Ferro fluid based squeeze film in a longitudinally rough surface bearing of infinite width: A comparative study

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Abstract:

This investigation aims to discuss a hydro magnetic squeeze firm in a longitudinally rough parallel surface bearing considering two different forms of the magnitude of the magnetic field. In the light of the stochastic model of Christensen and Tonder regarding surface roughness, the associated stochastically averaged Reynolds' type equation is found. Thereafter, the load bearing capacity is obtained for both the forms of magnitude of the magnetic field. The results presented here indicate that the magnetization offers a good amount of help in reducing the adverse effect of roughness at least in the case of the trigonometric form of magnitude. Besides, providing an additional degree of freedom, this article offers some scopes for reducing the adverse effect of variance positive, skewness positive by the positive effect of magnetization and standard deviation in the case of negatively skewed roughness when negative variance is involved. A comparison of performance for both the forms of the magnitude informs that the trigonometric form of the magnitude presents a better picture to be used in the industry.

Key words:

Squeeze film, Ferro fluid lubrication, Rough surface, Bearing of infinite width, Load bearing capacity.

Introduction:

The effect of longitudinal roughness has been analysed for slider bearing (Andharia et. al. (1) and for spherical bearing (Andharia et. al. (2). These investigations confirmed that the longitudinal roughness was a little better than transverse roughness pattern in terms of bearing design. The fact that the longitudinal roughness pattern improved the load carrying capacity of a hydrodynamic short journal bearing in the presence of a couple stress fluid was assorted by Hsu et. al. (3). Andharia and Deheri (4,5) discussed longitudinal roughness effect on ferrofluid squeeze film between conical plates and truncated conical plates. These two discussions also submitted that the longitudinal roughness was of more help as compared to transverse roughness pattern.

Andharia and Deheri (6) considered the ferrofluid lubrication of a squeeze film in longitudinal rough elliptical plates. Panchal et. al. (7) studied the influence of ferrofluid through a series of flow factors on the performance of a longitudinal rough finite slider bearing. Shimpi and Deheri (8) discussed the bearing deformation effect on the performance of a ferrofluid based squeeze film when longitudinal roughness occurred. Here, velocity slip affect was also investigated for truncated conical plates.

The ferrofluid has been fund to be extremely useful in many tribological problems occurring in bearing industry. Different properties and several flow models for ferrofluid has been discussed in Bhat (9). The friction was found to be lowering at the moving plate of an infinitely long bearing as discussed by Patel et. al. (10) when a ferrofluid was employed for lubrication. Hsu et.al. (11) investigated the ferrofluid lubrication of a short journal bearing. The friction coefficient was found to be modified by combined influence of magnetism and roughness. Acharya et. al. (12) deliberated on behaviour of a ferrofluid squeeze film infinitely long porous rough rectangular plates. Here, the magnitude of the external magnetic field was quite different from the usually adopted ones. (9).

Wang et. al. (13) conducted experimental and numerical studies on the surface roughness effect lubricated point contact. The roughness amplitude strongly influences the bearing performance here. In (14) Lin investigated the effect of longitudinal surface roughness on sub critical and super critical limit cycles of short journal bearings. It was established that for fixed bearing parameter the effects of longitudinal roughness structure extended the linear stability region. The effect of surface roughness on hydrodynamic lubrication of slider bearing was studied by Andharia et. al. (2). The friction was found to be decreased depending on the roughness patterns.

In the literature one comes across various forms of the magnitude of applied magnetic field. But little comparison has been made. Thus, here it has been proposed to compare the behavior of squeeze film considering different forms of magnitude for a longitudinally rough ferrofluid based squeeze film in parallel surface bearing of infinite width.

Analysis:

The geometry and configuration of the bearing system is shown below.

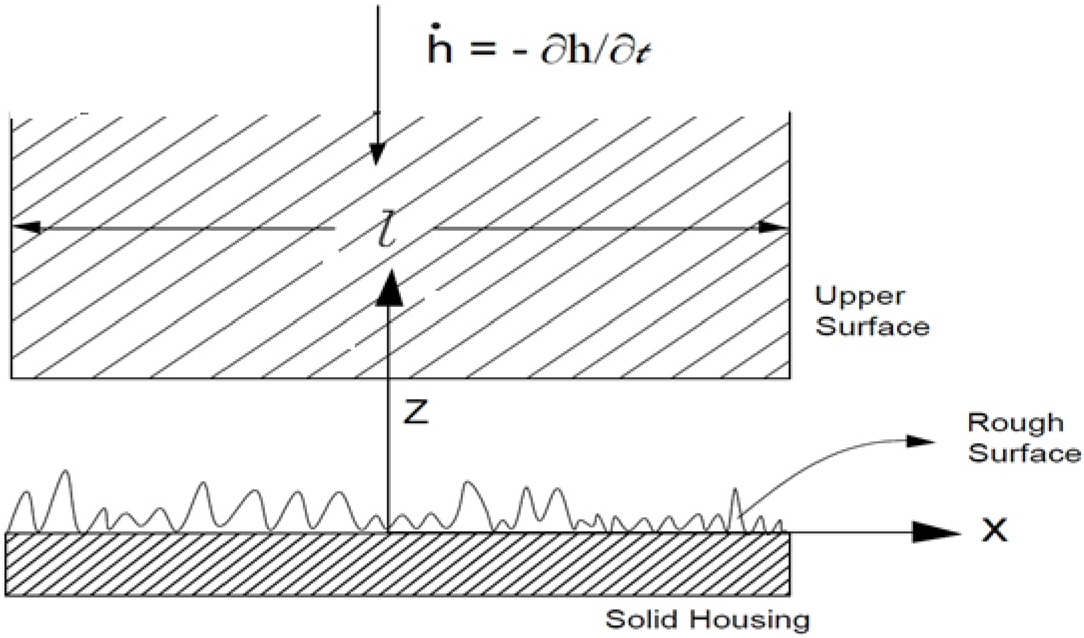

Figure – I Configuration of the bearing system

Adopting the stochastic averaging method of Christensen and Tonder (15,16,17) one is eventually led to the following governing Reynolds' equation for pressure distribution (Hamrock book 18, Prajapati Thesis 19)

$$\frac{\partial^2}{\partial x^2}\left(p - 0.5\mu_0\bar{\mu}H^2\right) = -\frac{12\,\mu\,\dot{h}}{m(h)^{-1}} \qquad \ldots (1)$$

where μ_0 is the permeability of the free space, $\bar{\mu}$ is the magnetic susceptibility, μ is the fluid viscosity and

$$m(h) = h^{-3}\left(1 - 3\alpha h^{-1} + 6h^{-2}\left(\sigma^2 + \alpha^2\right) - 10h^{-3}\left(\varepsilon + 3\sigma^2\alpha + \alpha^3\right)\right)$$

The details regarding the mean α, the standard deviation σ and skewness ε can be obtained from the deliberation of Christensen and Tonder (15,16,17).

For the comparative study we have considered the following two different forms of magnitude of the magnetic field.

Form I

$$H^2 = k\left(x^2 - \frac{l^2}{4}\right) \qquad \ldots (2)$$

Form II

$$H^2 = kl^2\left(\frac{3\pi x}{2l} + \frac{3\pi}{4}\right)\cos\left(\frac{3\pi x}{2l} - \frac{\pi}{4}\right) \qquad \ldots (3)$$

where k is a suitably chosen constant so as to manufacture a required magnetic strength.

Boundary conditions associated are:

$$p = 0 \text{ when } x = \pm\frac{l}{2} \qquad \ldots (4)$$

Integrating equation (1) with respect to the above mentioned boundary conditions, one gets the pressure distribution for the Form I as

$$p_1 = 0.5\mu_0\bar{\mu}k\left(x^2 - \frac{l^2}{4}\right) + \frac{3}{2}\,\mu\dot{h}\,m(h)\left(l^2 - 4x^2\right) \qquad \ldots (5)$$

and for the Form II, the pressure distribution is obtained as

$$p_2 = 0.5\mu_0\bar{\mu}kl^2\left(\frac{3\pi x}{2l} + \frac{3\pi}{4}\right)\cos\left(\frac{3\pi x}{2l} - \frac{\pi}{4}\right) + \frac{3}{2}\,\mu\dot{h}\,m(h)\left(l^2 - 4x^2\right) \qquad \ldots (6)$$

It is easily observed that pressure distribution is parabolic in nature for the form I while this profile appears to be distorted in the form II.

Introducing the non-dimensional quantities

$$\bar{x} = \frac{x}{l} \qquad \mu^* = -\frac{k\mu_0\bar{\mu}h^3}{\mu\dot{h}} \qquad P = -\frac{ph^3}{\mu\dot{h}l^2} \qquad W = \frac{wh^3}{\mu\dot{h}l^3}$$

$$M(h) = m(h)h^3 = \left(1 - 3\alpha^* + 6\left(\sigma^{*2} + \alpha^{*2}\right) - 10\left(\varepsilon^* + 3\sigma^{*2}\alpha^* + \alpha^{*3}\right)\right)$$

$$\sigma^* = \frac{\sigma}{h} \qquad \alpha^* = \frac{\alpha}{h} \qquad \varepsilon^* = \frac{\varepsilon}{h^3}$$

and using

$$w = \int_{-1/2}^{1/2} p\,dx$$

the load carrying capacity in dimensionless form for form I comes out to be

$$W_1 = \frac{\mu^*}{12} + M(h) \qquad \ldots (7)$$

while the load bearing capacity in non-dimensional form for the form II turns out to be

$$W_2 = \frac{\mu^*}{2}\left(1 + \frac{2}{3\pi}\right) + M(h) \qquad \ldots (8)$$

Results and discussion:

Equations (7) and (8) confirm that the non-dimensional load carrying capacity gets raised by

$$\frac{\mu^*}{12} \approx 0.083\mu^*$$

and

$$\frac{\mu^*}{2}\left(1+\frac{2}{3\pi}\right) \approx 1.212\mu^*$$

with regards to the conventional lubricant based bearing system. Further, the trigonometric form of the magnitude registers more load carrying capacity. This study reduces to the investigation of Prakash and Vij (20) for smooth bearing system for conventional fluid.

The linearity of the expressions with respect to magnetization says that an increase in magnetization inevitably leads to increased load carrying capacity. Needless to say is that magnetization increased the viscosity of the fluid causing increased pressure and hence augmented load carrying capacity. (C.F Figures (1) to (3) and (7) to (9))

A noticeable fact is that the standard deviation associated with roughness causes sharply increased load carrying capacity which can be seen from Figures (4, 5, 10 and 11). This trend of standard deviation is rarely seen in the case of transversely rough bearing surfaces. An appealing scenario occurs in the case of negatively skewed roughness because the effect of roughness can be countered at least in the case of trigonometric form of the magnitude of the magnetic field when variance (– ve) is in placed which can be depicted from Figure (6) and (12).

Conclusion:

The trigonometric form of the magnitude registers a comparatively better performance in comparison with the algebraic form of magnitude, although, the effect of roughness, remains adverse in general. Unlike, the case of conventional lubricant based bearing system, this type of bearing system bears a good amount of load even when there is no flow. This investigation underlines that it is the standard deviation which make the difference between the performances in the case of transverse and longitudinal surface roughness. Although, a good picture emerges from this investigation, roughness needs to be given due respect while designing the bearing system.

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Figure: 1 Variation of load carrying capacity for μ* and σ*

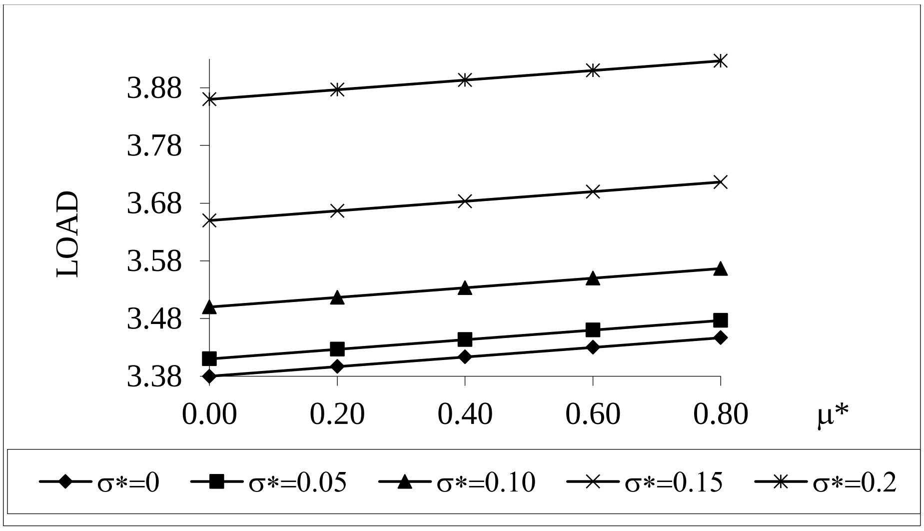


Figure: 2 Distribution of load carrying capacity with respect to μ* and α*

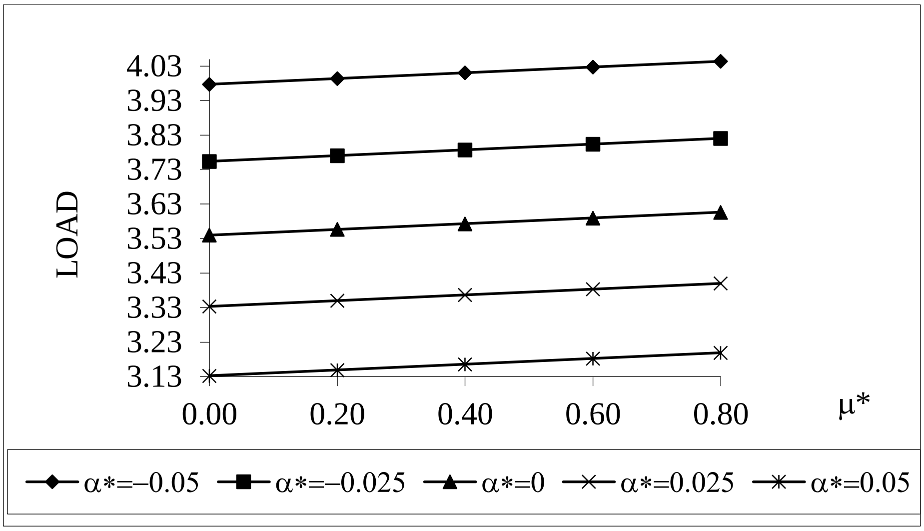


Figure: 3 Profile of load carrying capacity for μ* and ε*

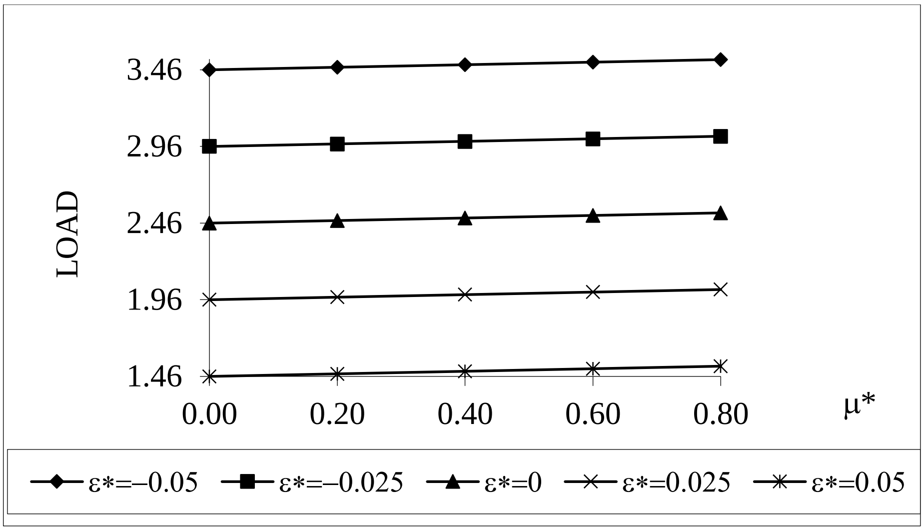


Figure: 4 Variation of load carrying capacity for σ* and α*

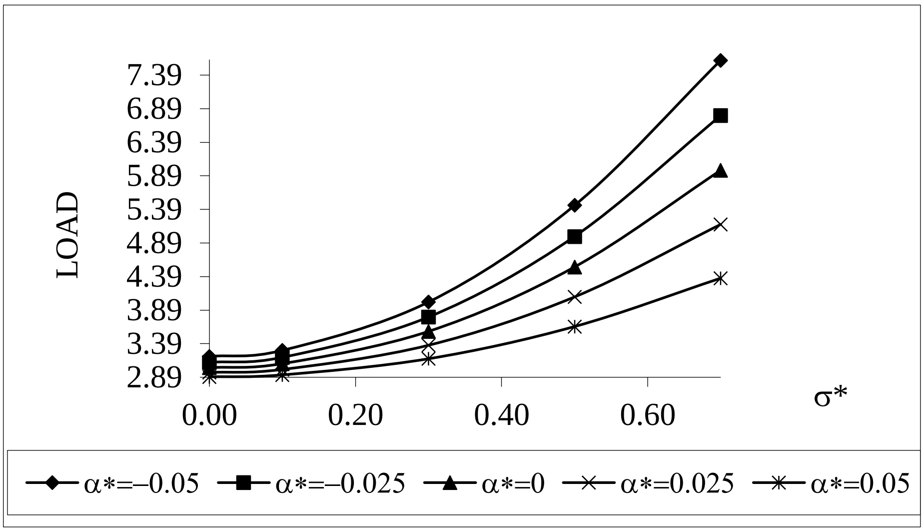


Figure: 5 Distribution of load carrying capacity with respect to σ* and ε*

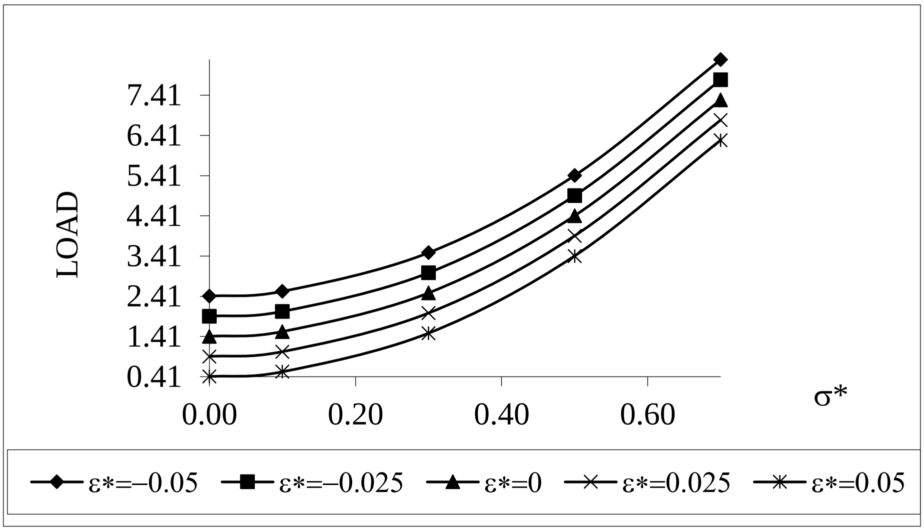


Figure: 6 Profile of load carrying capacity for α* and ε*

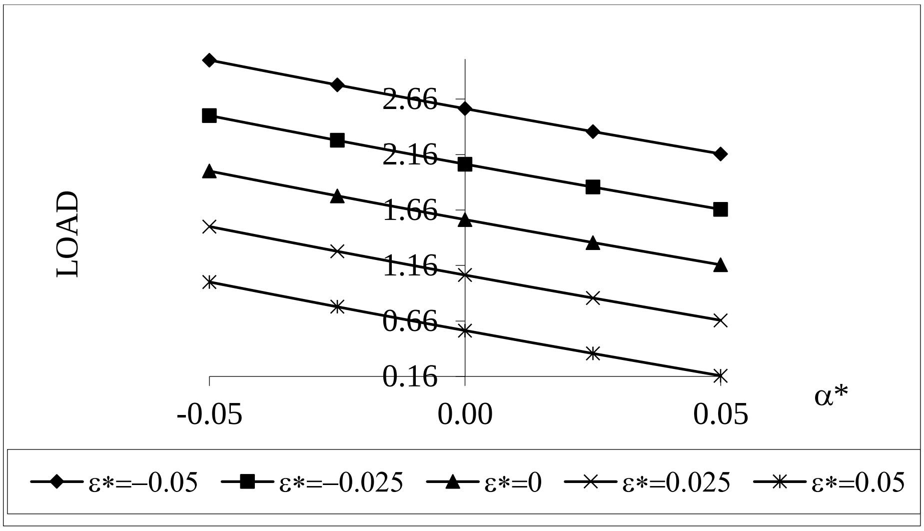


Figure: 7 Variation of load carrying capacity for μ* and σ*

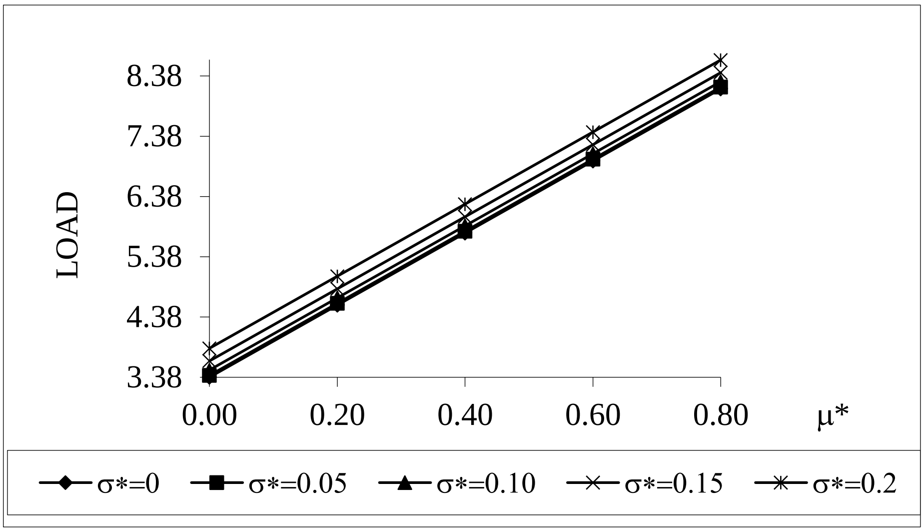


Figure: 8 Distribution of load carrying capacity with respect to μ* and α*

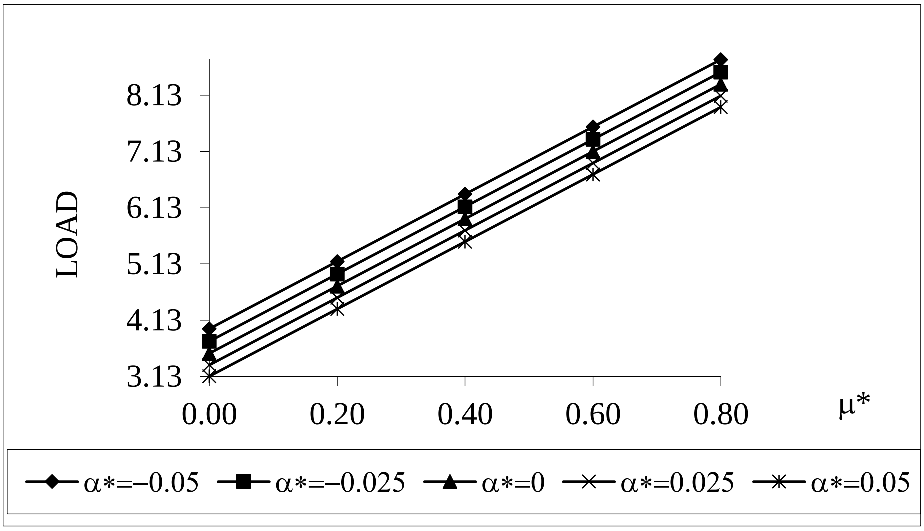


Figure: 9 Profile of load carrying capacity for μ* and ε*

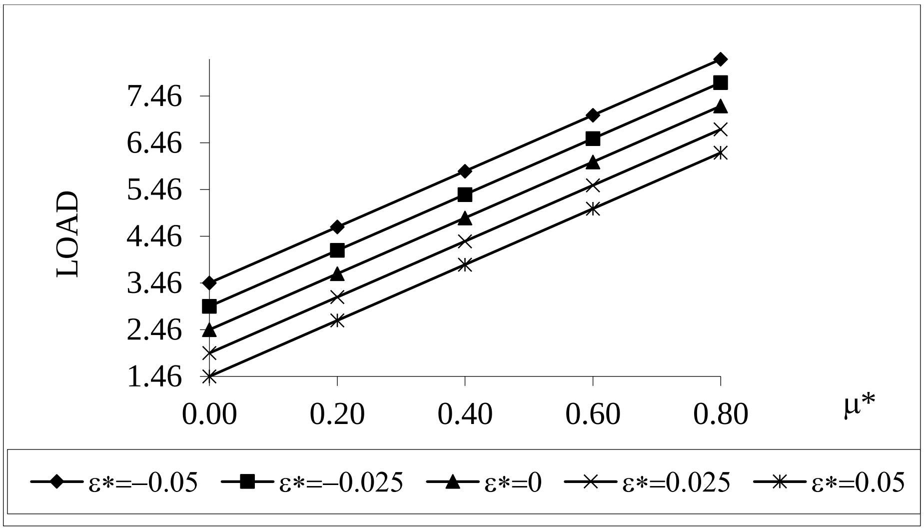


Figure: 10 Variation of load carrying capacity for σ* and α*

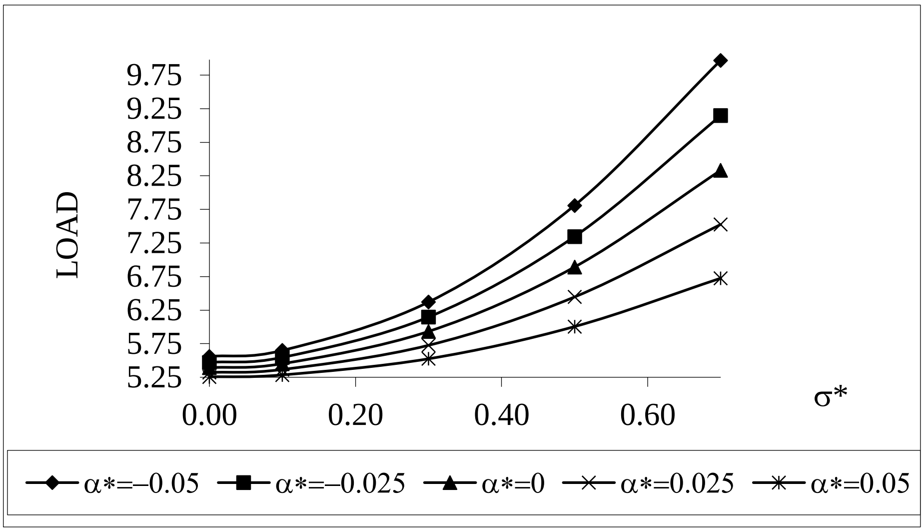


Figure: 11 Distribution of load carrying capacity with respect to σ* and ε*

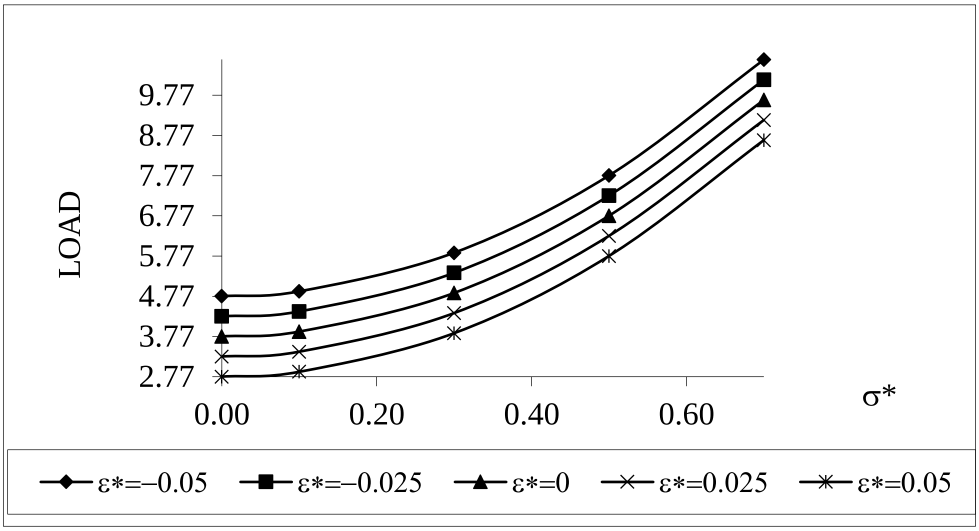
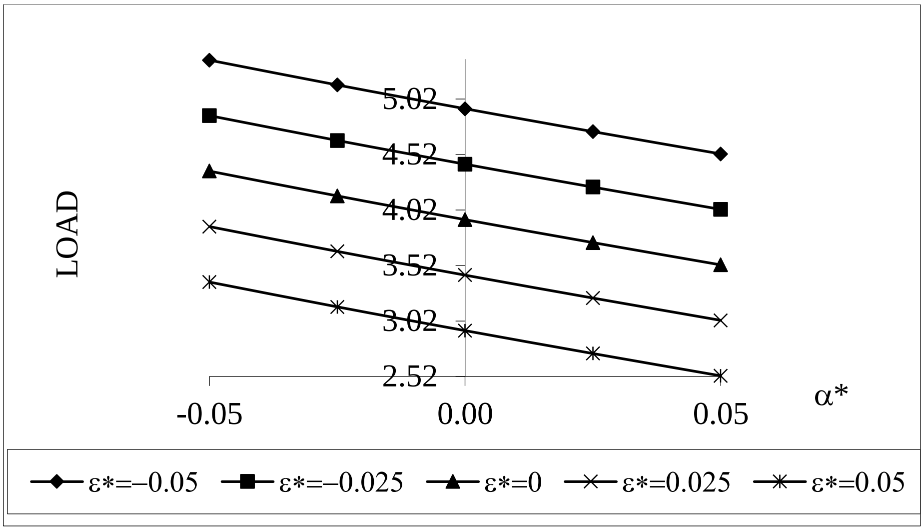


Figure: 12 Profile of load carrying capacity for α* and ε*



Gururajan and Prakash (2008) studied the surface roughness effects in infinitely long porous journal bearings. There was considerable influence of surface roughness. Patel et. al. (2010) dealt with the lubricate of an infinitely long bearing by a magnetic fluid. The friction was found to be decreasing at the moving plate while it increased marginally due to the magnetization. Hsu et. al. (2013) considered the lubrication performance of short journal bearing considering the effect of surface roughness and magnetic field. The combined influence reduced the modified friction coefficient. Shukla and Deheri (2016) studied the effects of slip velocity on the performance of a magnetic fluid based transversely rough porous narrow journal bearings. The combined effect of slip and transverse roughness decreased the load carrying capacity heavily. Shimpi and Deheri (2013) discussed the effect of deformation on a ferrofluid based transversely rough short bearing. Here the friction remains unchanged because of magnetic fluid lubrication but the load carrying capacity increased for almost all the value of deformation.

Here it has been proposed to study ferrofluid based squeeze film in a longitudinally rough surface bearing of infinite width taking different forms of the magnitude of the magnetic field.