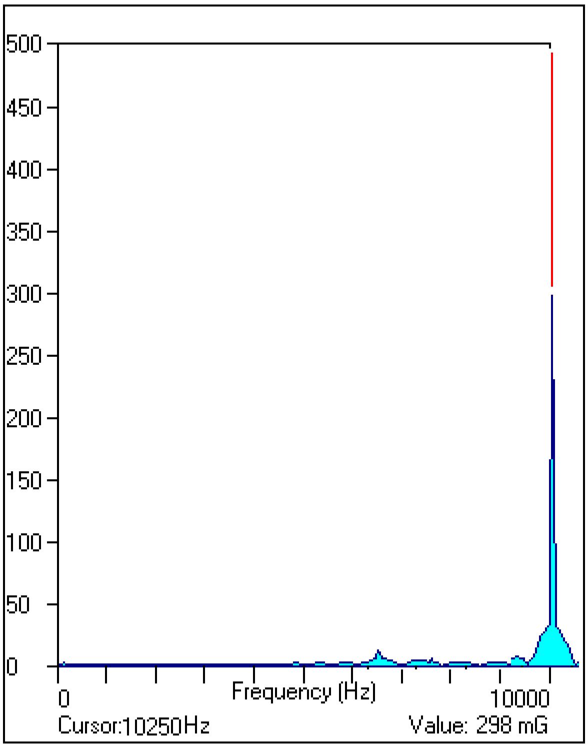


Figure15: First mode shape of both ends clamped aluminum- aluminum debonded plate (10250Hz)

The above experimental graphs are plotted between force and frequency illustrating the force with which the specimen is hammered and the frequency recorded on FFT analyzer.

The percentage deviation in frequency is given

$$e = \frac{|\text{Analytical value-Experimental value}|}{\text{Analytical value}} \times 100$$

For the above analytical and experimental values (from Figures2-7 &10-15), the percentage deviation is observed in Table2

Table2: Experimental and analytical (FEM) values percentage deviation of one end clamped and both ends clamped debonded metallic plates

Metallic plate	percentage deviation of FEM with experiment (one end edge clamped)	percentage deviation of FEM with experiment (both ends edge clamped)
Stainless steel-stainless steel	2.6%	3.04%
Stainless steel-aluminum	2.04%	4.2%
Aluminum- aluminum	4.5%	4.9%

In Table2, for one end edge clamping, the arrangement between the FEM with experiment results is very good for stainless steel-stainless steel and stainless steel-aliminum debonded metallic plates except in aluminum-aluminum debonded metallic plate, a considerable deviation of nearly 5% is observed.

In Table2, for both ends edge clamping, the arrangement between the FEM with experiment results is good in stainless steel-stainless steel debonded metallic plate except in stainless steel-aluminum and aluminum-aluminum debonded metallic plates, a considerable deviation of nearly 5% is observed.

In both ends edge clamping configuration, the percentage deviation is high in all cases, when compared to the one end edge clamping, because of the shorter length and boundary conditions, results in natural frequencies that is higher than those for the other configuration. It may not be a considerable reason for the increase in the percentage difference between the FEM with experimental predictions are due to the ecological conditions.

V. CONCLUSIONS

The free vibration analysis of isotropic materials of debonded metallic plates under various boundary conditions is solved using finite element method. The experimental modal analysis validation is also carried out, the finite element results are in close agreement with experimental results of isotropic materials. It is observed that, as the number of free edges decreases i.e. from CFFF(clamped-free-free-free) to CCFF(clamped-clamped-free-free), the natural frequencies increases in all the cases of isotropic materials of metallic plates. The present analysis is useful for the design of debonded plates for dynamic response point of view.

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