Analysis of Failure Phenomena in Multi- Fiber polymer composite material at varying volume fraction using Finite Element Modeling

Prince[1,a] , Mukesh Verma[2,b] and Sarabjot Singh[3,c]
[1] Department of Mechanical Engineering, Maharishi Markandeshwar University, Mullana,India
[2,3] Department of Mechanical Engineering, S.S.I.E.T, Derabassi, India

ABSTRACT

In present work 2D FE (finite element) analysis of deformation and damage evolution site in fiber reinforced composites are carried out. The fiber cracking point and stresses is simulated in the fibers/matrix interface, using the ANSYS FE software at varying volume fractions. The effect of matrix cracks and the interface strength on the fiber failure is investigated. Multi-fibre model were used to study the fracture process of polymer composites in uniaxial loading. The investigations were focused on numerical results determining the influence of multi fiber as compare to the single fiber model. Results shows that in multi-fiber models failure decreases due to decreased stress concentrations at the fracture site and the strength of the composite material increases by reinforced with multi fiber than single fiber at same volume fraction.

Keywords: **short-fiber composites, multi-fiber model composites, interfacial strength, FE-analysis**.**I.**

INTRODUCTION

The purpose of this work is to analyze the damage evolution of fiber reinforced composites considering the microscale properties and the interaction between matrix and fibers interface. The micro mechanisms of damage in fiber reinforced composites (FRC) can be described as follows [1]. If a fiber reinforced composite is subject to longitudinal tensile loading, the main part of the load is born by the fibers, and they tend to fail first. After weakest fibers fail, the load on remaining intact fibers increases. That may cause the failure of other, first of all, neighboring fibers. The cracks in the fibers cause higher stress concentration in the matrix, which can lead to the matrix cracking. However, if the fiber/matrix interface is weak, the crack will extend and grow along the interface. In the case of ceramic and other brittle matrix composites, the crack is formed initially in the matrix. If intact fibers are available behind the crack front and they are connecting the crack faces, the crack bridging mechanism is operative. In this case, the load is shared by the bridging fibers and crack tip, and the stress intensity factor on the crack tip is reduced. A higher amount of bringing fibers leads to the lower stress intensity factor on the crack tip, and the resistance to crack growth increases with increasing the crack length [2, 3]. The extension of acrack, bridged by intact fibers, leads to the debonding and pull out of fibers that increase the fracture toughness of the material.

The effective properties of the fiber reinforced composites strongly depend upon the geometrical arrangement of the fibers within the matrix [4]. This arrangement is characterized by the volume fraction, the fiber aspect ratio and the fiber spacing parameters. The factor aspect ratio affects the stress transfer from matrix to the fiber. When discontinuous fibers are used, the attainment of good mechanical properties depends critically upon the efficiency of the stress transfer between the matrix and the fibers. Presence of short fiber in composite increases the damping behavior [9]. In the short fiber reinforced composites, there is the possibility of failure in the fiber, in the matrix phase or at the fiber/matrix interface. Shear failure of the matrix is another common mechanism in the failure of the composites Von Misses criterion is one of the most successful in assessment of the shear failure. Ghassemieh [4, 5, 6] developed a micro-mechanical model to understand the behavior of fiber and particulate reinforced polymeric composites. This model was used to simulate stress distribution and to identify the maximum stress concentrations locations. The interfacial stresses evaluated by model were compared with the well known shear lag and modified shear lag models [7]. Present work focuses on evolution of damage sites and effect of fiber matrix interface on strength of composite by FE analysis.

II. FINITE ELEMENT MODELING FOR SINGLE AND MULTI-FIBER MODELS

Single and multi-fiber models for FE analysis is shown in Fig. 3 and Fig. 4. The commercial FE software ANSYS is used in the FE simulation. Due to axisymmetry, the specimen can be considered as a 2-D elastic body and 4-node quadrilateral element PLANE42 is used in the analysis. Following parameters are used in all calculations [8]:

1). Reinforced glass fibers with Young's modulus E_f =64GPa and Poisson ratio v_f = 0.2

2). Matrix is of nylon66 with Young's modulus E_m = 3GPa and Poisson ratio $v_m = 0.35$.

Following two cases are to be considered:
a). Interfacial stress distribution in single fiber model (radial & transverse) at 20% and 40% volume fraction of fiber in matrix.
b). The effect of multi-fiber model at 20% and 40% volume fraction.

FEA model of composite is similar to Prince [8] is considered to understand failure phenomena of Composite with single and multi fiber reinforcements.
The continuous composite domain is assumed to consist of interconnected axisymmetric unit cells. For rod like (i.e. short) fibers, the selected unit cell is shown in Fig. 1 and Fig. 2.
When this unit cell is rotated 360º around y axis, a cylinder embedded in an outer cylinder is produced. This unit cell domain geometry is defined in terms of the following parameters:

L_f, d_f, r_f : length, diameter and radius of the fiber

L_m, d_m, r_m : length, diameter and radius of the cell

a_f fiber aspect ratio: $a_f = L_f / d_f$

x_f fiber spacing parameter : $L_m - L_f = x_f \frac{L_f}{a_f}$

The dimensions of the unit cell are hence related to the volume fraction of the fibers in the composite by the following expression (1):

$$L_f = \sqrt[3]{4\left(r_m a_f\right)^2 v_f L_m} \qquad (1)$$

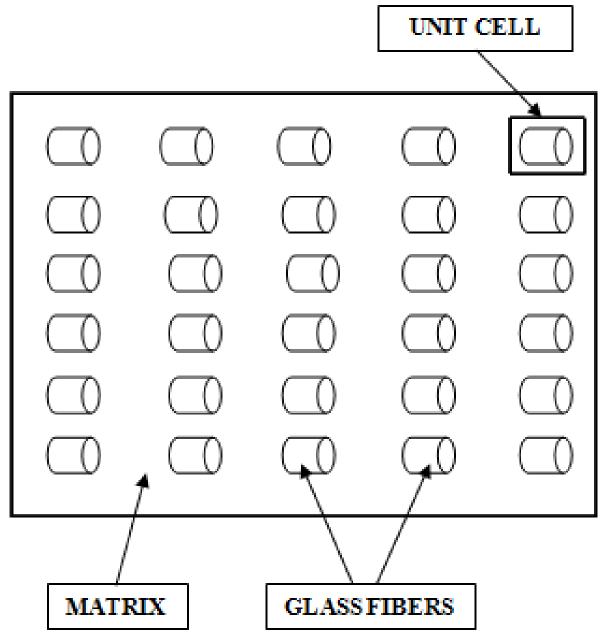

Fig 1: Composite domain showing short fibers reinforced in matrix

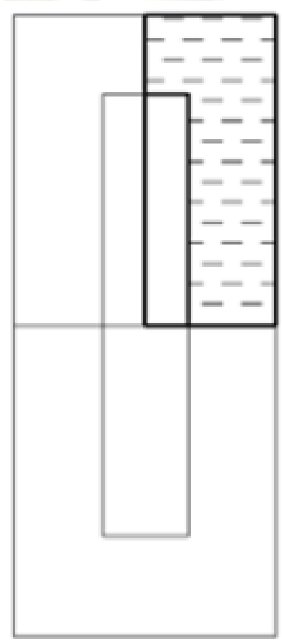

Fig 2: Complete model of fiber and matrix in unit cell

Table 1 and Table 2 shows the model dimensions of single and multi-fiber models.

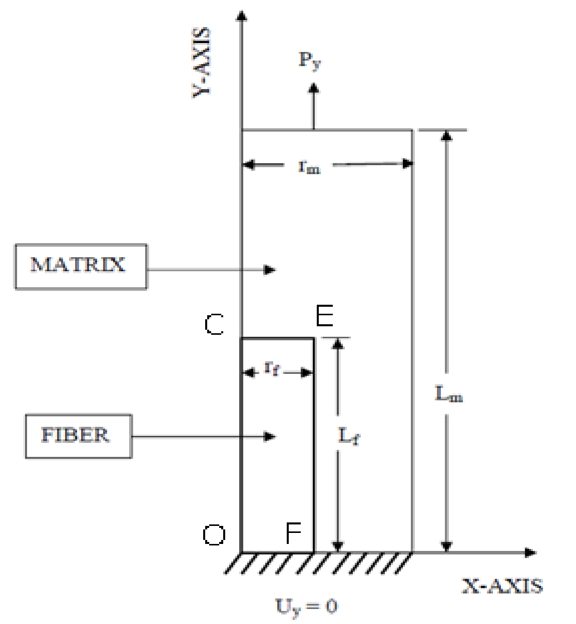

Fig 3: Single fiber model for finite element analysis

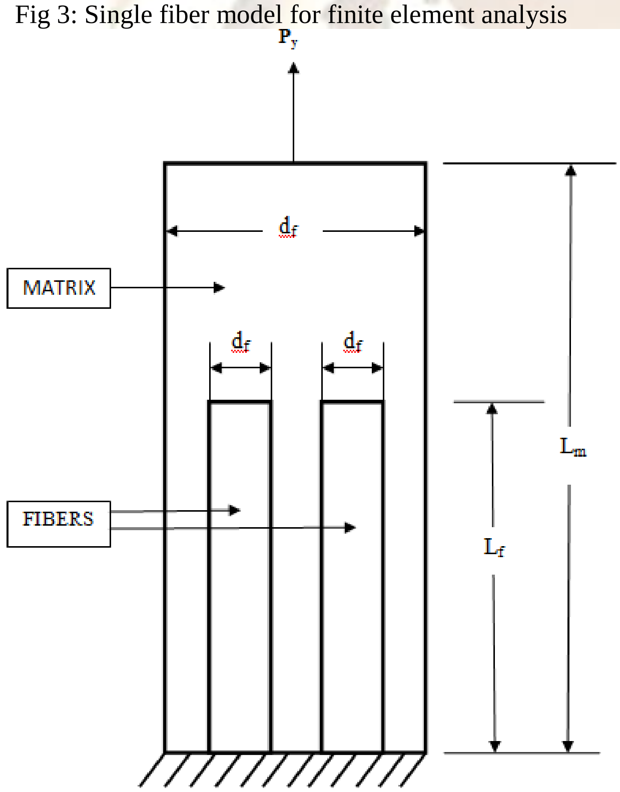

Fig 4: Multi fiber model for finite element analysis

Table 1: Dimension of single fiber model with varying volume fraction

	Matrix		Fiber	
Volume fraction (%)	l_m (μm)	r_m (μm)	l_f (μm)	r_f (μm)
10	150	7.5	69.62	3.48
20	150	7.5	87.72	4.38
30	150	7.5	100.41	5.02
40	150	7.5	110.52	5.52

Table 2: Dimension of multi fiber model with varying volume fraction

Volume fraction (%)		Matrix		Fiber	
Single fiber	Double fiber	l_m (μm)	r_m (μm)	l_f (μm)	r_f (μm)
10	**20**	150	7.5	87.72	4.38
20	**40**	150	7.5	110.52	5.52
30	**60**	150	7.5	126.51	6.32

III. BOUNDARY CONDITIONS

The boundary conditions representing the application of tensile loads to a short fiber filled composite are constrained boundary conditions i.e. at *Y*=0, *Uy*=0, matrix and fiber have zero movement in *Y*-direction. Here the *Y*-axis is in the direction of length interface of fiber and matrix and the model is axis-symmetric to it we have applied the p_y = 5.65 x e-8 N/μm^2 pressure at the end face of the matrix i.e. at *y*=*Lm* (ref. Fig. 3 and Fig. 4).

IV. INTERFACIAL STRESS AT VARYING VOLUME FRACTION WITH SINGLE AND MULTI FIBER MODEL

Quantitative prediction of the strength of the short fiber reinforced thermoplastics is a complex problem. A reason for this is non uniformity of stress distribution along the short fiber length and radial interface in these composites, this implies that the average stress carried by fibers at the point of failure will be less than their ultimate tensile strength. In short fiber reinforced polymer composites; the failure is mainly dependent upon the mechanical properties of their constituents and the tensile and shear strengths of the interfacial bonding of the fibers and the matrix. Another factor influencing the failure mechanism in these composites is the fiber aspect ratio (or fiber length), which affects stress transfer from matrix to fiber, thus, in these materials there is always a possibility of failure in fiber or matrix at interface.

Numerical studies in this paper shows that the number of fiber involved in the model have marked influences on the analysis of failure phenomena of the composites. Fig. 6 shows that maximum stress occurs at sharp point interface. Fig. 5 represents the stress distribution along radial direction in single fiber model at 20% and 40% volume fraction which confirms maximum stress value at the sharp point due to stress concentration. As volume fraction increases stress decreases sharply because to fibers are main load carrying members and strength of composites increases with increse in reinforcement. Similar results are obtained for length interface showing von mises stress and tensile stress which are shown in Fig. 7.

Multi fiber composite model is shown in Fig. 8. In multi fiber model the stress value decreases than single fiber model at same boundary conditions due to increase in inferface as shown by Fig. 9. Comparision of results of single fiber and multi fiber models are shown in Fig. 10.

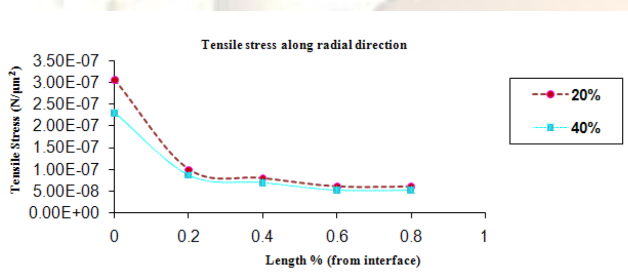

Fig. 5 Interfacial Tensile stress at varying volume fraction in single fiber model

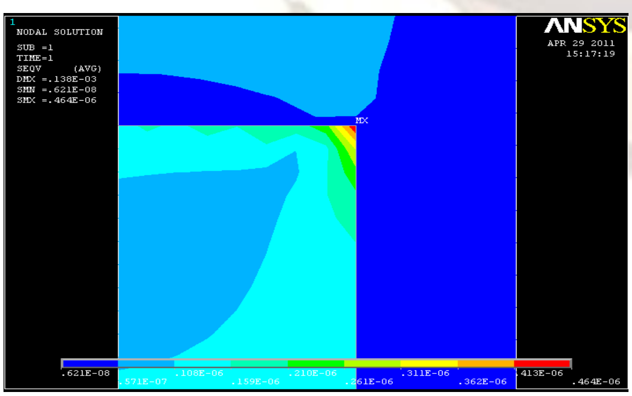

Fig. 6 Von Misses stress at 20% volume fraction in single fiber model

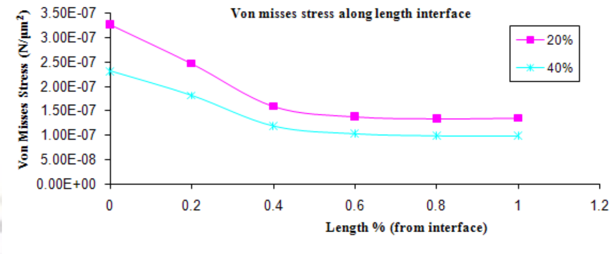

Fig. 7 Interfacial Von Misses stress at varying volume fraction in single fiber model

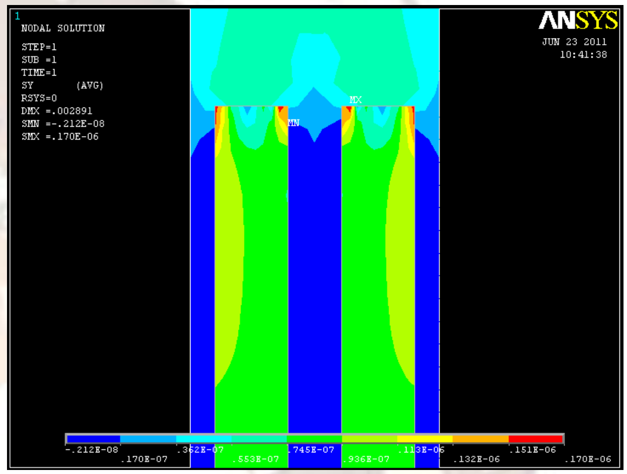

Fig. 8 Von Misses stress at 20% volume fraction in multi fiber model

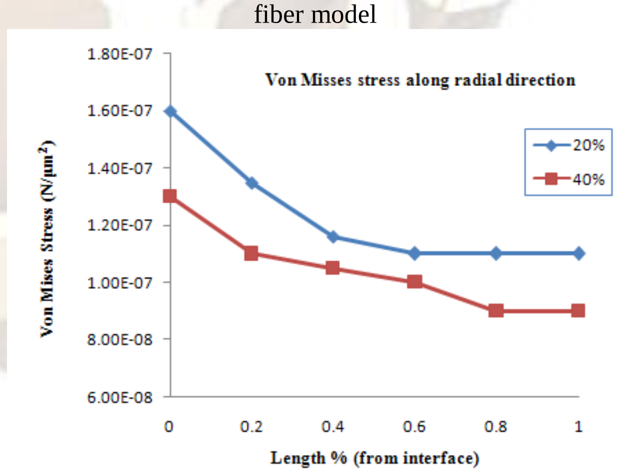

Fig. 9 Interfacial Von Misses stress at varying volume fraction in multi fiber model

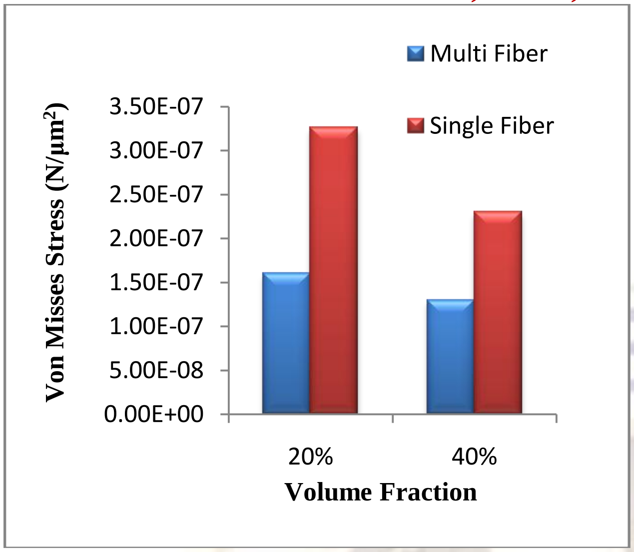

Fig. 10 Effect of the single and multi fiber reinforcement composite on stress at 20% and 40% volume fraction

V. CONCLUSION

Computational simulations of the deformation and damage evolution in fiber reinforced composites are presented. Maximum stress occurs at the sharp interface due to stress concentration which is favorable site for cracks to appear. The stress decreases along radial and length interface as distance increases from sharp edge. Increased in volume fraction of fiber shows lower interfacial stress which reduces the chances of cracking and composites shows more strength. Similar results are shown by multi fiber composites because of increased interface, the stress reduces at particular volume fraction.

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