Study on Behavior of Plate Element Subjected to Dynamic Loading using ANSYS

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***Abstract*— There are many heterogeneous materials that are widely used in construction practice. Heterogeneous materials are used because of their high strength-weight ratio. Due to heterogeneity there is change in stiffness of the element. Delamination in heterogeneous structures can be serious threat to the safety of structure as it leads to loss of stiffness and strength of laminates. Crack propagation behavior is important which may lead structure to be unsafe and hence unreliable. Under any loading, it is necessary to know the time of initial crack of certain size that may become critical size at which point the structure becomes unsafe and fails. By knowing the rate of propagation of crack, estimation of residual service life of a component under normal loading is done. Stress redistribution occurs in heterogeneous material and hence lowers compressive strength and load carrying capacity. In the present work, an attempt has been made to assess the dynamic behavior of homogeneous and heterogeneous plate element with and without crack using commercially available finite element software ANSYS.**

Keywords*— *Crack, Dynamic Analysis, Modeling, Delamination, Heterogeneous material

I INTRODUCTION

Usage of heterogeneous materials in various construction elements have substantially increased over time. These materials are used in high strength-weight ratio and are subjected to various damages like crack and delamination due to dynamic loads, transient load swings, higher than expected intermittent loads, creep or defective component materials and etc. Due to heterogeneity, there is change in stiffness of the element made of such type of materials. This also contributes to dynamic loading condition that can cause micro crack formation at material grain boundaries in stress concentrated regions. Changed in natural frequencies, mode shapes, amplitudes of forced vibrations and coupling of vibrations formed are observed.

The dynamic characteristics of element can be correlated with local size and characteristics of damages (crack or delamination). Efforts are made to model and predict specific type of failure in complex material and structural systems. Time domain method will be used to accommodate the diversity of failure modes exhibited by homogeneous and heterogeneous materials in structures.

Heterogeneous laminates due to their high strength and stiffness to weight ratio are widely used in different load carrying structures. Laminates with complicated lay-up are used in order to obtain high stiffness. During the service laminates are subjected to complex thermo-mechanical loading that cause damage accumulation. After that limits recharged damage is progressing during further increase of load. The investigation of transverse cracking can be separated in two stages: initiation of transverse cracking and damage accumulation.

Delamination in heterogeneous structures can be serious threat to the safety of structure as it leads to loss of stiffness and strength of laminates. Crack propagation behavior is important which may lead structure to be unsafe and hence unreliable. Under any loading it is necessary to know the time of initial crack of certain size that may become critical size at which point the structure becomes unsafe and fails. By knowing the rate of propagation of crack, estimation of residual service life of a component under normal loading is done. Stress redistribution occurs in heterogeneous material and hence lowers compressive strength and load carrying capacity. Delamination occurs in heterogeneous structure and classified as

a) Material induced
b) Process induced
c) Thermally induced
d) Stress/ environmentally induced.

These stresses re not visible on the surface but they cause loss of stiffness and critical compressive strength of laminated panel.

A. Objectives

1) To assess the behaviour of stresses near internal damage
2) To study the response and damage distribution within the plate elements subjected to dynamic loading.

II CONCEPTS

A. *Fracture and damage mechanics*

Fracture mechanics deals with the study of how a crack or flaw in a structure propagates under applied loads. It involves analytical predictions which are made by calculating fracture parameters such as stress intensity factors in the crack region, which can be used to estimate crack growth rate.

A crack is a type of fracture that separates a solid body into two, or more, pieces under the action of stress. There are three types of modes of failure stated below (Fig 1):

Mode I: The forces are perpendicular to the crack, pulling the crack open, and the crack surfaces move directly apart. This is referred to as the opening mode.

Mode II: The sliding mode, the forces are parallel to the crack. One force is pushing the top half of the crack back and the other is pulling the bottom half of the crack forward, both along the same line. The crack surfaces move normal to the crack tip and remain in the plane of the crack. This creates a shear crack; the crack is sliding along itself. It is called in-plane shear because the forces are not causing the material to move out of its original plane.

Mode III: The tearing mode, the forces are perpendicular to the crack, the crack surfaces move parallel to the crack tip and remain in the plane of the crack. This causes the material to separate and slide along itself, moving out of its original plane so it is called out-of-plane shear.

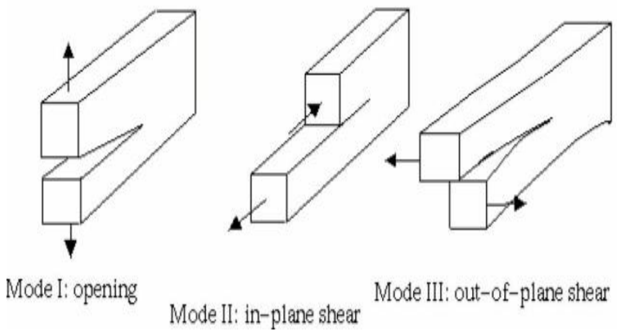

Fig. 1. Modes of failure

IV *Element Type Used in ANSYS*

The element used in the analysis is PLANE82. PLANE82 is a higher order version of the 2-D, four-node element (PLANE42). It provides more accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The 8-node elements have compatible displacement shapes and are well suited to model curved boundaries. The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axi-symmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

PLANE82 Assumptions

- The area of the element must be positive.
- The element must lie in a global X-Y plane. Y-axis must be the axis of symmetry for axi-symmetric analyses. An axi-symmetric structure should be modeled in the +X quadrants.
- A face with a removed mid side node implies that the displacement varies linearly, rather than parabolic variation along that face.

PLANE82 Restrictions

- The DAMP material property is not allowed.
- Influence body loads are not applicable.
- The only special feature allowed is stress stiffening.

V ANALYSIS

A. *Homogeneous Plate*

a) Analytical detail

Homogenous plate is assumed as Aluminium Alloy which in nonferrous metal with the following material properties.
Density of Aluminium =2700kg/m^3
Poisson's ratio of Aluminium=0.3
Young's modulus of Aluminium=7x10^{10}pa

b) Modeling

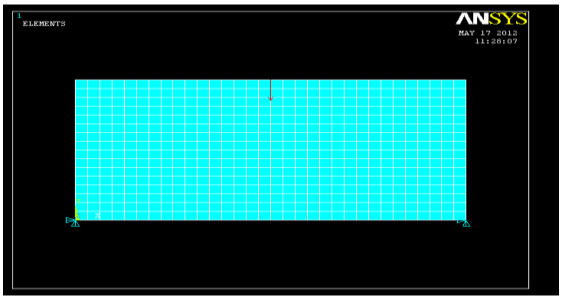

Fig. 2. Solid model of homogenous plate with element

Dimensions of the metal block are 1m x 0.5m as seen in the figure 4.1. A 2-D model is modeled and meshed with approximately 16 elements across the width of the metal block. (Fig 2).

Modal analysis is done for the first 5 natural frequencies and presented in below table 1 and the corresponding 5 mode shapes are also given in figure 3a, 3b, 3c, 3d and 3e. Here the force 0.01 N is applied on top at 0.5m from left edge which is of course the centre of the model.

TABLE 1 Modal frequencies for homogeneous model

Modes	Modal frequencies(Hz)
1	629.26
2	634.63
3	854.15
4	1887
5	2649

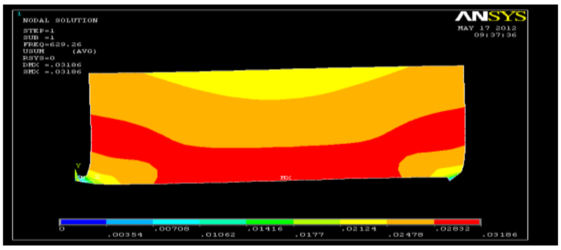

Fig .3 Mode shape 1 of homogeneous plate

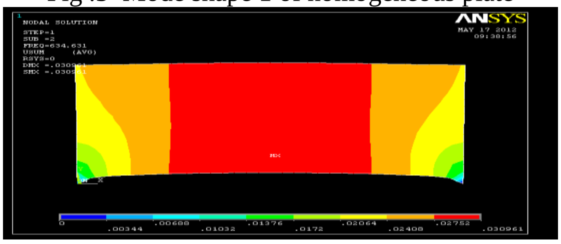

Fig .3b. Mode shape 2 of homogeneous plate

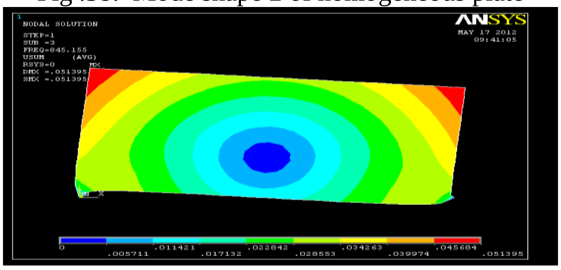

Fig. 3c. Mode shape 3 of homogeneous plate

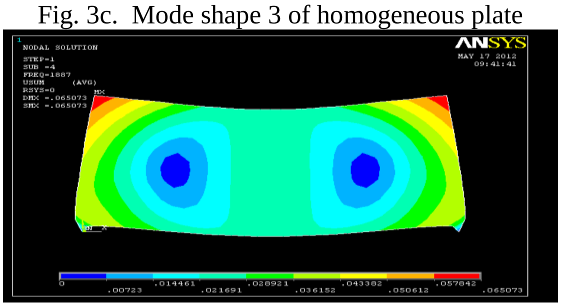

Fig. 3d. Mode shape 4 of homogeneous plate

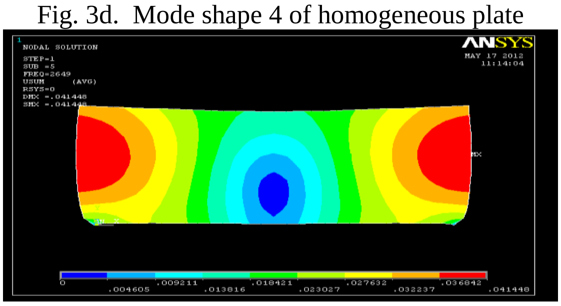

Fig. 3e. Mode shape 5 of homogeneous plate

c. *Dynamic analysis*

Transient dynamic analysis (sometimes called time-history analysis) is a technique used to determine the dynamic response of a structure under the action of any general time-dependent loads. This analysis can be used to determine the time-varying displacements, stress, strains, and force in a structure as it responds to any combination of static, transient, and harmonic loads. The time scale of the loading is such that the inertia or damping effects are considered to be important.

The input (excitation) is a time variant force. Here the time variant force is half sine curve with time as x-axis and force as y-axis, as mentioned in the previous analysis. The impact time is 1×10^{-5} sec, since one full period of sine wave is 2×10^{-5} sec. When the dynamic force is applied at top centre of the model and the model is constrained at bottom extreme nodes, the responses at three points were plotted as displacement amplitude in y-axis and time in x-axis. Fig 4a and 4b.

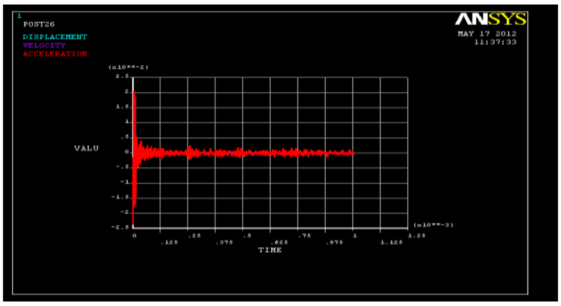

Fig. 4a. Acceleration -Time response of homogenous plate at 3 points of the model which is constrained at the bottom extreme nodes

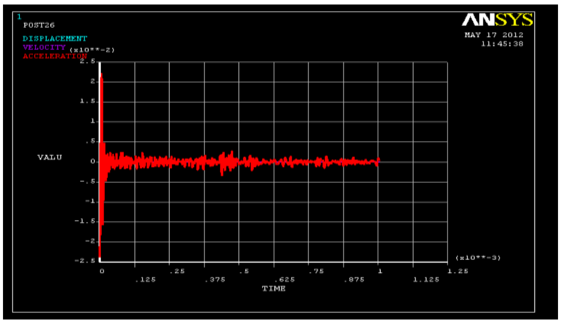

Fig. 4b. Acceleration -Time response of homogenous plate at 3 points of the model which is constrained at all bottom nodes

B. *Homogeneous Plate with Crack*

a) Analytical detail

Homogenous plate is assumed as Aluminium Alloy. A small crack is modeled at a distance 0.25m from top and 0.5m from the side edge, it is an elliptical shaped crack having dimension 0.04m in major axis and 0.0001m in minor axis.

Density of Aluminium =2700kg/m^3

Poisson's ratio of Aluminium=0.3

Young's modulus of Aluminium=7×10^{10}pa

b) Modeling

Modeling is done using solid 82 type element in ANSYS. Because of elliptical shape a fine mesh is generated near crack tips. Except at the crack tips the whole model is meshed coarsely. Bottom extreme nodes are fixed.

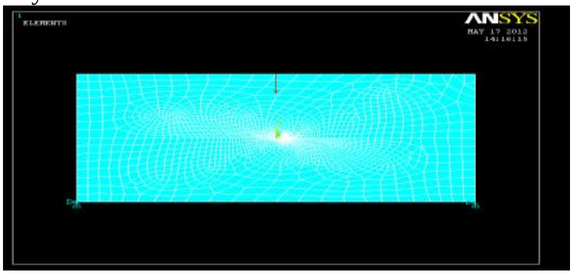

Fig .5. Finite element model of crack within homogeneous plate

TABLE 2 Modal frequencies for homogeneous model with crack.

Modes	Modal Frequencies (HZ)
1	624.551
2	633.301
3	844.496
4	1885
5	2647

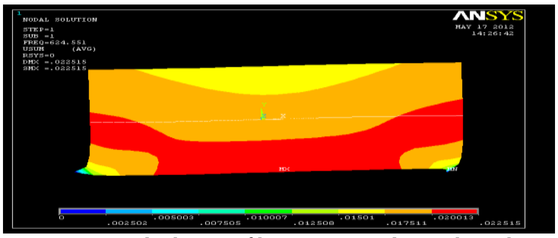

Fig .6a. Mode shape 1 of homogeneous plate with crack

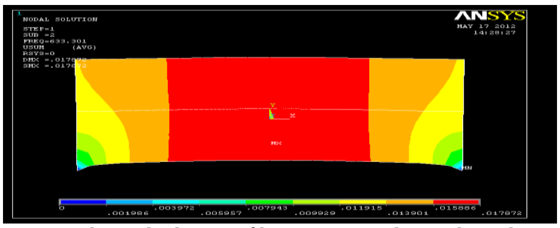

Fig .6b. Mode shape 2 of homogeneous plate with crack

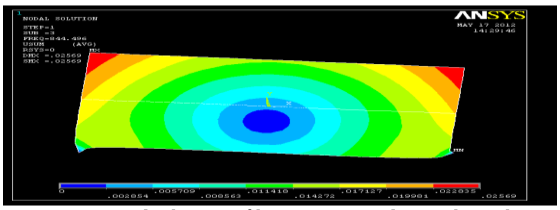

Fig.6c. Mode shape 3 of homogeneous plate with crack

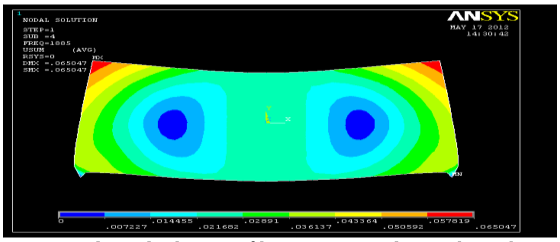

Fig. 6d. Mode shape 4 of homogeneous plate with crack

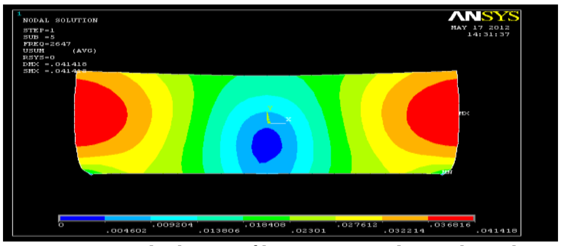

Fig. 6e. Mode shape 5 of homogeneous plate with crack

c) Dynamic analysis

The same procedure as that of the previous is done but with different impact time as calculated from frequency analysis. The displacement-time, velocity-time plot and acceleration-time plot are represented below.

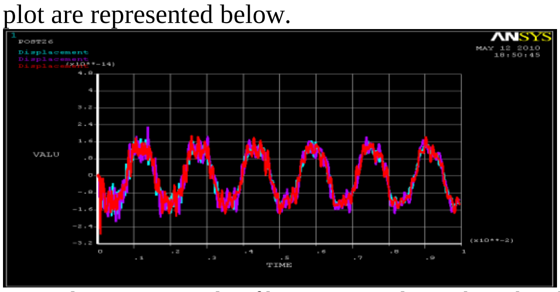

Fig.7a. Displacement-Time plot of homogeneous plate with crack at three different points

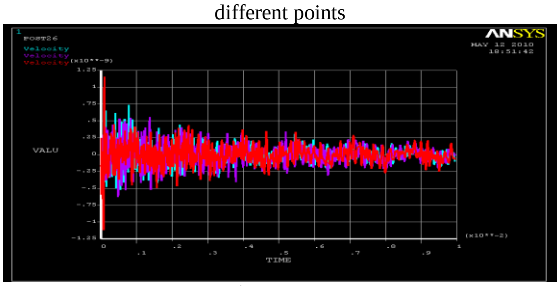

Fig. 7b. Velocity-Time plot of homogeneous plate with crack at three different points

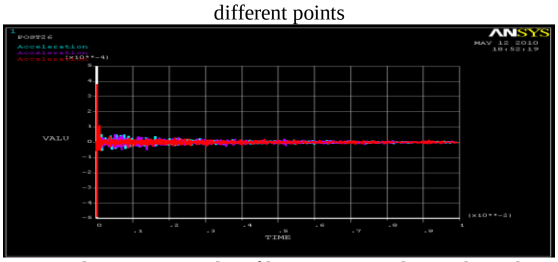

Fig .7c. Acceleration-Time plot of homogeneous plate with crack at three different points

C. *Laminated Heterogeneous Plate*

a) Analytical detail

Laminated heterogeneous plate is assumed as the combination of Aluminium and Low Carbon Steel with following material properties.

Material properties of low carbon steel:

Density of steel= 7872 Kg/m^3
Poisson's ratio=0.29
Young's modulus of steel=$2x10^{11}$pa
Material properties of Aluminium:
Density of Aluminium =2700kg/m^3
Poisson's ratio of Aluminium=0.3
Young's modulus of Aluminium=$7x10^{10}$pa

b) Modeling

Since heterogeneous material is used, both aluminium and low carbon steel.

Fig. 8. Solid model of laminated heterogeneous plate

TABLE 3 Modal frequencies for laminate heterogeneous plate

Modes	Modal Frequencies (HZ)
1	624.551
2	633.301
3	844.496
4	1885
5	2647

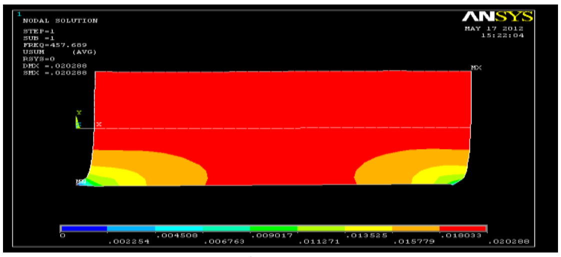

Fig 9a. Mode shape 1 of laminated heterogeneous plate

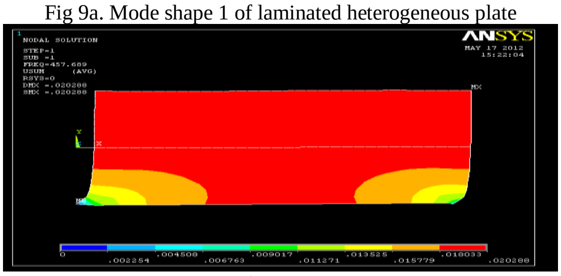

Fig 9b. Mode shape 2 of laminated heterogeneous plate

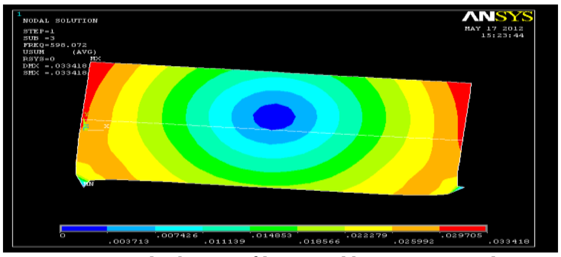

Fig .9c. Mode shape 3 of laminated heterogeneous plate

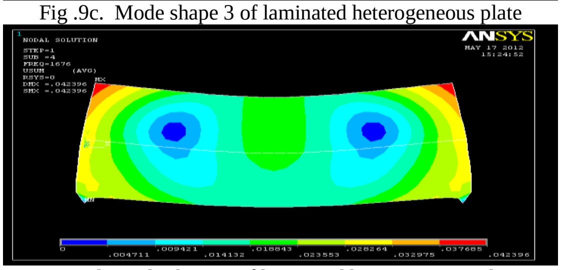

Fig. 9d. Mode shape 4 of laminated heterogeneous plate

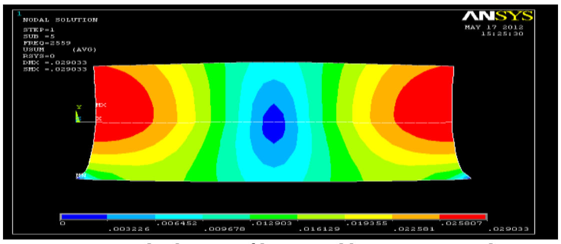

Fig. 9e. Mode shape 5 of laminated heterogeneous plate

c) Dynamic analysis

Dynamic analysis is done using the excitation force but with different impact time at the middle of the model as described in previous analysis. The displacement, velocity and acceleration are plotted

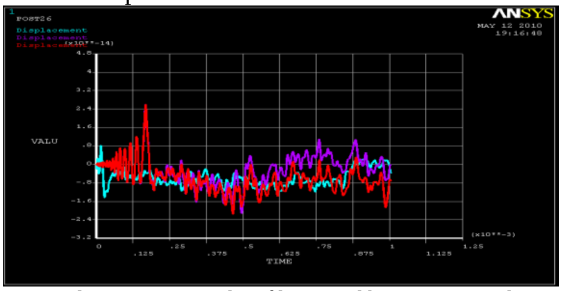

Fig. 10a. Displacement- Time plot of laminated heterogeneous plate at three different points

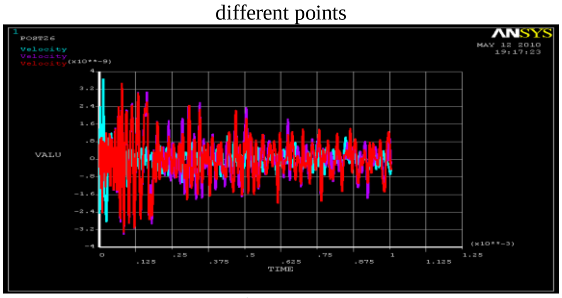

Fig. 10b. Velocity-Time plot of laminated heterogeneous plate at three different points

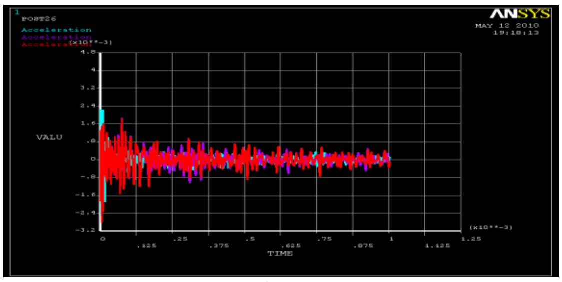

Fig. 10c. Acceleration-Time plot of laminated heterogeneous plate at three different points

D. *Laminated Heterogeneous Plate with Crack*

a) Modeling

Heterogeneous material is assumed as the combination of Aluminium and Low Carbon Steel, the crack is situated exactly at the interface between steel and aluminium as shown in figure which is often called as interfacial crack occurs in the heterogeneous laminates, material properties of aluminium and low carbon steel are assumed as in the previous analysis.

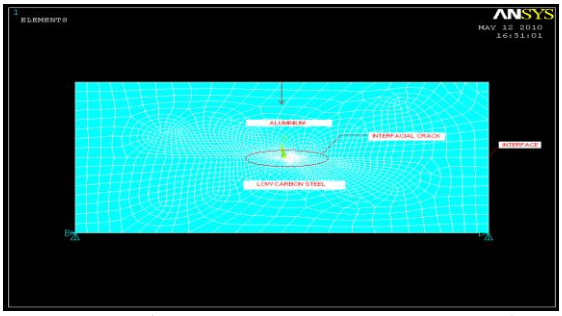

Fig. 11. Solid model of laminated heterogeneous plate with interfacial crack

TABLE 4 Natural frequencies for laminated heterogeneous plate with crack

Modes	Modal Frequencies (HZ)
1	624.551
2	633.301
3	844.496
4	1885
5	2647

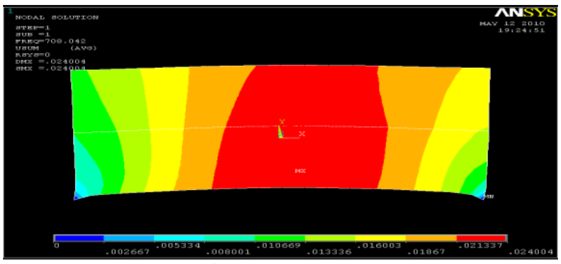

Fig. 12a. Mode shape 1 of laminated heterogeneous plate with crack

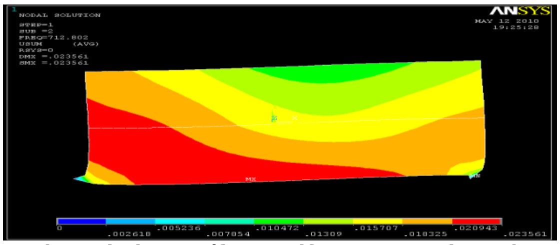

Fig. 12b. Mode shape 2 of laminated heterogeneous plate with crack

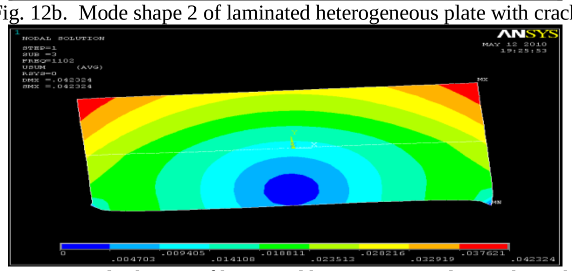

Fig. 12c Mode shape 3 of laminated heterogeneous plate with crack

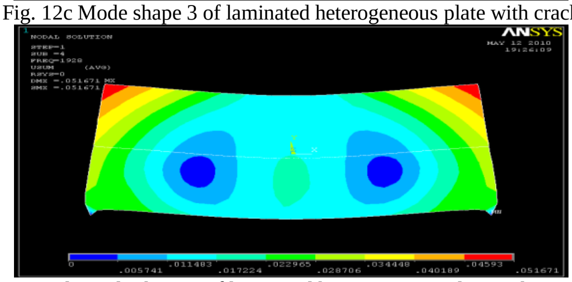

Fig. 12d. Mode shape 4 of laminated heterogeneous plate with crack

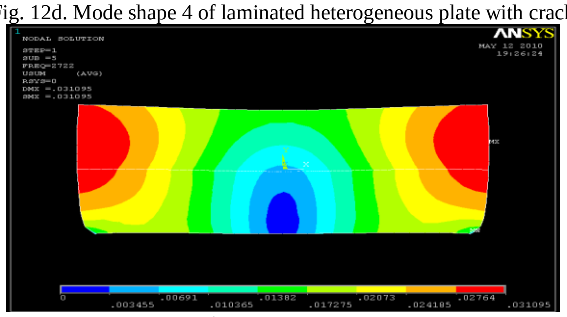

Fig. 12e. Mode shape 5 of laminated heterogeneous plate with crack

b) Dynamic analysis

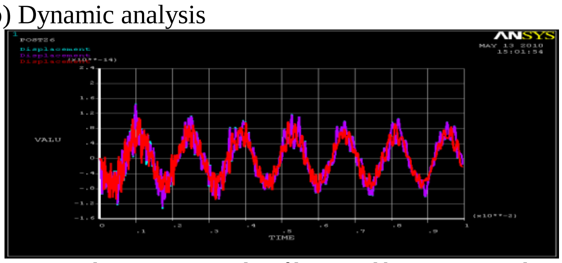

Fig. 13a. Displacement- Time plot of laminated heterogeneous plate with crack at three different points

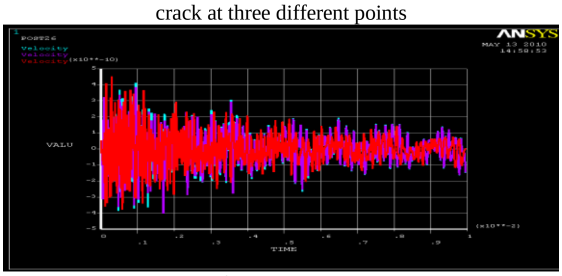

Fig. 13b. Velocity- Time plot of laminated heterogeneous plate with crack at three different points

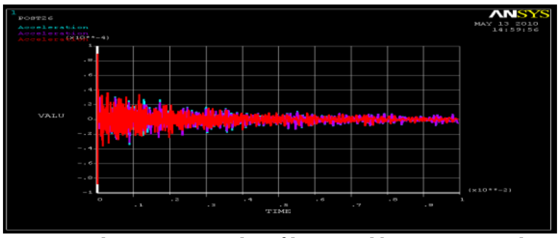

Fig. 13c. Acceleration- Time plot of laminated heterogeneous plate with crack at three different points

CONCLUSIONS

1. Modal frequency of homogenous plate is more compared to laminated heterogeneous plate. Modal frequency of homogenous plate with crack is approximately equal to modal frequency of homogeneous plate but for the laminated heterogeneous plate modal frequency is very high.
2. In displacement v/s time the amplitude is very high for the laminated heterogeneous plate with crack; this may be due to the reflection of different material densities.
3. Heterogeneous plate elements are more susceptible to dynamic impact due to the reduction in carrying load, this may be due to the huge stress accumulation which was reasonable for stress redistribution within the interface.
4. The study will be useful in assessing the behavior of plate element by knowing the rate of propagation of crack, stress redistribution and modal frequencies along with dynamic amplitudes for the estimation of residual service life of a structural component under dynamic loading.

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