Effect of Surface Roughness on the Behaviour of Ferrofluid Based Squeeze Film Between Porous Annular Discs

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Abstract*: *Efforts have been made to study and analyse the performance of a ferrofluid based squeeze film between rotating porous transversely rough circular plates. The Neuringer and Rosenweig model for ferrofluid flow has been adopted to get the effect of magnetization. The stochastic model of Christensen and Tonder has been used to evaluate the surface roughness. The stochastically Reynolds` equation is utilized to get expression for pressure distribution which results in calculation of load carrying capacity. The effect of magnetization improves the performance of bearing system by increasing the values of load carrying capacity. The results are presented in graphical, which shows that bearing suffers due to transverse roughness. The combined effect of porosity and aspect ratio enhances the load carrying capacity. The negative mean and negative skewness also advances the attainment of bearing system. Proper value of magnetization parameter and ferrofluid as a lubricant extends the performance of bearing compare to conventional lubricant.

***Keywords*: Surface roughness, Porosity, Ferrofluid, Reynolds equation, Pressure distribution, Load carrying capacity**

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I. INTRODUCTION

The squeeze film actions rise from the phenomena of two lubricated surfaces advancing toward one another in the normal direction, produce a positive pressure, and hence maintain a load. The squeeze film lubrication can be obtained in bearings, machine tools, human body joins, IC engines and gears applications. Ferro fluids are steady colloidal suspensions of magnetic particles in a thick fluid (carrier liquid). Such fluids can be situated, confined or controlled at chosen places under remotely applied magnetic field. The outside magnetic field additionally offers ascend to an expansion in powerful viscosity of ferro solutions. This has prompted increasing utilization of ferrofluids as ointments in course.

Shah and Bhat [1] analysed the impacts of rotation of the magnetic particles on the characteristics of the squeeze film between two annular plates. It was found that the load carrying capacity and response time increased as the volume concentration of the solid phase, Langevin's parameter or the curvature of the upper plate increased. Kumar et al. [2] discussed ferrofluid squeeze film for spherical and conical bearings with a steady external magnetic field applied towards the path transverse to that of fluid flow. The governing equations were solved with the help of perturbation method in non-dimensional Brownian relaxation time parameter. Christensen and Tonder [3-5] considered random character of the surface roughness, who utilized a stochastic way to deal with numerically model the roughness of the bearing surfaces. They also discussed both transverse as well as longitudinal surface roughness dependent on a general probability density function. In the presence of magnetic fluids, the influences of fluid inertia forces on the ferrofluid squeeze film between a sphere and a plate was investigated by Lin [6]. It was observed that the load carrying capacity and the approaching time for the ferrofluid sphere increased due to the effect of fluid inertia forces. Shah and Bhat [7] used ferrofluid flow models of Neuringer–Rosensweig, Jenkins and Shliomis to study squeeze film behaviour of infinitely long journal bearing. It was discussed that a magnetic fluid could not generate magnetic pressure in the Neuringer–Rosensweig model, but it affected the bearing characteristics in the Shliomis model due to the rotational viscosity. Shah et al. [8] discussed a general equation of distinct slider squeeze film bearings by solid upper and lower porous plate using ferrofluid model of R.E. Rosensweig and obtained by considering the impacts of porosity, permeability, squeeze velocity, tangential velocity, magnetic field. It was concluded that the different type of bearings had better performance due to ferrofluid. Patel et al. [9] analysed the impact of roughness on the performance of squeeze film in parallel circular plates with non Newtonian ferrofluid with magnetic field. It was observed that the transverse roughness affects the performance of squeeze film and can be reduced by positive effects of non-Newtonian ferrofluid with suitable boundary conditions. Daliri [10] considered squeezing and rotating motions between two rough parallel circular discs with ferrofluid couple stress lubricant. It was found that the combine effects of couple stress and ferrofluid increased squeeze film performance related to Newtonian lubricant.

Sinha et al. [11] studied ferrofluid lubrication of cylindrical rollers with rolling and normal motion. It was observed that due to ferrofluid lubrication load carrying capacity increased without affecting the point of cavitation and concluded that the performance of rollers with thinner oil film could be enhanced due to magnetic field. Hsu, Tze-Chi, et al.[12] studied the impact of ferrofluids on the lubrication execution of stochastic surface roughness and magnetic field created by infinitely long wire. It was analysed that due to higher power law index and magnetic force, the transverse roughness increased pressure, load carrying capacity and decreased attitude angle and modified friction coefficient. Mishra et al. [13] discussed the impact of surface roughness, porosity and magnetic field on an inclined slider bearing. Here, different form of magnetic field was used, due to this pressure and load carrying capacity increased. It was also found that the adverse effect on slip parameter over load carrying capacity turns sinusoidal to be great due to the pattern of variation of magnetic field. Toloian et al. [14] investigated couple stress ferrofluid lubricants effects on the performance of squeeze film with external magnetic field. It was found that due to couple stress ferrofluid lubricant with magnetic field increased performance of squeeze film.

Majority of the above examinations omitted the impact of surface roughness by believing the bearing surface to be smooth. However, it is established that the bearing surfaces are rough to certain extent. Hence, it has been proposed to study the effect of surface roughness on the behaviour of ferrofluid squeeze film between porous annular discs.

II. ANALYSIS

The bearing configuration is introduced below

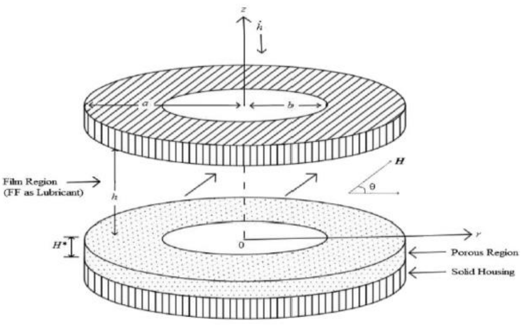

Fig.1. Porous annular discs squeeze film

It represents porous annular discs for squeeze film bearing. It comprises of annular discs at both end of inner radius r = b and outer radius r = a. The lower disc is joined with a porous matrix of thickness H*.

Following the method of Christensen and Tonder [3-5] the thickness h(x) is considered as

$$h(x) = \bar{h}(x) + h_s \qquad (1)$$

The associated probability density function $F(h_s)$ is given as

$$F(h_s) = \begin{cases} \dfrac{32}{35b}\left(1 - \dfrac{{h_s}^2}{b^2}\right)^3 & -b \le h_s \le b \\ 0 & elsewhere \end{cases} \qquad (2)$$

The random vaivable h_s is determined by the relations

$$\alpha = E(h_s) \qquad (3)$$

$$\sigma^2 = E\left[(h_s - \alpha)^2\right] \qquad (4)$$

and

$$\varepsilon = E\left[(h_s - \alpha)^3\right] \qquad (5)$$

where E denotes the expected value defined by

$$E(R) = \int_{-c}^{c} R f(h_s)\, dh_s \qquad (6)$$

The details of charecterization of the roughness aspects can be taken from Christensen and Tonder [3-5]

In view of Shah et al. [8], the modified Reynolds type equation is given by,

$$\frac{1}{r}\frac{d}{dr}\left[r\frac{d}{dr}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] = \frac{12\eta\left(dh/dt\right)}{h^3 + 12kH^*} \qquad (7)$$

With the aid of the stochastical avereging method of Christensen and Tonder [3-5], equation (7) is transformed to

$$\frac{1}{r}\frac{d}{dr}\left[r\frac{d}{dr}\left(p - \frac{1}{2}\mu_0\bar{\mu}H^2\right)\right] = \frac{12\eta\left(dh/dt\right)}{g(h) + 12kH^*} \qquad (8)$$

where

$$g(h) = h^3 + 3\sigma^2 h + 3\alpha^2 h + 3h^2\alpha + 3\sigma^2\alpha + \varepsilon + \alpha^3$$

By selecting angle and variable magnetic field to the lower plate, so that it is zero at the boundary of annular discs,

$$H^2 = K(r - b)(a - r) \qquad (9)$$

Where K is selected to adjust the dimension of both sides, the associated Reynolds type of equation for the film pressure becomes

$$\frac{1}{r}\frac{d}{dr}\left[r\frac{d}{dr}\left(p - \frac{1}{2}\mu_0\bar{\mu}K(r - b)(a - r)\right)\right] = \frac{12\eta\left(dh/dt\right)}{g(h) + 12kH^*}$$

(10)

Integrating equation (10) two times with respect to ‘r’, using following boundary conditions solving the equation

$$p(a) = 0, \quad p(b) = 0$$

one gets the pressure distribution as

$$p=\frac{1}{2}\mu_0\bar{\mu}K\left(r-b\right)\left(a-r\right)+\frac{3\eta\,{}^{dh}\!/_{dt}\left(a^2-b^2\right)}{g(h)+12kH*}\left[\frac{\left(r/b\right)^2-1}{\left(a/b\right)^2-1}-\frac{\ln\left(r/b\right)}{\ln\left(a/b\right)}\right]$$

(11)

Which can be expressed in non dimensional form as

$$P=-\frac{ph^3}{\eta\frac{dh}{dt}\pi\left(a^2-b^2\right)}=\frac{1}{2}\mu*\frac{\left(r-b\right)\left(a-r\right)}{\pi\left(a^2-b^2\right)}+\frac{3}{\pi\left(G+12\psi\right)}\left[\frac{\ln\left(r/b\right)}{\ln\left(a/b\right)}-\frac{\left(r/b\right)^2-1}{\left(a/b\right)^2-1}\right]$$

(12)

Where

$$G=\frac{g(h)}{h^3}$$

$$=1+3\sigma*^2+3\alpha*^2+3\alpha*+3\sigma*^2\alpha*+\alpha*^3+\varepsilon*$$

$$\sigma*=\frac{\sigma}{h},\alpha*=\frac{\alpha}{h},\ \varepsilon*=\frac{\varepsilon}{h^3},\mu*=-\frac{\mu_0\bar{\mu}KH^3}{\eta\frac{dh}{dt}},\psi=\frac{KH*}{h^3}$$

The load carrying capacity of squeeze film can be obtained as

$$w=2\pi\int_a^b pr\,dr \qquad (13)$$

$$w=2\pi\left[\begin{array}{l}\frac{1}{2}\mu_0\bar{\mu}K\left\{\frac{a^4}{12}-\frac{a^3b}{6}+\frac{ab^3}{6}-\frac{b^4}{12}\right\}+\\ \frac{3\eta\frac{dh}{dt}\left(a^2-b^2\right)^2}{g(h)+12KH*}\left\{\frac{\left(a^2-b^2\right)/4b^2}{\left(a/b\right)^2-1}-\frac{a^2/2}{a^2-b^2}+\frac{1/4}{\ln\left(a/b\right)}\right\}\end{array}\right]$$

(14)

In non dimensional form, load carrying capacity is given by

$$W=-\frac{wh^3}{\eta\frac{dh}{dt}\pi^2a^4}$$

$$=\frac{1}{\pi}\left[\begin{array}{l}-\frac{\mu*}{\left(1-{}^{b^2}\!/_{a^2}\right)^2}\left\{\frac{\left({}^{b}\!/_{a}\right)^4}{12}-\frac{\left({}^{b}\!/_{a}\right)^3}{6}+\frac{\left({}^{b}\!/_{a}\right)}{6}-\frac{1}{12}\right\}+\\ \frac{3}{2(G+12\psi)}\left\{\frac{1+\left({}^{b}\!/_{a}\right)^2}{1-\left({}^{b}\!/_{a}\right)^2}+\frac{1}{\ln\left({}^{b}\!/_{a}\right)}\right\}\end{array}\right] \qquad (15)$$

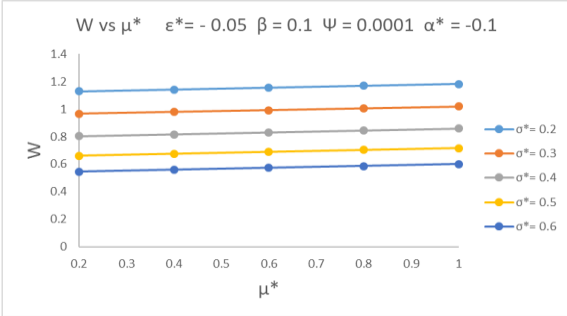

Fig. 2. W versus μ* for different values of σ*

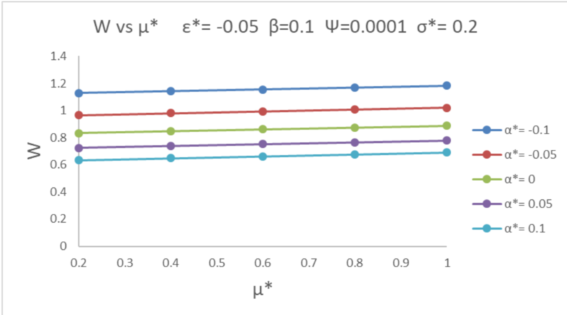

Fig. 3. W versus μ* for different values of α*

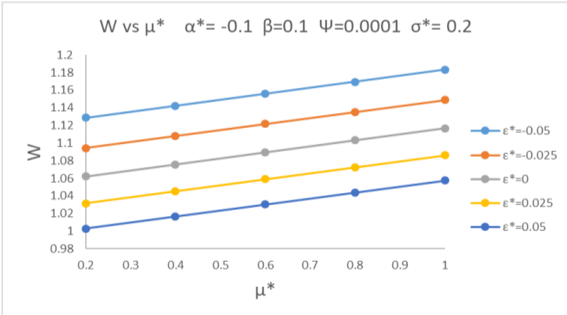

Fig. 4. W versus μ* for different values of ε*

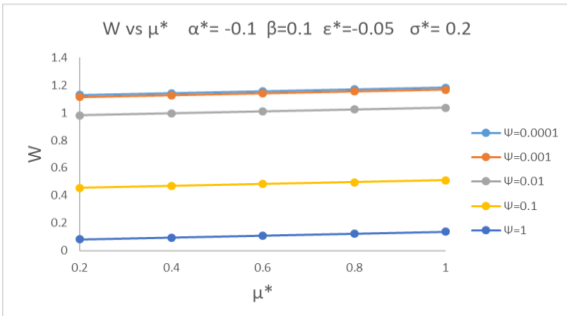

Fig. 5. W versus μ* for different values of Ψ

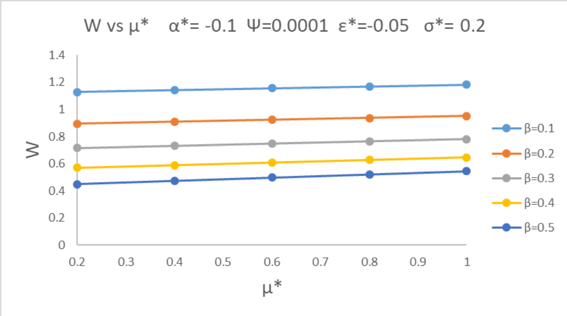

Fig. 6. W versus μ* for different values of β

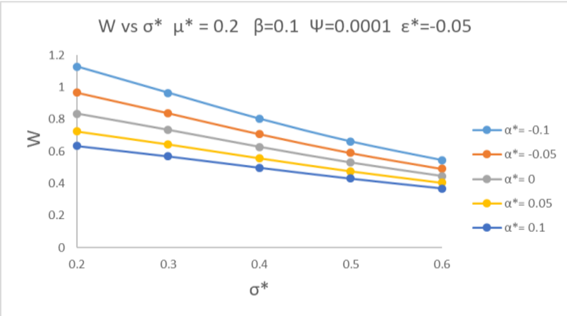

Fig. 7. W versus σ* for different values of α*

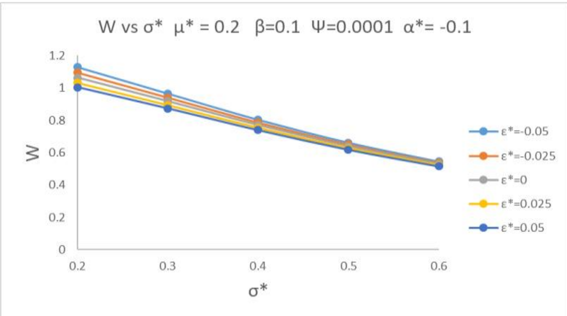

Fig. 8. W versus σ* for different values of ε*

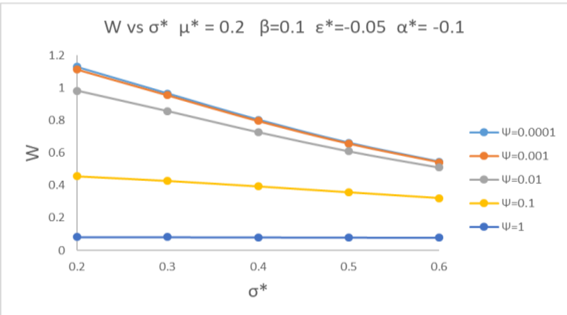

Fig. 9. W versus σ* for different values of Ψ

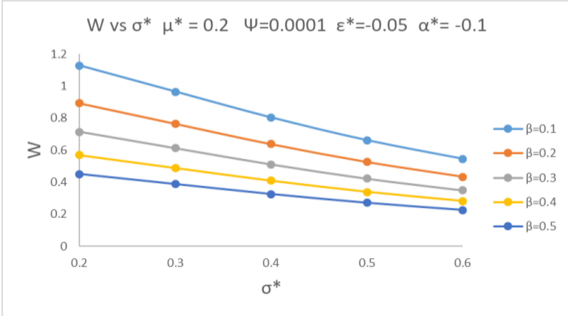

Fig. 10. W versus σ* for different values of β

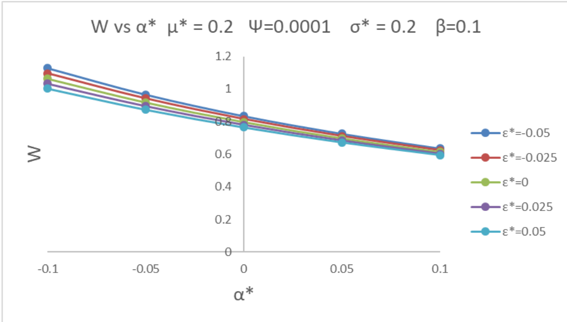

Fig. 11. W versus α* for different values of ε*

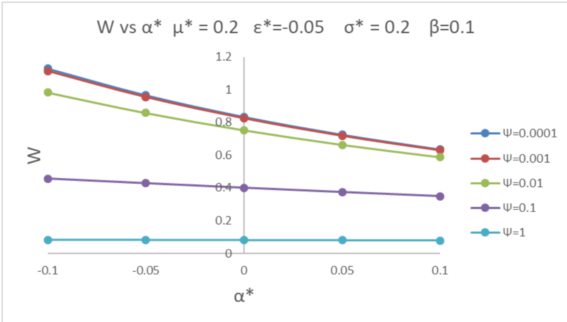

Fig. 12. W versus α* for different values of Ψ

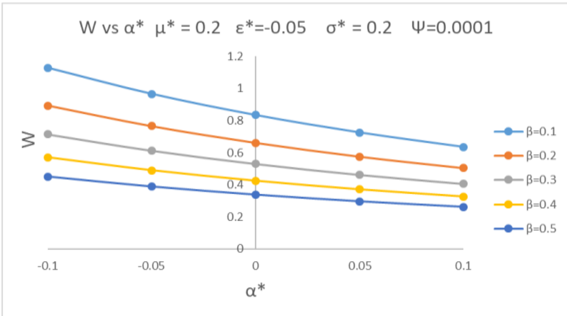

Fig. 13. W versus α* for different values of β

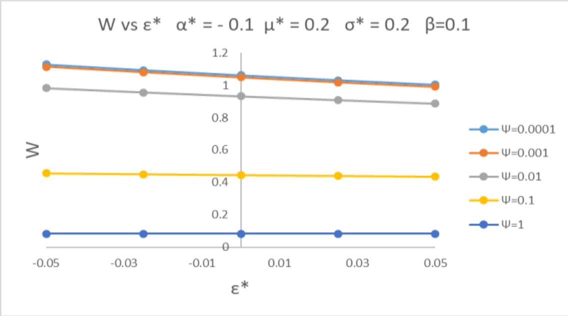

Fig. 14. W versus ε* for different values of Ψ

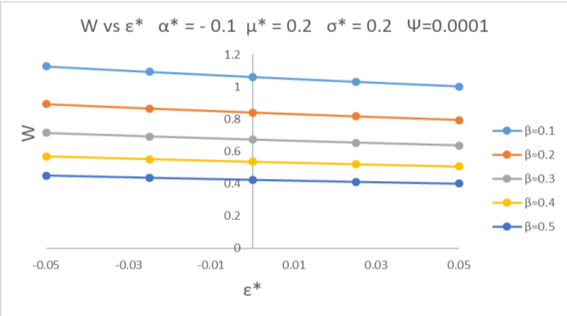

Fig. 15. W versus ε* for different values of β

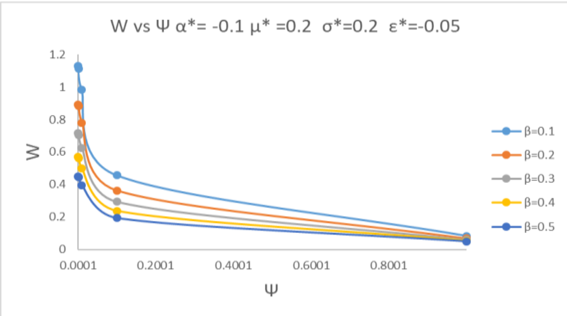

Fig. 16. W versus Ψ for different values of β

III. Result and Discussion

Equation (12) represents non dimensional pressure distribution, while equation (15) gives the non dimensional load carrying capacity. For a porous smooth bearing, this investigation reduces to the results of Shah et al. [8]. The non dimensional load carrying capacity W with respect to μ* for distinct values of standard deviation, mean, skewness and porosity and aspect ratio can be observed from figures (2-6). One can observe that the effect of magnetic parameter is positive as it increases the value of load carrying capacity. The variation of load carrying capacity with respect to σ* for distinct values of mean, skewness, porosity and aspect ratio are mentioned in figures (7-10). From figure (8) it is clearly seen that the effect of skewness on load carrying capacity with respect to σ* is negligible when σ* exceeds 0.4. It is interesting to note that from figure (9), the values of load carrying capacity more for Ψ=0.0001 compare to other values of porosity. Figure (10) shows that the negative effect of aspect ratio on load carrying capacity with respect to standard deviation by decreasing load carrying capacity. Figures (11-13) describes the trend of load carrying capacity with respect to mean for different values of skewness, porosity and aspect ratio. The negative mean improves the performance of bearing by increasing the values of load carrying capacity. The influence of skewness on load carrying capacity can be seen from figures (14-15). The negative values of skewness gives better results by enhancing the values of load carrying capacity. The negative effect of aspect ratio on load carrying capacity with respect to porosity can be observed from figure (16).

IV. Conclusion

The study makes it clear that the performance of bearing depends on proper selection of aspect ratio and magnetic parameter play an important role. It is recommended to take the value of permeability parameter $\psi \le 0.01$ for annular discs. As a result of quality of extra term containing μ* in the expression of W, load increases reasonably due to magnetization parameter when ferrofluid is used as a lubricant. It is observed that the magnetization parameter reduces the adverse effect of roughness and ferrofluid lubricant has significant effect on squeeze film than the conventional lubricant. The negative mean, negative skewness improves the results of bearing while standard deviation decreases load carrying capacity by disregards bearing. Therefore, it is recommended that while designing a bearing system roughness must be considered.

V. Nomenclature

a : Outer radius of annular disc

b : Inner radius of annular disc

α : Variance

σ : Standard deviation

ε : Skewness

α^* : Dimensionless variance

σ^* : Dimensionless standard deviation

ε^* : Dimensionless skewness

p : Lubricant Pressure (N/mm^2)

P : Dimensionless Pressure

w : Load carrying capacity (N)

W : Dimensionless load carrying capacity

H*: Thickness of porous medium (m)

k: Permeability of porous matrix (m^2)

K: Quantity choose to set the dimension on both sides

η : Fluid viscosity (Ns/m^2)

$\bar{\mu}$: Magnetic susceptibility

μ^* : Dimensionless magnetization parameter

μ_0 : Permeability of free space (N/A^2)

$\bar{h}$: Mean film thickness

h_s : Deviation from mean film thickness

$\frac{dh}{dt}$: Squeeze velocity

Ψ : Dimensionless

porosity

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