MICROMECHANICAL MODELING OF SHORT –FIBER REINFORCED POLYMERIC COMPOSITE

Kareem N. Hussien
Engineering College / Al.Qadisiyah University
kareem_najem@yahoo.com

Abstract

This paper presents a method considering the effect of fiber geometry and volume fraction for predicting the tensile strength, shear stress and Von Mises stress. The finite element scheme for the micromechanical modeling of the behavior of fiber reinforced polymeric composites under external load is developed. The model is used to estimate the stress distribution throughout the composite domain and to identify the location where maximum stresses occur. The ratio between fiber modulus and matrix modulus must be high enough to improve the mechanical properties and to reduce the premature interfacial failure. The prediction of the stress distribution by using a simulation tool could be helpful for more understanding the real reasons behind failure of polymer composites.

Keywords: Polymer composite, Finite element, Stress distribution, Short-fiber reinforced composite,

النمذجة الميكانيكية الدقيقة لمركب مسلح بألواح البوليمر

كريم نجم حسين
جامعة القادسية/ كلية الهندسة

الخلاصة

يقدم هذا البحث طريقة لحساب تأثير أبعاد الألياف ونسبتها الحجمية للتنبؤ بقيم مقاومة الشد, أجهاد القص وأجهاد فون ميسيس. اعتمد هذا البحث على تطوير طريقة العناصر المحدودة لنمذجة التصرف المايكروميكانيكي للبوليمر المقوى بالألياف تحت تأثير الحمل الخارجي. أستخدم النموذح العددي لتقدير توزيع الأجهاد على مدى المادة المركبة بغرض تحديد أماكن الأجهاد الاقصى. تعتبر النسبة العالية بين معامل الليف الى البوليمر أساسا لتحسين الخواص الميكانيكية ولمنع الأنهيار المبكر . أن التنبؤ بتوزيع الأجهاد باستخدام نماذج المحاكاة الدقيقة يساهم في زيادة الفهم لأسباب الأنهيار للمواد البوليمرية المركبة.

***Received at 21/7/2013** *** Accepted at 4/9/2013**

Introduction

Short-fiber composites do have following attractive characteristics that make them worthy of consideration for many engineering applications.

Components having complex geometrical contours, continuous fibers may not be of practical use because they may not conform to the desired shape without being damaged or distorted from the desired pattern.

Fast and inexpensive processing methods can be used to produce short fiber reinforced composites for high volume applications.

The advantages of low cost, ease of fabricating geometrically complex parts, and isotropic behavior are enough to make short fibercomposites the material of choice.

Ghassemieh [1, 2, 3] developed a micro-mechanical model to [1] understand thefiber behavior and particulate reinforced polymeric composites. This model was used toestimate the stress distribution and to identify the maximum stress concentration locations. Theinterfacial stresses that evaluated using this model were compared with the well known shear lag andmodified shear lag models [2]. It also predicts the dominant failure and crack growthsmechanisms in the reinforced polymeric composites. This model also demonstrated thedifferences between the continuous fibers and the short fibers. In this work, glass fiber that reinforced byepoxy was examined and cylindrical shape was assumed; because of axis symmetry, quarterof this model was analyzed. It was assumed that the fibers were distributed uniformly in thematrix and there was no overlapping of the fibers end [3].The effective properties of the discontinuous fiber reinforced composites strongly depend upon the geometrical arrangementof the fibers within the matrix. This arrangement was characterized by the volume fraction,the fiber aspect ratio and the fiber spacing parameters [3]. The factor aspect ratio affects thestress transfer from matrix to the fiber.

Hayeset. al. [4, 5]studied the effect of an interphase on strain developmentin fiber-fragments. In order to form an interphase, an epoxy resin with known properties wasapplied to the surface of the upsized reinforcing cured fibers. These were then embedded in a Matrix resin coupon, prior to fragmentation test.

Shao-Yun Fuaet. al. [6] carried an analyses on the micromechanics of theelastic stress transfer that taking place across the fiber/matrix interface in both single- and multi-fiber pull-out tests. A two-cylinder model for the single fiberpull-out test and a three-cylinder model for the multi-fiber pull-out test were employedin order to study the fiber pull-out problems. The difference in the stress transfer between thetwo models is clearly shown.

Goh1et. al[7] invested the finite element (FE) analysis forunderstanding the various processes that can occur and contribute to stress transfer betweenthe matrix and the fibers in short-fiber composite materials. These processes are elastic stresstransfer, plastic stress transfer, matrix yielding, interfacial debonding, matrix cracking, andfiber pull-out and fiber fragmentation.

Satnam Singh et.al. [8]used the finite element method to study the effect of reinforced fibers dimensions to increase interfacial strength. Increasing the interfacial strength increases the ability of material to absorb shocks and vibrations without getting fractured.

Their experimental results confirms that the presence of the reinforced fibers increasing the damping capacity and among reinforcements, short fiber reinforced polypropylene shows increasing damping capacity than long glass fiber reinforced..

ANALYSIS

Short-Fiber Reinforced Composites

Short-fiber reinforced composites consist a matrix that reinforced by a dispersed phase in form of discontinuous fibers (length < 100 times the diameter) [9]. Orientation of those fibers may be in one particular direction or it may be random. Short fiber-reinforced composites are not as strong or as stiff as continuous-fiber-reinforced composites and should not be used in critical structural applications.

The main purpose for using the short fibers to the thermoplastic is to increase the stiffness of the base polymer and to extend its range of applications in load-bearing applications; hence it is used in a wide range of applications.

Finite Element Concept

The finite element method is proved to be a powerful method of analysis in many fields of engineering. The finite element method involves dividing the continuum into a finite number of elements connected at a nodal points. These elements could have any shape (usually rectangular or triangular) and this is approximately represented by a proper assemblage of these elements. Any difficulties due to complex loading conditions can be simplified by assuming that the load can be applied only at the nodes of the element. The accuracy of the method depends not only on the idealization of the continuum, but also on the properties of the shape functions that assumed to represent the deformed elements shapes. Many good books about this method are available like [10]

Practical Modeling Considerations

In order to reduce the computational time, minor details that do not influence the results shouldnot be included in the FE model. Minor details can also be ignored in order to render thegeometry symmetric, which leads to a reduced FE model. However, in a certain structures, "small' details such as fillets or holes may be the areas of maximum stresses, which mightprove to be extremely important in the analysis and design. Engineering judgment is essentialto balance the possible gain in computational cost against the loss of accuracy.

Dimensions of the Model

According to [8], the following formula that used fordimensioning the model with any given volume fraction v_f

$$l_f = \sqrt[3]{4(r_m a_f)^2 v_f l_m} \quad \text{--------------} \; 1$$

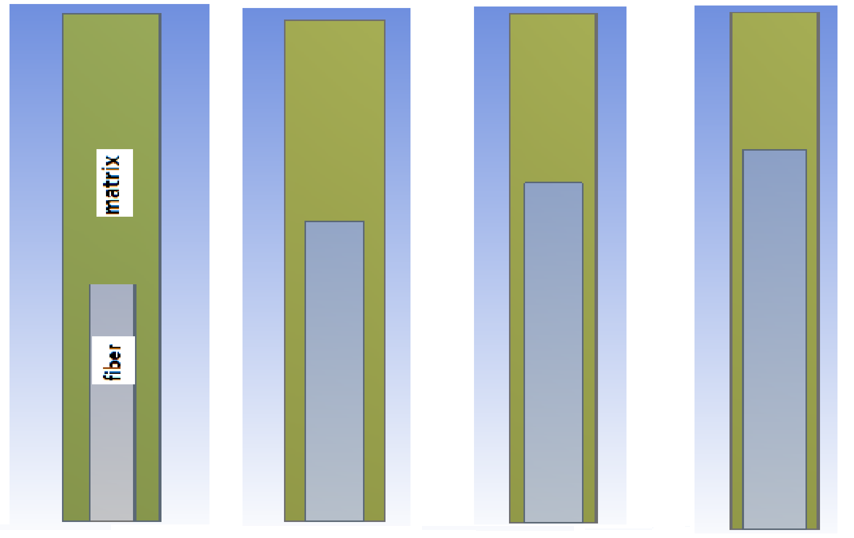
In which l is the length, r is the radius and the subscripts f and m refer to fiber and matrix, respectively.

Taking that aspect ratio as 10, the dimensions of the fiber at different volume fractions and this is given in table 1.

Table 1: Dimensions of the model

Volume Fraction %	**lm (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

The geometry model for different volume fraction is given in figure 1.



volume fraction 10% volume fraction 20% volume fraction 30% volume fraction 40%

Figure 1: Geometry of the model

Material Model

The material model is given in table 2.

Table 2: Material properties

	Modulus of Elasticity	Poisson's ratio
Fiber reinforce fiber glass	0.70 N/μm^2	0.21
Matrix polyamide 6	0.0301 N/μm^2	0.35

Load and Boundary Conditions

A plane strain problem is considered with constant displacement in x-direction 0f 4.8μm at the top of the matrix. The matrix and fiber are fixed as shown in figure 2.

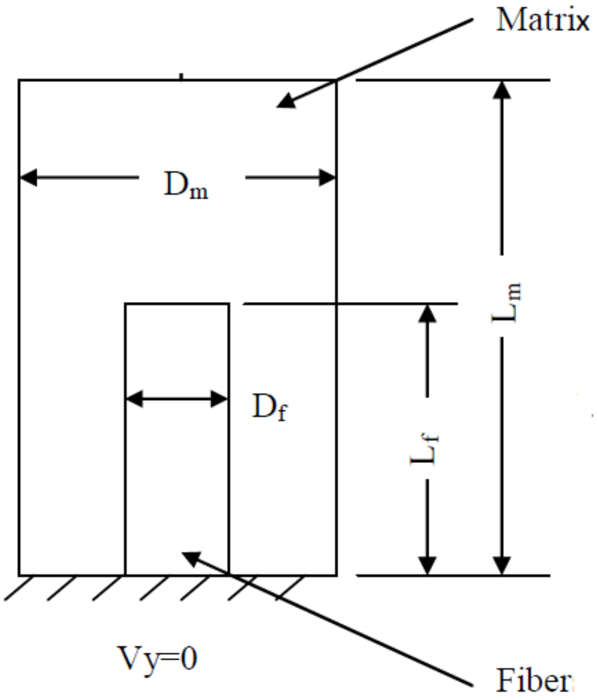


Figure 2: A matrix and fiber geometry

Numerical Results and Discussion

ANSYS V-14 was used for analysing the stresses in the matrix and fiber structure . Figure 4 shows the tensile stress; figure 5 shows the Von Mises stress and figure 6 shows the shear stress at 10% volume fraction.

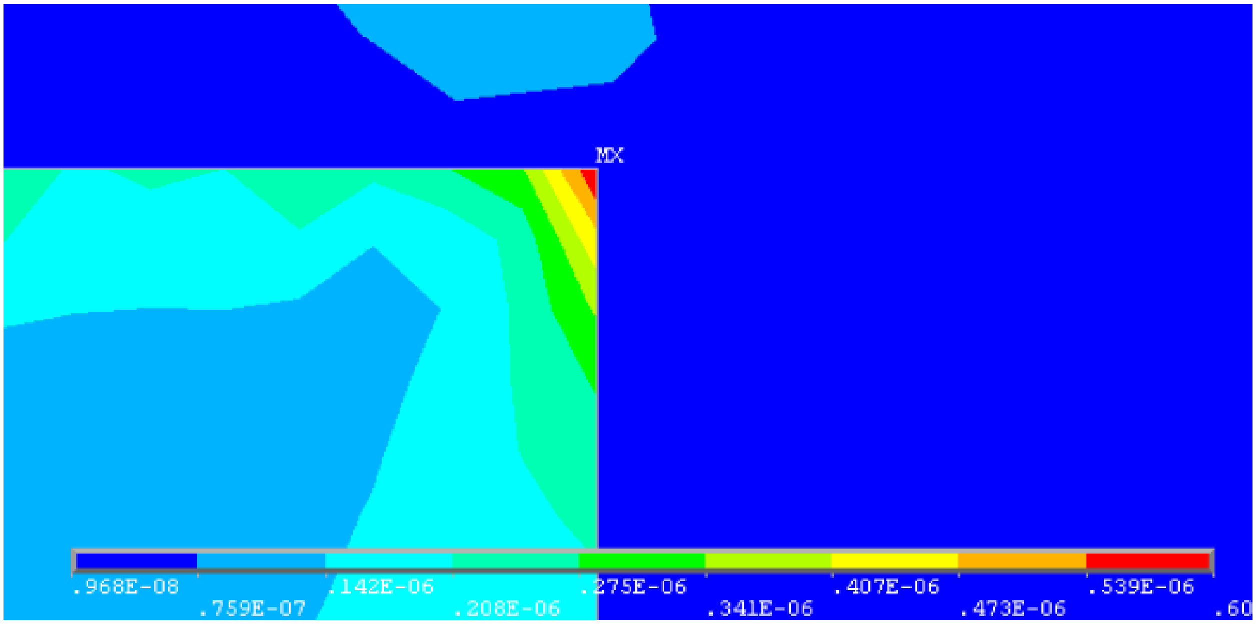


Figure: 4 Tensile stresses at 10% volume fraction

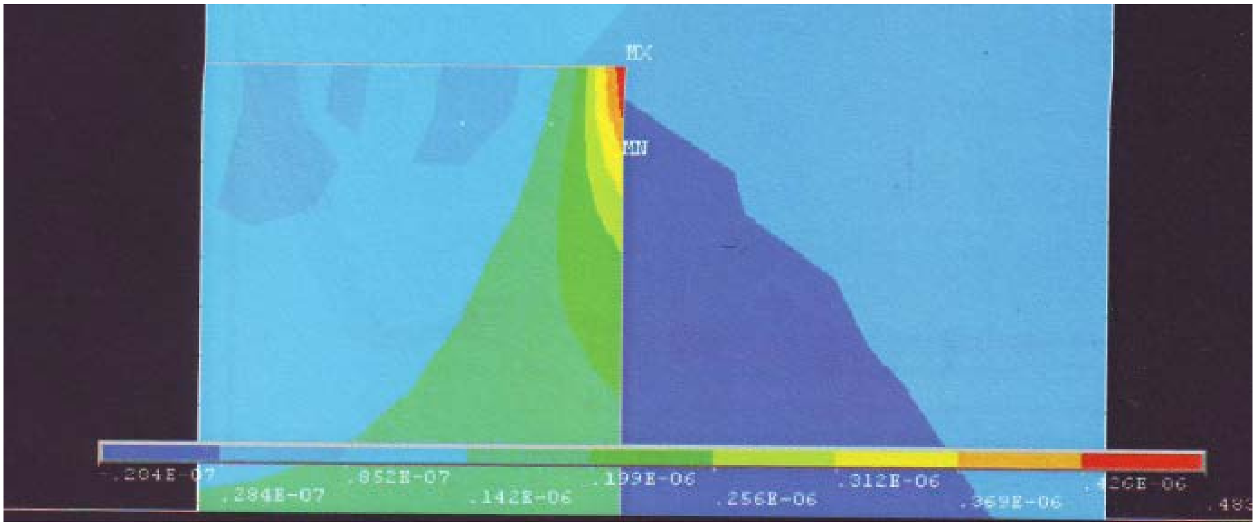


Figure: 5 Von Mises stresses at 10% volume fraction

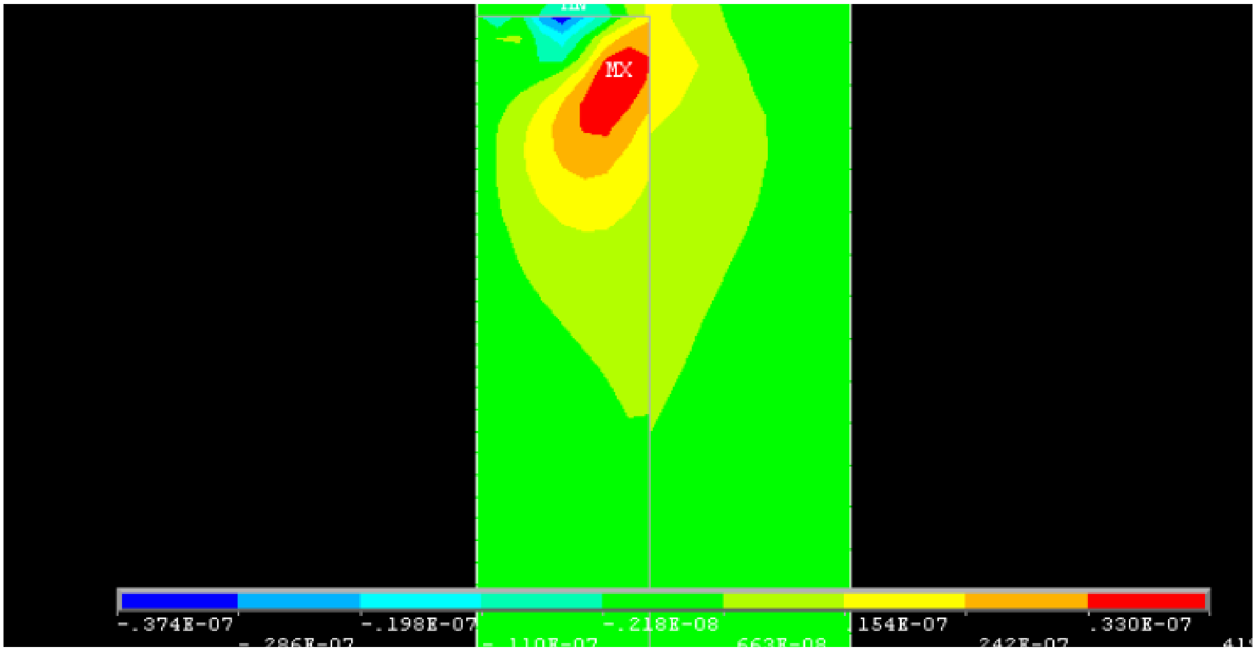


Figure: 6 Shear stresses at 10% volume fraction

For different volume fraction, almost uniform stresses are gained after a certain length of the interfacing between the matrix and the fiber. Figure 7, 8 and 9 show the development of these stresses with length from the sharp edge.

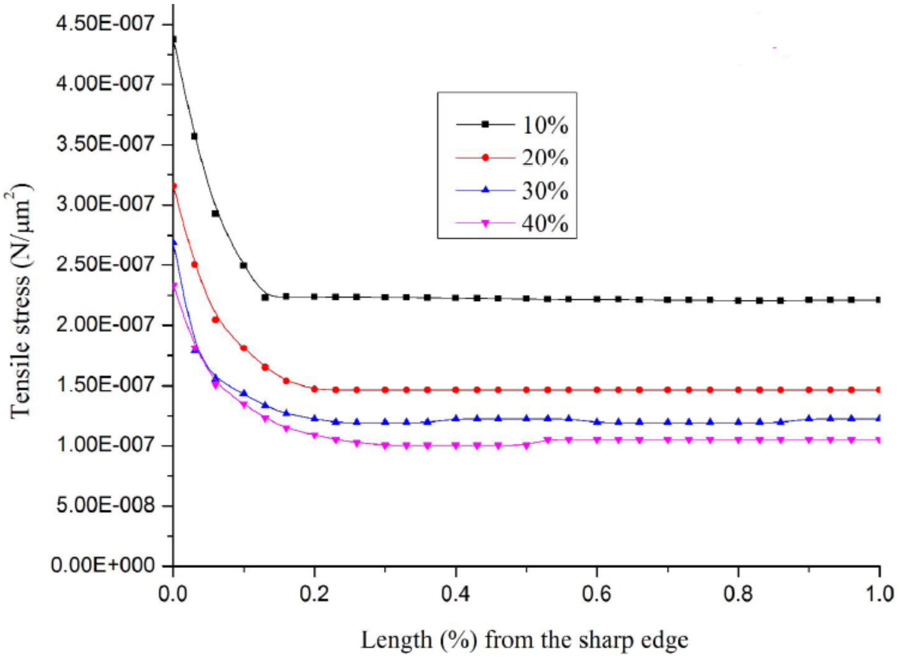


Figure:7 Tensile stress along length interface

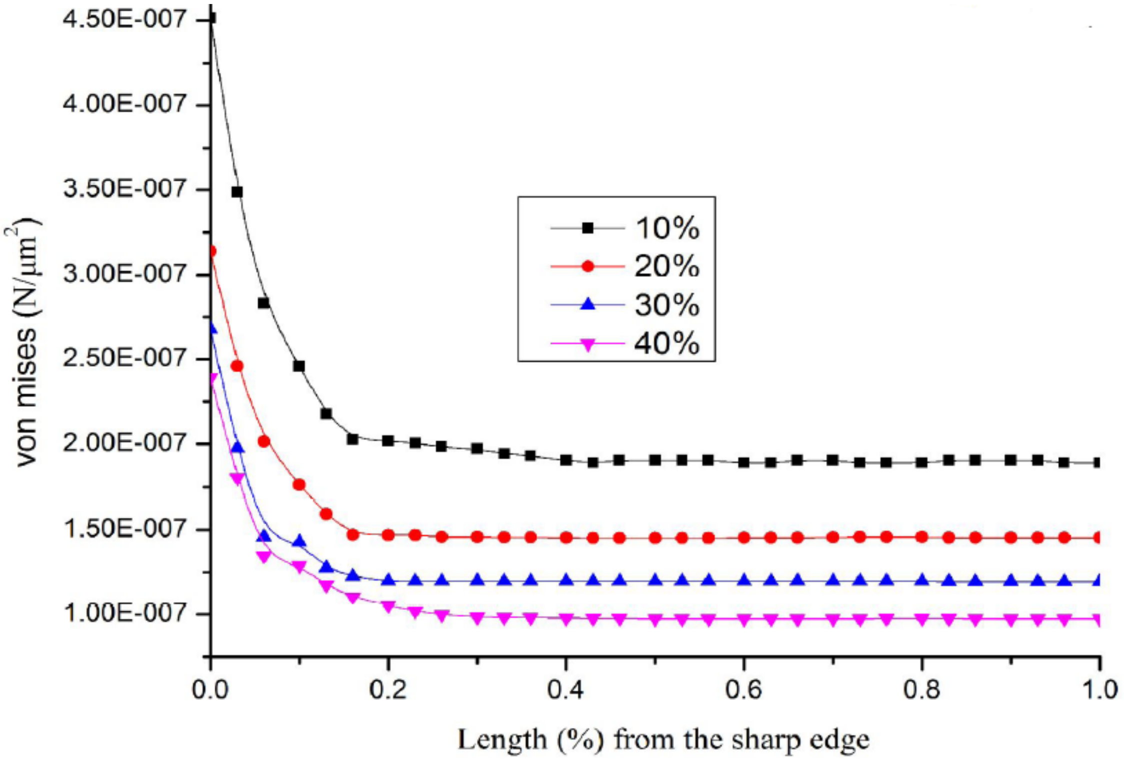


Figure:8 Von Mises stress along radial direction

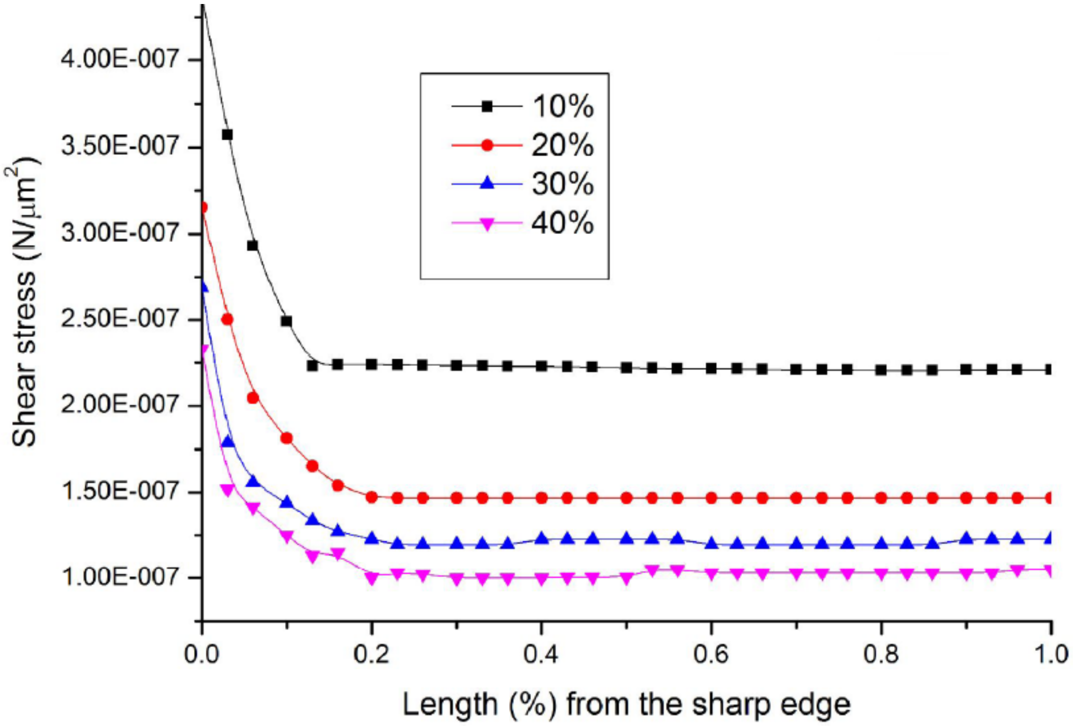


Figure:9Shear stress along length interface

10%,20%,30%and40% in figures(7,8,9) -Different volume fraction

Along the length interface as volume fraction increases, the tensile stress along the lengthwise interface decreases. There is a large tensile stress at the tip of fiber as shown.
This can be explained as the distortion of tip of fiber due to large stress which can be seenduring simulation of model. The shear stress shows the similar trend of higher stressas the volume fraction decreases. This shear stress has high values near the tip and almostzero elsewhere, along the length interface. It is observed that the sudden decrease of shearstress is very close to tip of fiber. This dip is due to the movement of tip in inward directionof the model. At this point tensile force is more dominant due to distorted shape of the fiber tip. Thisis justified by seeing the sharp increase in tensile stress at the same length. Von-misses stress
Increases by decreasing volume fraction of fiber-matrix showing the critical region at the tipof the fiber.

Conclusions

- Short-fiber composites do have following attractive characteristics thatmakethem worthy of consideration for many engineering applications.
- It explains that the failure/breaking will start at the tip of short fiber reinforced
- Stress distribution along fiber length strongly depends on fiber volume fraction.
- The stress distribution in the matrix region predicted by the model is used to assess the shear failure in the matrix region. The tensile str esses built up in the fibers are used to estimate the potential of fiber breakage

References

1. Ghassemieh E.,(2001),” Micro-mechanical analysis of polymeric composite using finite element Method “, Loughborough University UK, Composite science and technology, 62, 67-82.
2. Ghassemieh E. and Nassehi V. ,(2001),” Prediction of failure and fracture mechanism of polymeric composite using finite element analysis Part: 1”, Loughborough University, UK, Polymer composites, 24, 4 528-541.
3. Ghassemeih E.,(2001),” Advance in polymer Technology”. John Wiley & Sons, Inc. Adv Polymer Technology, 20, 42-57.
4. Hayes S.A., Lane and Jones F.R.,(2001),” Fiber/matrix stress transfers through a discrete interphase. Part 1: single-fiber model composites”, 32, 379-389.
5. Hayes S.A., Lane and Jones F.R.,(2001),”Fiber/matrix stress transfers through a discrete interphase. 2. High volume fraction systems”,32,3-4 379-389.
6. Yun Fu, Chee-Yoon, Xiao Hu, Yiu-Wing Mai,(2001),” Analyses of the micromechanics of stress transfer in single – and multi- fiber pull-out tests”, composites science and technology 60, 569-579.
7. Goh, Aspden, Hukins, (2004), “finite element analysis of stress transfer in short-fiber composite materials”, UK, Composites Science and Technology, 64, 1091–1100.

8. Singh S, Batra N.K., Rattan R. ,(2012),"Analysis and Experimental Investigation of Effect of Reinforcement Dimensions on Vibration Characteristics of Polypropylene Composite", International Journal of Engineering Research and Development, Volume 1, Issue 2.
9. Wang, Backer and V.C.LI,(1989),"Astatistical tensile model of fiber reinforcedcomentitious composites", Ltd composites, 20. 120-132.
10. Reddy J.N. ," an Introduction to Finite Element Method", TATA McGRAW-HiLL