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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 important different possible mechanisms carry in the materials. It is to a large extent due to the difficulty of measuring the dynamic behavior of cracks, debonds and delamination's inside the material, there should exist a need to simulate the action of different mechanisms in order to understand the basic physics and possibly identifying the signatures of measured vibration and acoustic signals. In this work we study vibrational responses from a specimen which has different types of non-linearity's like fractures in it at different locations and understand various factors concerned with fracture location, fracture behavior and so on.

Keywords: *Dynamic analysis, Cracks, Debonds, Delamination's, Acoustic signals, Stress intensity factors.*

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).

Structural systems may be composed of homogeneous or heterogeneous materials such as composites, plastics, ceramics, fabrics and metal-alloys. Heterogeneous structures have complicated dynamics of their own in addition to numerous types of damage and failure modes (crack growth, delamination's, fiber breakage, matrix cracking, component failures), which interact in complicated

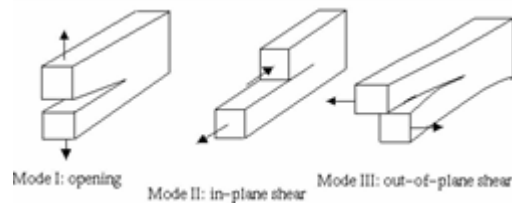
ways that vary tremendously for different initial states, levels of damage accumulation and loading history, making it very difficult to forecast their remaining useful life in operation. Though there have been abundant, relatively successful efforts to model and predict specific types of failure in complex material and structural systems, this work is directed towards the investigation of a more universal approach 'time-domain' technique can accommodate the diversity of failure modes exhibited by structures. This work is mainly concerned about time-domain plots for various types of damages in composite as well as homogeneous materials.

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.

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Fracture mechanics deals with the study of how a crack or flaw in structure 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.

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

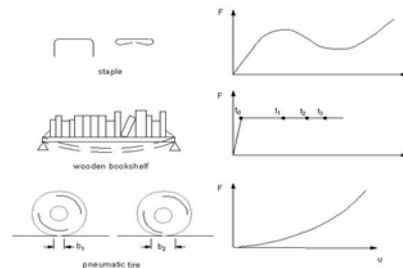


Figure No 1. Load-deflection curves for different types of structural non-linearity

LITERATURE REVIEW

During fatigue crack propagation, the crack closure is affected by material properties, environment loading and geometry of the specimen. A review of the application of these parameters is presented in this chapter.

It is well established that large stresses produced due to stress concentration at the crack tip are responsible growth. Stress intensity range (ΔK) at the crack tip is therefore a dominant parameter. Though use of ΔK is a well-established phenomenon in correlating crack growth curves, its use requires experimental determination of constant amount of empiricism. One of the main causes of

this deficiency is that derivation of ΔK solely depends upon equilibrium equation.

METHODOLOGY

In chapter 04 the work on effect of work hardening at the crack tip on crack growth and crack closure under constant (CA) loading was presented. In these studies empirical relationship describing U as a function of work hardening at the crack tip of the material was developed for five Al alloys. It was further shown that application of this model to CA loading gives a fairly good relationship between crack growth rate and work hardening exponent at the crack tip. In service, real

structures are subjected to complex variable loads and any attempt to even partly predict their fatigue life requires consideration of these loads. A large number of attempts have been made in the past for studying the effect of variable amplitude loading on fatigue crack loading on fatigue crack growth.

The various causes of the retardation during crack propagation are as follows:

1. Fatigue crack closure
2. Residual Stresses
3. Crack tip blunting and sharpening
4. Cyclic strain hardening and softening

It is difficult proposition to separate the effect of all possible mechanism described above. Fortunately it is possible to measure crack closure though with same amount of difficulty. It is therefore a factor, whose effect needs to be studied-particularly to justify and account for the correction offered by other factors.

The problem of variable amplitude loading has been attempted basically by offering modification in the stress intensity factor after overload.

The problem of fatigue retardation after overloads is a complex one and no satisfactory solution of the problems exists till date. Some factors involved in finding solution of the problem are:

- a. The effect of work hardening at crack tip on crack growth rate
- b. The effect of work hardening at crack tip on crack closure

The thesis is concerned with the effect of work hardening at the crack tip on crack opening and crack closing. We will therefore consider the effect by modifying the parameter U only.

As already described the work has been done on the five materials 3003, 5052, 6061, 6063, 6351 Al Alloys for changing the material properties of the material.

RESULTS & DISCUSSIONS

Analytical Data and Calculations

Homogeneous material is assumed as Aluminum Alloy. A small crack is modeled at a distance 0.25 m from the top and 0.5 m from the side edges. It is an elliptical shaped crack having dimensions 0.2 m major axis and 0.0001 m minor axis.

Modeling

Modeling is done using solid 82 type elements in ANSYS. To avoid the singularity near the crack tip regions this solid 82 type elements were used. Because of the elliptical shape a fine mesh is generated near crack tips. Except at the crack tips the whole model is meshed coarsely because to reduce the computer resources. Bottom extreme nodes were fixed. Finite element model of the homogeneous material with a center crack is presented below in figure 4.18.

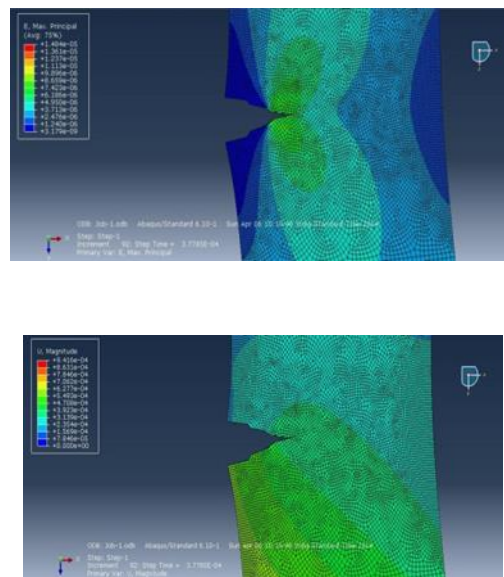


Fig (a), (b) FEM Results

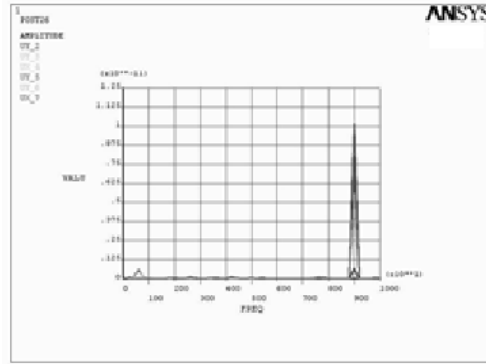


Figure - Frequency response plot between 0 Hz to 10 kHz at various points.

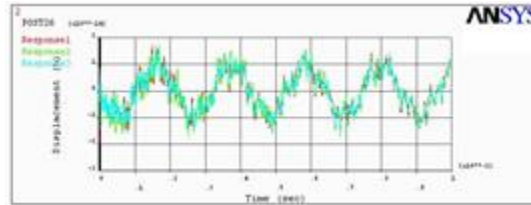


Figure- Displacement-Time plot of response points 1,2 and 3 with time range as 0 - 1×10^{-2} sec.

Modal analysis used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. Modal analysis in the ANSYS is a linear analysis. Any nonlinearity, such as plasticity and contact (gap) elements, are ignored even if they are defined.

Modal analysis is done to note the first 5 modal frequencies and tabulated below. We can observe that there is no much difference in the frequencies when compared with homogeneous model.

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.

In this work the modal analysis is done on different types of materials for finding modal frequencies which are very useful to do the frequency analysis which requires the range of frequencies in the system vibrates more (natural frequencies). After doing the frequency analysis the next step is to perform a static analysis or dynamic analysis depending on the requirement. Finding the damages in the materials is of course a very important non-destructive testing which dealt with ease here with computer simulation by using dynamic analysis. Not only finding the damages but the location of damages is always required in process, this is also done here by plotting the Displacement-Time curves for different types of materials and examining the plots by using basic formulas.

Time axis is adjusted for different values from 5×10^{-4} seconds to 0.1 seconds and the displacement response is documented for analyzing the after effects in the vibrations of different types of materials with different damage locations. It is perceived that there are many things to be noticed from those plots and further work certainly needed to distinguish the differences in each plot.

FURTHER WORK

This work leads to very appealing thoughts about dynamic analysis. This work is carried out to find the fracture location. But the type of damages range from fractures to debone and plasticity etc. Modeling debones and delaminations and doing the dynamic analysis and finding the type of damage can be done further to extend this work. Here in this work the materials used are very dirt free and hygienic i.e. apart from the fracture there are no damages in the materials, in real life situations can

be encountered with many unclear materials like concrete structures with air filled voids everywhere, steel bridges with so many cracks, this work will certainly help in those types of situations where a small part of the structure is to be examined. But doing analysis for the whole structure is often required. There are many factors concerned with fractures differs when the dynamic time plots were extended to higher time values, which is of course done here for variety of materials, but those factors should be accounted for higher studies in this perspective.

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