ANALYSIS OF SELF LUBRICATING FIBRE REINFORCED POLYMER COMPOSITES WITH ANALYTICAL AND FEM ANAYSIS

K.SANGEETA RAO[#1],[*2] M.VENKAYYA

Mechanical Department, Narasaraopet, College, Narasaraopet, Andhra Pradesh, India-5226
Jawaharlal Nehru technological university Kakinada
[1]sangeetaraomech@gmail.com
[2]venkat.mandula304@gmail.com

ABSTRACT

Fiber reinforced polymer (FRP) composites are an important class of tribological materials. They possess unique self-lubrication capabilities and low noise which make them suitable for applications like seals, bearings, gears. The FRP composite bearings are ideal for high load, low speed applications or where normal lubrication is difficult or costly. For the purpose of fully utilizing the beneficial contact characteristics of FRP composites, it is necessary to obtain an in-depth knowledge of their contact behavior. This work attempts to apply Hwu and Fan's analytical solution to FRP composite bearings in order to obtain a better understanding of their compliance behavior. The frictional sliding contact between a FRP composite and a rigid parabolic cylinder was analyzed. The influence of sliding direction, fiber and matrix material combinations, volume fraction of the fiber, friction coefficient and fiber ply orientation on the contact pressure distribution and the contact area for unidirectional FRP composite bearings were evaluated. The finite element model was developed using ANSYS 10.0 and the results obtained from FEM were compared with the analytical results. The influence of sliding direction on the contact pressure distribution for cross ply FRP composite bearings was studied and compared with unidirectional FRP composite bearings. The contact parameters for unidirectional FRP composite bearings were optimized using genetic algorithm.

INTRODUCTION

New requirements for high performance defense and space systems have led to the development of advanced engineered materials. Service requirements that could be met with conventional materials are now being met through the recent development of advanced composites. Composites consist of two or more materials or material phases that are combined to produce a material that has superior properties to those of its individual constituents. A composite is a structural material, which consists of combining two or more constituents in order to obtain a combination of properties that cannot be achieved with any of the constituents acting alone. The constituents are combined at a macroscopic level and or not soluble in each other. The constituents as well as the interface between them are recognizable and it is the behavior and properties of the interface that generally control the properties of the composite. The main difference between a composite and an alloy is that in a composite the constituent materials are insoluble in each other and the individual constituents retain their properties, where as in alloys, constituent materials are soluble in each other and form a new material which has different properties from their constituents. Genetic algorithm (GA).

LITERATURE REVIEW

Unidirectional continuous fiber-reinforced polymeric composites exhibit significant tribological anisotropy due to their heterogeneity. Tsukizoe and Ohmae [1] investigated the wear performance between carbon FRP and steel by considering the effect of sliding direction and type of carbon fiber.

[2] and Viswanath et.al. [4] Investigated the effect of fiber orientation on the wear of FRP composites.

Their experimental work showed that the largest wear resistance was obtained when the sliding was normal to the fiber orientation, while the lowest wear resistance was obtained when the fiber orientation was transverse.

FINITE ELEMENT ANALYSIS

For the purpose of assessment, a three dimensional finite element model was constructed to simulate a cylinder that slides with respect to a unidirectional continuous FRP composite substrate. The finite element model was generated using ANSYS 7.0 and the boundary conditions were given to obtain results under the idealized condition of an infinitely long rigid cylinder that was in normal and tangential contact with an elastic half-plane. The FEM results were compared with the results obtained from the analytical solutions.

CONTACT ANALYSIS

Contact analysis is a non-linear analysis and requires significant computer resources to solve. Contact problems fall into two general classes such as rigid-to-flexible and flexible-to-flexible.

In rigid-to-flexible contact problems, one or more of the contacting surfaces are treated as rigid (i.e., it has a much higher stiffness relative to the deformable body it contacts). In general, any time a soft material comes in contact with a hard material, the problem may be assumed to be rigid-to-flexible. Many metal forming problems fall into this category.

In flexible-to-flexible contact problems, both contacting bodies are deformable (i.e., have similar stiffness). An example of a flexible-to-flexible contact is bolted flanges.

FE MODEL OF HALF-PLANE

The finite element model of the elastic half-plane was given in Fig. 1 The details of the model and the material properties were given below: Element type : SOLID46

Real constant :Set1

No. of layers = 1

Material ID = 1; Theta = 0;

Thickness = 0.02 m

Material : Material ID = 1;

(E-Glass/Epoxy)

(E_L = 44.52 GPa, E_T = 1.5 GPa,

ν_{12} = 0.33, G_{12} = 0.562 GPa)

Model : Solid model

(Length = Width = Height = 0.02 m)

Mesh : Volume mesh

Size control (Line): No. of element divisions = 8

No. of nodes = 162

No. of elements (Layered) = 706

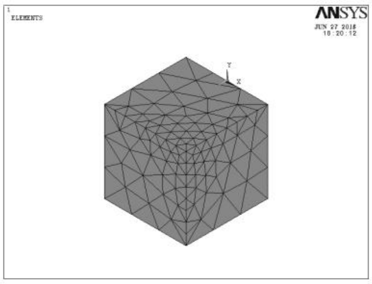

Fig.1 Finite element model of half-plane

FE MODEL OF PAPRABOLIC CYLINDER

The finite element model of the rigid parabolic cylinder was given in Fig. 1.5 The details of the model and the material properties were given below:

Element type : SOLID92

Material : Material ID = 2

Steel (E = 200 GPa, ν = 0.3)

Model : Solid model

Radius = 0.008 m, Length=0.02m

Mesh :Volumemesh Size control (Line): No. of element divisions = 8

No. of nodes = 1044

No. of elements = 509

The finite element model of the assembly of half-plane and parabolic cylinder was given in

Fig.2 The layered elements with 0° orientation and 90° orientation were shown in Fig.1 and Fig. 2

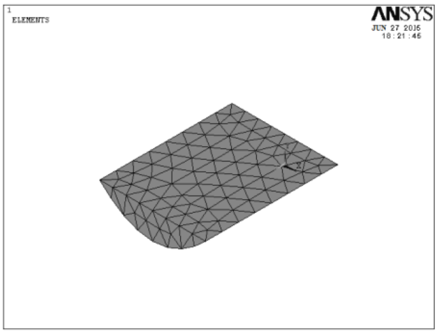

Fig.2 Finite element model of parabolic cylinder

RESULTS AND DISCUSSION

Based on the representations of elastic properties of FRP composites, law of mixture and the analytical solutions, the influence of sliding direction, material combinations, fiber volume fraction, frictional coefficient and fiber ply orientation on the contact pressure distributions was determined for the unidirectional FRP composite bearing.

The finite element model was generated using ANSY 7.0 and the results obtained from FEM were compared with the analytical results for unidirectional FRP composites. The influence of sliding direction on the contact pressure distribution for crossply FRP composite bearing was also studied and compared with the results of the unidirectional FRP composite bearings. The contact parameters were optimized using Genetic Algorithm (GA) for the unidirectional FRP composite bearings.

ANALYTICAL RESULTS

The influence of various parameters on the contact pressure distribution for FRP composite bearings were calculated using computer programming. Here, a normal force of 1 N and an indent radius of 8 mm are considered. Three different sliding directions are considered: (1) Transverse direction (TL); (2) Normal direction (NL) and (3) Parallel direction (PL).

The pressure distributions for a wide range of contact conditions are plotted in Fig. 1.6.1 to Fig.1.6.2 In these figures, the horizontal co-ordinate is marked according to the fraction of the average contact half-width, x_0.

$$x_0 = (a_1 + b_1)/2 \quad (6.1)$$

In equation (6.1), (a_1, b_1) represents the interval of the contact patch. The vertical co-ordinate represents the pressure values.

Influence of Sliding Direction

The influence of the sliding direction was shown in Fig. 1.6.1 for E-Glass/Epoxy composite. It is found that the contact pressure distribution and the contact patch can significantly vary with the sliding directions. In this figures, the largest maximum pressure and the smallest contact patch occur in the normal sliding direction. There is only a slight variation in the contact pressure between the transverse and parallel directions. The maximum contact pressure in the normal direction deviates the farthest distance from the vertical axis of the cylinder and is nearest to the vertical axis of the cylinder in the case of the transverse and parallel directions. This is due to the fact that the normal direction is very stiff and has a small contact area than the other two directions.

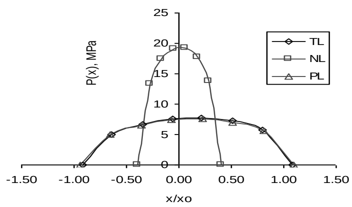

Fig.3 Influence of sliding direction

Influence of Fiber Material

The fibers of FRP composites give them their unique mechanical characteristics. Fig. 1.6.2(a) – Fig. 1.6.2(c) illustrate the variation of the contact pressure distributions of four different fiber materials in the transverse, normal and parallel sliding directions respectively. The fiber materials and their properties were given in Table 1 It was important to note that the matrix material was identical for all the results in Fig. 4(a) – Fig. 4(c). Here the fiber volume fraction of 60% was considered.

From the figures, it was found that the fiber material has little influence on the contact profile and magnitude of the pressure in the transverse direction. The contact pressure increased from 7.69 MPa for the glass fiber to 7.73 MPa for the carbon fiber and there was negligible change in the area of the contact patch. The symmetry parameter δ increased from 0.4612 for the glass fibers to 0.4894 for the carbon fibers.

Table 1:Material properties

Material	Modulus (GPa)	Poisson's ratio	Frictional coefficient
E-Glass	72	0.2	0.43
Aramid	130	0.36	0.17
Stainless steel	186	0.3	0.18
AS4 - Carbon	235	0.2	0
Epoxy	0.33	0.34	0.3
PEEK	3.6	0.3	0.4

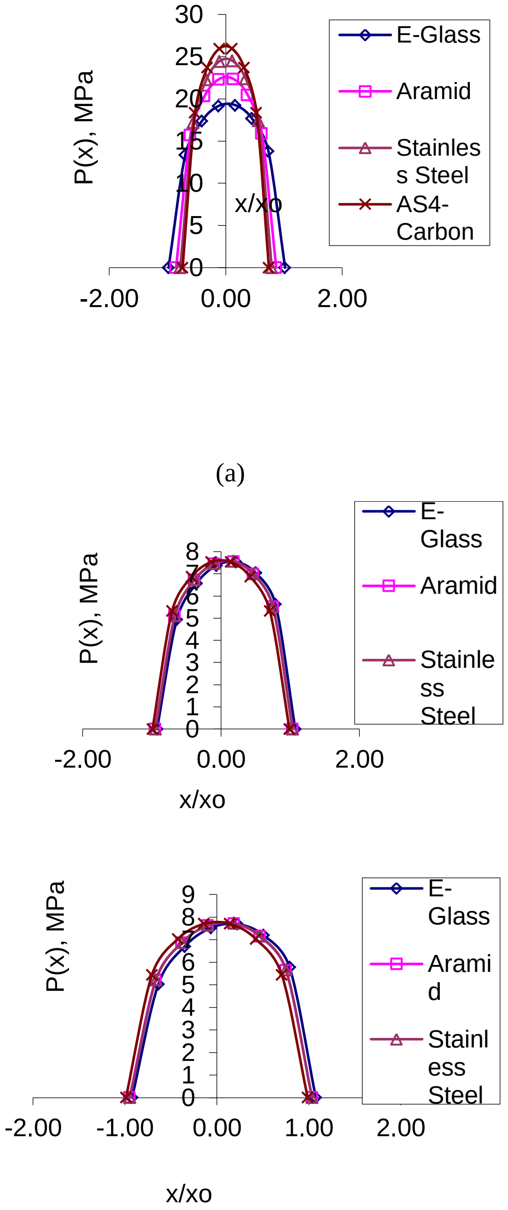

Fig. 4 Influence of fiber material (a) Transverse direction (b) Normal direction (c) Parallel direction

FEM RESULTS

The finite element model was solved and the results were obtained. The distribution of the contact pressure within the elements and the nodal solution for the stress along the normal direction were shown in Fig.5 – Fig.6 for the three sliding directions. The maximum contact pressure developed in all the three directions were used for the comparison with analytical results.

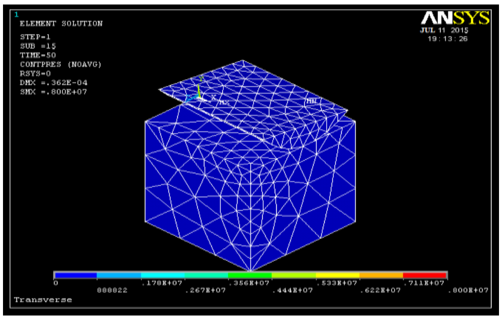

Fig.5 Contact pressure in Normal direction

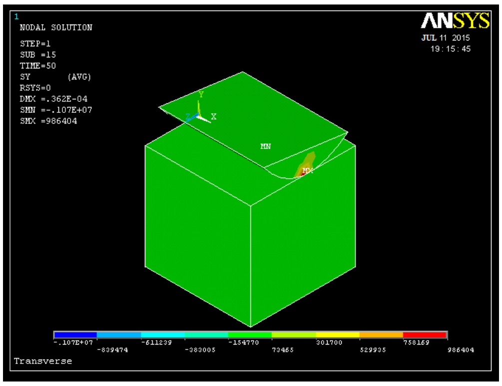

Fig.6 Normal stress in Normal direction

COMPARISON OF FEM AND ANALYTICAL RESULTS

The values of the maximum contact pressure along the three sliding directions were compared for E-Glass/Epoxy composite between the analytical and FEM results. Excellent correlation was found in all the three sliding directions. The differences in the maximum contact pressure predicted analytically and by FEM were very small.

In fact, the pressures vary by only 3.8 percent and 6.5 percent respectively in the transverse and parallel directions. The largest difference between values is in the normal direction where the analytical and FEM results differ by 15 percent.

CONCLUSIONS

The influence of sliding direction, fiber and matrix material combinations, the volume fraction of fiber, frictional coefficient and fiber ply orientation on the contact pressure distribution and the contact patch for unidirectional FRP composite bearing had been evaluated. The finite element model was developed and the results obtained from FEM were compared with the analytical results. The contact parameters were optimized using GA. The influence of sliding direction on the contact pressure distribution for crossply FRP composite bearing was also studied.

- Parallel directions and less strength along the normal direction than the unidirectional bearings. This is due to the reason that only one half of the fibers carry the load in normal direction.

REFREENCES

[1]Tsukizoe and Ohmae investigated the wear performance between carbon FRP and steel by considering the effect of sliding direction and type of carbon fiber.

[2] and Viswanath et.al. Investigated the effect of fiber orientation on the wear of FRP composites. Their experimental work showed that the largest wear resistance was obtained when the sliding was normal to the fiber orientation, while the lowest wear resistance was obtained when the fiber orientation was transverse.

[3]Continuous Fiber-Reinforced Composites", STLE Tribology Transactions, 36, pp. 120-126.

[4]Viswananth, B., Verma, A. P., and Rao, V. S. K., 1993, "Effect of Reinforcement on Friction and Wear of Fabric Reinforced Polymer Composites", Wear 167, pp.93-99.

[5] Gardos, M.N., 1982, “Self Lubricating Composites for Extreme Environment Applications”, Tribology International, 15, pp. 273-284.

[6]Ishigaki, H., Nagata, R., Iwasa, M., Tamarai, N., andKondo, I., 1988, "Tribological Properties of Silicon Carbide Whisker Containing Silicon Nitride Composite", ASME Journal of Tribology, 110, pp. 434-438.

[7]Ralph A. Burton, and Gaines Burton, R., 1990, "Wear Experiments on Glassy-Carbon Based Materials", ASME Journal of Tribology, 112, pp. 68-72.

[8]Xiao, Y., Wang, W.X. Takao., and Ishikawa, T., 2000, "The Effective Friction Coefficient of Laminate Composite, and Analysis of Pin-Loaded Plates", Journal of Composite Materials, 34, pp. 69-87.

[9]Navin Chand, Majumdar, B., and Fahim, M., 1994, "Theory of Abrasive Wear Mechanism for FRP Composite", Indian Journal of Engineering and Materials Science, 1, pp. 273-278.

[10]Overeat, T.C., and Wu, J.P., 1993, "Theoretical estimates of Asperity-Scale Stresses in Normally-Oriented Continuous Fiber-Reinforced Composites", STLE Tribology Transactions, 36, pp. 120-126.

[11]Wu, J.P., and Ovaert, T.C., 1994, "Effect of Asperity-Scale Tensile Stresses on the Wear Behaviour of Normally Oriented Fiber Reinforced Composites", STLE Tribology Transactions, 37, pp. 23-32.