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ANALYSIS OF SQUEEZE FILM PERFORMANCE IN POROUS ROUGH RECTANGULAR PLATES UNDER THE PRESENCE OF A MAGNETIC FLUID LUBRICANT

ABSTRACT:
Efforts have been a foot to study and analyze the performance of magnetic fluid based squeeze film between porous infinitely long rough rectangular plates. A magnetic fluid is used as lubricant and the external magnetic field is oblique to the lower plate. The random roughness of the bearing system is modeled by stochastic random variable with non-zero mean, variance and skewness. The associated stochastically averaged Reynolds equation is solved with suitable boundary conditions in dimensionless form to obtain the pressure distribution resulting in the calculation of load carrying capacity. This investigation indicates that the bearing system registers an improved performance as compared to that of bearing system working with conventional lubricant. It is observed that the bearing suffers owing to transverse surface roughness in general. However, the present study reveals that the negative effect of the standard deviation and porosity can be compensated to some extent by the positive effect of magnetization parameters in the case of negatively skewed roughness by suitably choosing the aspect ratio. Further, this compensation becomes more evident when negative variance is involved.

KEYWORDS:
Surface Roughness, Magnetic Fluid, Porosity, Reynolds Equation, Pressure, Load Carrying Capacity

INTRODUCTION

It was Archibald [3] who presented the classical theory of squeeze film between plane parallel surfaces. The squeeze film behavior of a porous bearing was analysed by Wu [22][23][24] for mainly annular and rectangular geometries. Later on, Prakash and Vij [17] investigated the squeeze film performance between porous plates of different shapes resorting to Morgan Cameron approximation. Interestingly, it was proved here that amongst the various geometries of equivalent surface area for the plates, circular plates recorded the highest transient load carrying capacity other parameters remaining same.

All these above analysis considered the bearing surfaces to be smooth. It is a well known fact that bearing surfaces after having some run-in and wear developed roughness. Sometimes even the contamination of lubricants and chemical degradation of the surfaces contribute to roughness. The roughness appears to be random in character which does not appear to follow a particular structural pattern. This request that while modeling the roughness stochastic method must be invoked.

In order to study and analyzed the effect of roughness of bearing system on the performance of squeeze film bearing various methods have been considered. Several investigators have proposed a stochastic approach to mathematically model the random character of the roughness [Tzeng and Saibel [20], Christensen and Tonder [7-9]]. In fact, the method adopted by Tzeng and Saibel was modified and developed by Christensen and Tonder [7-9] in order to present a comprehensive general analysis both for transverse as well as longitudinal surface roughness. Subsequently, the investigation carried out by Ting [19], Prakash and Tiwari [18], Prajapati [15], Guha [11], Gupta and Deheri [12] was based on the approach of Christensen and Tonder. Andharia, Gupta and Deheri [2] dealt with the analysis of the effect of surface roughness on the performance of squeeze film bearings using more general stochastic analysis for characterization the roughness.

In all the above studies, the squeeze film was based on conventional lubricants. The use of magnetic fluid as a lubricant modified the performance of bearing system has been very well recognized. Verma [21] studied the applications of magnetic fluid as a lubricant taking in to account the tangential slip velocity at the porous matrix lubricant interface while Agrawal [1] observed the effect of magnetic fluid by considering no slip conditions.

Oil based or other lubricant fluid based magnetic fluid can be used as a lubricant. The advantage of magnetic fluid as a lubricant over the conventional ones is that the former can be retained at the desired location by an external magnetic fluid. The magnetic fluid is prepared by suspending fine magnetic grains coated with surfactants and dispersing it in non-conducting magnetically passive solvent such as kerosene, hydrocarbons and fluorocarbons when magnetic field is applied each particle experiences a body force thereby causing a drag to flow.

Bhat and Deheri [4][5] analyzed the performance of a magnetic fluid based squeeze film behaviors between porous annular disks and curved porous circular plates and found that its performance with the magnetic fluid as a lubricant was relatively better than with a conventional lubricant. Patel and Deheri [13] discussed the performance of a squeeze film based on magnetic fluid in rough annular plates.

All the above studies established that the performance of bearing system gets improved due to the presence of magnetic fluid lubricant and the effect of transverse surface roughness is adverse in general. However, the investigation of Patel and Deheri [13] reported that the negatively skewed roughness resulted in increased load carrying capacity. Therefore, it was deemed approach to launch the investigation in to the performance of a magnetic fluid based squeeze film between infinitely long porous rough rectangular plates.

THE ANALYSIS

Figure 1 shows the configuration of the bearing system consisting of rectangular plates.

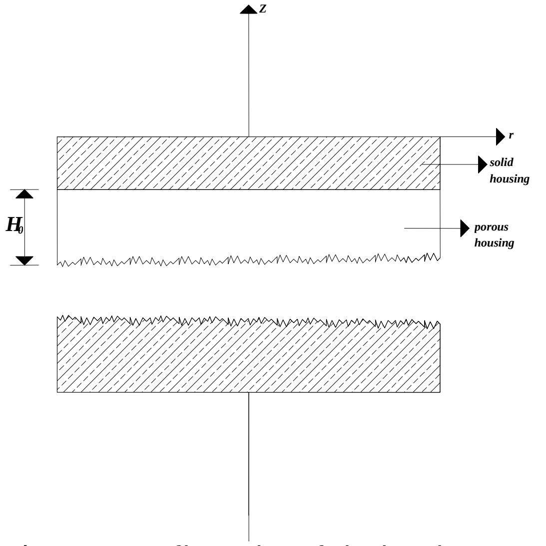

Figure 1. Configuration of the bearing system

The upper plate moves normally towards the lower plate with uniform velocity $\dot{h} = \frac{dh}{dt}$. Both the plates are considered to a transversely rough surface and a magnetic fluid used as the lubricant. Following Christensen and Tonder [7-9] the film thickness of the lubricant film is taken as

$$h = \bar{h} + h_s$$

where $\bar{h}$ is the mean film thickness and h_s is the deviation from the mean film thickness characterizing the random roughness of the bearing surfaces. h_s is considered to be stochastic in nature and governed by the probability density function

$$f(h_s) = \begin{cases} \frac{35}{32}\left(1 - \frac{h_s^2}{c^2}\right)^3, & -c \le h_s \le c \\ 0, & \text{otherwise} \end{cases}$$

where c is the maximum deviation from the mean film thickness. The mean α, the standard deviation σ and the parameter ε, which is the measure of symmetry of random variable h_s are defined by the relationships

$$\alpha = E(h_s)$$
$$\sigma^2 = E[(h_s - \alpha)^2]$$

and $\varepsilon = E[(h_s - \alpha)^3]$

where E denotes the expected value defined by

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

From the performance point of view several forms of the magnetic field have been discussed in Prajapati [15]. Following Prajapati and ignoring the self field created by magnetization it has been preferred to consider the form of magnitude as

$$M^2 = kb^2\left[1 - \cos\left(\frac{4\pi z}{b}\right)\right]$$

where k is suitably chosen so as to have a magnetic field of strength over 10^5 [Bhat [6]]. Assuming axially symmetric flow of the magnetic fluid between the rectangular plates under an oblique magnetic field

$$\bar{H} = (H(r)\cos\phi(r,z), 0, H(r)\sin\phi(r,z))$$

whose magnitude H vanishes at $z = \pm\frac{b}{2}$, the modified Reynolds equation governing the film pressure p is obtained as [Prajapati [15], Patel et. al. [13], Gupta and Deheri [12]]

$$\frac{d^2}{dz^2}[p - 0.5\mu_0 \bar{\mu} M^2] = \frac{12\mu \dot{h}}{h^3 + 3\alpha h^2 + 3\alpha^2 h + 3\sigma^2 h + 3\sigma^2\alpha + \alpha^3 + \varepsilon + 12\phi H}$$

where μ_0 is permeability of free space, $\bar{\mu}$ is the magnetic susceptibility of particles and μ is the viscosity of the lubricant, ϕ is the permeability of porous facing, H is the thickness of porous medium.

Solving the above equation under the boundary conditions:

$$P\left(\pm\frac{b}{2}\right) = 0$$

And with the usual assumptions of hydromagnetic lubrication, the modified Reynolds equation governing the film pressure p turns out to be

$$P = 0.5\,\mu_0 \bar{\mu} M^2 + \frac{6\mu\dot{h}}{h^3 g(\bar{h})}\left[z^2 - \frac{b^2}{4}\right] \qquad (1)$$

where

$g(\bar{h}) = 1 + 3\bar{\sigma} + 3\bar{\sigma}^2 + 3\bar{\sigma}^2\bar{\alpha} + 3\bar{\alpha}^2 + \bar{\alpha}^3 + \bar{\varepsilon} + 12\psi$

Introducing the non-dimensional quantities

$$P = -\frac{h^3 p}{\mu\, a^2 h}, \quad \bar{Z} = \frac{z}{b},$$

$$\beta = \frac{a}{b}, \quad \psi = \frac{\phi H}{h^3}, \quad \alpha = (12\,\psi_0)^{\frac{1}{3}}$$

$$\psi_0 = \frac{\phi H}{h_0^3}, \quad \mu^* = -\frac{k h_0^3 \mu_0 \bar{\mu}}{\mu h}, \quad \bar{\sigma} = \frac{\sigma}{h},$$

$$\bar{\alpha} = \frac{\alpha}{h}, \quad \bar{\varepsilon} = \frac{\varepsilon}{h^3};$$

In view of the non-dimensional quantities introduced above, the associated non-dimensional Reynolds equation governing the dimensionless pressure P is obtained as

$$P = \frac{\mu^*}{2}\left[1 - \cos\left(\frac{4\pi z}{b}\right)\right] + \frac{6}{g(\bar{h})}\left[\frac{1}{4} - Z^2\right] \qquad (2)$$

The load carrying capacity w is given as

$$w = a\int_{-\frac{b}{2}}^{\frac{b}{2}} p(z)dz = ab^3\left[0.5\,\mu_0\bar{\mu}k - \frac{\mu h}{h^3 g(\bar{h})}\right]$$

Thus, the load carrying capacity in non-dimensional form can be expressed as

$$W = -\frac{h^3 w}{\mu\, h b^4} = \bar{\beta}\left[\frac{\mu^*}{2} + \frac{1}{g(\bar{h})}\right] \qquad (3)$$

RESULTS AND DISCUSSION

The dimensionless pressure distribution is presented by Equation (2) while Equation (3) determines the load carrying capacity. The corresponding non-magnetic case regarding a smooth bearing [Prakash and Vij [16]] can be obtained by taking the magnetization and roughness parameters to be zero in these above expressions. This analysis also tends to suggest that the performance of the associated rough bearing system can be analysed by considering μ^* to be zero. It is clear from Equation (2) that the pressure increase by

$$\frac{\mu^*}{2}\left[1 - \cos\left(\frac{4\pi z}{b}\right)\right]$$

while the increase in load carrying capacity recorded here is $\frac{a\mu^*}{2b}$

A comparison of this investigation with the discussion carried out by Deheri, Patel and Patel [10] indicates that is at least approximately six times increase in load carrying capacity.

Figures [2-6] depicting the variation of load carrying capacity with respect to the magnetization parameter μ^* for different values of $\bar{\sigma}, \bar{\varepsilon}, \bar{\alpha}, \bar{\beta}$ and ψ indicate that the load carrying capacity increases sharply due to the magnetic fluid lubricant. However, the effect of $\bar{\sigma}$ and ψ at the initial stage appear to be negligible.

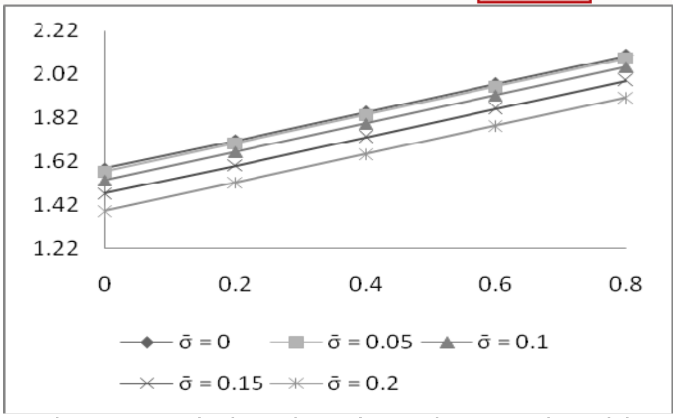

Figure 2. Variation of Load carrying capacity with respect to μ^* and $\bar{\sigma}$

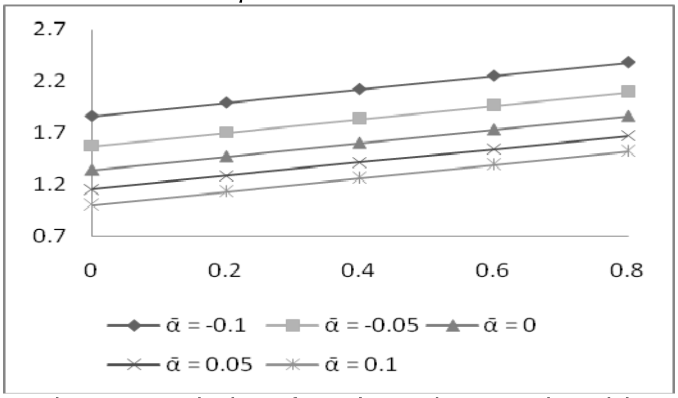

Figure 3. Variation of Load carrying capacity with respect to μ^* and $\bar{\alpha}$

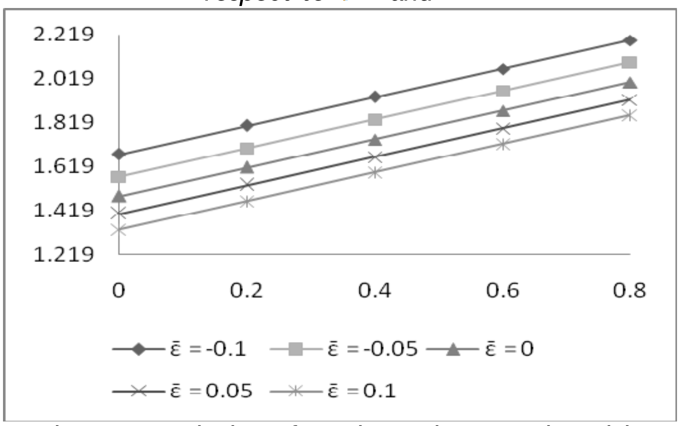

Figure 4. Variation of Load carrying capacity with respect to μ^* and $\bar{\varepsilon}$

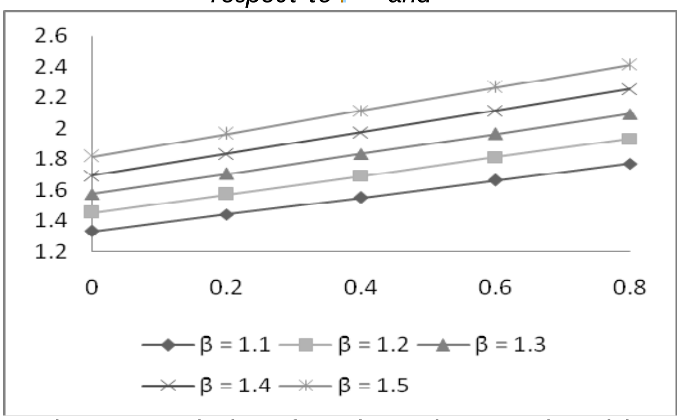

Figure 5. Variation of Load carrying capacity with respect to μ^* and $\bar{\beta}$

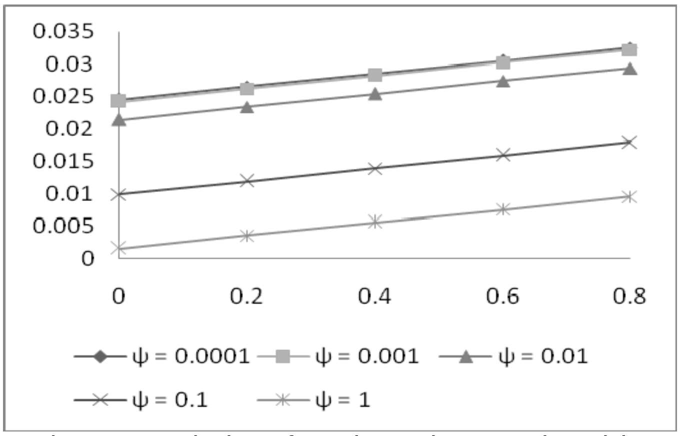

Figure 6. Variation of Load carrying capacity with respect to μ^* and ψ

In Figures [7-10], one can visualize the effect of the standard deviation on the distribution of load carrying capacity with respect to various values of variance $\bar{\alpha}$, skewness $\bar{\varepsilon}$, aspect ratio $\bar{\beta}$ and porosity ψ respectively. These figures assert that the load carrying capacity decreases considerably due to the standard deviation. But the effect of porosity with respect to standard deviation is negligible up to the values of $\psi = 0.001$.

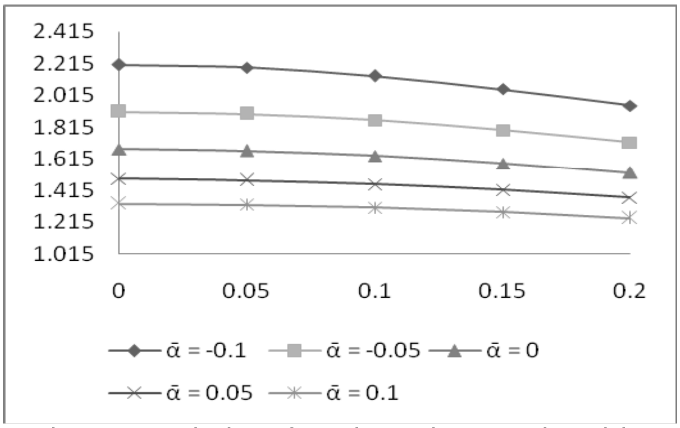

Figure 7. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and $\bar{\alpha}$

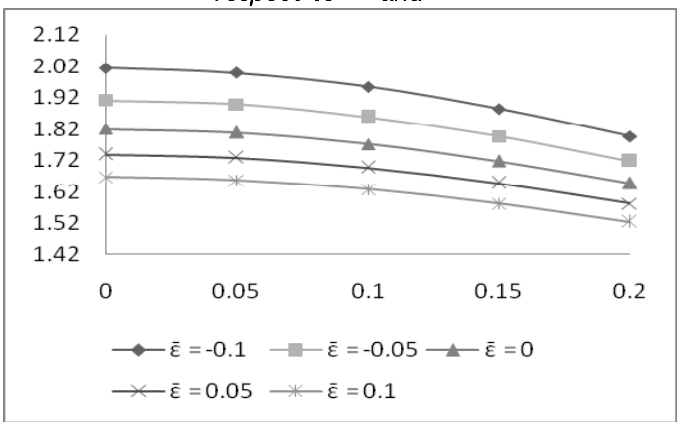

Figure 8. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and $\bar{\varepsilon}$

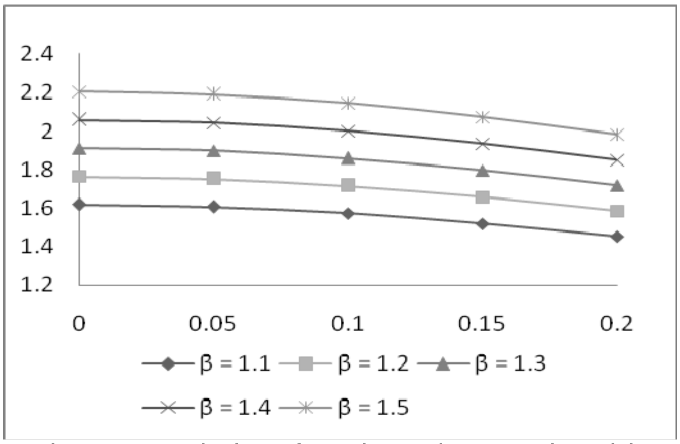

Figure 9. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and $\bar{\beta}$

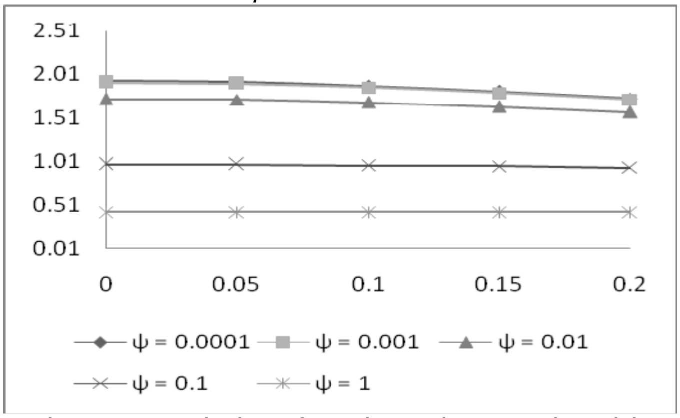

Figure 10. Variation of Load carrying capacity with respect to $\bar{\sigma}$ and ψ

Figures [11-13], describe the variation of the load carrying capacity with respect to the variance for different values of skewness $\bar{\varepsilon}$, aspect ratio $\bar{\beta}$ and porosity ψ respectively. It is clear from these figures that variance $\bar{\alpha}$ (+ ve) decreases the load carrying capacity while the load carrying capacity increases due to variance $\bar{\alpha}$ (- ve). As before, the effect of ψ with respect to $\bar{\alpha}$ is negligible from the values of ψ less than 0.001.

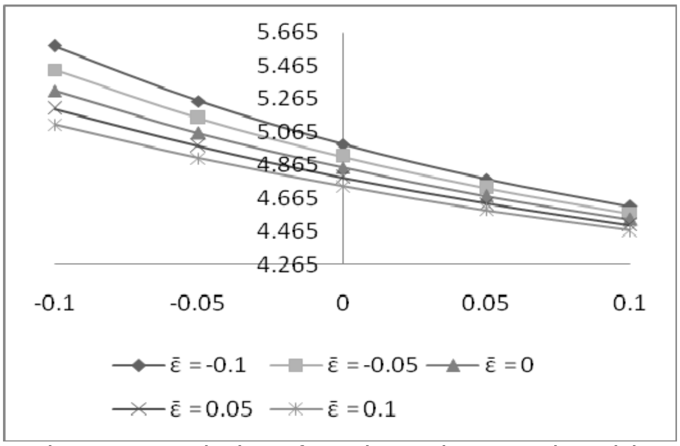

Figure 11. Variation of Load carrying capacity with respect to $\bar{\alpha}$ and $\bar{\varepsilon}$

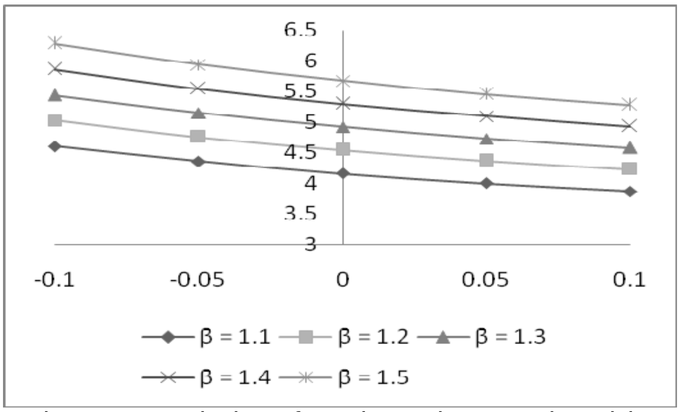

Figure 12. Variation of Load carrying capacity with respect to $\bar{\alpha}$ and $\bar{\beta}$

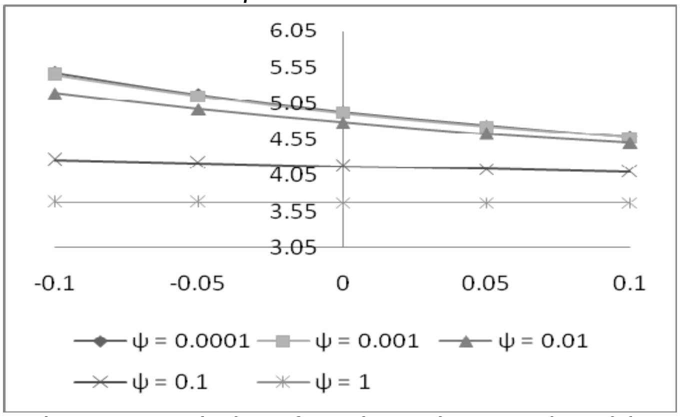

Figure 13. Variation of Load carrying capacity with respect to $\bar{\alpha}$ and ψ

Figures [14-15], present the distribution of load carrying capacity with respect to skewness for different values of $\bar{\beta}$ and ψ respectively. It is clearly seen that the skewness follows the trends of the variance. The fact that, the combined effect of $\bar{\beta}$ and ψ is considerably adverse is manifest in Figure 16.

The variation of load carrying capacity for different values of standard deviation with respect to other two roughness parameters is negligible up to the value of 0.05 so far as the distribution of load carrying capacity is concern.

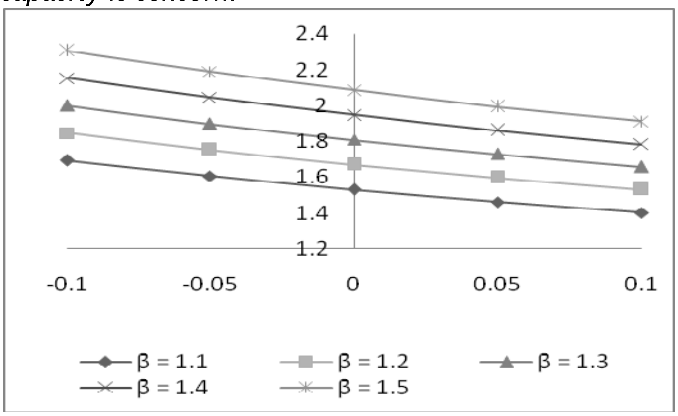

Figure 14. Variation of Load carrying capacity with respect to $\bar{\varepsilon}$ and $\bar{\beta}$

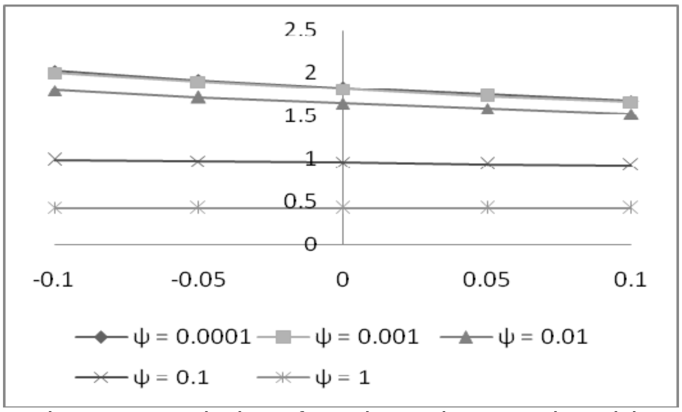

Figure 15. Variation of Load carrying capacity with respect to $\bar{\varepsilon}$ and ψ

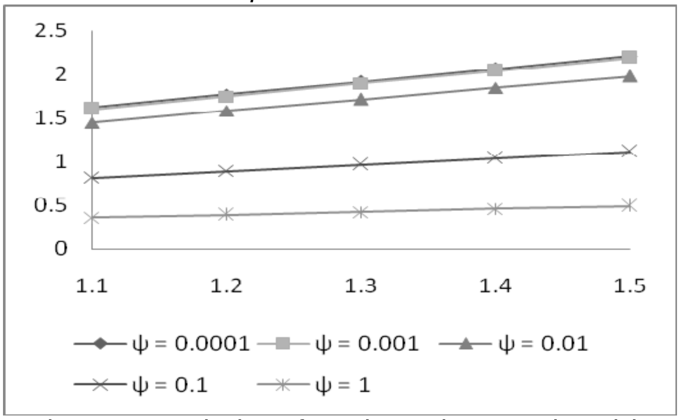

Figure 16. Variation of Load carrying capacity with respect to $\bar{\beta}$ and ψ

It is needless to say that the porosity decreases the load carrying capacity. Besides, if becomes clear that the combined effect of standard deviation and porosity is considerably adverse. Some of these figures indicate that this negative effect of porosity and standard deviation can be reduced by the positive effect of magnetization parameters in the case of negatively skewed roughness by suitably choosing the aspect ratio $\bar{\beta}$. This reduction becomes all the more evident when variance (-ve) occurs

CONCLUSION

It is noticed that the bearing can support a load even when there is no flow. Further, it is found that the roughness needs to be accounted for while designing the bearing system even if the suitable form of magnitude of magnetic field has been considered.

This is all the more necessary especially; from bearings life period point of view. Besides, this investigation offers an additional degree of freedom in the form of magnitude of magnetic field from design point of view.

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