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Dynamic Analysis of Cracks in Composite Materials



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Abstract:

Dynamic analysis of damages in materials is a difficult task and it is currently not known what importance different possible mechanisms carry. It is to a large extent due to the difficulty of measuring the dynamic behavior of cracks, debonds and delaminations inside material. It there exists a need to simulate the action of different mechanisms in order to understand the basic physics and possibly identify the signatures of measured vibration and acoustic signals. In this work we study vibrational responses from a specimen which has different types of non-linearities like fractures in it and understand various factors concerned with fracture location, fracture behavior and so on. After finding the fracture location and fracture size, stress intensity factors can be calculated and from them fatigue tests and other failure tests can be done.

Introduction:

In homogeneous material systems, damage almost always involves cracks. From dynamics and fracture mechanics, it is well known that accelerated crack nucleation and micro-crack formation in components can occur due to various reasons, such as transient load swings, higher than expected intermittent loads, or defective component materials. Normal wear causes configuration changes that contribute to dynamic loading conditions that can cause micro-crack formation at material grain boundaries in stress concentrated regions (acute changes in material geometry) [1].

Fracture and Damage Mechanics:

Cracks and flaws occur in many structures and components, sometimes leading to disastrous results. The engineering field of fracture mechanics was established to develop a basic understanding of such crack propagation problems.Fracture mechanics deals with the study of how a crack or flaw in astructure propagates under applied loads. It involves correlating analytical predictions of crack propagation and failure with experimental results.

The analytical predictions are made by calculating fracture parameters such as stress intensity factors in the crack region, which you can use to estimate crack growth rate. Typically, the crack length increases with each application of some cyclic load, such as cabin pressurization-depressurization in an airplane. Further, environmental conditions such as temperature or extensive exposure to irradiation can affect the fracture propensity of a given material [2].

Damages in Heterogeneous Materials:

Damages in the material lead to non-linear behavior. You encounter structural nonlinearities on a routine basis. For instance, whenever you staple two pieces of paper together, the metal staples are permanently bent into a different shape. If you heavily load a wooden shelf, it will sag more and more as time passes. As weight is added to a car or truck, the contact surfaces between its pneumatic tires and the underlying pavement change in response to the added load.

If you were to plot the load-deflection curve for each of these examples, you would discover that they all exhibit the fundamental characteristic of nonlinear structural behavior - a changing structural stiffness [3].

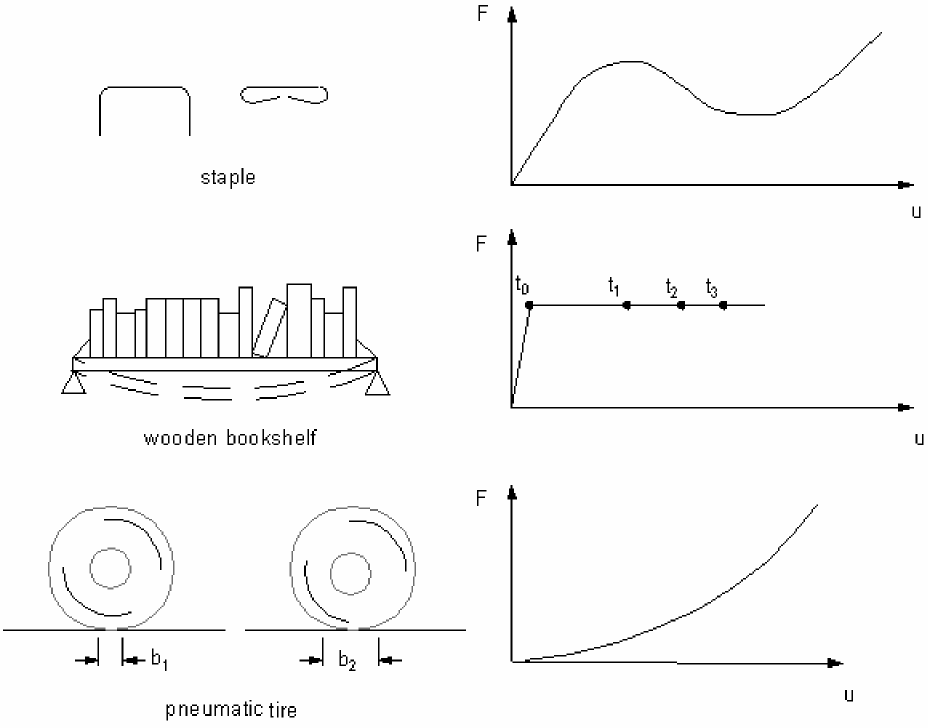


Figure 2.1. Load-deflection curves for different types of structural non-linearities. [3]

Nonlinear structural behavior arises from a number of causes, which can be grouped into these principal categories:

Geometric nonlinearities
Material nonlinearities

Geometric nonlinearities:

If a structure experiences large deformations, its changing geometric configuration can cause the structure to respond nonlinearly. Geometric nonlinearity is characterized by "large" displacements and rotations [3].

Material nonlinearities:

A number of material-related factors can cause your structure's stiffness to change during the course of an analysis. Nonlinear stress-strain relationships of plastic, multilinear elastic, and hyperelastic materials will cause a structure's stiffness to change at different load levels (and, typically, at different temperatures). Creep, viscoplasticity, and viscoelasticity will give rise to nonlinearities that can be time, rate, temperature, and stress-related. Swelling will induce strains that can be a function of temperature, time, neutron flux level (or some analogous quantity), and stress [3].As mentioned above Viscoplasticity can occur because of fracture. This occurs at near crack tip field with certain radius of curvature. Plasticity region highly depend of type of material in which fracture situated and plane strain and plane stress conditions. Non-linearity due to crack is differ from non-linearity occur due to plasticity around the crack tip, which is detailed in later chapters. Some types of non-linear causing damages are explained below.

Cracks:

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 [4].Mode I: The forces are perpendicular to the crack (the crack is horizontal and the forces are vertical), pulling the crack open. This is referred to as the opening mode. Mode II: 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. 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 forces are perpendicular to the crack (the crack is in front-back direction, the forces are pulling left and right). This causes the material to separate and slide along itself, moving out of its original plane (which is why it's called out-of-plane shear).

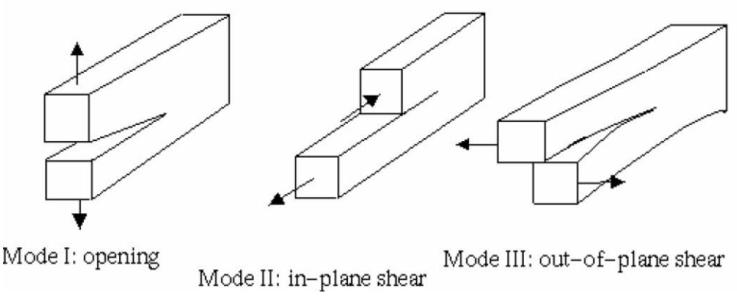


Figure 2.2. Three loading modes.

Analysis

Modeling

Aluminium is taken as homogeneous material and the modeling is done. Dimensions of the metal block are 1 x 0.5 m 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. To see the wave effects in the model when the force is applied, approximately 20 elements per wavelength is required, but here less than 20 elements are meshed across the width because to diminish the computer resources. 3-D model for dynamic analysis takes lot of computer resources so only 2-D model is done.

Plane 82 (solid 82) type elements were used for modeling which are 8 node elements in ANSYS. Plane stress condition is used when creating the model. Now on all the models of homogenous as well as heterogeneous are of plane stress condition.

Above material properties are entered in ANSYS simulation. Bottom extreme nodes both are constrained. When the dynamic force (time variant) is applied at the top, due to the difference in impedances of aluminium and air reflection occurs at the interface, the reflection of shear waves from aluminium to air is maximum (chapter 3.3).

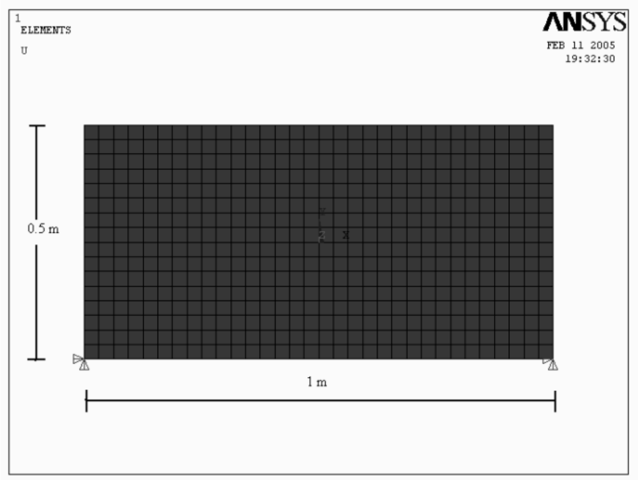


Figure 4.1. Solid model of homogeneous material with elements.

Model analysis is done for first 5 natural frequencies and presented in below table 4.1. Here the force 0.01 N is applied on top at 0.5 m from left edge which is of course the center of the model.When the dynamic force is applied at the center of the model and the entire bottom nodes are constrained, the responses at 1, 2 and 3 is plotted as time-domain plot in figure 4.8.

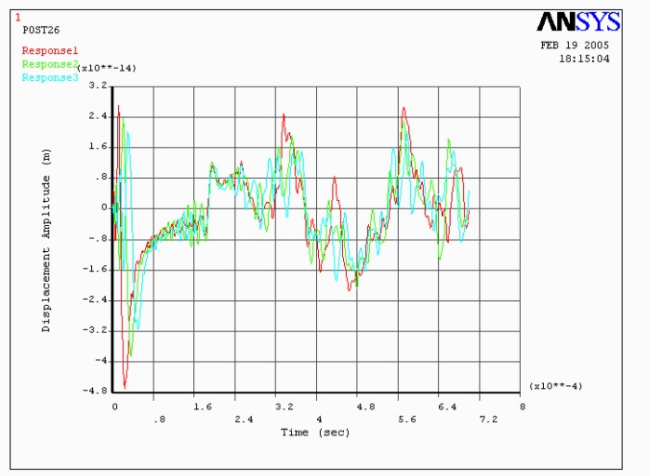
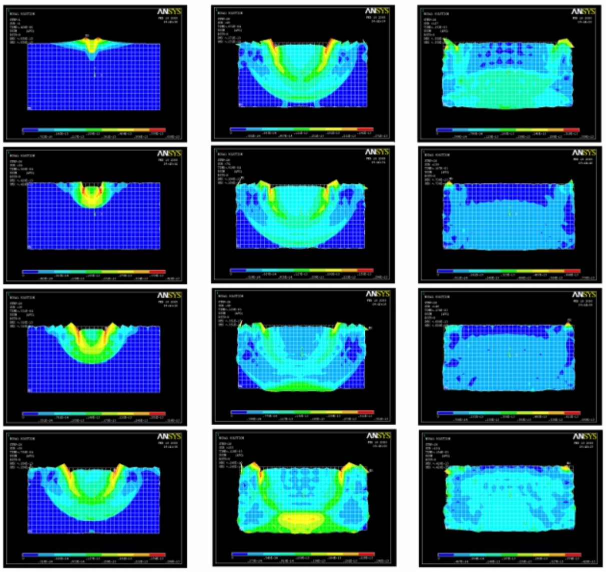


Figure 4.8. Time-domain responses at 3 points of the model whichis constrained at all bottom nodes.

The integration time step is taken as 102x10-5/100 which will of course agrees with the ITS described in the session 3.7. It can be observed that in the figures 4.6 and 4.8 the wave pattern after 2.8 x10- sec differs a lot.This is because when the 2 bottom extreme nodes are constrained, the bottom edge of the plate vibrates when the dynamic force is applied at the top, and when it vibrates it also gives away stress waves, these accounts for the extra peaks in the amplitude plot.

These can be seen clearly in the figure 4.6. When the entire bottom surface is fixed, there will not be any extra stress waves and the wave pattern can be seen clearly as in the Figure 4.8. It also can be observed that the sudden change in the amplitude



Results:

Different time domain plots were presented below with different time period ranges.

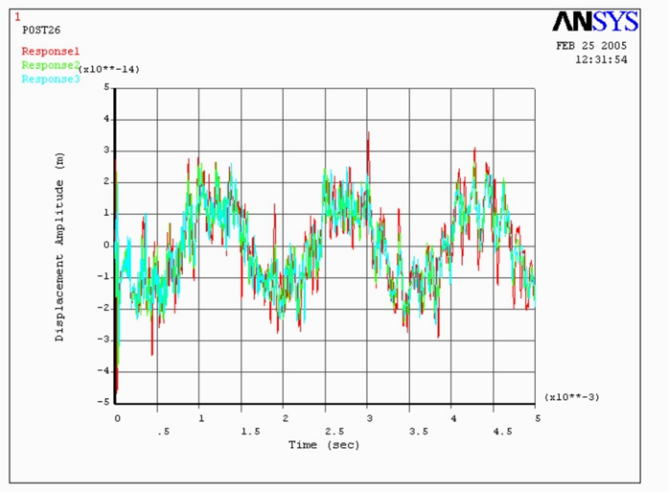


Figure 4.10. Displacement-Time plot of three response points with time range as 0 - 5x10-3 sec.

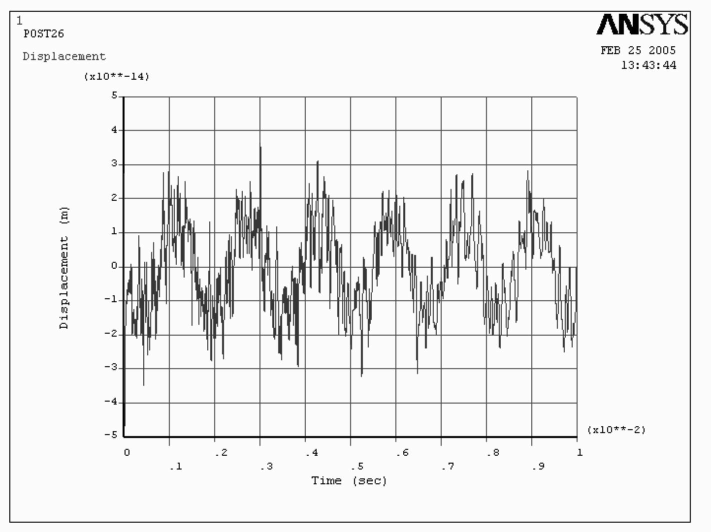


Figure 4.11. Displacement-Time plot of response point 1 with timrange as 0 - 1x10-2 sec.

Similarly above model, a model with a crack embedded at the center ofaluminium material which is surrounded by low carbon steel as shown in below figure. This type of materials is often used for high strength and light weight. These are called laminate composites. Cracks may occur for different reasons, like because of differences in densities of materials, coefficient of elongation etc.

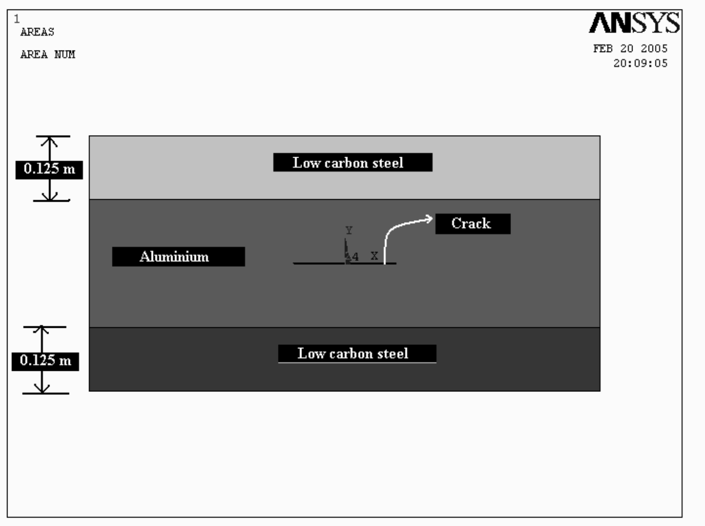


Figure 4.58. Solid model of a crack embedded at the center material in composite laminate.

A frequency analysis is done in the range 0 to 100 kHz and the graph is plotted between Displacement amplitude and Frequency. There are more frequency peaks in the frequency domain plot than previous analysis. This is due to different materials included in the model with different material properties. The reflections from each layer of the material will cause each peak in the spectrum along with the crack.

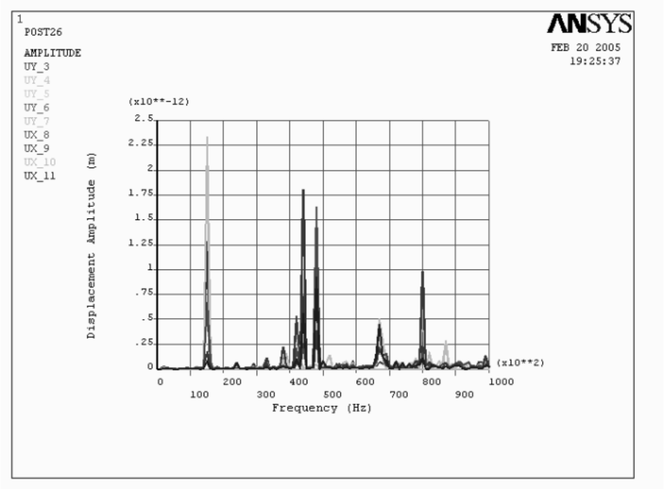


Figure 4.59. Frequency responses

A dynamic analysis is also done using the variable amplitude loading the excitation frequency is taken as 49000 Hz and is given at the surface with 0.01 n of force. Response near impact point and near bottom of the material were plotted in the below figures.

Conclusions:

Dynamic analysis is a very important investigation when it comes to the composite materials, where these can exhibit diversity in material properties as well as shapes. The main idea of this work is to perform dynamic analysis which gives the information about various factors including cracks, voids, interfaces and the locations of the damages etc. on different types of materials ranging from normal homogeneous material to complex composite laminates. In real life situations doing a dynamic analysis on structures requires great skill and experience, because the excitation force which is dynamically given on the structure should be chosen very carefully and the excitation point is also plays very important role in dynamic analysis. By doing the computer simulation of dynamic analysis gives us the variety in choosing excitation signal as well as the excitation points.

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