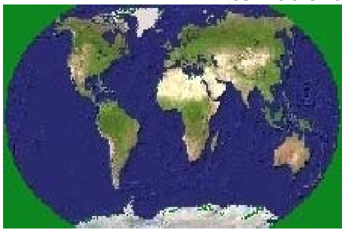

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H. Khaisar Basha
M.Tech Student, Department of Mechanical Engineering, Nimra College of Engineering and Technology (NCET) Ibrahimpatnam, Vijayawada, Andhra Pradesh, India.

K. Durga Sushmitha
Assistant Professor Department of Mechanical Engineering, Nimra College of Engineering and Technology (NCET) Ibrahimpatnam, Vijayawada. Andhra Pradesh, India.

Correspondence:
H. Khaisar Basha
M.Tech Student, Department of Mechanical Engineering, Nimra College of Engineering and Technology (NCET) Ibrahimpatnam, Vijayawada, Andhra Pradesh, India.

Analysis of frictional sliding contact between a fiber reinforced polymer (FRP) composites and a rigid parabolic cylinder by using fem

H. Khaisar Basha, K. Durga Sushmitha

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 behaviour.

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 behaviour. 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.

1. 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.

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. The fiber orientation has a significant influence on the wear and friction behaviour of FRP composites. Sung and Suh [2], Cirino *et al.* [3] 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.

The coefficient of friction was found to depend on several factors including the material combination, the fiber orientation and the surface roughness. Sung and Suh [1] showed for graphite/epoxy composites that the friction coefficient was minimized when the orientation of the fibers was normal to the sliding direction. Conversely, for Kevlar/epoxy composites, the normal orientation was found to yield the highest friction.

Gardos [5] derived wear equations for composites. Ishigaki, Nagata, Iwasa, Tamarai and Kondo [6] studied the influence of silicon carbide whisker content and its orientation on the wear rate ad friction.

Burton and Gaines Burton [7] studied the friction and wear behaviour of monolithic glass carbon and a composite made of copper fibers in a glassy carbon matrix in the presence of oxygen and nitrogen. In other related work, Xiao et al. [8] tested the frictional coefficient in a unidirectional lamina with the variation of the fiber orientation angle and the surface roughness. Navin Chand, Majumdar and Fahim [9] modeled abrasive wear mechanism using spring network model. They also studied the influence of microstructural parameters, residual stresses and critical stress intensity factor on the wear. In order to theoretically explain anisotropic wear phenomena, Ovaert and Wu [10, 11] constructed a relationship between the wear rate of normally oriented FRP composites and the fiber debonding depth using the indentation of a spherical asperity. For the wear of FRP composites in the parallel direction, Ovaert [12, 13] later introduced a model of a beam lying on a foundation to simulate the fibers in polymer matrix.

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 behaviour. Hertzian and other fundamental contact theories are not valid for FRP composites due to their anisotropy. Fan and Hwu [14] recently studied general contact problems for anisotropic elastic half-plane by combining analytical continuation [15] and Stroh's formalism [16]. Fan and Hwu [17, 18] also derived a general closed-form solution for the sliding contact of bodies on anisotropic elastic planes.

2. 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.

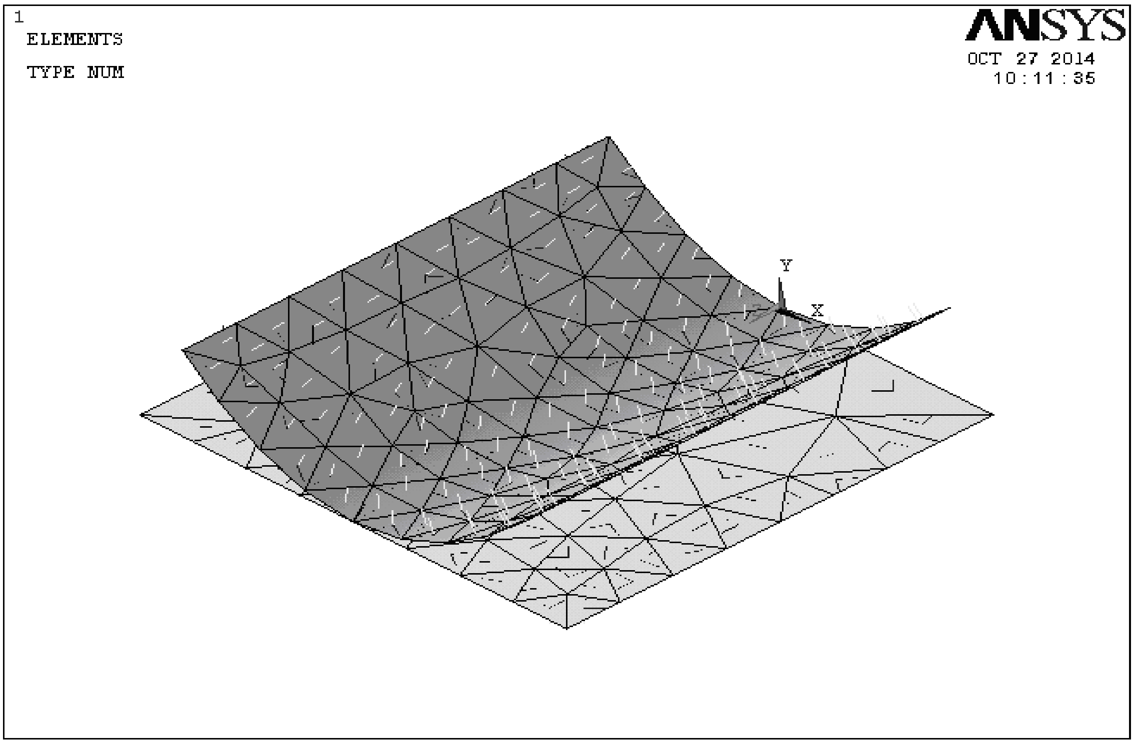
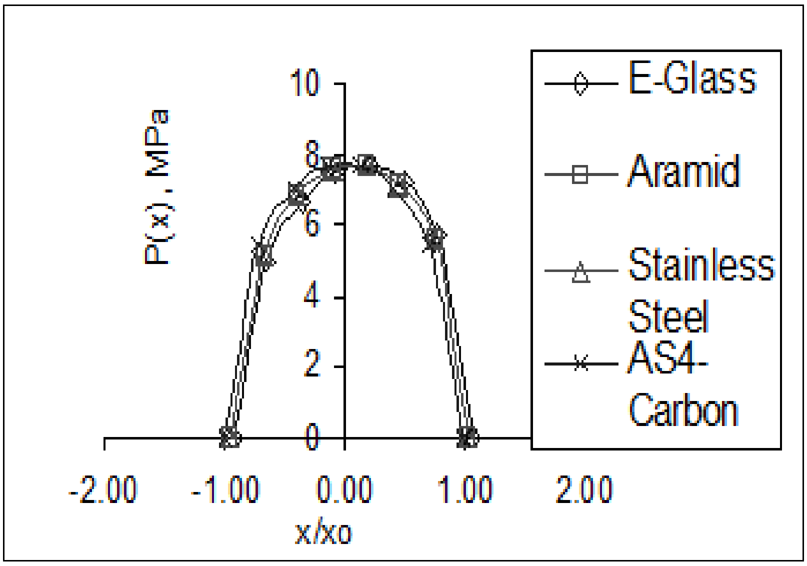


Fig 1: Contact pair and elements

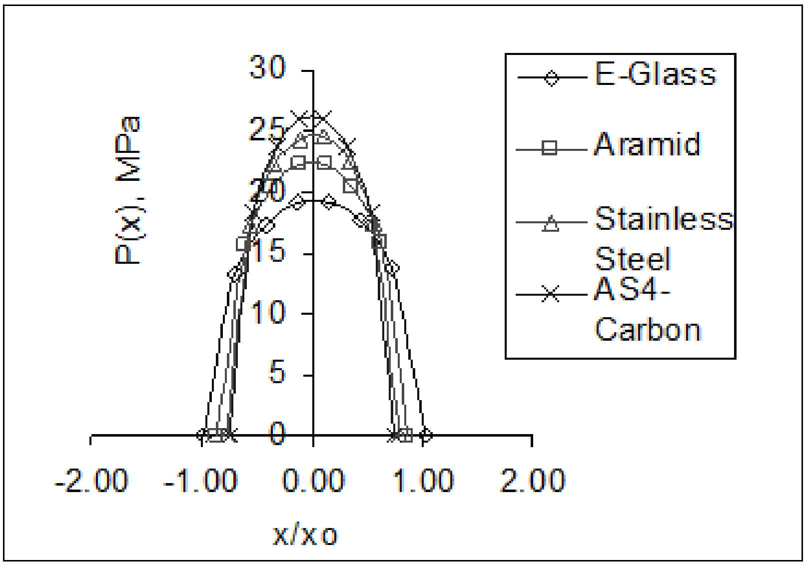
3. Results and Discussion

Table 1: Material properties

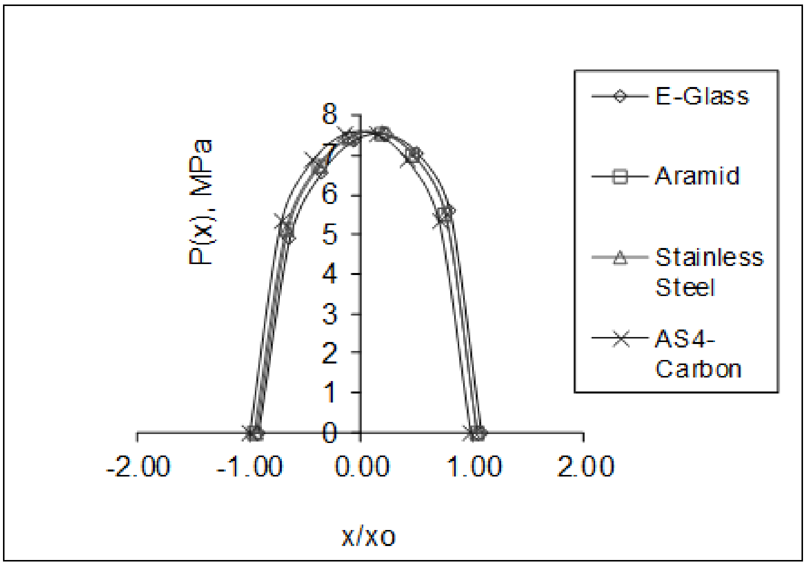
Material	Modulus (GPa)	Poisson's ratio	Frictional coefficient
E-Glass	72	0.2	0.43
Aramid	130	0.36	0.17
Stainless steel	186	0.3	0.18
AS4 - Carbon	235	0.2	0
Epoxy	0.33	0.34	0.3
PEEK	3.6	0.3	0.4



(a)

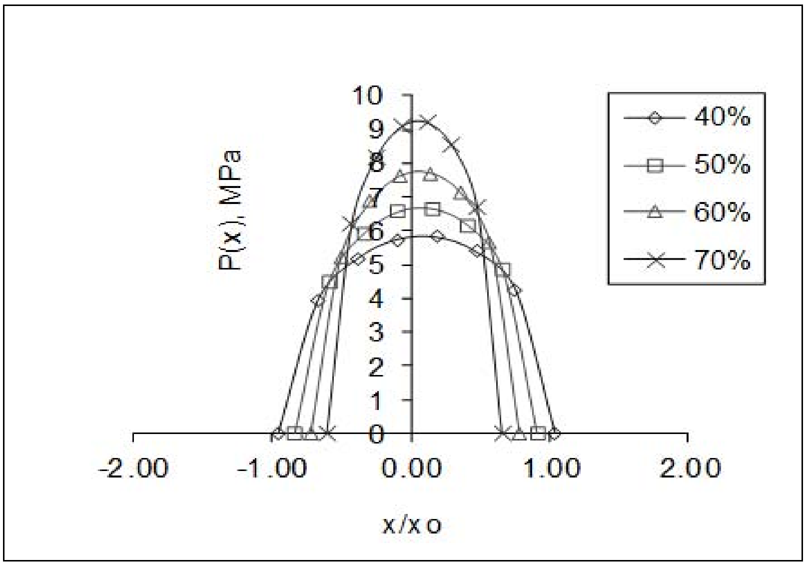


(b)

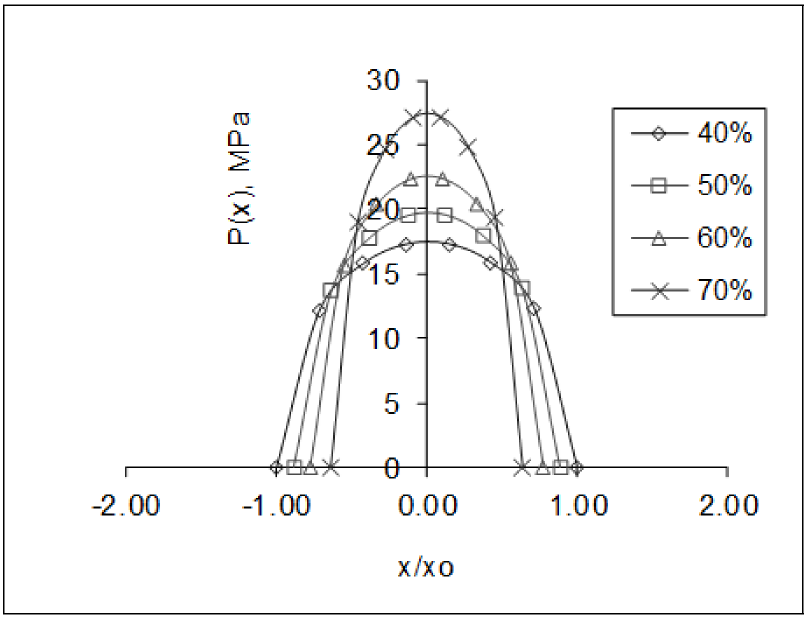


(c)

Fig 2: Influence of fiber material
(a) Transverse direction (b) Normal direction (c) Parallel direction



(a)



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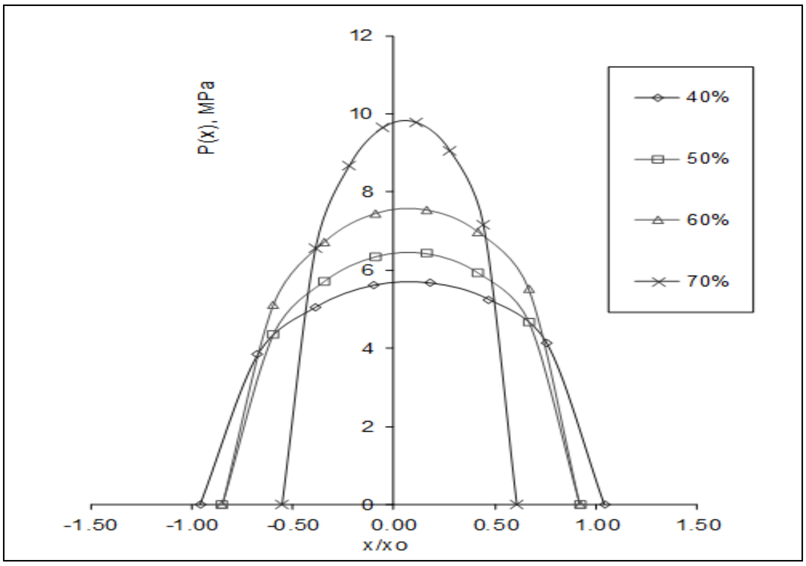

(c)

Fig 3: Influence of fiber volume fraction for Aramid/Epoxy
(a) Transverse direction (b) Normal direction (c) Parallel direction

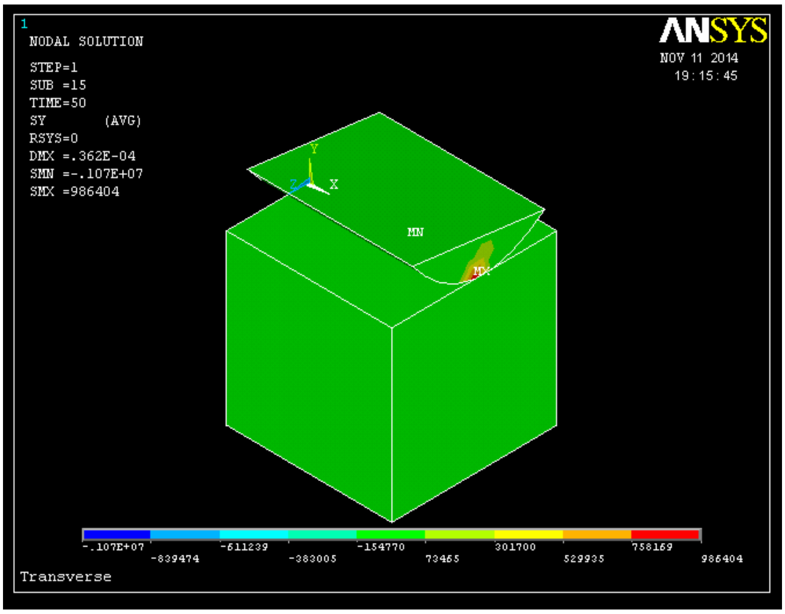

Fig 4: Normal stress in Transverse direction

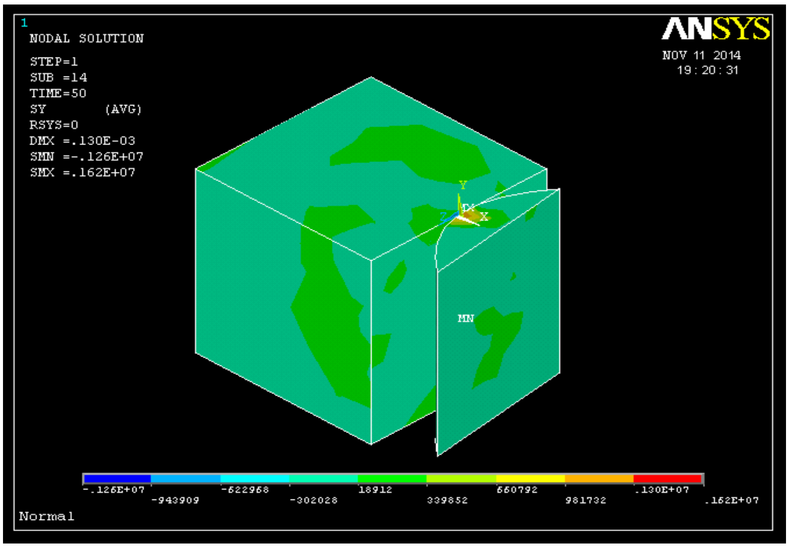

Fig 5: Normal stress in Normal direction

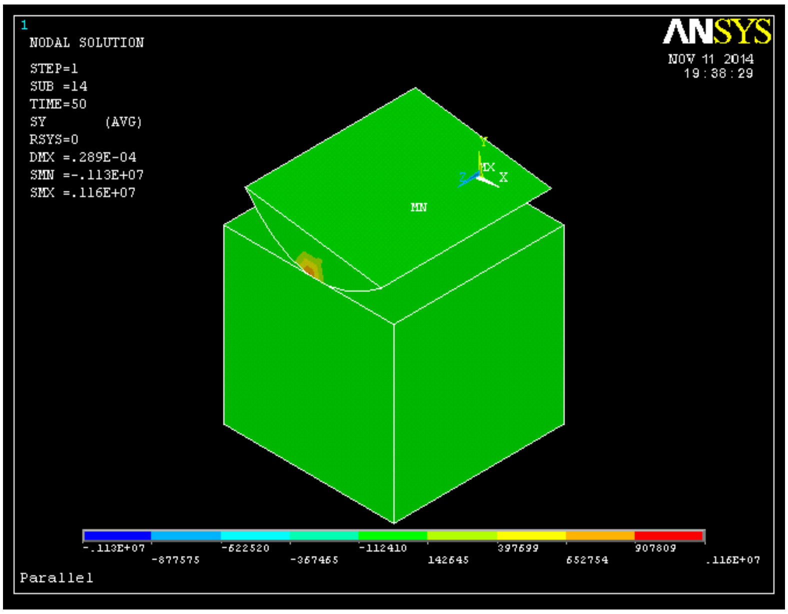

Fig 6: Normal stress in Parallel direction

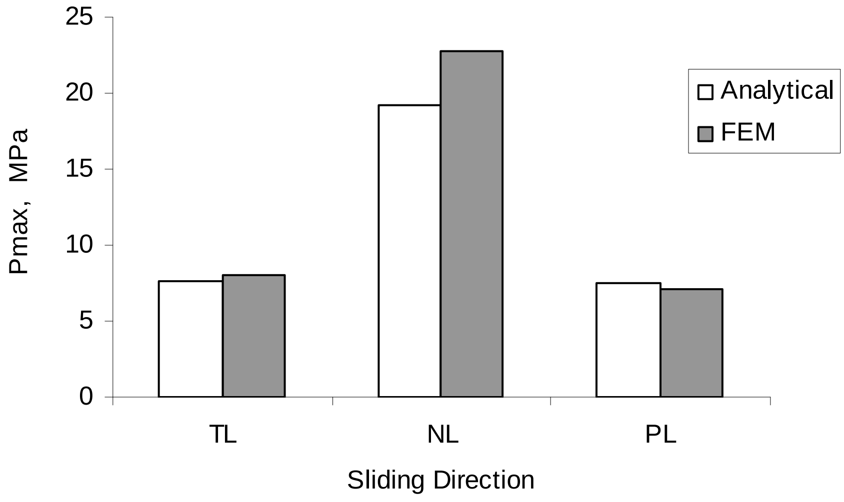

Fig 7: Comparison of FEM and analytical results

4. 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.

4.1 Unidirectional FRP composite bearings

Some of the important findings in the sliding contact characteristics of unidirectional FRP composite bearings were summarized below:

- The highest maximum contact pressure was obtained in the normal direction. This was due to the fact that the fibers were carrying a large portion of the load.
- The analytical results indicated that the contact pressure and contact patch play critical role in the wear of FRP composite bearings. Therefore similar to that found by the experiments [2, 3, 23], the normal direction had the highest wear resistance.
- The contact pressure distribution was not symmetrical. The normal sliding direction had the least symmetric contact area, whereas the parallel direction had the most symmetric area.
- The contact pressure in the transverse and parallel directions showed little change, whereas significant influence was there in the normal direction with a variation of fiber materials because the fibers were carrying a large portion of the load in the normal direction.
- Since the fibers were stiffer than the matrix materials, increasing the volume fraction of fibers increased the maximum contact pressure in all the three directions.
- The maximum contact pressure varied significantly with the elastic modulus of the matrix materials. The normal direction was the least sensitive to changes in the matrix materials.
- The frictional coefficient had little effect on the magnitude of the contact pressure in all the three directions.
- The transverse and parallel directions were least sensitive to the fiber ply orientation, whereas the normal direction showed a considerable change in the maximum contact pressure, contact patch and symmetry parameter with a variation of the fiber ply orientation.
- The contact parameters such as sliding direction, material combinations, fiber volume fraction and fiber ply orientation were optimized using GA.

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