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Stress Analysis of Composite Material using ANSYS

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***Abstract*—The development of composite materials and related design and manufacturing technologies is one of the most important advances in the history of materials. Composites are multi-functional materials having unprecedented mechanical and physical properties that can be tailored to meet the requirements of a particular application. Composites technology also makes possible the use of an entire class of solid materials, ceramics, in applications for which monolithic versions are unsuited. Steel-reinforced concrete is the most wieldy used building materials and for other applications in the world. There are number of composite materials used for various applications out of which bamboo as a composite material is significant. In this paper, the stress analysis of composite material as steel-brass-steel with and without crack is presented by using ANSYS. The stress acting on composite material with crack was found to be 10.305 times higher than without crack. Also, various testing results of mechanical properties of bamboo material reported by earlier investigators are discussed.**

Keywords— Composite material, crack, bamboo, stress.

I. INTRODUCTION

Composite materials are formed by combining material together to form an overall structure that is better than the sum of the individual components. It is material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different [1]. Each material retains its separate chemical, physical, and mechanical properties. The main advantages of composite materials are their ability to tailor the lay up for optimum strength and stiffness, excellent resistance to fatigue, corrosion resistance combined with low density as compared with bulk materials [2].

Strength and stiffness is provided by reinforcement phase. The reinforcement is harder, stronger, and stiffer than the matrix. In most of the cases, the reinforcement is usually a fiber or a particulate. Continuous fibre composites are much more superior to particulate composites which are weaker and less stiff; still they are usually much less expensive. As far as reinforcement is to be considered, Particulate reinforced composites shows low value of fibers (up to 40 to 50 volume per cent). This is attributable to processing difficulties and brittleness.

Composites are important materials that are now used widely such as internal combustion engines, thermal control, connecting rod, machine components, rubber products, polymer matrix composites and light weight packaging materials, automobile sector, train, aircraft structures and mechanical components. Some of the biomedical applications such as tissue engineering, implants e.g. dental implants, bone transplants are finding large use of composite type of materials.

Dental implants and 3D printing is one of the areas where composite technology is being implemented across the globe and India is just recently entered into this market. Usual implants find it difficult for the patient to suit as materials are not biocompatible. Recent trend in this area is to go with biocompatible materials while simultaneously maintaining strength of supporting structure to enhance the life of implants [2].

Bamboo is a naturally occurring composite material which grows abundantly in world wide. It is a type of grass that is the largest in the world which matures in the period of five years [3]. Bamboo is an important structural material, grown in many parts of the world. Being very fast growing it provides a renewable resource which is extensively employed in construction work and other load-bearing applications [4].

Bamboo is fast growing plant that has the potential not only to replace wood for certain applications but also to replace non-environmentally friendly and non-recyclable raw materials such as fiber glass and polyurethane. Bamboo shows high tensile strength, flexural strength, impact strength, specific gravity. Bamboo as a composite material used in building construction, bridge construction, automotive, domestic industries, packaging [6].

II. STRUCTURE OF COMPOSITE MATERIALS

A composite material consists of two or more components. The components have different mechanical properties. There are the following types of composite structures shown in figure 1:

A. Particle reinforced composites.
B. Composites with chopped strands.
C. Uniaxial composites.
D. Composite laminates.
E. Plastics with fiber reinforcement

F. Composite structure of honeycomb type
G. Composite structure of bamboo

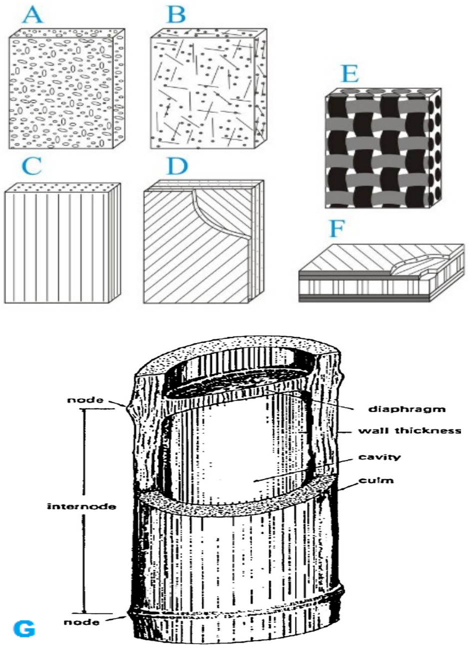


Fig. 1 Different Types of composites structure [1, 6]

A) Particle reinforced composite

I. Large particle composite: The particle in these composites is larger than in dispersion strengthened composites, the particles carry major portion of the load.

II. Dispersion strengthened composites: In this small particle of the order of 10 to 100 nm in diameter are added to the matrix particle with make the composite harder and stronger.

B) Composites with chopped strands:

Chopped strands mat is widely used traditional reinforcement solution, CSM is produced by chopping continuous strand are roving into short 1.5 -3-inch length and dispersing the cut fibers randomly over a moving belt to form a “sheet” of random fiber mat.

C) Uniaxial composites:

In this composite fiber are uniformly spaced in suitable matrix phase. In this tensile stress is directed parallel to fibers.

D) Composite laminates:

A laminar composite consist of two –dimensional sheets or panel that have preferred high strength direction as is found in wood and continues and aligned fiber reinforced plastic. e.g. plywood.

E) Plastics with fiber reinforcement:

Fiber reinforcement composite involve three components namely filaments, polymer matrix and a bonding agent, such composite possess high specific strength and high specific modules stiffness and lower overall density.

F) Composite structure of honeycomb type

This type of sandwich panel usually consist of two strong outer sheets called “faces”, separated by a layer of less dense material called “core”. A popular type of core material comprises of a “honeycomb” structures.

III. FRACTURE MECHANICS

Crack nucleation and micro crack formation may be caused by transient load swings. It may be higher than expected periodic loads or defective component materials in different components. Periodic loads cause fatigue and accelerate the cracks in materials like composite, plastics, ceramics, fabrics and metal alloys. Cracks occur in many different types of material and geometries. It causes damages in different type of mechanism or different part of equipment. Crack size depends upon on material toughness. Stress levels are determined. Material damages lead to non –linear behaviour [7].

In presence of sub surface or internal cracks failure starts at stresses much lower than those compared to stress levels without crack. Magnification of the applied stress results at the crack tip. This is due to theoretically zero area around crack tip. Drama is different for a ductile material, as in presence of higher stress it can deform locally; changing the profile of the crack tip thereby intensity of stress gets reduced. The crack will propagate with little deformation through the stressed region for brittle material. Around the crack, through the specimen the small scale plastic region will propagate.

Separation of solid, mechanically due to presence of stress can be termed as fracture. They are categorized as ductile or brittle fracture. Brittle fractures absorb little energy, while ductile fractures absorb more energy, and former are generally known for fracture with flat surfaces. The amount of energy required to create fracture surfaces determines fracture toughness, through relations. Intrinsic surface energy of the material determines energy required for fracture of brittle materials explained by Griffith. Whenever plastic deformation is more in the fracture, it involves more consumption of energy in that part. This is well applicable to structural alloys at room temperature. The application of fracture mechanics concepts has identified and quantified the primary parameters that affect structural integrity. The parameters such as magnitude and range of the applied stresses, orientation of cracks, crack like defects, size, shape, the fracture toughness of the material, rate of propagation of the existing cracks are being identified and quantified through fracture mechanics concepts.

Fracture mechanics is classified as:

(a)Linear Elastic Fracture Mechanics (LEFM) and

(b) Elastic-Plastic Fracture Mechanics (EPFM).

For The Linear Elastic Fracture Mechanics (LEFM) approach to fracture analysis, except for a small region of inelastic deformation at the crack tip, material behaves elastically at regions away from the crack. K, the stress- intensification factor, and strain energy release rate G are some terms which determines fracture resistance. The basic material property is energy released during rapid crack propagation. According to ASTM the stress intensity factor K can be written as

$$K_I = \sigma\sqrt{\pi \ a \ f(g)}$$

Where 'a' is the initial crack length, 'f (g)' is the dimensionless factor for the specimen geometry and loading condition and the K_I, the Mode I critical stress intensity factor. The specimen size must be chosen such that there is small scale plasticity around the crack tip. If ahead of the crack tip, a large plastic zone develops then LEFM theory is not applicable for such problem. One of the underlying principles of fracture mechanics is that the unstable fracture occurs for critical stress intensity factor K_c.

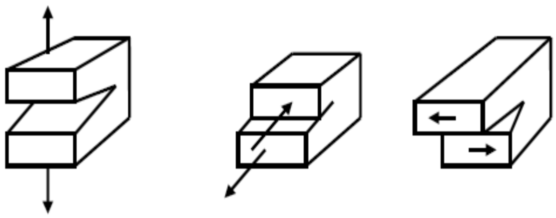
With greater value of fracture toughness more energy will be required for prorogation of fracture, hence higher value of stress will be required to do this task and this leads to the greater resistance of the material to brittle fracture. The critical stress intensity factor is determined using relatively simple laboratory specimen, the limiting value being K_{IC} / K_{IIC} / K_{IIIC}. The Elastic-Plastic fracture mechanics is used when there is large scale crack tip plasticity (blunting).

IV MODES OF FRACTURE

There are three types of failure modes. Firstly, the forces are perpendicular to the crack. In this situation, crack is horizontal and the forces are vertical. Secondly, the forces are parallel to crack. Finally, the forces are perpendicular to the crack. In this case, the crack is in front-back direction and the forces are pulling left and right. Loading modes are shown in Figure 4,

Mode I: Opening or tensile mode,
Mode II: Sliding or shear mode, and
Mode III: Tearing mode.

Fracture mechanics concepts won't change from mode to mode. Cracking in metals are summarised under mode I problem. In early stage of development, crack will turn into a direction in which it withstands. Only restriction here is geometric confinement only. For this reason, fracture mechanics of metal is generally confined to Mode I.



I-Tensile mode   II-Sliding mode   III-Tearing mode

Fig. 2 Different Modes of the Fatigue life [7].

V. ANALYSIS OF COMPOSITE MATERIAL

A steel, brass and steel combination has been used here as it is representing perfect example of most of the application requirement. Secondly, it more or less represents suitable candidature of large class of composites. Steel is having sufficient strength while brass is ductile allowing perfect redistribution of stress and avoid stress jumps in the structure. Sudden fractures will be avoided due to presence of such fantastic combination. Crack growth may be suppressed due to this. Therefore, this type of combination is considered here.

A) COMPOSITE DELAMINATES WITHOUT CRACK:

TABLE : 1. SPECIFICATION OF COMPOSITE STRUCTURE (WITHOUT CRACK).

Parameters	Description
No of layers	3
Dimensions of layers	3 mm each
Thickness	10 mm
Modulus of Elasticity of Material	E_s = 200GPa and E_b = 83GPa
Material of Layers	Steel, Brass, steel (according to sequence of layers)
Load Applied	On Steel layer (3rd Position)
Magnitude and direction of load	350N and horizontally towards right
Element Type	Single line element

The model (without crack) has been drawn by using Solid Work. The sequence of layer as follows (steel –brass-steel).

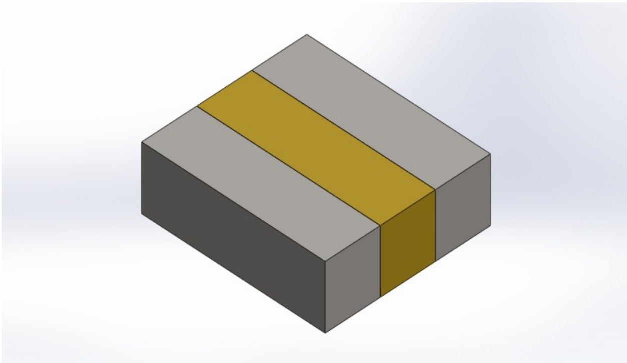


Fig.3 Model of Composite Material (without crack).

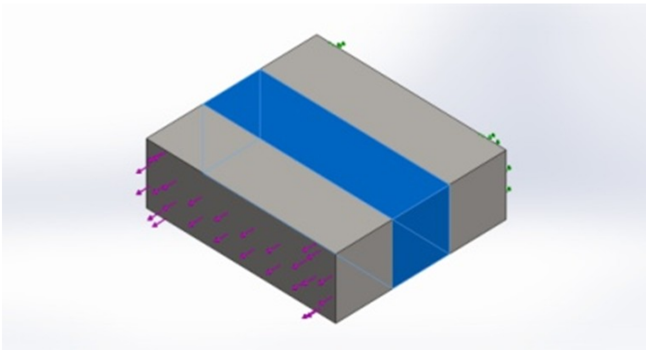


Fig. 4 loading and Boundary Condition (without crack).

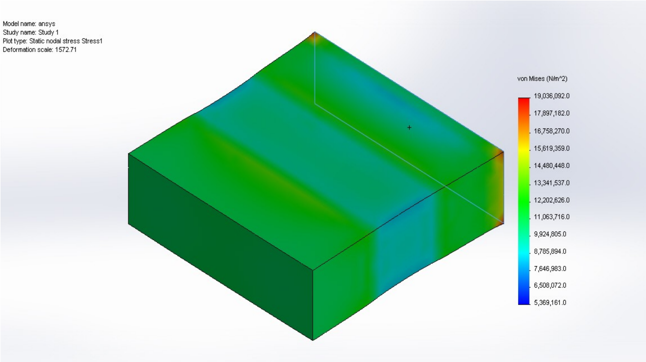


Fig. 5 Von Mises Stress Distribution (without crack).

The above figure 5 indicates the Maximum stress value is $1.90361e^{+007}N/m^2$ and the minimum stress value is $5.36916\ e^{+006}N/m^2$.

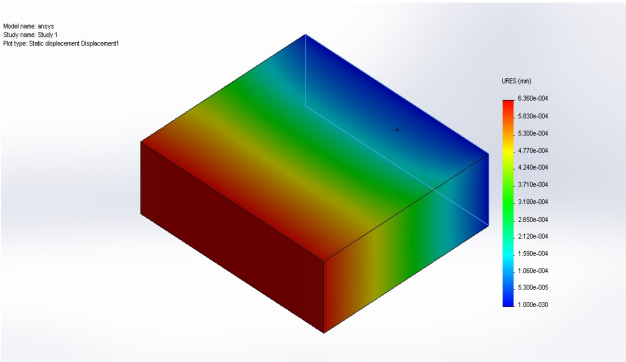


Fig. 6 Resultant Displacement (without crack).

The above figure 6 indicates the maximum displacement is 0.000635992 and minimum displacement is zero.

B) COMPOSITE DELAMINATES WITH CRACK:

TABLE : 2. SPECIFICATION OF COMPOSITE STRUCTURE (WITH CRACK) .

Parameters	Description
No of layers	3
Dimensions of layers	3mm each
Thickness	10mm
Crack Position	At 1.45mm away on middle brass layer
Modulus of Elasticity of Material	E_s = 200GPa and E_b = 83GPa
Material of Layers	Steel, Brass, steel (according to sequence of layers)
Load Applied	On Steel layer (3^{rd} Position)
Magnitude and direction of load	350N and horizontally towards right
Element Type	Single line element

The model (with crack) has been drawn by using Solid Work, the sequence of layer as follows (steel –brass-steel), position of crack on the middle brass layer.

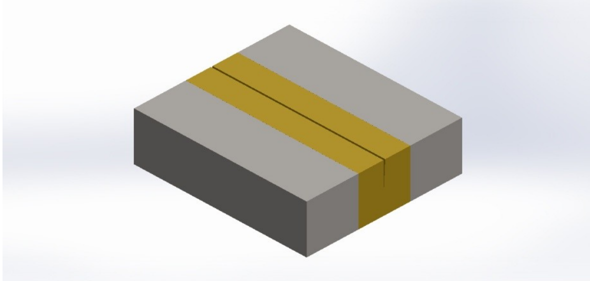


Fig. 7 Model of Composite Material (with crack)

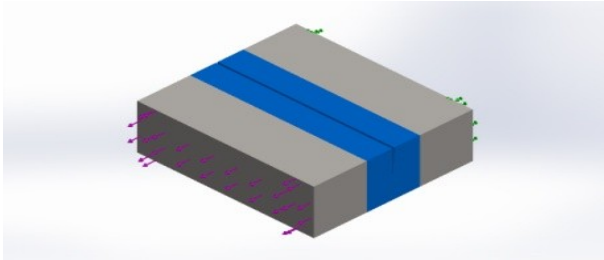


Fig.8 Loading and Boundary Condition (with crack).

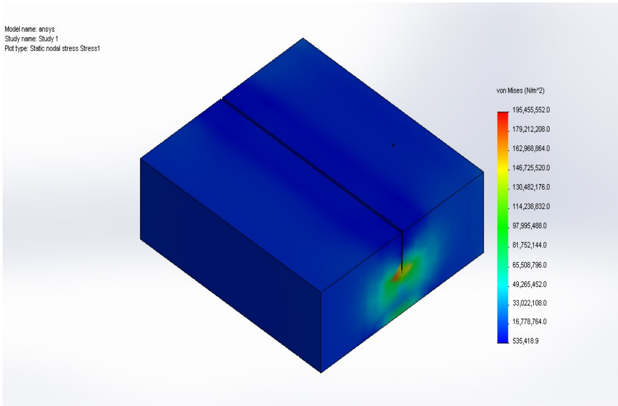


Fig. 9 Von Mises Stress Distribution (with crack).

The above figure 9 indicates the Maximum stress value is $1.95456e^{+008}N/m^2$ and the minimum stress value is $535419N/m^2$.

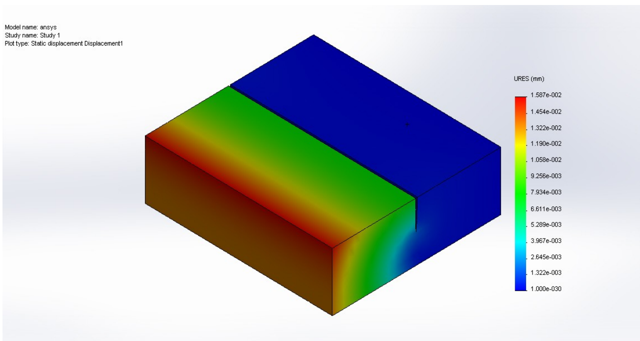


Fig. 10 Resultant Displacement (with crack).

The figure 10 indicates the maximum displacement is 0.0158672 and minimum displacement is zero.

VI. RESULTS AND DISCUSSION

The following table 3 shows the comparison of results of a studied composite material (Steel-Brass-Steel) with and without crack.

TABLE: 3. COMPARISION OF RESULTS WITH & WITHOUT CRACK.

Parameters	Analysis	
	Without Crack	With Crack
Max. stress	$1.90361e^{+007} N/m^2$	$1.95456e^{+008} N/m^2$
Min. stress	$5 .36916e^{+006} N/m^2$	$5.35419e^{+005} N/m^2$
Max. displacement	0.000635992 mm	0.0158672 mm
Min. displacement	0	0

Tests were carried out to detect and compare the mechanical strength properties of bamboo with other two materials steel and spruce wood, from the literature. These are shown in the below table 4.

TABLE: 4. THE STRENGTH RESULTS OBTAINED AFTER WOOD, BAMBOO, STEEL MATERIALS WERE TESTED [3].

	Materials Spruce wood (KN/cm^2)	Bamboo (KN/cm^2)	Steel (KN/cm^2)
Elastic modulus	1100	2000	2100
Compressive Strength	4.3	6.2-9.3	14
Tension Strength	8.9	14.8crac	16
Bending Strength	6.8	7.6-27.6	14
Shearing Strength	0.7	2.0	9.2

VII. CONCLUSION

The comparison of stress analysis for composite material with and without crack was carried out using ANSYS. The results showed that the stress induced with crack is 10 times higher than stress induced without crack. This happens due to reduction in resistance area in case of composite material having crack. Hence, the presence of crack in the material reduces strength of the base material which is significant from design point of view.

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