DAMAGE DETECTION IN COMPOSITE MATERIALS USING LAMB WAVE METHOD

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ABSTRACT: A composite material is a material which is made up of two or more constituent materials with variation in their physical or chemical properties that, when combined produce a material with different characteristics from the individual components. The individual components remain separate and distinct within the finished structure, differentiating composites from mixtures and solid solutions. Glass fiber is a material which consists of numerous extremely fine fibers of glass. In this project both E-glass and S-glass materials were analyzed by using CAE tool abacus to detect damages of each material, and calculating results like stress, displacements, for both objects with and without damage, by knowing all these results with suitable tables and graphs project can be concluded e-glass and s-glass material behavior.

Keywords: S-glass, E-glass, composite, lamb wave propagation.

1. INTRODUCTION:

The propagation of Lamb waves are in solid plates or spheres. The waves are elastic whose particle motion lies in the plane that contains the direction of wave propagation and the plane normal (the direction perpendicular to the plate). In the year 1917, the Horace Lamb is an English mathematician who published the classic analysis and description of acoustic waves of this type. Their turned out properties are to be quite complex. An infinite medium supports just two wave modes traveling at unique velocities; but plates support two infinite sets of Lamb wave modes, whose velocities which depend on the relationship between length of wave and thickness of plate.

The usage and understanding of Lamb waves has advanced greatly since 1990s, the availability of computing power is rapidly increased. Theoretical formulations of Lamb’s hadgave practical application substantially, particularly in the field of nondestructive testing.

The word Rayleigh–Lamb waves enclose the Rayleigh wave, a kind of wave which propagates on a single surface. Both Rayleigh and Lamb waves are constrained by the elastic properties of the surface(s) that guide them.

A brief review about the Lamb wave-based damage detection literature is given here:

Cesnik et al. “gave an overview of damage prognosis, description of the basic methodology of guided wave SHM, and reviewed developments from the open literature of this multidisciplinary field” [1]. Zhongqing et al. “provided a comprehensive review on the Lamb wave-based damage identification approaches for composite structures” [2]. Beadle et al. “studied the interaction of the first antisymmetric A0 mode of Lamb wave in an aluminium plate with small surface notches” [3]. Mofakhami et al. “studied the Lamb wave propagation in an aluminium plate containing a circular hole with edge notches, both theoretically and experimentally” [4]. Willberg et al. “studied the use of Lamb wave for damage detection and nondestructive evaluation” [5]. Silva et al. “studied a piezoelectric transducer network based system to be applied to aluminium and composite plates” [6]. Kessler et al. “presented the experimental and analytical survey of candidate methods for in situ damage detection of composite materials” [7]. Yamada et al. “studied the development of a new source location method using Lamb wave on anisotropic carbon fibre reinforced plastic plates” [8]. Liu et al. “studied a signal analysis method using a WT for nondestructive damage detection in the life cycle management of wind energy converters” [9]. Zabel et al. “studied wavelet analysis for applying to the numerous problems within the general field of SHM” [10]. Giurgiutiu et al. “presented the results of a systematic theoretical and experimental investigation of the fundamental aspects using PW active sensors to achieve embedded ultrasonic in thin gage beam and plate structures” [11]. Finally, Gangadharan et al. “proposed a geodesic-based approach using Lamb wave to locate a damage in an isotropic metallic plate” [12].

1.1 Lamb's characteristic equations: Generally elastic waves in strong materials are guided by the limits of the media in which they propagate. A way to deal with guided wave spread, generally utilized in physical acoustics, is to look for sinusoidal answers for the wave condition for straight versatile waves subject to limit conditions speaking to the auxiliary math. This is an exemplary eigenvalue issue.

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Waves in plates were among the main guided waves to be dissected along these lines. The examination was created and distributed in 1917 by Horace Lamb, a pioneer in the numerical material science of his day.

Lamb's conditions were inferred by setting up formalism for a strong plate having interminable degree in the x and y headings, and thickness d in the z course. Sinusoidal answers for the wave condition were hypothesized, having x- and z-directions of the structure

\[ \xi = A_\alpha f_\alpha(z)e^{i(\omega t - kx)} \]  
\[ \eta = A_\alpha f_\alpha(z)e^{i(\omega t - kx)} \]  

This structure speaks to sinusoidal waves engendering in the x heading with frequency \(2\pi/k\) and recurrence \(\omega/2\pi\). Uprooting is an element of x, z, t just; there is no dislodging in the y heading and no variety of any physical amounts in the y bearing.

The physical limit condition for the free surfaces of the plate is that the segment of worry in the z heading at \(z = \pm d/2\) is zero. Applying these two conditions to the above-formalized answers for the wave condition, a couple of trademark conditions can be found. These are:

\[ \tanh \left( \frac{\beta d}{2} \right) \tanh \left( \frac{\alpha d}{2} \right) = \frac{4 \propto \beta k^2}{(k^2 + \beta^2)^2} \]  

For symmetric modes and

\[ \tanh \left( \frac{\beta d}{2} \right) \tanh \left( \frac{\alpha d}{2} \right) = \frac{(k^2 + \beta^2)^2}{4 \propto \beta k^2} \]  

For asymmetric modes, where

\[ \alpha^2 = k^2 - \frac{w^2}{c_1^2} \quad \text{and} \quad \beta^2 = k^2 - \frac{w^2}{c_t^2} \]

Inalienable in these conditions is a connection between the precise recurrence \(\omega\) and the wave number \(k\). Mathematical techniques are utilized to discover the stage speed \(c_p = \lambda \omega / k\), and the gathering speed \(c_g = d\omega / dk\), as elements of \(d/\lambda\) or \(fd\). \(c_1\) and \(c_t\) are the longitudinal wave and shear wave speeds separately.

The arrangement of these conditions additionally uncovers the exact type of the molecule movement, which conditions (1) and (2) speak to in conventional structure as it were. It is discovered that condition (3) offers ascend to a group of waves whose movement is balanced about the midplane of the plate (the plane \(z = 0\)), while condition (4) offers ascend to a group of waves whose movement is antisymmetric about the midplane. Figure 1 delineates an individual from every family.

2. MATERIALS:
The material used for our project are Glass fiber. It is a material comprising of various amazingly fine filaments of glass. Glassmakers from the beginning of time have explored different avenues regarding glass strands, however mass assembling of glass fiber was just made conceivable with the innovation of better machine tooling.

| MATERIAL     | S-glass  | E-glass  |
|--------------|----------|----------|
| Young’s modulus | 86e9 Pa  | 72e9 Pa  |
| Poisson’s ratio  | 0.21     | 0.21     |
| Density        | 2485 kg/m³ | 2550 kg/m³ |

3. METHODOLOGY: The following Steps used in methodology:
- Pre-processing or modeling: In modeling it creates an input file which contains a proper design for a finite-element analyzer (it is also known as "solver").
• Processing or finite element analysis: In finite element analysis it gives a visual file as output.
• Post-processing or producing report, picture, animation, and etc., from the system as output file: In post processing it can visualize the analysis results approximately.

4. CAE Modeling:
The modelling of the material done in ABAQUS Software according to the requirements.

4.1 Meshing:
Now to create sensor and exciter here we need to divide complete object into small parts, to do this here partition option were used, to do partition either there should be plane or axis should have, and here planes were chosen and created in “XY” plane direction with a distance of 10mm and repeated this process in all 4 directions at a distance of 10mm from edge.

5. RESULTS AND DISCUSSION:
5.1 Without crack result of S-glass.
Displacement vs time graphs in U1, U2 and U3 directions

**Figure 7:** Displacement vs time in U1 direction.

**Figure 8:** Displacement vs time in U2 direction.

**Figure 9:** Displacement vs time in U3 direction

**Figure 10:** Strain energy vs time.

5.2 Without crack result of E-glass.

**Figure 11:** Von misses stress.

**Figure 12:** Equivalent pressure stress.
Displacement vs time graphs in U1, U2 and U3 directions

Figure 13: Displacement vs time in U1 direction.

Figure 14: Displacement vs time in U2 direction.

Figure 15: Displacement vs time in U3 direction.

Figure 16: Strain energy vs time.

Discussion: The above results are of S and E glass without crack materials. Both the materials have different properties, based on their properties the results are obtained. Through FE simulation it is found to be good and there is no damage in the material. The below graphs are plotted by comparing the results like von misses stress, pressure stress, displacement in U1, U2 and U3 directions. Comparing both the results S-glass has less stress values and E-glass has more stress values which shown in below graphs.

Graphs: Below graphs are for both S-glass and E-glass of without crack plate

Figure 17: Von misses stress.

Figure 18: Pressure stress.
5.3 Lamb wave propagation with crack result of S-glass.

Figure 19: Total Displacement.

Figure 20: Displacement in U1

Figure 21: Displacement in U2

Figure 22: Displacement in U3

Figure 23: Von misses stress.

Figure 24: Equivalent pressure stress.
Displacement vs time graphs in U1, U2 and U3 directions

Figure 25: Displacement vs time in U1 direction.

Figure 26: Displacement vs time in U2 direction.

Figure 27: Displacement vs time in U3 direction.

Figure 28: Strain Energy vs time

5.4 Lamb wave propagation with crack results of E-glass.

Figure 29: Von misses stress.

Figure 30: Equivalent pressure stress.
Displacement vs time graphs in U1, U2 and U3 directions

**Figure 31:** Displacement vs time in U1 direction.

**Figure 32:** Displacement vs time in U2 direction.

**Figure 33:** Displacement vs time in U3 direction.

**Figure 34:** Strain Energy vs time.

**Discussion:** The above results are of S and E glass with crack material. Both the glasses have different properties, based on their properties the results are obtained. Through FE simulation it is found to be known that the damage occurred in the material. Below graphs are plotted by comparing the results like von misses stress, pressure stress, displacement in U1, U2 and U3 directions. The stress value in S-glass has high and E-glass has less which compare to without crack, which leads to be known that there is a damage in the material.

**Graphs:** Below graphs are for both S-glass and E-glass of with crack plate.

**Figure 35:** Von misses stress

**Figure 36:** Pressure stress
6. CONCLUSIONS:

In this article calculating displacement and stress values for e-glass and s-glass materials by using lamb wave method with the help of CAE tool ABAQUS, in this process it is observe that S glass has less stress values on the plate, and high displacement results compare to E glass materials,

From the results of both models here it is observe that the strain energy value is increasing while increasing time period and it has maximum value at 0.08e-3 time period, similarly it has maximum displacement value at 0.08e-3 time period.

If there is any damage on material, the stress values will increases for both materials, compare to without crack object, and the displacement of each material will be decreases, among 2 materials, e-glass material is having less stress values with and without crack when compare to s-glass material, it shows the results as, less stress can increases the object performance in durability, and their fatigue conditions.
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