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Numerical Modelling of Jenkins Model Based Ferrofluid Lubricated Double Layered Porous Rough Inclined Slider Bearing with Effect of Slip Velocity

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Abstract:

This article discusses the ferrofluid lubrication of a double layered porous rough inclined slider bearing with the consideration of slip velocity. The ferrofluid flow model of Jenkins is found to be used here. For the development of Reynolds's equation, the stochastic averaging of Christensen and Tonder for roughness and Beavers and Joseph slip model are factored in to the derivation. The results confirm that the Jenkins model based magnetic fluid flow introduces a better positive effect as compared to Neuringer - Rosensweig model. The adverse effect of transverse roughness can be countered effectively by the Ferrofluid lubrication when the slip is less and this positive effect advances due to the double layered. Lastly, it is seen that some amount of load is always supported even in the absence of flow which is rarely found in the case of traditional lubrication.

Keywords: Slider Bearing, Roughness, Pressure, Friction Coefficient, Porosity, Agricultural Equipment

1. Introduction:

Many agricultural equipment are based onperiodic lubrication of bearings in order to keep them away from wearing or seizing. The purpose of the bearing is basically to support rotating machinery, shafts and components for instance wheels on tractors, rolls on hay balers, disk on tillage equipment and gears in transmission etc. Applications of porous bearings in mounting water pumps, horsepower motors include vacuum cleaners, tape recorders, record players, and generators.

Fluids with strong magnetic properties have drawn considerable attentions in recent years. For lubricating the bearing system in technical applications in the domain of nano scale Science and Technology, significant progress has been made. Therefore, the use of magnetic fluid lubrication adds an additional importance from nano science point of view. Magnetic fluid consists of colloidal magnetic nano particles dispersed with the aid of surfactants in a continuous career phase. In fact, Magnetic fluid is a typical hybrid of soft material and the nano particles. The average diameter of the dispersed particles ranges from 5 to 10 nm. The ferrofluids contain enormous magnetic nano particles and therefore can be influenced by either parallel or perpendicular magnetic field.

Jenkins [1] used a simple continuum model for a paramagnetic fluid to analyze a simple shearing flow and parallel flow through a pipe and examined the possibility of maintaining a steady circular flow in a circular cylinder by rotating a magnetic field, Verma and Singh [2] considered the interaction between magnetic and mechanical forces in the case of flow of an incompressible paramagnetic fluid through a porous annulus subjected to external magnetic field. However, increase in the material parameter caused decreased load carrying capacity and increased friction.

It is well known that the roughness of the bearing surfaces retards the motion of the lubricant thereby affecting adversely the bearing system. Tzeng and Saibel [3] recognized the random character of the roughness and adopted a stochastic approach to study the effect of surface roughness. This modeling of Tzeng and Saibel [3] was modified by Christensen and Tonder [4-6] to deal with the effect of surface roughness in general, on the performance of the bearing system. Below are some of the investigations which made use of the method of Christensen and Tonder [4-6] to account for surface roughness.Patel and Deheri [7] investigated the performance of a ferrofluid lubricated rough porous inclined slider bearing considering slip velocity. It was observed that magnetization introduced a positive effect on the performance, the bearing suffer owing to transverse surface roughness. The performance of the bearing system can be made to improve by suitably choosing the magnetization parameter and slip coefficient in the case of negatively skewed roughness, which turns out to be more sharp with the occurrence of variance (-ve).

From last two decades, the interface region of multilayer flows has drawn interest in the fluid mechanics due to its applications in various physical settings. These applications include packed-bed heat exchangers, heat pipes, thermal insulation petroleum reservoirs nuclear waste repositories, and geothermal engineering. The problem of two layers flow was investigated by numerous authors (Verma [8], Rao et al. [9-10], Phani Kumar et al. [11] in Journal bearing and Srinivasan [12], Patel and Deheri [13] in slider bearing).

It is well established that the roughness of the bearing surfaces tends to obstruct the movement of the lubricant and thus influencing the bearing framework unfavorably. The behaviour of the flow of magnetic fluids has been the subject of many articles over the past decade. A number of authors (Shah and Bhat [14] in exponential slider bearing; Shah and Bhat [15] in circular convex pad slider bearing; Patel and Deheri [16] in annular bearing; Patel and Deheri [13] in circular bearing; Patel and Deheri [17] in Parallel plate slider bearing; Deheri et al. [18] in convex pad slider bearing, Patel and Deheri [19] in circular bearing and Laghrabli et. al [20] in Journal bearing) analyzed the performance of different geometries of bearing system with Jenkins's magnetic fluid flow model. All these studies indicated that Jenkins's magnetic fluid flow model effect viscosity of the fluid therefore it might be improve the load carrying capacity of the bearing up to some extent. Mishra et al. [21] analyzed the effects of surface roughness, porosity and magnetic field on an inclined slider bearing. It was manifest that the adverse effect of slip parameter, reported in earlier studies over load carrying capacity turns rather sinusoidal to be favorable which might be due to the pattern of variation of magnetic field considered.At present, the literature talks of less about double layer porous medium with roughness and ferrofluid lubrication in the bearing systems. This study aims to analyze the performance of combined effect of slip velocity and surface roughness on the ferrofluid based squeeze film lubrication in double layered porous inclined slider bearing.

2.Analysis:

The ferrofluid based squeeze film lubrication in double layered porous inclined slider bearing with roughness and slip velocity is accessible in figure 1.

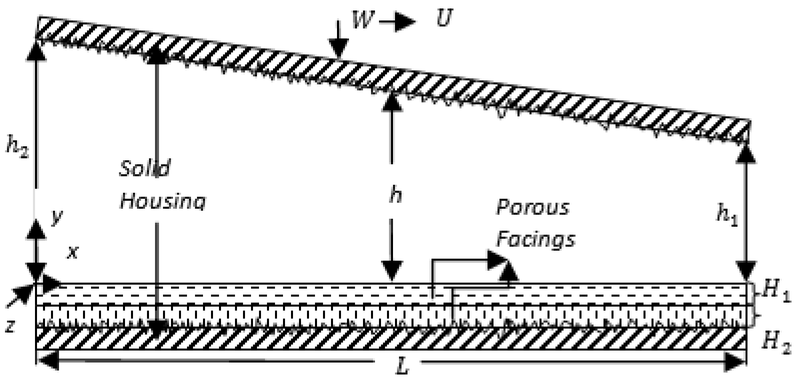

Fig1. Configuration of the Bearing System

Considering above basic postulates, for ferrofluid based squeeze film lubrication (in double layered porous inclined slider bearing), the roughness and slip characteristics are visualized in the shape as illustrated in Figure 1, where physical configurations depicting all such forces & elements of bearing system are clearly illustrated. The film thickness for above bearing system was considered as that of Bhat[22], by adhering to following mathematical shape,

$$\overline{h} = a - (a-1)X \ , \quad a = \frac{h_1}{h_2}, \ \overline{h} = \frac{h}{h_1} \ , \ X = \frac{x}{L}$$

Where, $\overline{h}$:Uniform fluid film thickness (mm), h_0 : Fluid film thickness at x=0, X : coordinate of the centre of pressure, and L : Length of the bearing.

The porous regions are assumed to be homogeneous and isotropic, and the lubricant as an incompressible Newtonian fluid. Slip model of Beavers and Joseph [23] was adopted, while model given by Jenkins [1] was considered to describe the flow of a magnetic fluid. Accordingly, the equation for these model for steady flow is taken as follows,

$$\rho(\overline{q}.\nabla)\overline{q} = -\nabla p + \eta \nabla^2 \overline{q} + \mu_0 (\overline{M}.\nabla)\overline{H} \tag{1}$$

$$\rho(\overline{q}.\nabla)\overline{q} = -\nabla p + \eta \nabla^2 \overline{q} + \mu_0 (\overline{M}.\nabla)\overline{H} + + \frac{\rho \alpha^2}{2} \nabla \left[\frac{\overline{M}}{M} \{ (\nabla \overline{q}) \overline{M} \} \right] \tag{2}$$

$$\nabla.\overline{q} = 0 \tag{3}$$

$$\nabla \times \overline{H} = 0 \tag{4}$$

$$\overline{M} = \overline{\mu}\, \overline{H} \tag{5}$$

$$\nabla.(\overline{H} + \overline{M}) = 0 \tag{6}$$

Using equations (4) and (5) then equation (1) resumes the form

$$\rho\left(\bar{q}.\nabla\right)\bar{q} = -\nabla\left(p - \frac{\mu_0\mu' H^2}{2}\right) + \eta\nabla^2\bar{q} + \mu_0\left(\bar{M}.\nabla\right)\bar{H} \quad (7)$$

Keeping in view the popular Neuringer - Roseinweig model for magnetic fluid flow and the stochastic averaging model of Christensen and Tonder [4] along with their inherent assumptions on hydromantic lubrication; the ultimate Reynolds' type equation for pressure distribution is derived as follows,

$$\frac{d}{dx}\left[\frac{T(h)}{1 - \frac{\rho\alpha^2\bar{\mu}H}{2\eta}}\frac{d}{dx}\left(P^* - \frac{\mu_0\bar{\mu}}{2}H^2\right)\right] = 6\eta U\frac{dh}{dx} + 12\eta\dot{h}_1 \quad (8)$$

Where

$$T(h) = \left\{h^3 + 3\alpha h^2 + 3\left(\alpha^2 + \sigma^2\right)h + 3\sigma^2\alpha + \alpha^3 + \varepsilon + 12\phi_1 h_1 + 12\phi_2 h_2\right\}\frac{(4+sh)}{(2+sh)} \quad (9)$$

The magnitude of the magnetic field (H^2) was derived by using a simpler but effective relationship i.e. $H^2 = KA^2\sin(\pi X)$.

2.1 Dimensional analysis

Studying relationships between physical quantities with the help of their dimensions and units of measurements, was taken as a sound base for attaining superior solutions of above derived governing equation/s. It was well achieved by adhering to fundamental units and principle of dimensional homogeneity that defy analytical solution and be solved via numerical experimentations. In many of the studies on bearing and related mechanical aspects, accomplishing non-dimensional forms of respective governing equations is established as a good practice to study the relative influences of multiple variables. In present study it is achieved by selecting certain characteristic quantities and then substituting suitable entities to make them dimensionless. About 11 such distinct dimensionless quantities were worked out in this study, whose elaborative expressions are presented provided below, distinguished dimensionless parameters as considered in mathematical analysis

$\beta = \frac{h_1 h^3}{2\dot{h}_1 L}$	$\bar{\mu} = \frac{K\mu_0\bar{\mu}h_1^2 L}{\eta U}$	$\bar{\alpha}'^2 = \frac{\rho\alpha^2\bar{\mu}L\sqrt{K}}{2\eta}$	$P^* = \frac{h_1^3 p}{\eta L^2\dot{h}_1}$
$W^* = \frac{h_1^3 w}{\eta L^4\dot{h}_1}$	$\bar{s} = sh_1$	$\bar{\varepsilon} = \frac{\varepsilon}{h_1^3}$	$\bar{\alpha} = \frac{\alpha}{h_1}$
$\bar{\sigma} = \frac{\sigma}{h_1}$	$\bar{\psi}_1 = \frac{\phi_1 h_2}{h_1^3}$	$\bar{\psi}_2 = \frac{\phi_2 h_2}{h_1^3}$	

Appropriate boundary conditions were carved of, which remained as follows,

$$P^*(1) = P^*(a) = 0 \quad (10)$$

Using above relationship, the equation (8) gets its outcomes in following form,

$$\frac{d}{dx}\left[P^* - \frac{1}{2}\bar{\mu}\ X(1-X)\right] = \frac{6}{T(\bar{h})}\left(T_1\frac{(2+\bar{s}\bar{h})}{(1+\bar{s}\bar{h})}\bar{h} - \beta^{-1}X + T_2\bar{K}\right)\left(1 - \bar{\alpha}'^2\sqrt{X(1-X)}\right) \quad (11)$$

where,

$$T_1 = 3\left(\bar{\alpha}^2 + \bar{\sigma}^2\right),\ T_2 = \left(3\bar{\sigma}^2\bar{\alpha} + \bar{\alpha}^3 + \bar{\varepsilon} + 12\bar{\psi}_1 + 12\bar{\psi}_2\right),\ K(\bar{h}) = \left\{\bar{h}^3 + 3\bar{\alpha}\bar{h}^2 + T_1 + T_2\right\}\frac{(4+\bar{s}\bar{h})}{(2+\bar{s}\bar{h})}$$

By integrating equation (11) and then adopting the boundary conditions (10), the realistic expression for the dimensionless pressure distribution was found in following form,

$$P^* = \frac{1}{2}\bar{\mu}\ \sin(\pi X) + \left\{ 6\int_0^1 \frac{1}{T(\bar{h})}\left(T_1 \frac{(2+\bar{s}\,\bar{h})}{(1+\bar{s}\,\bar{h})}\bar{h} - \beta^{-1}X + T_2\bar{K} \right) \right\} \left(1-\bar{\alpha}'^2\sqrt{X(1-X)} \right) dX \qquad (12)$$

Where,

$$\bar{K} = -\int_0^1 \frac{\frac{1}{T(\bar{h})}\left(T_1 \frac{(2+\bar{s}\,\bar{h})}{(1+\bar{s}\,\bar{h})}\bar{h} - \beta^{-1}X \right)\left(1-\bar{\alpha}'^2\sqrt{X(1-X)} \right) dX}{\frac{1}{T(\bar{h})}\left(1-\bar{\alpha}'^2\sqrt{X(1-X)} \right) dX}$$

Ultimately the mathematical formulation for load carrying capacity (W^*) and Friction Coefficient (F^*)in its dimensionless form was attained as follows,

$$W^* = \frac{2\bar{\mu}}{\pi} - \left\{ 6\int_0^1 \frac{X}{T(\bar{h})}\left(T_1 \frac{(2+\bar{s}\,\bar{h})}{(1+\bar{s}\,\bar{h})}\bar{h} - \beta^{-1}X + T_2\bar{K} \right) \right\} \left(1-\bar{\alpha}'^2\sqrt{X(1-X)} \right) dX \qquad (12)$$

$$F^* = -\int_0^1 \left[\frac{1}{T_1 \frac{(2+\bar{s}\,\bar{h})}{(1+\bar{s}\,\bar{h})}\bar{h}} + \frac{1}{\alpha \bar{h}^2}\left(T_1 \frac{(2+\bar{s}\,\bar{h})}{(1+\bar{s}\,\bar{h})}\bar{h} - \beta^{-1}X + T_2\bar{K} \right) \right] dX \qquad (13)$$

3. Results and Discussion:

It is observed from the equation of load carrying capacity that as compared to traditional lubrication there is a load increase of $\frac{2\bar{\mu}}{\pi}$ due to Ferrofluid lubrication. The linearity of the expression in with respect to $\bar{\mu}$ tends that the load will be increase with increasing values of $\bar{\mu}$.

The variation of load carrying capacity with respect to magnetization parameter displayed in Figures 2-7 indicates that the magnetization increases the load carrying capacity significantly. This effect is relatively less in the case of material parameter.

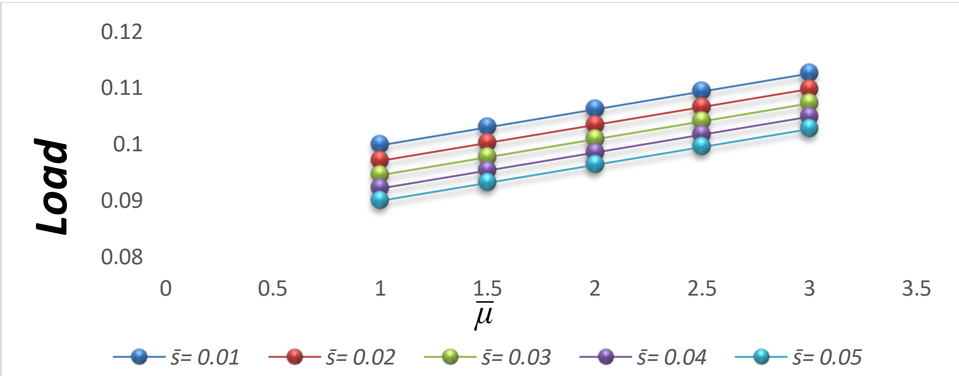

Fig 2. Variation of load carrying capacity with respect to $\bar{\mu}$ and $\bar{s}$

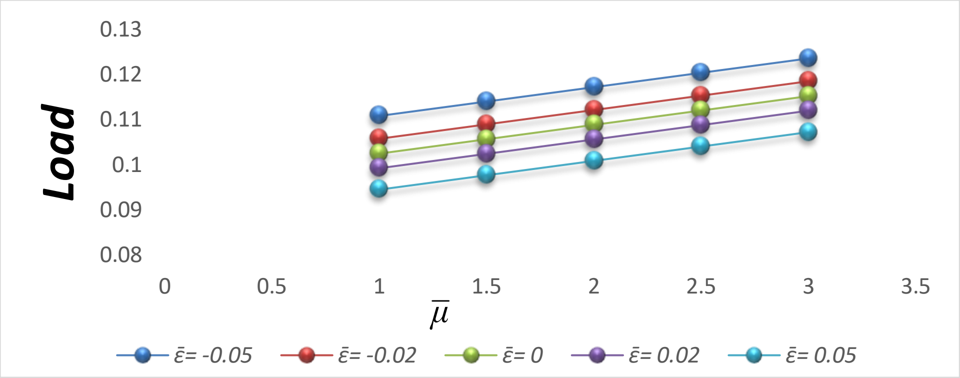

Fig3. Variation of load carrying capacity with respect to $\overline{\mu}$ and $\overline{\varepsilon}$

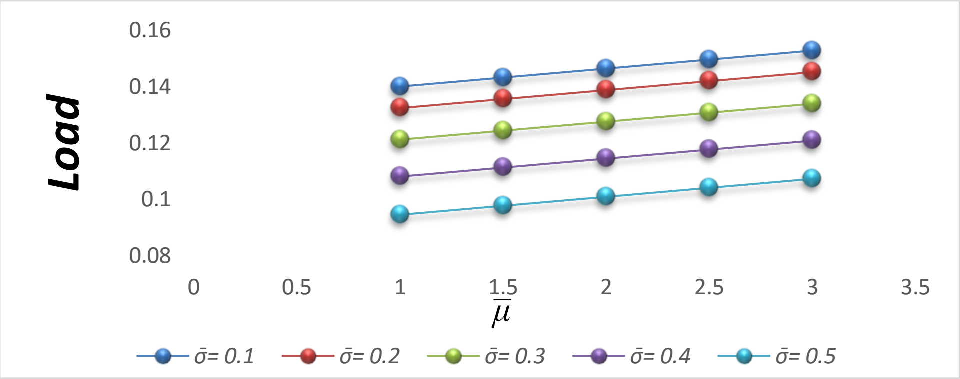

Fig4. Variation of load carrying capacity with respect to $\overline{\mu}$ and $\overline{\sigma}$

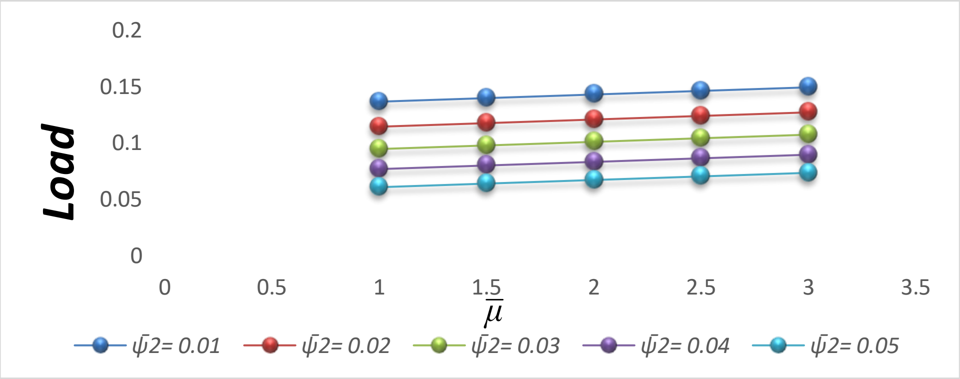

Fig5. Variation of load carrying capacity with respect to $\overline{\mu}$ and $\overline{\psi}_2$

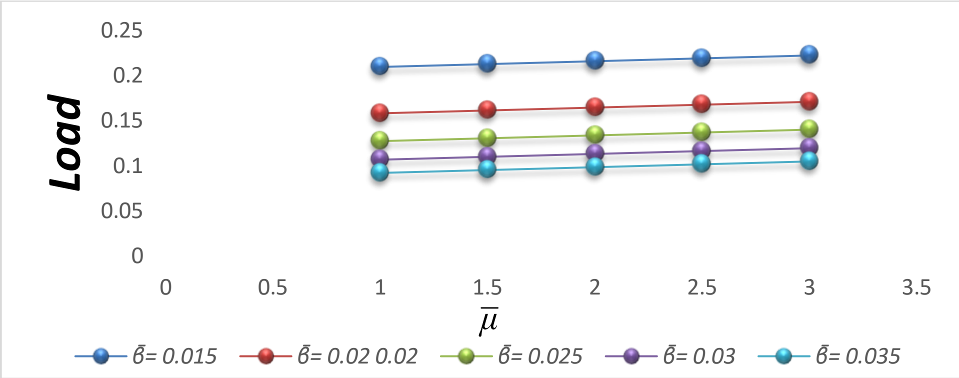

Fig6. Variation of load carrying capacity with respect to $\overline{\mu}$ and β

The variation of load carrying capacity with respect to the slip parameter is presented in Figures 8-12. It is clear that the load carrying capacity decreases considerably with increasing values of slip parameter. Therefore, slip is required to be kept at minimum for evaluating the bearing performance.

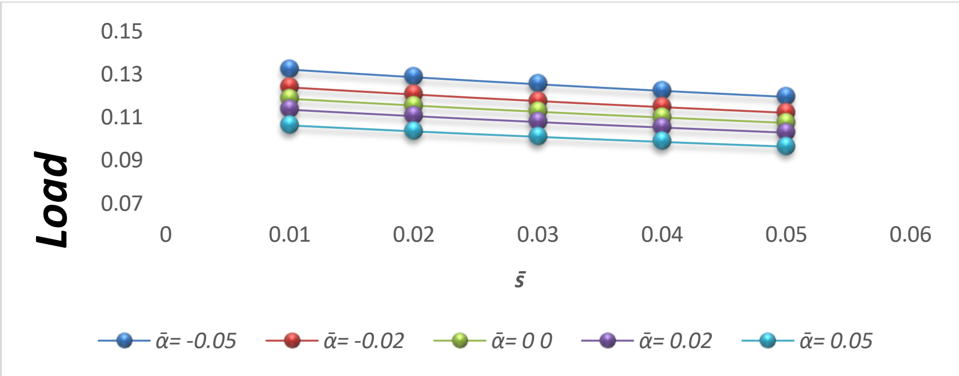

Fig7. Variation of load carrying capacity with respect to $\overline{s}$ and $\overline{\alpha}$

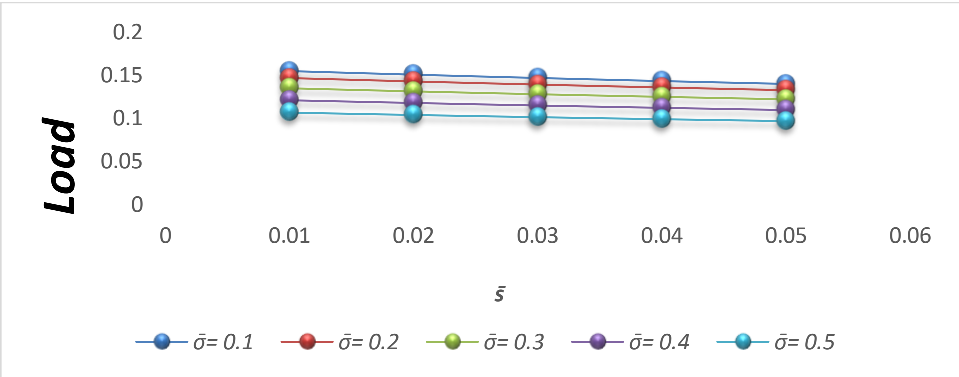

Fig8. Variation of load carrying capacity with respect to $\overline{s}$ and $\overline{\varepsilon}$

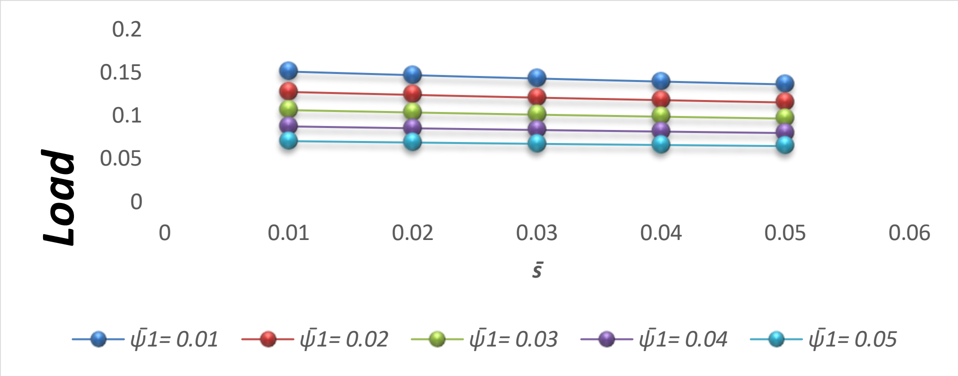

Fig9. Variation of load carrying capacity with respect to $\bar{s}$ and $\overline{\psi}_1$

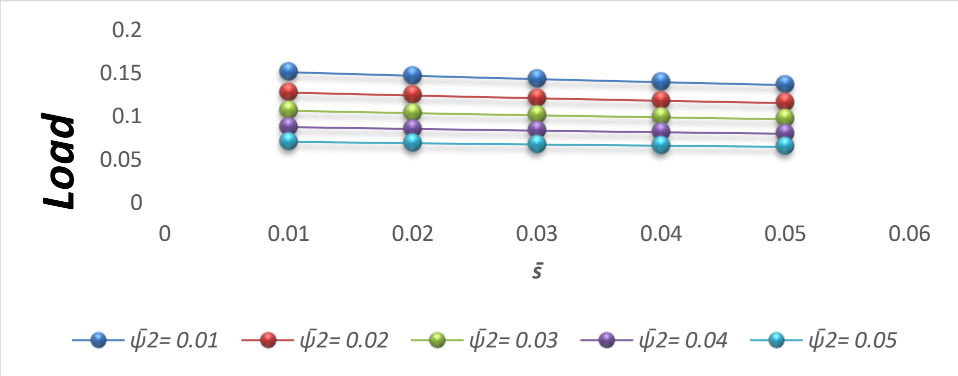

Fig10. Variation of load carrying capacity with respect to $\bar{s}$ and $\overline{\psi}_2$

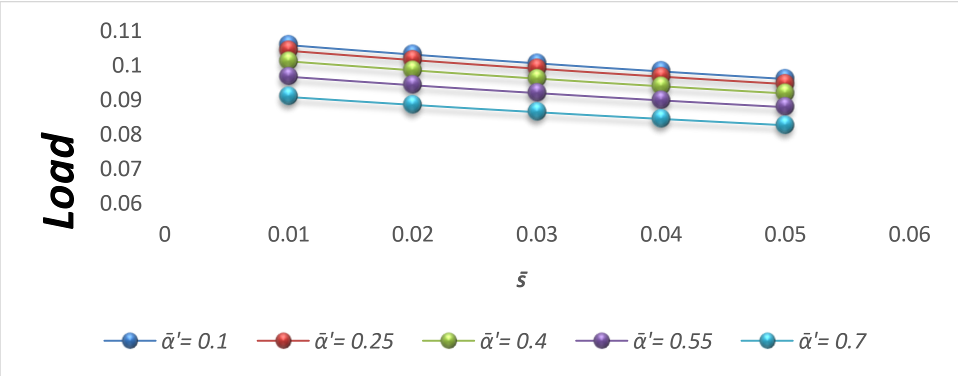

Fig11. Variation of load carrying capacity with respect to $\bar{s}$ and $\overline{\alpha}'$

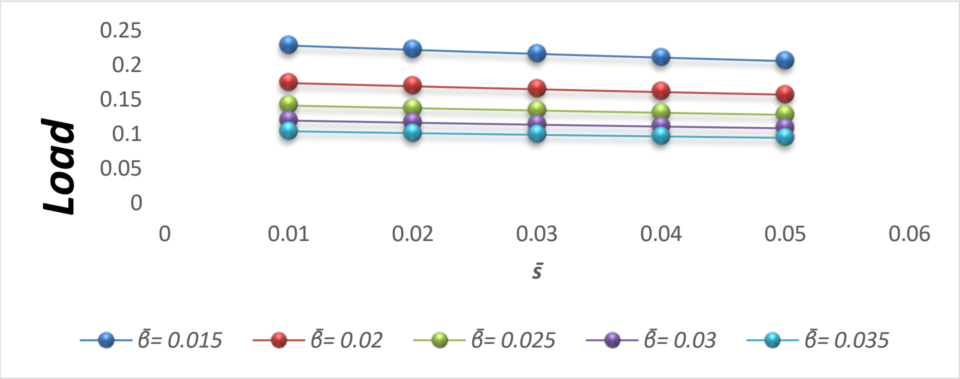

Fig12. Variation of load carrying capacity with respect to $\bar{s}$ and β

The effect of variance on the distribution of load carrying capacity is displayed in Figures 13-15. It is clearly seen that the variance (+ve) decreases the load carrying capacity while the variance (-ve) increases the load.

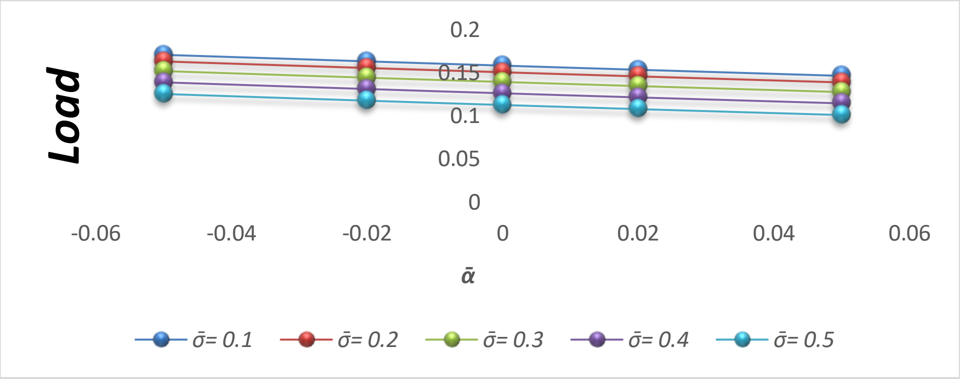

Fig13. Variation of load carrying capacity with respect to $\bar{\alpha}$ and $\bar{\sigma}$

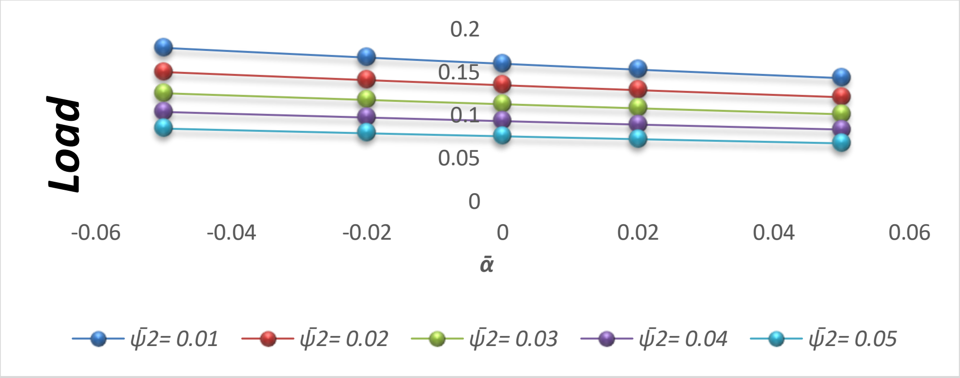

Fig14. Variation of load carrying capacity with respect to $\bar{\alpha}$ and $\bar{\psi}_2$

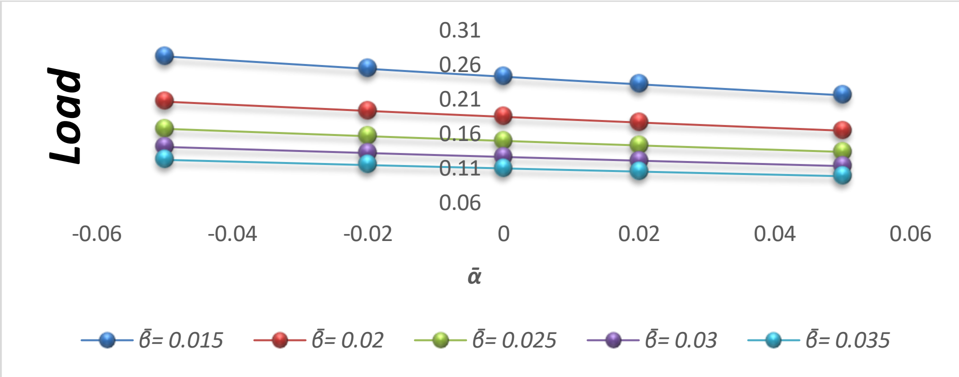

Fig15. Variation of load carrying capacity with respect to $\overline{\alpha}$ and β

The fact that the porosity of the upper layer influences the bearing performance as compared to the lower layer porosity. These is reflected in figure 16-17.

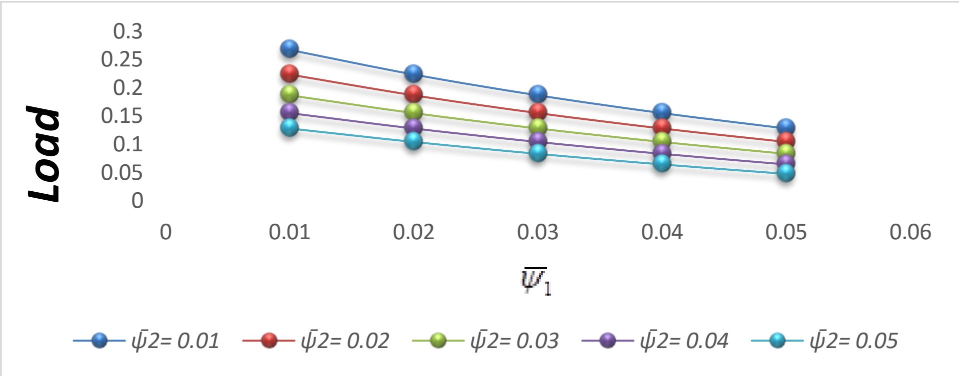

Fig16. Variation of load carrying capacity with respect to $\overline{\psi}_1$ and $\overline{\psi}_2$

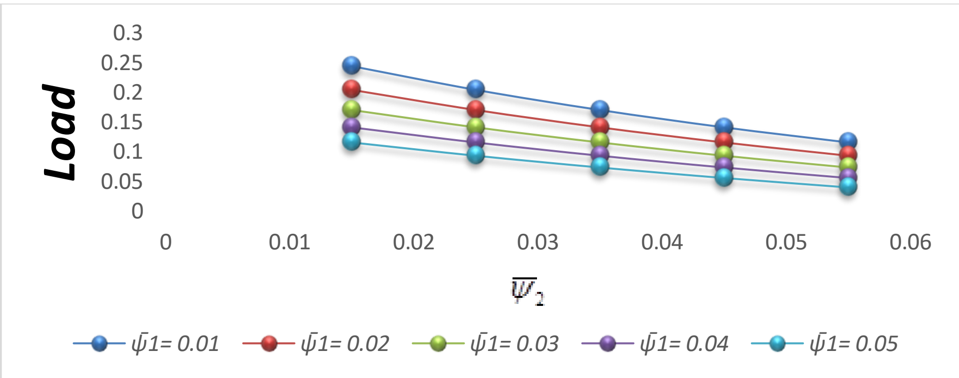

Fig17. Variation of load carrying capacity with respect to $\overline{\psi}_2$ and $\overline{\psi}_1$

It can be seen from the figure 18 that the material parameter (β) also modifies the squeeze film behavior.

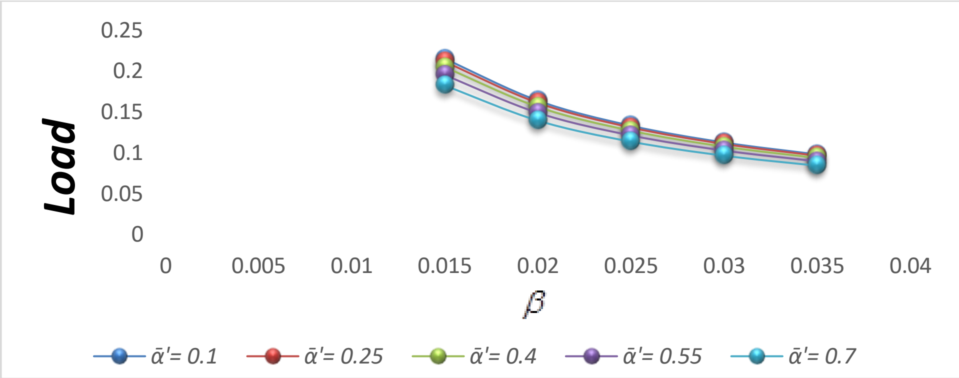

Fig18. Variation of load carrying capacity with respect to β and $\overline{\alpha}'$

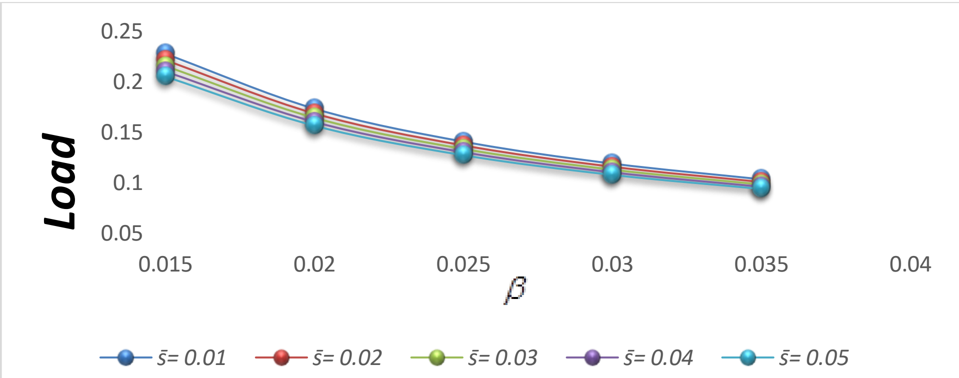

Fig19. Variation of load carrying capacity with respect to β and $\bar{s}$

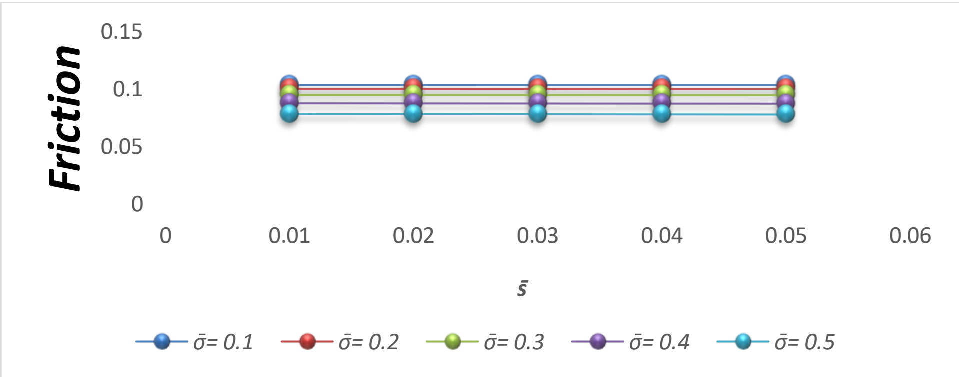

Fig 20. Variation of Coefficient of Friction with respect to $\bar{s}$ and $\overline{\sigma}$

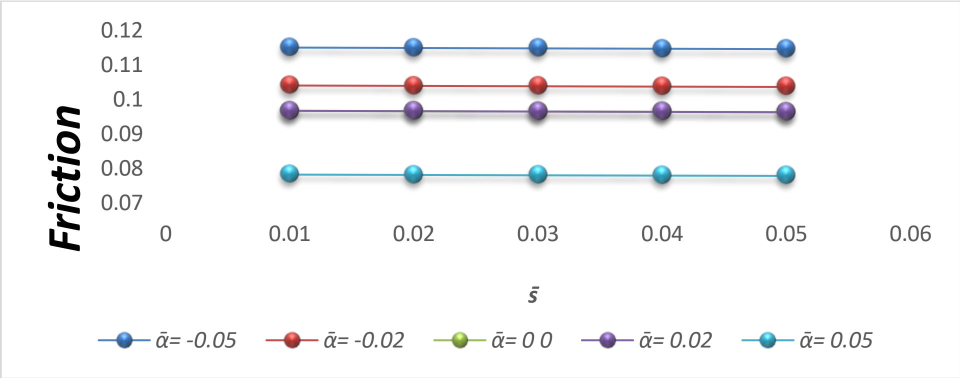

Fig21. Variation of Coefficient of Friction with respect to $\bar{s}$ and $\bar{\alpha}$

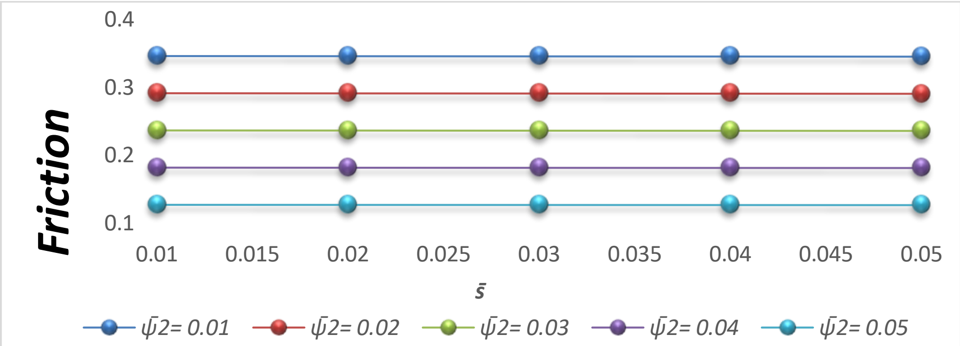

Fig22. Variation of Coefficient of Friction with respect to $\bar{s}$ and $\overline{\psi}_2$

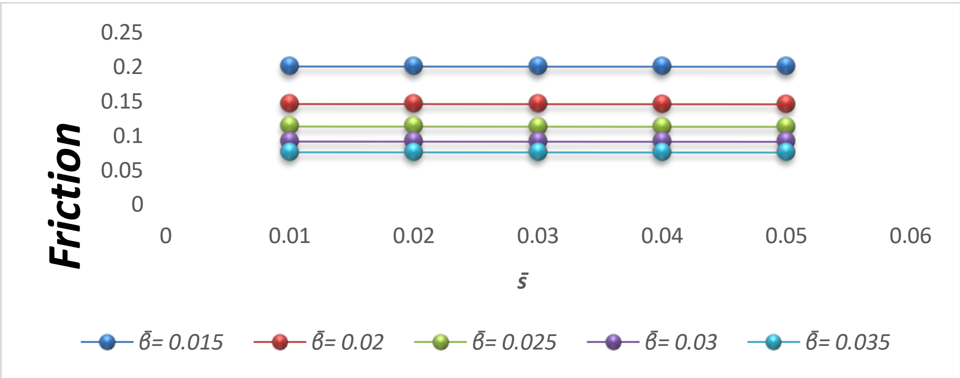

Fig23. Variation of Coefficient of Friction with respect to $\bar{s}$ and β

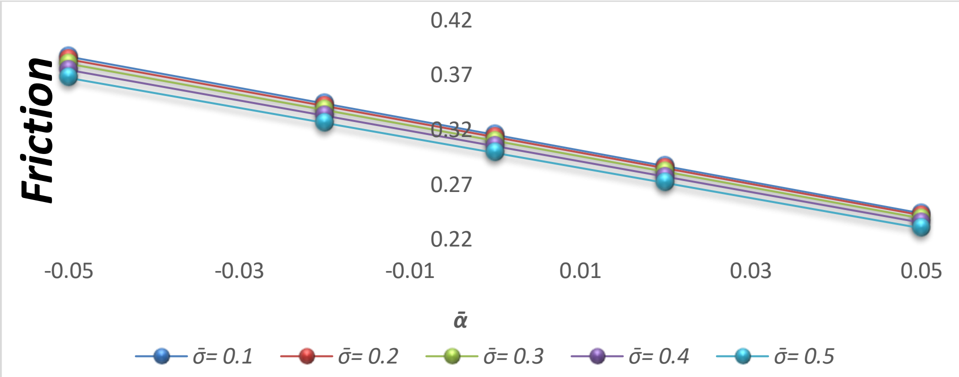

Fig24. Variation of Coefficient of Friction with respect to $\overline{\alpha}$ and $\overline{\sigma}$

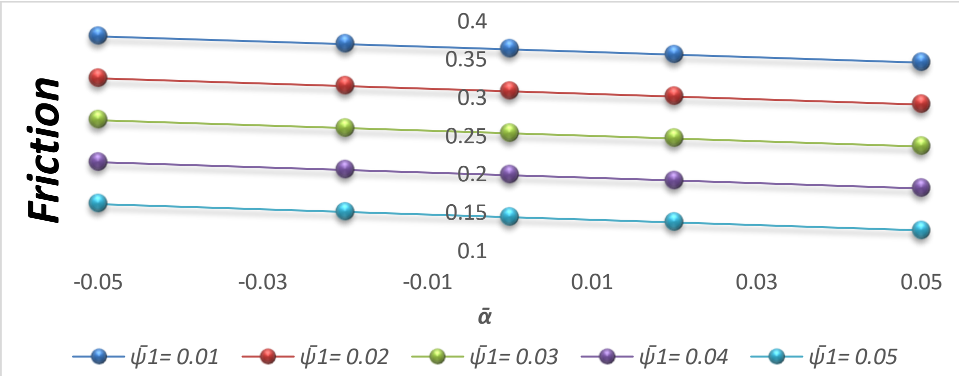

Fig25. Variation of Coefficient of Friction with respect to $\overline{\alpha}$ and $\overline{\psi}_1$

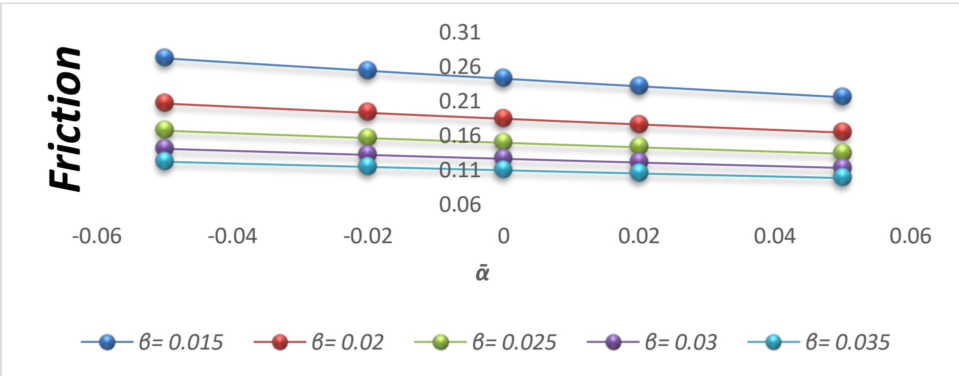

Fig26. Variation of Coefficient of Friction with respect to $\overline{\alpha}$ and β

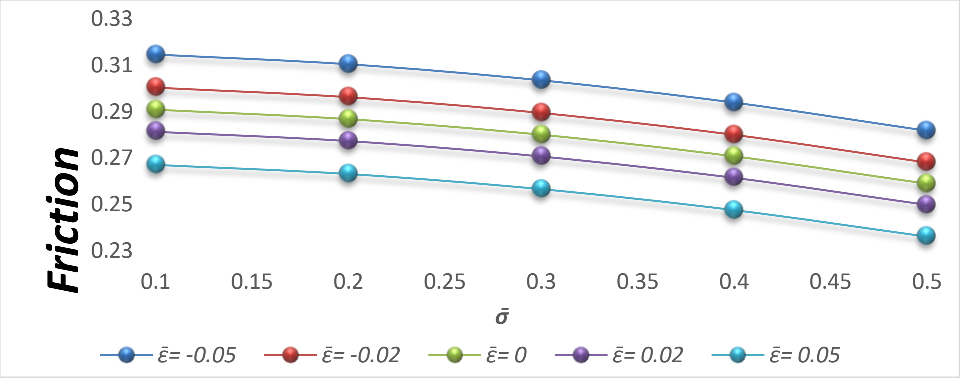

Fig27. Variation of Coefficient of Friction with respect to $\overline{\sigma}$ and $\overline{\varepsilon}$

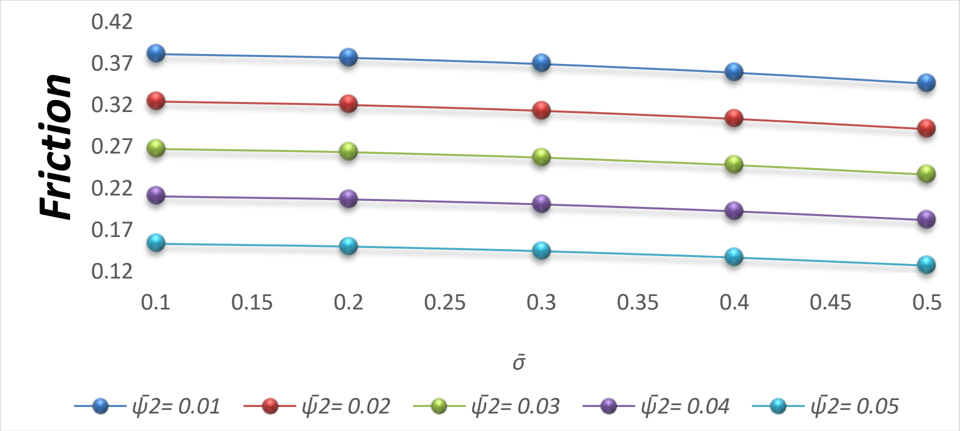

Fig28. Variation of Coefficient of Friction with respect to $\overline{\sigma}$ and $\overline{\psi}_2$

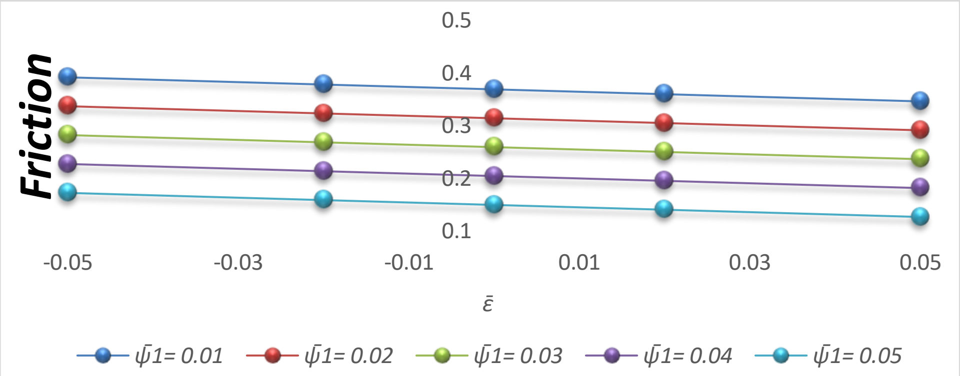

Fig 29. Variation of Coefficient of Friction with respect to $\overline{\varepsilon}$ and $\overline{\psi}_1$

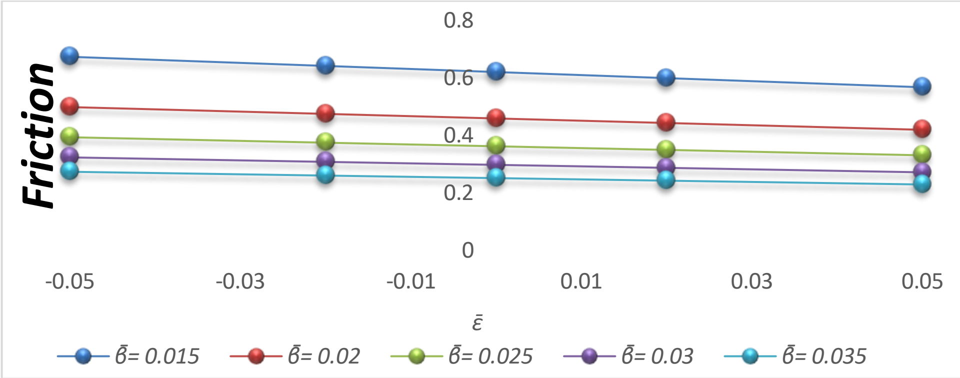

Fig30. Variation of Coefficient of Friction with respect to $\bar{\varepsilon}$ and β

4. Conclusion:

This article confirms that the squeeze film behavior improves by the double layered. The magnetic fluid lubrication goes a long way in countering the effect of roughness and slip velocity when negatively skewed roughness occurs. The load bearing capacity is found to be atleast 5% more as compared to the Neuringer Rosensweig model based magnetic fluid flow. If designed properly then the combination of material parameter, variance (-ve) and lower values of lower layered porosity can play a crucial role for offering better measures in order to uplift the squeeze film bearing system.

Nomenclature:

w	Load carrying capacity (N)	μ_0	Permeability of free space (N/A^2)
H	*Magnitude of the magnetic field*	$\bar{\sigma}$	*Dimensionless standard deviation*
A	*Length of the bearing*	μ'	*Magnetic susceptibility*
P_{mn}	*Dimensionless pressure*	U	*Velocity of slider*
H_1	The thickness of the inner layer of the porous plate (mm)	H_2	The thickness of the outer layer of the porous plate (mm)
W_{mn}	*Dimensionless load carrying capacity*	ϕ_1	The permeability of inner layer (col^{2}kgm/s^2)
$\bar{X}$	*X coordinate of the centre of pressure*	ϕ_2	The permeability of outer layer (col^{2}kgm/s^2)
$\bar{H}$	*External magnetic field*	$\bar{\psi}_1$	Porosity of inner layer
$\bar{s}$	*Dimensionless slip parameter*	$\bar{\psi}_2$	Porosity of outer layer
$\bar{\beta}$	*Material Parameter*	η	Viscosity of the suspension
σ	*Standard deviation*	$\bar{q}$	Fluid velocity
α	*Variance*	$\bar{M}$	Magnetization vector
ε	*Skewness*		

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