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CRACK ANALYSIS OF COMPOSITE LAMINATE

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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. Many composites also exhibit great resistance to high-temperature corrosion and oxidation and wear. These unique characteristics provide the mechanical engineer with design opportunities not possible with conventional monolithic (unreinforced) materials.Composites technology also makes possiblethe use of an entire class of solid materials, ceramics, in applications for which monolithicversions are unsuited because of their great strength scatter and poor resistance to mechanicaland thermal shock. Further, many manufacturing processes for composites are well adaptedto the fabrication of large, complex structures, which allows consolidation of parts, reducingmanufacturing costs. In this paper, it is shown that by using compostite material, there is less stress acting on material and if there are surface irregularities or defect present in the material, more stress acting on that defected area which result in failure of material.

KEYWORDS:Composite material, crack, delamination

INTRODUCTION

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components used alone. In contrast to metallic alloys, each material retains its separate chemical, physical, and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part.
The reinforcing phase provides the strength and stiffness. In most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions that are approximately equal in all directions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness.

Composites are important materials that are now used widely, not only in the aerospace industry, but also in a large and increasing number of commercial mechanical engineering applications, such as internal combustion engines; machine components; thermal control and electronic packaging; automobile, train, and aircraft structures and mechanical components, such as brakes, drive shafts, flywheels, tanks, and pressure vessels; dimensionally stable components; process industries equipment requiring resistance to high-temperature corrosion, oxidation, and wear; offshore and onshore oil exploration and production; marine structures; sports and leisure equipment; and biomedical devices.

It should be noted that biological structural materials occurring in nature are typically some type of composite. Common examples are wood, bamboo, bone, teeth, and shell.
Further, use of artificial composite materials is not new. Straw-reinforced mud bricks were employed in biblical times. Using modern terminology, discussed later, this material would-be classified as an organic fiber-reinforced ceramic matrix compositeComposites belong to a new class of materials developed that are strong, have low densities, and not easily corroded. Polymer matrix composites can be processed to get higher mechanical strength

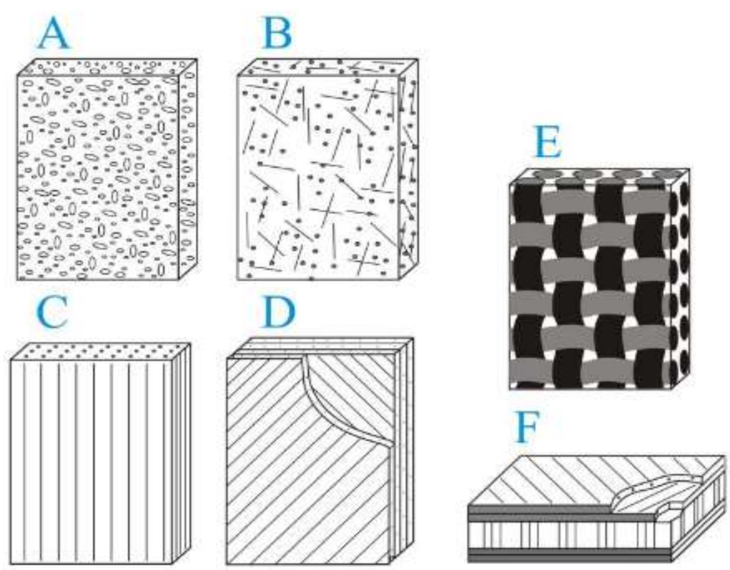
and other desired properties. Composite materials are heterogeneous in composition and an-isotropic in mechanical behavior. Polymer composites have emerged as important structural engineering materials in automotive, marine, aerospace, transportation, infrastructure applications and as well as in civil engineering applications, because of their high strength to weight ratio. Compared to metals, fracture toughness characterization of composite materials are still in the process of development. The 'composites' concept is not a human invention. Wood is a natural composite material consisting of one species of polymer cellulose fibers with good strength and stiffness in a resinous matrix of another polymer, the polysaccharide lignin. Nature makes a much better job of design and manufacturethan we do, although Man was able to recognize that the way of overcoming two major disadvantages of natural wood that of size (a tree has a limited transverse dimension), and that of anisotropy (properties are markedly different in the axial and radial directions) was to make the composite material that we call plywood. Bone, teeth and mollusk shells are other natural composites, combining hard ceramic reinforcing phases in natural organic polymer matrices. Man was aware, even from the earliest times, of the concept that combining materials could be advantageous, and the down-to-earth procedures of wattle-and-daub (mud and straw) and 'pide' (heather incorporated in hard-rammed earth) building construction, still in use today, pre-date the use of reinforced concrete by the Romans which foreshadowed the pre-tensioned and post-tensioned reinforced concretes of our own era. But it is only in the last half century that the science and technology of composite materials have developed to provide the engineer with a novel class of materials and the necessary tools to enable him to use them advantageously.

STRUCTURE OF COMPOSITES

A composite material consists of two or more components. The components have different mechanical properties. There are the following types of composites:

A. composites reinforced by particles;
B. composites reinforced by chopped strands;
C. unidirectional composites;
D. laminates;
E. fabric reinforced plastics;
F. honeycomb composite structure

Figure:



Types of composite materials

CRACK THEORY

Engineering structures are designed to withstand the loads they are expected to be subject to while in service. Large stress concentrations are avoided, and a reasonable margin of security is taken to ensure that values close to the

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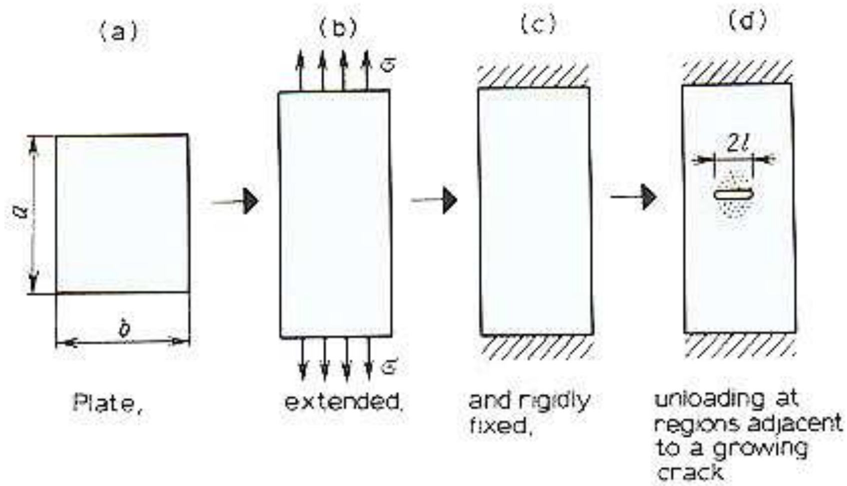
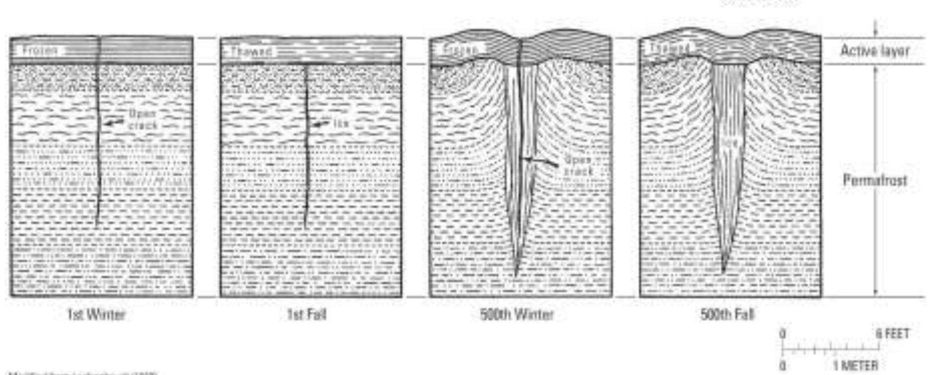
maximum admissible stress are never attained. However, material imperfections which arise at the time of production or usage of the material are unavoidable, and hence must be taken into account. Indeed even microscopic flaws may cause structures which are assumed to be safe to fail, asthey grow over time.In the past, when a component of some structure exhibited a crack, it waseitherrepaired or simply retired from service. Such precautions are nowadays in many cases deemed unnecessary, not possible to enforce, or may prove too costly. In fact, on one hand, the safety margins assigned to structures have to be smaller, due to increasing demands for energy and material conservation. On the other hand, the detection of a flaw in a structure doesnot automatically mean that it is not safe to use anymore. This is particularly relevant in the case of expensive materials or components of structureswhose usage it would be inconvenient to interrupt.In this setting fracture mechanics plays a central role, as it provides usefultools which allow for an analysis of materials which exhibit cracks. The goalis to predict weather and in which manner failure might occur.Historically, in the western world, the origins of this branch of science seem to go back to the days of Leonardo da Vinci (15th-16thcenturies). According to some authors records show that the renowned scientist underwent the study of fracture strength of materials, using a device described on theCodexAtlanticus.He looked into the variation of failure strength indifferent lengths of iron wire of the same diameter. The conclusion was thatshort wires, with less probability of containing a defect, were apparently stronger than long wires. Centuries later, at the time of the First World War, the English aeronautical engineer Alan Griffith was able to theorize on the failure of brittle materials. He used a thermodynamic approach to analyze the centrally cracked glass plate present in an earlier work of Ingles. Note that Griffith'stheory is strictly restricted to elastic brittle materials like glass, in which virtually no plastic deformation near the tip of the crack occurs. However, extensions which account for such a deformation and further extend this theory have been suggested, for example in. In this work, we shall focus on the brittle fracture of elastic materials. Forthat we will perform a numerical analysis of a cracked plate in a plane stress situation. This requires three distinct problems to be solved. Firstly, numerical methods to determine the stress and displacement fields around the crack must be available. The second problem consists of the numerical computation of thefractureparameters,such as the stress intensity factors,the J integral, the energy release rate or another. Finally one needs to decideon criteria to determine under which conditions the crackwill propagate, as well as the direction of propagation.





ENGINEERING APPROACH TO THE FATIGUE PROBLEM

From the engineering point of view there are traditionally two ways to approach the fatigue design problem. The first and the oldest approach is the safe-life design methodology. Thismethodology is based on the assumption of no existing flaws in the component/structure andno distinction is made between initiation and propagation of the fatigue crack. Furthermore,the stress amplitude and mean stress level are chosen such that the fatigue life (number ofcycles to failure) is either finite or infinite based on the knowledge of the material fatigueproperties and other significant factors. In order to maintain the design safety when thedesign life is used, the component is replaced with a new one, even though a considerably large part of the functional life may remain. Another assumption is that no inspections of the component/structure needs to made during the design life.

Traditionally, because of the observed large scatter in the fatigue life, safety factors are included. These reduce the allowed load level, or instead of reducing the load level, increase the dimensions of the component/structure. However, safety factors are hard to interpretfrom reliability and a durability point of view. A better approach, allowing for an easier interpretation of the component/structural reliability, is to use statistical methods to judgethe probability of survival. From a historical point of view the inherent scatter in the fatiguelife was observed as early as in 1860, which also is the time around which the safe-life design methodology originates. However, the scatter was first treated on a scientific level around 1945. From the engineering point of view the use of statistical methods has still not penetratedsome branches of the mechanical industry. For a comprehensive historical review on fatigue see for instance.

The second approach is called damage-tolerant design. Here it is assumed that initialcracks exist in the component/structure and periodical inspections for the presence of theseneeds to be performed in order to maintain the reliability. The size of the assumed initialcrack is connected to the largest crack size that may be missed during an inspection, whichin turn is set by the detection limit of the non-destructive technique used for the inspection.
The design life of the component/structure then becomes the number of in-service fatigueload cycles required for the initial crack to grow to a critical size. The damage-tolerant methodology consequently focuses on predictions of the fatigue crack growth rate and theremaining fatigue life whereas the safe-life design methodology focuses on estimating thetotal life. Thus, estimations of the remaining fatigue life of a flawed component/structureis only possible through use of the damage-tolerant approach. The strive for increasing theaccuracy and the precision of the estimated fatigue crack growth rate is driven by cuttingcosts by increasing the inspection length interval since inspections are expensive (downtimeof the industrial process) while maintaining the safety requirements.

FRACTURE MECHANICS

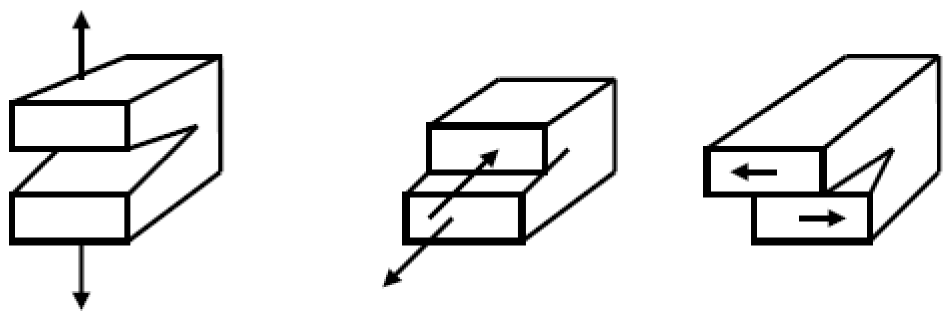
Tensile test results apply to material that does not contain cracks or stress concentrators, such as brittle inclusions. When crack like defects are present either as surface cracks or internal ones, failure may begin at much lower applied stresses. The applied stress is greatly magnified at the crack tip due to zero area (theoretically). For a ductile material, it can deform locally when the stress is high, blunting the crack tip reducing the intensity of stress. For brittle material, the crack will propagate through the stressed region with little deformation. The small scale plastic region around the crack will continue to propagate across the specimen. Fracture may be defined as the mechanical separation of a solid owing to the application of stress. Fractures of engineering material are categorized as ductile or brittle fractures. Ductile fractures absorb more energy, while brittle fractures absorb little energy, and are generally characterized by fracture with flat surfaces. Fracture toughness is related to the amount of energy required to create fracture surfaces. In brittle materials such as glass the energy required for fracture is simply the intrinsic surface energy of the material, as demonstrated by Griffith. For structural alloys at room temperature considerably energy is required for fracture because plastic deformation accompanies the fracture process. The application of fracture mechanics concepts has identified and quantified the primary parameters that affect structural integrity. These parameters include the magnitude and range of the applied stresses, the size, shape, orientation of cracks / crack like defects, rate of propagation of the existing cracks and the fracture toughness of the material. Two categories of fracture mechanics are Linear Elastic Fracture Mechanics (LEFM) and Elastic-Plastic Fracture Mechanics (EPFM). The Linear Elastic Fracture Mechanics (LEFM) approach to fracture analysis assumes that the material behaves elastically at regions away from the crack, except for a small region of inelastic deformation at the crack tip. The fracture resistance is determined in terms of the stress- intensification factor, K and strain energy release rate G. The energy released during rapid crack propagation is a basic material property and is not influenced by part size. 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 KI, 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 a large plastic zone develops ahead of the crack tip then the condition of "small scale is yielding" for LEFM applicability are not met. One of the underlying principles of fracture mechanics is that the unstable fracture occurs when the stress intensity factor at the crack tip reaches a critical value, K_C. The greater the value of fracture toughness, the higher the intensity of stress required to produce crack propagation and the greater the 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).

MODES OF FRACTURE

Figure defines the three modes of loading, Mode I, opening or tensile mode, Mode II, sliding or shear mode, and Mode III, tearing mode. Fracture mechanics concepts are essentially the same for each mode. However the great majority of all actual cracking and fractures cases in metals are mode I problems. A crack in the very early stage of development will turn into a direction in which it experiences only Mode I loading, unless it is prevented from doing so by geometrical confinement. For this reason fracture mechanics of metal is generally confined to Mode I.



Tensile Sliding shear ***Tearing shear***

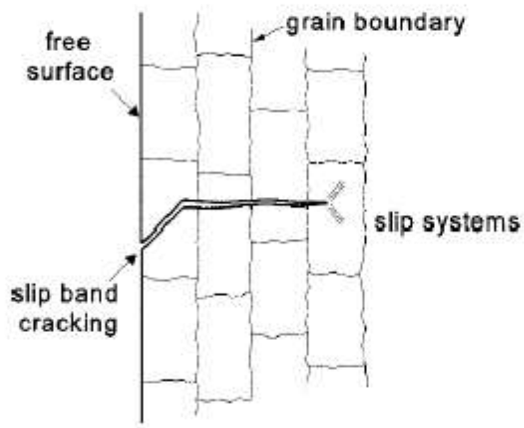
CRACK GROWTH

As long as the size of the micro crack is still in the order of a single grain, the micro crack is obviously present in an elastically anisotropic material with a crystalline structure and a number of different slip systems. The micro crack contributes to an inhomogeneous stress distribution on a micro level, with a stress concentration at the tip of the micro crack. As a result, more than one slip system may be activated. Moreover, if the crack is growing into the material in some adjacent grains, the constraint on slip displacements will increase due to the presence of the neighbouring grains. Similarly, it will become increasingly difficult to accommodate the slip displacements by slip on one slip plane only. It should occur on more slip planes. The micro crack growth direction will then deviate from the initial slip band orientation. In general, there is a tendency to grow perpendicular to the loading direction, see Figure. Because micro crack growth is depending on cyclic plasticity, barriers to slip can imply a threshold for crack growth. This has been observed indeed. The crack growth rate measured as the crack length increment per cycle decreased when the crack tip approached the first grain boundary. After penetrating through the grain boundary the crack growth rate increased during growth into the next grain, but it decreased again when approaching the second grain boundary.

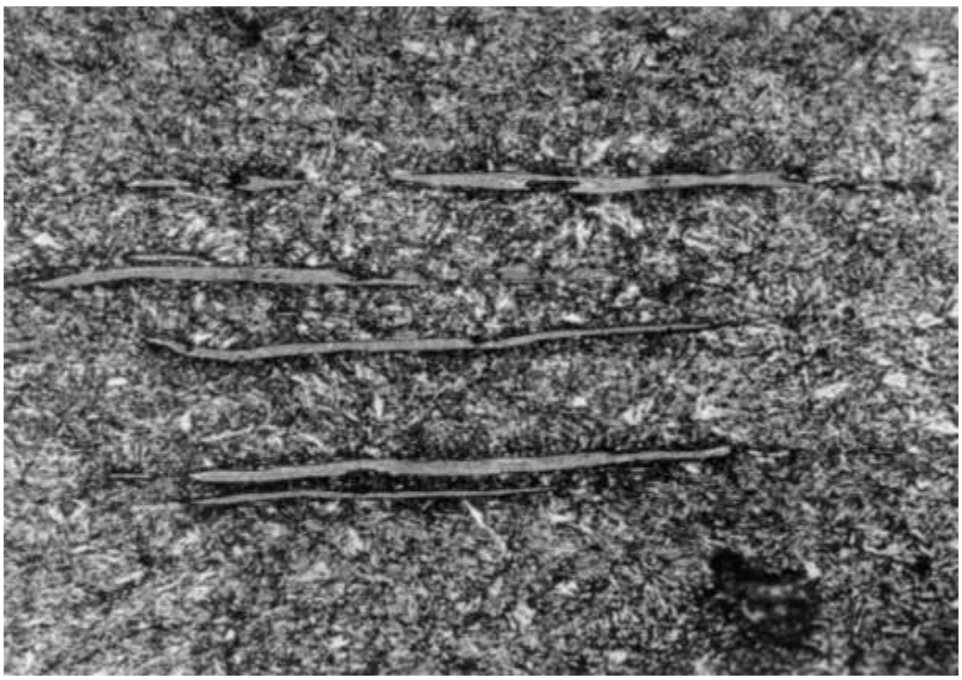
After passing that grain boundary, the micro crack continued to grow with a steadily increasing rate.

In the literature, several observations are reported on initially inhomogeneous micro crack growth, which starts with a relatively high crack growth rate and then slows down or even stops due to material structural barriers. However, the picture becomes different if the crack front after some crack growth passes through a substantial number of

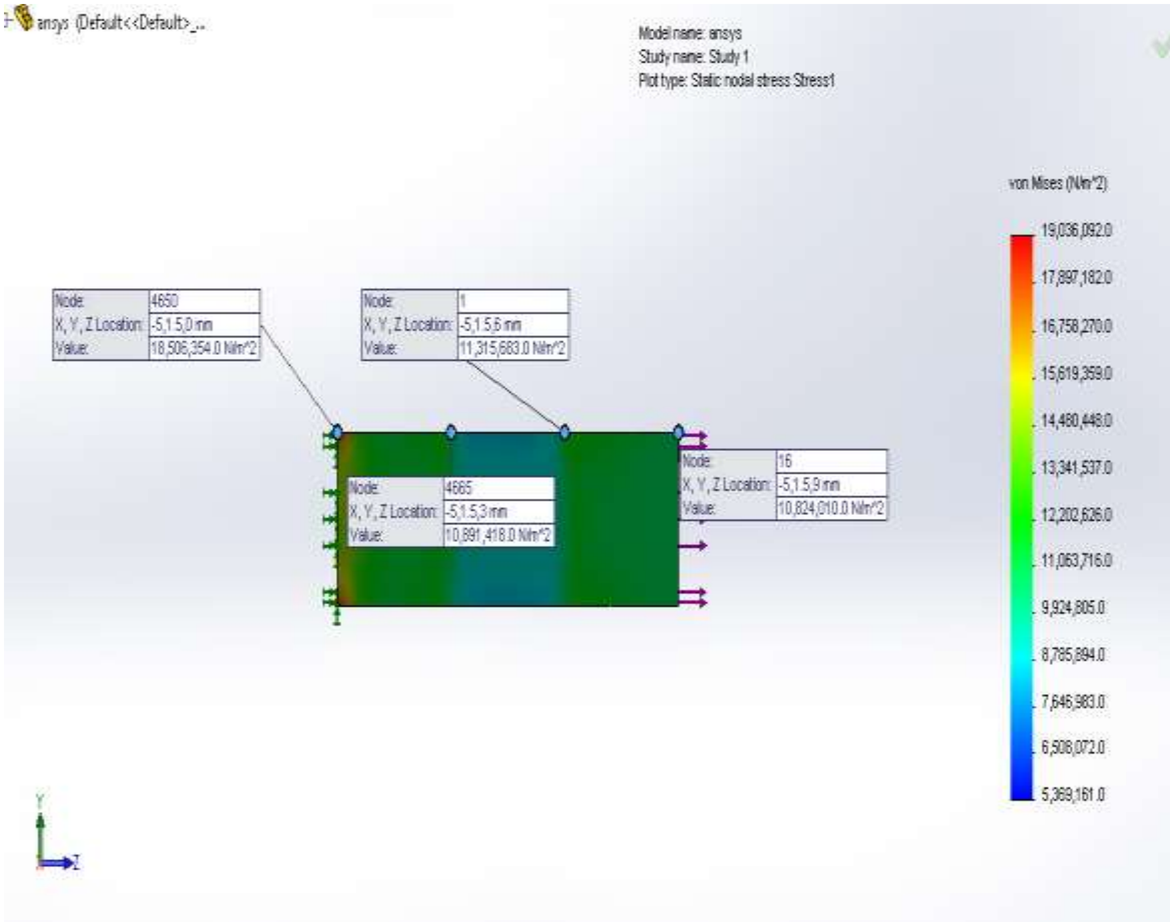
grains. Because the crack front must remain a coherent crack front, the crack cannot grow in each grain in an arbitrary direction and at any growth rate independent of crack growth in the adjacent grains.
This continuity prevents large gradients of the crack growth rate along the crack front. As soon as the number of grains along the crack front becomes sufficiently large, crack growth occurs as a more or less continuous process along the entire crack front. The crack front can be approximated by a continuous line, which could have a semi-elliptical shape. How fast the crack will grow depends on the crack growth resistance of the material. Two important surface aspects are no longer relevant. The lower restraint on cyclic slip at the surface is not applicable at the interior of the material. Secondly, surface roughness and other surface conditions do not affect crack growth.



Cross section of micro crack.



Crack growth resistance when the crack penetrates into the material depends on the material as a bulk property. Crack growth is no longer a surface phenomenon.



ANALYSIS OF COMPOSITE MATERIAL

WITHOUT CRACK

WITH CRACK

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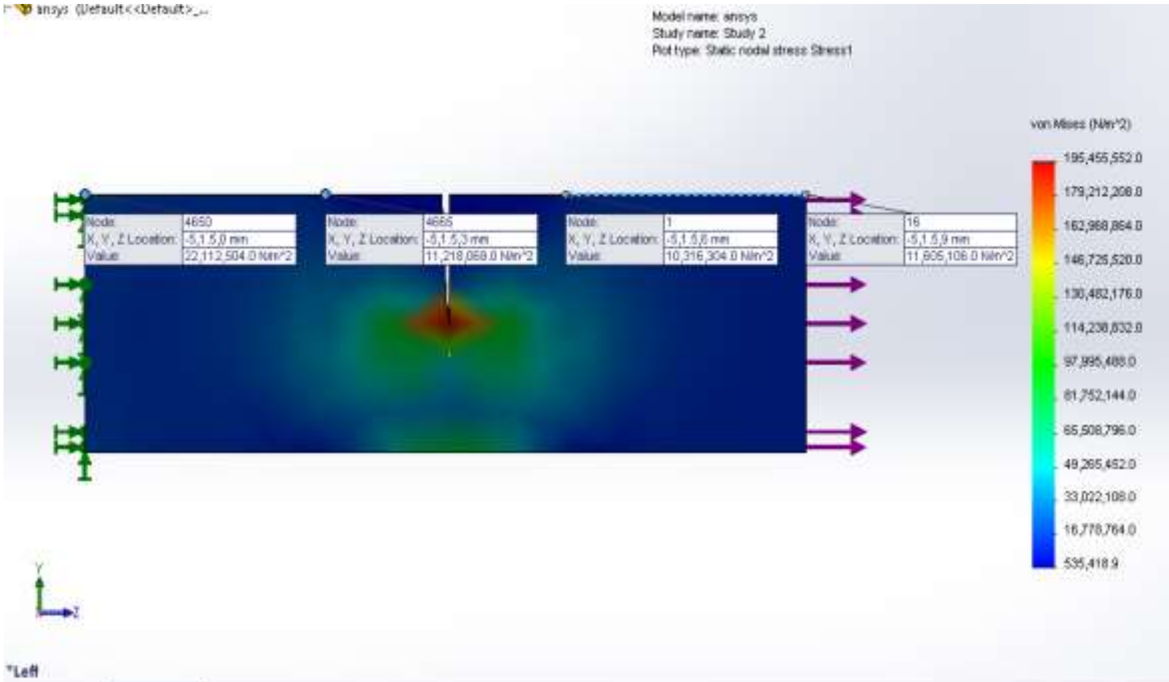

RESULTS AND DISCUSSION

Table 1. Comparison table crack analysis

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	535419 N/m^2
Max. displacement	0.000635992 mm	0.0158672 mm
Min. displacement	0	0

CONCLUSION

From above result it is concluded that, by use of composite material there is less stress acting on the material. But if there are surface irregularities or defect present in the material, more stress acting on that defected area which result in failure of material.

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