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*Research Paper*

# BUCKLING ANALYSIS OF FIBRE REINFORCED COMPOSITE BEAM WITH A TRANSVERSE CRACK

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In many structures like high speed machineries, aircrafts and light weight structures composite beams and beam like structures are main constituent elements. Cracks induced in these structural elements cause serious failure and monitoring of these cracks is essential. The presence of these cracks influences the dynamic characteristics of the structural elements. The influence of cracks on dynamic characteristics like natural frequencies, modes of vibration of structures, buckling loads has been the subject of many investigations. However studies related to behaviour of composite cracked structures subject to in-plane loads are scarce in literature. Hence the changes in buckling behaviour have been the subject of interest of many investigations. Present work deals with the buckling analysis of a cantilever beam made from graphite fiber reinforced polyimide with a transverse one-edge non-propagating open crack using ANSYS 14.5. The effects of various parameters like crack location, crack depth and fibers orientations upon the changes of the buckling loads of the beam are studied. The results obtained are analyzed. The static buckling load of a cracked composite beam is found to be decreasing with the presence of a crack and the decrease is more severe with increase in crack depth for any location of the crack. Furthermore, the buckling load of the beam decreased with increase in angle of the fibres and is maximum at 0 degree orientation. Next comparison of buckling loads of two different beams are done and analysed and found that buckling loads of two beams in both cracked and non cracked conditions decrease with increase in fibre angle but by comparing both cases, it is clearly understood that rate of change of buckling loads of graphite fiber reinforced polymide is more compared to E-glass fiber reinforced polymide.

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Keywords: ANSYS, Crack, Fibre-reinforced composite beams, Modal analysis, Natural frequency, Static buckling

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## INTRODUCTION

In the modern decades, different engineering fields like automobile, aerospace, naval, and civil use fiber reinforced composite materials by some means. The various properties of composite materials like high strength, low

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weight, resistance to corrosion, impact resistance, and high fatigue strength increase their reputation. Fiber-reinforced composite beams include the major collection of structural members, which are extensively used as movable elements, such as robot arms, rotating machine parts, and helicopter and turbine blades. Structural damage recognition has gained increasing deliberation from the scientific society since unexpected major hazards, most with human losses, have been reported. Aircraft crashes and the catastrophic bridge failures are a few illustrations. The cracks can be present in structures due to their limited fatigue strengths or due to the manufacturing processes. These cracks open for a part of the cycle and close when the vibration reverses its direction.

Preventing failure of composite material systems has been an important issue in engineering design. Composites are prone to damages like transverse cracking, fiber breakage, delamination, matrix cracking and fiber-matrix debonding when subjected to service conditions. The two types of physical failures that occur in composite structures and interact in complex manner are interalaminar and interlaminar failures. Interalaminar failure is manifest in micro-mechanical components of the lamina such as fiber breakage, matrix cracking, and debonding of the fiber- matrix interface. Generally, aircraft structures made of fiber reinforces composite materials are designed such that the fibers carry the bulk of the applied load. Interlaminar failure such as delamination refers to debonding of adjacent lamina. The possibility that interalaminar and interlaminar failure occur in structural components is considered a design limit, and establishes restrictions on the usage of full potential of composites.Similar to isotropic materials, composite materials are subjected to various types of damage, mostly cracks and delamination. The crack in a composite structure may reduce the structural stiffness and strength, redistribute the load in a way that the structural failure is delayed, or may lead to structural collapse. Therefore, crack is not necessarily the ultimate structural failure, but rather it is the part of the failure process which may ultimately lead to loss of structural integrity.

As one of the failure modes for the fiber-reinforced composites, crack initiation and propagation have long been an important topic in composite and fracture mechanics communities. During operation, all structures are subjected to degenerative effects that may cause initiation of structural defects such as cracks which, as time progresses, lead to the catastrophic failure or breakdown of the structure. Thus, the importance of inspection in the quality assurance of manufactured products is well understood. Several methods, such as non-destructive tests, can be used to monitor the condition of a structure. It is clear that new reliable and inexpensive methods to monitor structural defects such as cracks should be explored. These variations, in turn, affect the static and dynamic behaviour of the whole structure considerably. In some cases this can lead to failure, unless cracks are detected early enough. To ensure the safe, reliable and operational life of structures, it is of high importance to know if their members are free of cracks and, should they be present, to assess their extent. The procedures that are often used for detection are called direct procedures such as ultrasonic, X-rays, etc.

However, these methods have proven to be inoperative and unsuitable in some particular cases, since they require expensive and minutely detailed inspections. To avoid these disadvantages, researchers have focused on more efficient procedures in crack detection based on the changes of modal parameters likes natural frequencies, mode shapes and modal damping values that the crack introduces.

Cracks or other defects in a structural element influence its dynamical behaviour and change its stiffness and damping properties. Consequently, the natural frequencies and mode shapes of the structure contain information about the location and dimensions of the damage. Vibration analysis can be used to detect structural defects such as cracks, of any structure offer an effective, inexpensive and fast means of nondestructive testing. What types of changes occur in the vibration characteristics, how these changes can be detected and how the condition of the structure is interpreted has been the topic of several research studies in the past. The use of composite materials in various construction elements has increased substantially over the past few years.

Cracks found in structural elements have various causes. They may be fatigue cracks that take place under service conditions as a result of the limited fatigue strength. They may also be due to mechanical defects, as in the case of turbine blades of jet turbine engines. In these engines the cracks are caused by sand and small stones sucked from the surface of the runway. Another group involves cracks which are inside the material: they are created as a result of manufacturing processes. Nikpur and Dimargonas (1988) developed the local compliance matrix for unidirectional composite materials. The extent of anisotropy in composites found as a function for increase of interlocking deflection modes were shown in their works. Manivasagam and Chandrasekaran (1992) found reduction in fundamental frequency of layered composite materials due to presence of cracks. Krawczuk and Ostachowicz (1995) examined Eigen frequencies of a cantilever beam prepared form Graphite Fiber-Reinforced Polyimide with a transverse open crack by generating two models of the beam, the effect of various parameters, the crack location, the crack depth, the volume fraction fibers and fiber s orientation were premeditated upon the deviations of natural frequencies of the beam. Ghoneam (1995) investigated the dynamic characteristics of laminated composite beams with an assortment of fiber orientations and dissimilar boundary conditions in non existence and existence of cracks. The possessions of assorted crack depths and positions, boundary conditions were studied both by mathematical development and experimental analysis. Przemieniecki and Purdy presented the general analysis for large deflections of frame structures using concept of discrete element idealizations. They were presented the results for deflections of a six-bay truss and buckling of columns with either constant axial load or gravity loading. Ozturk and Sabuncu (2005) examined the static and dynamic stabilities of a laminated composite cantilever beam having linear translation spring and torsional spring as elastic supports subjected to periodic axial loading. Akbulut *et al.* (2010) studied on the theoretical prediction of buckling loads for symmetric angle-ply and cross-ply laminated flat composite columns, consisting of two portions of different widths connected by fillets. The accord among the experimental and theoretical results was established well during analysis.

In the present work buckling analysis using ANSYS was carried out for intact and cracked composite beams of Graphite Fibre-Reinforced Polyamide for the purpose of study by modelling which enables saving of time and cost. Initially by modelling the beams in ANSYS and analyzing them, the buckling loads were estimated for different fibre orientations for different beams and then the variation of buckling loads of the beams were studied. In the next step the variations in the static buckling loads due to presence of crack of different depths at various locations on the beam were studied by taking constant and different angle of orientation.

## THEORETICAL ANALYSIS

The assumptions made in the analysis are:

- The analysis is linear. This implies constitutive relations in generalized Hooke's law for the materials are linear.
- The Euler-Bernoulli beam model is assumed.
- The damping has not been considered in this study.
- The crack is assumed to be an open crack and have uniform depth 'a'.

Mass and stiffness matrices of each beam element are used to form global mass and stiffness matrices. The dynamic response of a beam for a conservative system can be formulated by means of Lagrange s equation of motion in which the external forces are expressed in terms of time-dependent potentials and then performing the required operations the entire system leads to the governing matrix equation of motion.

$$M_q + K_e - P(t)K_g q = 0 \qquad \text{...(1)}$$

where '$q$' is the vector of degree of freedoms. $M$, $K_e$ and $K_g$ are the mass, elastic stiffness and geometric stiffness matrices of the beam. The periodic axial force $P(t) = P_o + P_t\cos\Omega t$ where $\Omega$ is the disturbing frequency, the static and time dependent components of the load can be represented as a fraction of the fundamental static buckling load $Pcr$ hence putting

$$P(t) = \sim Pcr + \quad Pcr\cos\Omega t \qquad \text{...(2)}$$

In this analysis, the computed static bucking load of the composite beam is considered the reference load. Further the above equation reduces to other problems as follows.

Static stability with $\sim = 1, \quad = 0, \Omega = 0$

$$K_e - PcrK_g q = 0 \qquad \text{...(3)}$$

The buckling loads are normalized according to the following relation

$$N_{buck} = PcrL^2/BE_{22}H^3 \qquad \text{...(4)}$$

where $N_{buck}$ denotes for the non-dimensional buckling load, $Pcr$ denotes for the critical buckling load, $L$, $B$, $H$ and $E_{22}$ denote for the length, width, height and material property of the non-cracked composite beam.

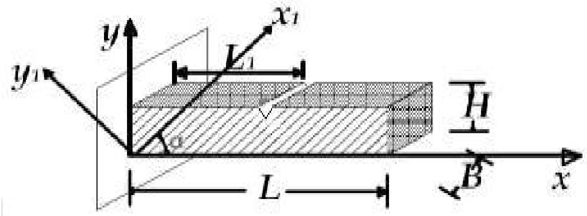
## MODELLING AND ANALYSIS OF COMPOSITE BEAM USING ANSYS

Static and Eigen Buckling analysis of ANSYS is used to determine the buckling loads which are important parameters in the design of a structure for dynamic loading conditions.

## Beam Model

The model chosen is a cantilever composite beam of uniform cross-section A, having an open transverse crack of depth ‘a’ at position L1. The width, length and height of the beam are B, L and H, respectively in Figure 1 below. The angle between the fibers and the axis of the beam is ~.

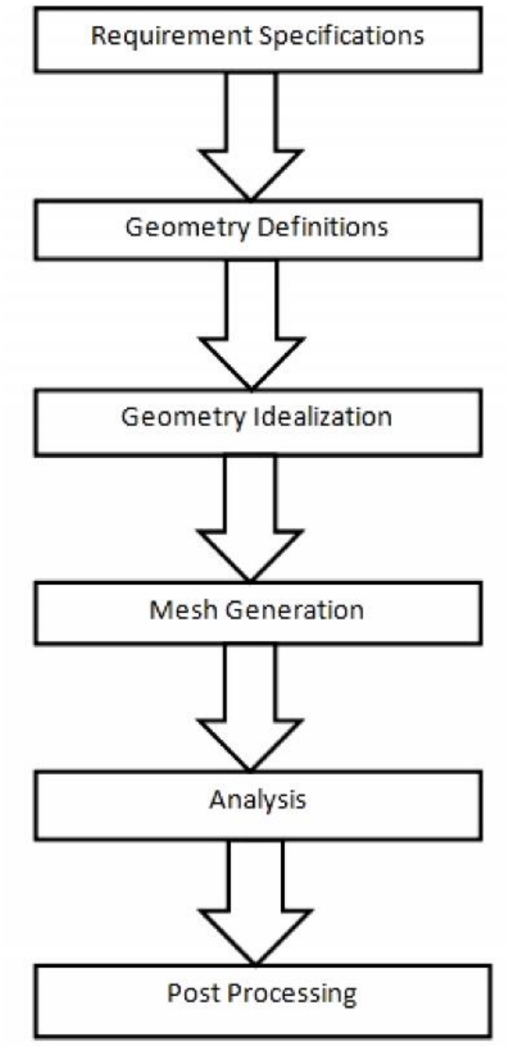
Figure 1: Schematic Diagram Cantilever Composite Beam with a Crack



## Modelling Procedure in ANSYS 14.5

The ANSYS procedure for any type of problem consist of mainly three stages, namely preprocessing, solution stage and post processing stage. In preprocessing stage the element type, material properties and real constants are specified. In the solution stage the boundary conditions and loads are defined. The ANSYS postprocessor stage provides a powerful tool for viewing results. The flow chart of the ANSYS procedure is represented in Figure 2. In the present work “SOLID SHELL190” has been selected. To create layered composites the layer thickness, material, orientation and number of integration points were specified. The beam was then created by using key points and the lines of the beam were obtained by joining these key points. These lines were then joined to obtain area. This area then extruded to get the 3dimensional beam. The boundary conditions were then applied to fix one end of the beam to make it clamped free. Modal and buckling analysis was then performed by using Block Lanczos method and the required first three natural frequencies were obtained from general post processor. The same procedure was adopted for the composite beam with a crack, by modifying the selection of key points in the initial stage to suit the generation of the

Figure 2: Flow Chart Representing ANSYS Procedure



crack of required dimensions at various locations on the beam.

## THEORETICAL RESULTS

For buckling analysis study the results of non-cracked composite beam obtained with the present element are compared with the analytical results of Reddy (1997) and Ozturk and Sabuncu (2005). Table below shows the comparison of present results of buckling load with the results of Reddy (1997) and Ozturk and Sabuncu (2005) for various values of the angle of the fiber (~).

The beam assumed to be made of unidirectional graphite fiber-reinforced polyamide. The geometrical characteristics and the material properties of the graphite fiber-reinforced polyamide composite beam are chosen as the same of those used in Ozturk and Sabuncu (2005). The material properties of the graphite fiber-reinforced polyamide composite are

The geometrical characteristics, the length (L), height (H) and width (B) of the composite beam were chosen as 1.0 m, 0.009525 m and 0.0127 m, respectively.

For comparison of buckling loads for two different beams Graphite fiber reinforced composite beam and E-glass fiber reinforced composite beam the material properties of graphite fiber reinforced beam same as in Ozturk and Sabuncu (2005) and assumed E-glass properties are as follows:

Table 1: Properties of the Graphite Fibre Reinforced Polyamide Composite

| | | |
|---|---|---|
| Modulus of Elasticity | E11 | 129.207 GPa |
| | E22 = E33 | 9.42512 GPa |
| Modulus of Rigidity | G12 | 5.15658 GPa |
| | G13 | 4.3053 GPa |
| | G23 | 4.3053 GPa |
| Poisson's Ratio | $^{3}{}_{12} = {}^{3}{}_{13} = {}^{3}{}_{23}$ | 0.3 |
| Mass Density | ° | 1550.0666 kg/m$^3$ |

Table 2: Properties of the E-glass Fiber Reinforced Composite Beam

| | | E-glass Fiber Reinforced Polymer |
|---|---|---|
| Modulus of Elasticity | E11 | 57.502 GPa |
| | E22 = E33 | 18.802 GPa |
| Modulus of Rigidity | G12 | 7.446 GPa |
| | G13 | 7.446 GPa |
| | G23 | 7.239 GPa |
| Poisson's Ratio | $^{3}{}_{12}$ | 0.25 |
| | $^{3}{}_{13}$ | 0.29 |
| | $^{3}{}_{23}$ | 0.29 |
| Mass Density | $°_{m}$ | 1910 kg/m$^3$ |

Table 3: Buckling Loads of a Non-Cracked Composite Beam for Angle of Fiber = 0, 30, 60 and 90 degree

| Angle of Fibers (deg.) | Present FEM | Ozturk and Sabuncu (2005) | Reddy (1997) |
|---|---|---|---|
| 0 | 9.7093 | 5.1404 | 5.14 |
| 30 | 1.6247 | – | – |
| 60 | 0.787 | – | – |
| 90 | 0.7090 | 0.2056 | 0.205 |

## NUMERICAL RESULTS

The buckling analysis is done for the same beam as considered by Ozturk and Sabuncu (2005) and Reddy (1997) for different crack locations and crack depths. The results are tabulated in Figure 3 and plotted in the Figures 3 to 10. The calculations have been carried out for 10%volume fraction of the fiber and the angle of fibers varying from 0 to 90 degrees. From the Figure 3, it is clear that the non-dimensional buckling load of the beam reduces from 9.7093 to 8.1547 with introduction of a crack at 0.1 L and relative crack depth of 0.2. The non-dimensional buckling load decreases substantially from 8.1547 to 4.2687 with increase of relative crack depth from 0.2 to 0.6 due to decrease in stiffness. Similarly the non-dimensional buckling load decreases with increase of relative crack depth from 0.2 to 0.6 for other cases of the crack position, i.e., 0.1 L, 0.2 L, 0.4 L, 0.6 L and 0.8 L. The variation of non-dimensional buckling loads of cantilever composite beam with crack location for different relative crack depth (0.2 to 0.6), when angle of fiber = 0 degree is shown in Figure 4. It is observed that the non-dimensional buckling load increases from 8.1547 to 8.3241 with increase of x/L from 0.1 to 0.8 for relative crack depth = 0.2. For relative crack depth 0.6 the non-dimensional buckling load increases from 4.2687 to 7.5791 when the location of crack shifts from 0.1 L to 0.8 L. It means the non-dimensional buckling load of a cracked cantilever composite beam is higher if the crack is near the free end than near the fixed

Figure 3: Critical Buckling Load vs. Relative Crack Depth for Different Crack Location When Angle of Fiber = 0 degree

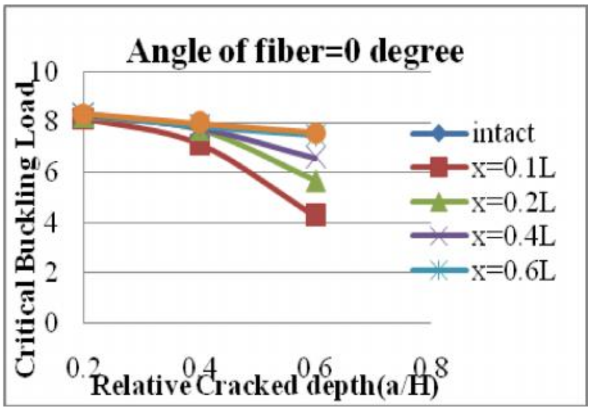


Figure 4: Critical Buckling Load vs. Crack Location for Different Relative Crack Depth When Angle of Fiber = 0 degree

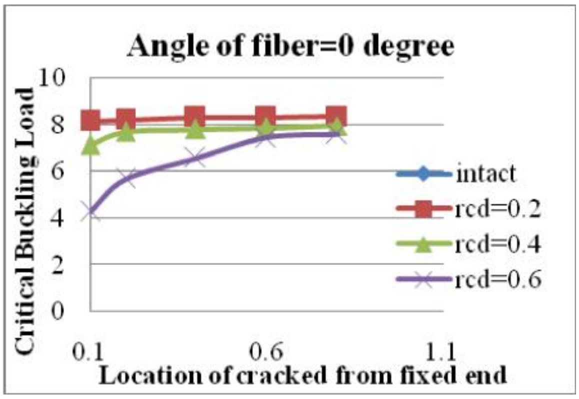


Figure 5: Critical Buckling Load vs. Relative Crack Depth for Different Crack Location When Angle of Fiber = 30 degree

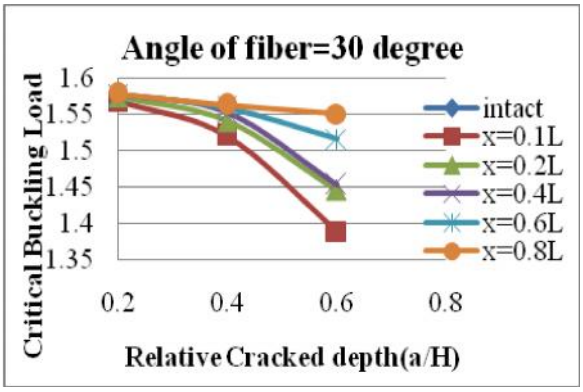


Figure 6: Critical Buckling Load vs. Crack Location for Different Relative Crack Depth When Angle of Fiber = 30 degree

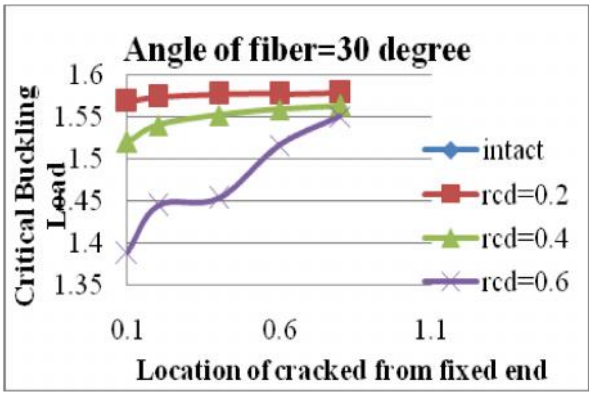


Figure 7: Critical Buckling Load vs. Relative Crack Depth for Different Crack Location When Angle of Fiber = 60 degree

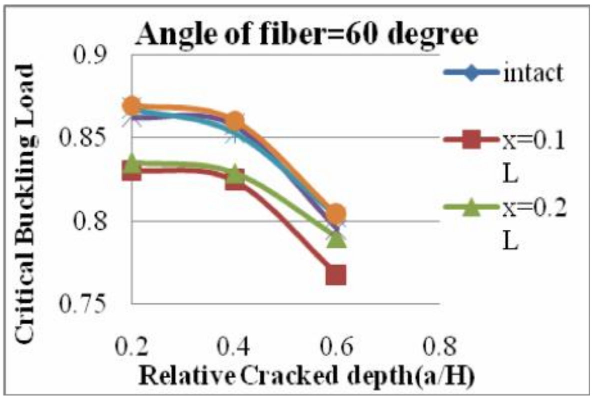


Figure 8: Critical Buckling Load vs. Crack Location for Different Relative Crack Depth When Angle of Fiber = 60 degree

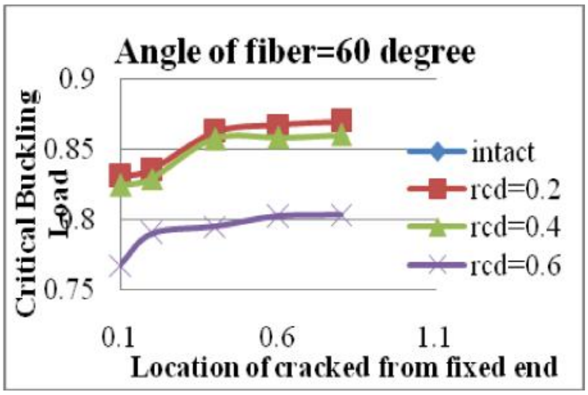


Figure 9: Critical Buckling Load vs. Relative Crack Depth for Different Crack Location When Angle of Fiber = 90 degree

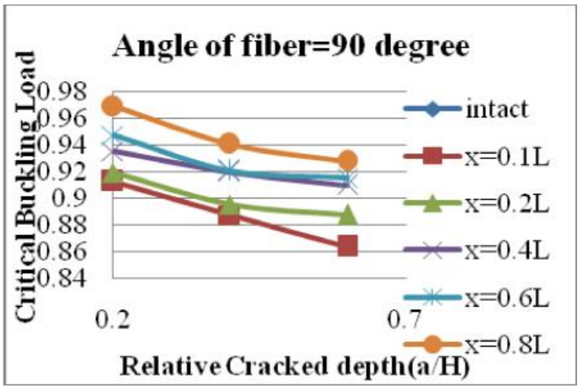
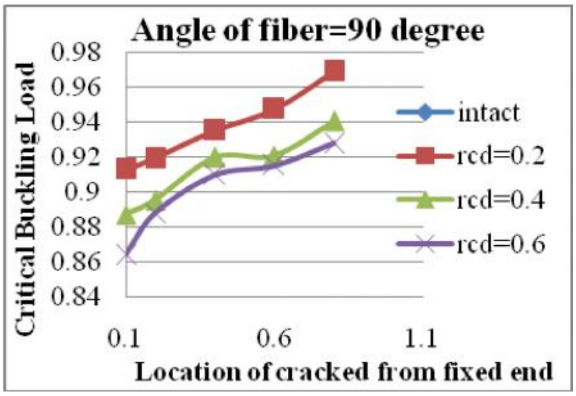


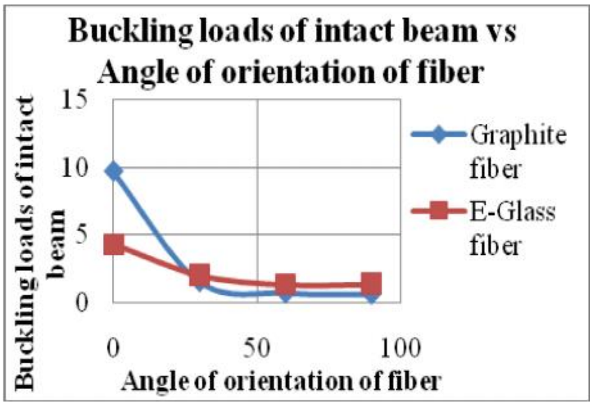
Figure 10: Critical Buckling Load vs. Crack Location for Different Relative Crack Depth When Angle of Fiber = 90 degree



end and non-dimensional buckling load decreases with increase in relative crack depth. For a given crack depth it increases as crack location moves from fixed end to free end. Buckling load decreases with increase in angle of fibers and is maximum at 0 degree. This is due to the fact that for 0 degree orientation the buckling plane normal to the fibers is of maximum stiffness and for other orientations stiffness is less hence buckling load is less.

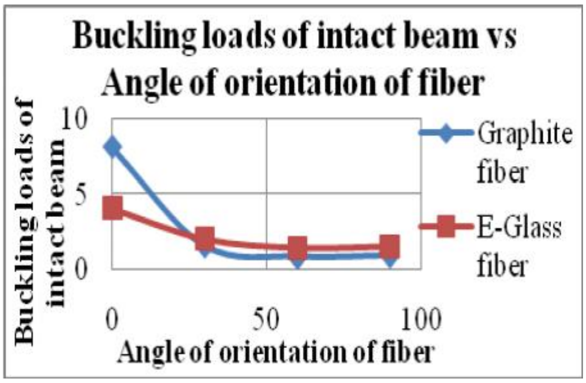
Comparison of buckling loads for two different beams are Graphite fiber reinforced

Figure 11: Buckling Loads of Intact Beam vs. Angle of Orientation of Fiber



composite beam and E-glass fiber reinforced composite beam (Figures 11 and 12).

Figure 12: Buckling Loads of Intact Beam vs. Angle of Orientation of Fiber



## CONCLUSION

The following conclusions can be made from the present investigations of the composite beam finite element having transverse non-propagating one-edge open crack. This element is versatile and can be used for static and dynamic analysis of a composite or isotropic beam.

From the present investigations it can be concluded that the buckling load of a cracked composite beam decrease with increase of crack depth for crack at any particular location due to reduction of stiffness. When, angle of fibers increase the values of the buckling loads decrease. This is due to the fact that for 0 degree orientation of fibers, the buckling plane normal to the fibers is of maximum stiffness and for other orientations stiffness is less hence buckling load is less.

Buckling loads of two beams in both cracked and non cracked conditions decrease with increase in fibre angle but by comparing both cases, it is clearly understood that rate of change of buckling loads of graphite fiber reinforced polymide is more compared to E-glass fiber reinforced polymide.

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