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SHLIOMIS MODEL BASED FERROFLUID LUBRICATION OF A ROUGH ANNULAR SQUEEZE FILM UNDER COUPLE STRESS EFFECT

HIMESH A. PATEL[1], HIMANSHU C. PATEL[2] AND G.M. DEHERI[3]

[1]Assistant Professor, Science & Humanities Department, Gujarat Power Engineering & Research Institute,
Mewad, Mehsana-383315, Gujarat State, India.
E-mail.himesh.patel4@gmail.com . Telephone.+91-9428389902
[2]Professor, Department of Mathematics, L. D. College of Engineering, Ahmedabad-380009,
Gujarat State, India. E-mail. dr.prof.hcpatel@ldce.ac.in . Telephone.+91-9978440975
[3]Associate Professor, Department of Mathematics, Saradar Patel University, Vallabh Vidyanagar-388120,
Gujarat State, India. E-mail. gmdeheri@rediffmail.com . Telephone.02692233289

ABSTRACT

This paper aims to analyze the combined effect of magnetism and couple stress effect on the performance of the squeeze film in rough annular bearings. Shliomis model has been adopted to describe the magnetic flow. The pressure distribution is obtained after solving the associated stochastically averaged Reynolds type equation. Then the load carrying capacity is calculated. The results presented in graphical forms indicate that the combined effect of magnetism and couple stress may be nearly sufficient to counter the adverse effect of transverse roughness by suitably choosing the aspect ratio.

Keywords: Squeeze film, Annular plates, magnetism, Couple stress, roughness, load carrying capacity.

INTRODUCTION

For centuries, many interesting materials have been attracting the investigators and scientists due to their extraordinary properties and industrial usage. Magnetic fluid is one of such smart materials, which are not obtainable free state in nature, but are to be synthesized. These fluids have a good number of applications in the field of science and engineering etc.

Due to the wide application of the magnetic fluid, many researchers have used magnetic fluids as a lubricant in various geometry of bearing systems. Tipei (1982) investigated the theory of lubrication using ferrofluid and applied it in short bearings. Sinha et al. (1993) studied the effect of ferrofluid lubrication on cylindrical rollers. Osman et al. (2001) worked on the static and dynamic characteristics of magnetized journal bearings lubricated with ferrofluid. Shah and Bhat (2005) examined the effect of magnetic fluid lubrication on a squeeze film between curved annular plates considering rotation of magnetic particles. Deheri et al. (2006) discussed the effect of circular step bearings under the presence of a ferrofluid. Ahmed and Singh (2007) analyzed the effect of porous-pivoted slider bearing with slip velocity using ferrofluid. Urreta et al. (2009) studied the performance of hydrodynamic journal bearing lubricated with magnetic fluids. Patel et al. (2010) investigated the effect of a short hydrodynamic slider bearing in the presence of a ferrofluid. Patel et al. (2012) studied the performance of hydrodynamic short journal bearings lubricated with magnetic fluid. All the above studies have found that the effect of the bearing system gets enhanced owing to magnetization.

The squeeze film performance is commonly applied in gears, aircraft engines, automotive engines, gyroscopes and the mechanics of synovial joints in human being and animals. A good number of researches with reference to squeeze films have been discussed for the parallel surfaces by Gould (1967), in curved annular plates by Gupta and Vora (1980), in annular disks by Lin (2001) and a sphere and plane surface by Chou et al. (2003).

Many methods were proposed to improve the performance of the bearing system, One such method was the use of couple stress fluid. Bujurke and Jayaraman (1982) analyzed the influence of couple stresses in squeeze films. Bujurke and Naduvinamani (1991) investigated the performance of narrow porous journal bearing lubricated with couple stress fluid. Lin (1997) dealt with the effect of squeeze film characteristics of long partial journal bearing lubricated with couple stress fluid. Lin (2000) studied the performance of squeeze film characteristics between a sphere and a flat plate using couple stress fluid model. These studies have predicted about higher load carrying capacity, lower coefficient of friction, and delayed time of approach in comparison with the Newtonian case.

The bearing surfaces are assumed smooth in all the above discussions. But it is not realistic because, after having some run-in and wear or through the manufacturing process and the impulsive damage, the bearing surfaces could be roughed. Various techniques have been proposed to deal with the effect of surface roughness on the performance characteristics of squeeze film bearings, Christensen and Tonder (1969a, 1969b, 1970) modified the stochastic theory of Tzeng and Saibel (1967) to study the effect of surface roughness in general. Many research papers are abound dealing with the hydrodynamic lubrication of rough surfaces using stochastic method of Christensen and Tonder (1969a, 1969b, 1970) such as the works on the porous annular disks by Ting(1975), the journal bearing by Guha (1993), Chiang et al. (2004), the spherical bearing by Gupta and Deheri (1996), Hydrodynamic slider bearing by Nanduvinamani et al. (2003), the curved annular plates by Bujurke et al. (2007), Deheri and Abhangi (2011) and Shimpi and Deheri (2012), the circular plates by Patel et al. (2009), Shimpi and Deheri (2010). All the above investigations make it clear that roughness affects the performance significantly. Patel and Deheri (2013) investigated the performance of various porous structures on the performance of a Shliomis model based magnetic fluid lubrication of a squeeze film in rotating rough porous curved circular plates. It was established that the adverse effect of transverse roughness could be overcome by the positive effect of ferrofluid lubrication in the case of negatively skewed roughness by suitably choosing curvature parameters and rotational inertia when Kozeny- Carman's model was used for porous structure.

ANALYSIS

Figure 1 presents the configuration of the bearing system. It consist of two parallel annular disks, each of inner radius $r_i$and outer radius r_0. The upper disk approaches the lower one with a squeezing velocity $-\frac{dh}{dt}$.

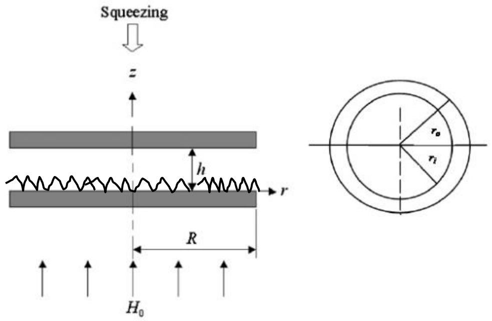

Fig.1 Cross section of Annular Disk

The bearing surfaces are considered to be transversely rough. The film thickness h(x) of the lubricant film for present study is assumed to be

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

where $\bar{h}$ is the mean film thickness characterizing the random roughness of the bearing surfaces, h_s is assumed to be stochastic in nature and governed by probability distribution function as discussed and derived by Christensen and Tonder (1969a, 1969b 1970). Also the mean $\bar{\alpha}$, the standard deviation $\bar{\sigma}$ and the parameter $\bar{\varepsilon}$ which is the measure of symmetry of the random variable h_s, are defined as in Christensen and Tonder (1969a, 1969b 1970). The details regarding the roughness aspects can be obtained from Christensen and Tonder (1969a, 1969b 1970).

Here the flow model of Shliomis (1972,1974) is considered to study the effect of magnetic fluid.Making use of discussion of Lin et al. (2013) the modified Reynolds equation governing the pressure distribution for the performance of a ferrofluid lubricated squeeze film in annular disks with non Newtonian couple stress effect is obtained as

$$f(h, l_c, \emptyset, \tau)\frac{1}{r}\frac{d}{dr}\left\{r\frac{dp}{dr}\right\} = 12\eta_0(1+\tau)(1+2.5\emptyset)\frac{dh}{dt} \qquad (1)$$

Where,

$$
\begin{aligned}
&g(h, lc, \emptyset, \tau) \\
&= h^3 - 12\frac{l_c^2}{(1+\tau)(1+2.5\emptyset)}h(3\bar{\alpha}^2 + 3\bar{\sigma}^2) \\
&+ 24\frac{l_c^3}{(1+\tau)^{3/2}(1+2.5\emptyset)^{3/2}}\tanh\left[\frac{\sqrt{(1+\tau)(1+2.5\emptyset)}}{2l_c}h(3\bar{\alpha}^2 \right. \\
&\left. + 3\bar{\sigma}^2)\right] + 3\bar{\sigma}^2\bar{\alpha} + \bar{\alpha}^3 + \bar{\varepsilon} \\
&+ 3h^2\bar{\alpha} \qquad (2)
\end{aligned}
$$

Introducing the non- dimensional quantities,

$$r^* = \frac{r}{r_0}, \quad P^* = \frac{ph_0^3}{\eta_0 r_0^2\left(\frac{dh}{dt}\right)}, h^* = \frac{h}{h_0},$$

$$g^*(h^*, C, \emptyset, \tau) = \frac{g}{h_0^3} \qquad (3)$$

and solving equation (1) with the boundary condition

$$p = 0 \text{ at } r = r_{i,}\, r = r_0 \qquad (4)$$

The expression for non dimensional pressure distribution is found to be

$$
\begin{aligned}
P^* = \frac{3(1+\tau)(1+2.5\phi)}{g^*(h^*, C, \emptyset, \tau)}&\left\{r^{*^2} + \frac{1}{logK}[(1-K^2)logr^*] \right. \\
&\left. - 1\right\} \qquad (5)
\end{aligned}
$$

where,

$$
\begin{aligned}
&g^*(h^*, C, \emptyset, \tau) \\
&= h^{*3} - 12\frac{C^2}{(1+\tau)(1+2.5\emptyset)}h^*\left(3\bar{\alpha}^{*2} + 3\bar{\sigma}^{*2}\right) \\
&+ 24\frac{C^3}{(1+\tau)^{3/2}(1+2.5\emptyset)^{3/2}}\tanh\left[\frac{\sqrt{(1+\tau)(1+2.5\emptyset)}}{2C}h^*\left(3\bar{\alpha}^{*2} \right.\right. \\
&\left.\left. + 3\bar{\sigma}^{*2}\right)\right] + 3\bar{\sigma}^{*2}\bar{\alpha}^* + \bar{\alpha}^{*3} + \bar{\varepsilon}^* \\
&+ 3h^{*2}\bar{\alpha}^* \qquad (6)
\end{aligned}
$$

where, α^* is non dimensional variance, σ^* is dimensionless standard deviation, ε^* is non dimensional skewness and K = aspect ratio $\frac{r_i}{r_0}$.

Integrating the film pressure over the film region yields the load carrying capacity in dimensionless form as

$$
\begin{aligned}
W^* = \frac{3(1+\tau)(1+2.5\phi)}{2g^*}(K^2-1)&\left[1\right. \\
&\left. - \frac{1}{logK}(K^2-1)\right] \qquad (7)
\end{aligned}
$$

Observe that in the limiting case $r_i \rightarrow 0$ the results of Lin et al. (2013) can be derived from the present analysis.

RESULTS AND DISCUSSION

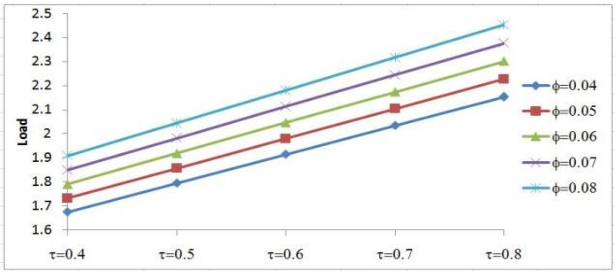

Figure- 2 Variation of Load carrying capacity with respect to ϕ and τ.

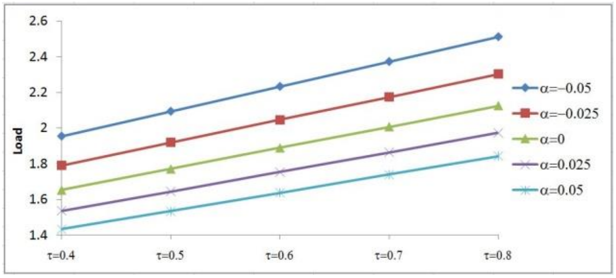

Figure- 3 Variation of Load carrying capacity with respect to α and τ.

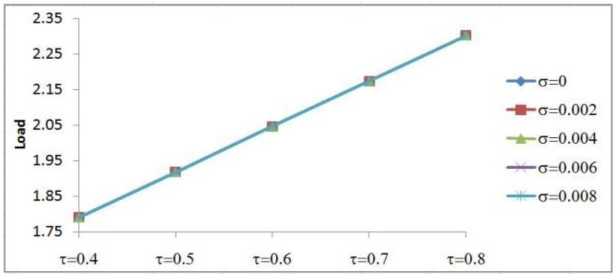

Figure- 4 Variation of Load carrying capacity with respect to σ and τ.

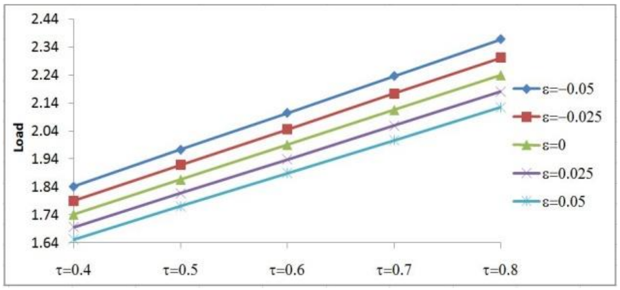

Figure- 5 Variation of Load carrying capacity with respect to ε and τ.

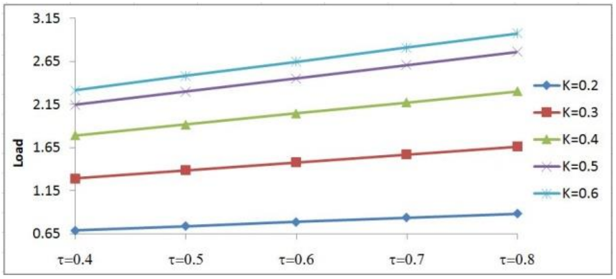

Figure- 6 Variation of Load carrying capacity with respect to ε and τ.

Figures 2 to 6 indicate that the load carrying capacity increases sharply due to the magnetization parameter. Further, from Figure 4 it is seen that the effect of standard deviation on the load carrying capacity with respect to magnetization is negligible.

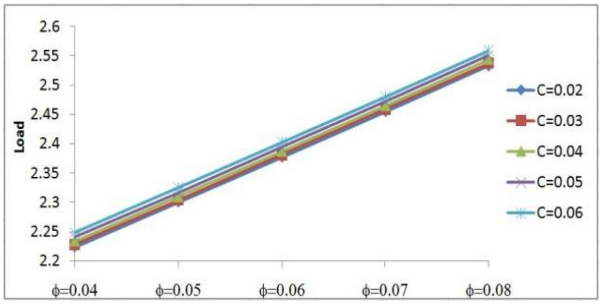

Figure- 7 Variation of Load carrying capacity with respect to C and ϕ.

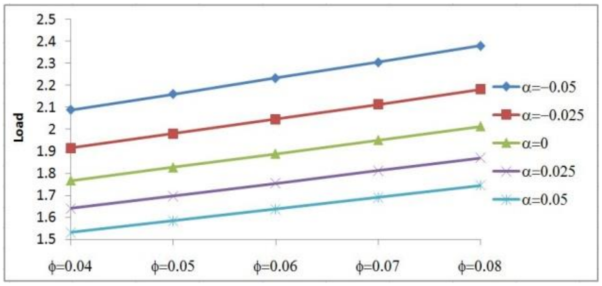

Figure- 8 Variation of Load carrying capacity with respect to α and ϕ.

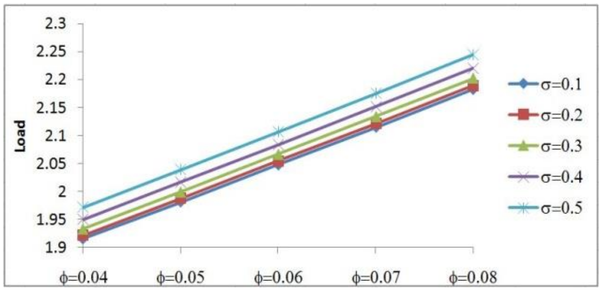

Figure- 9 Variation of Load carrying capacity with respect to σ and ϕ.

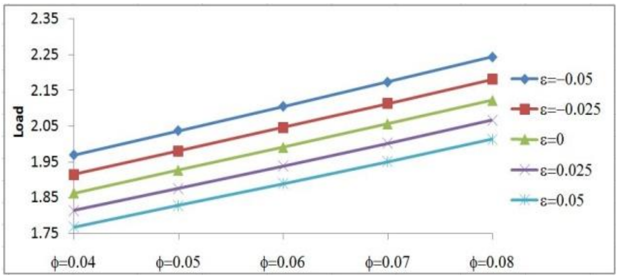

Figure- 10 Variation of Load carrying capacity with respect to $\boldsymbol{\varepsilon}$ and $\boldsymbol{\phi}$.

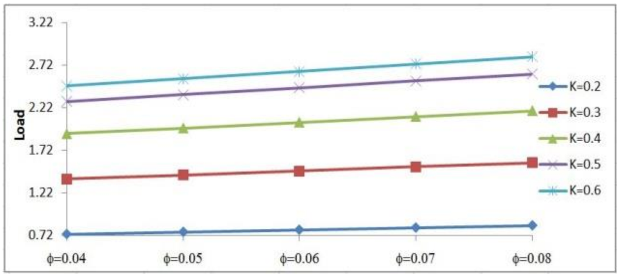

Figure- 11 Variation of Load carrying capacity with respect to K and ϕ.

Figures 7 - 11 dealing with the load profile with respect to volume concentration parameter suggest that the load carrying capacity increases considerably with the increase in volume concentration parameter.

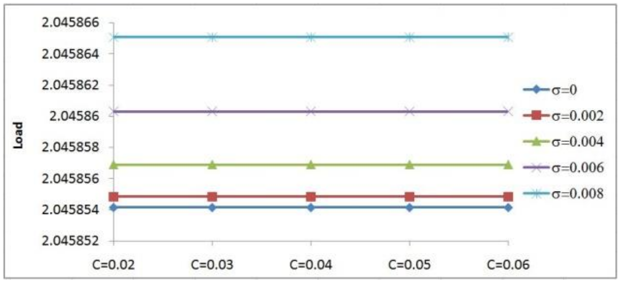

Figure- 12 Variation of Load carrying capacity with respect to σ and C.

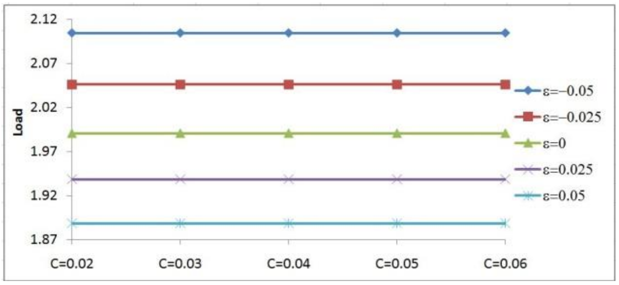

Figure- 13 Variation of Load carrying capacity with respect to ε and C.

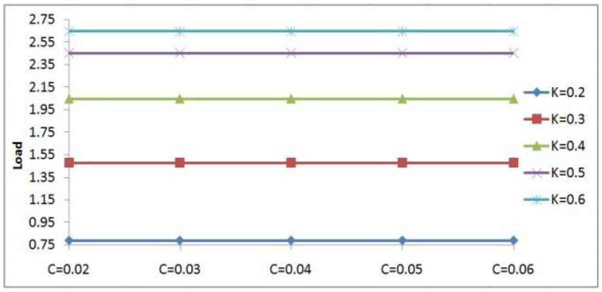

Figure- 14 Variation of Load carrying capacity with respect to $\boldsymbol{K}$ and $\boldsymbol{C}$.

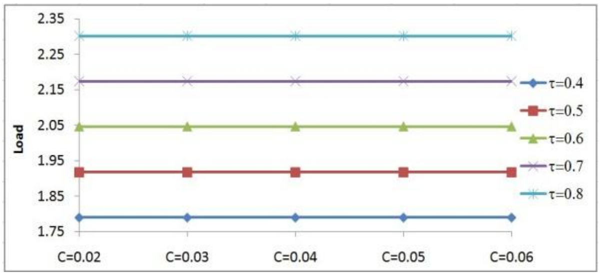

Figure- 15 Variation of Load carrying capacity with respect to τ and C.

The couple stress effect shown in Figures 12 - 15 establishes that it has just only nominal effect on the performance characteristics.

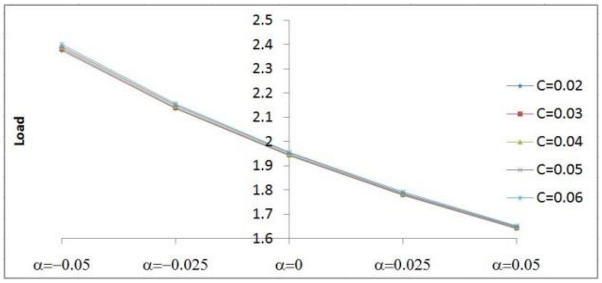

Figure- 16 Variation of Load carrying capacity with respect to C and α.

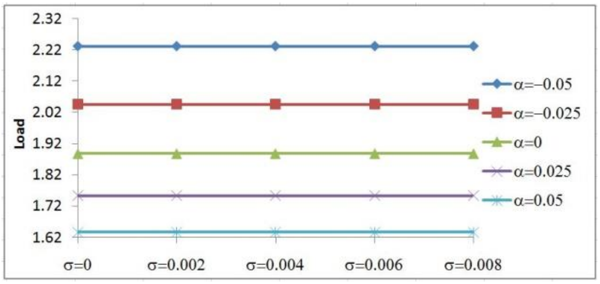

Figure- 17 Variation of Load carrying capacity with respect to α and σ .

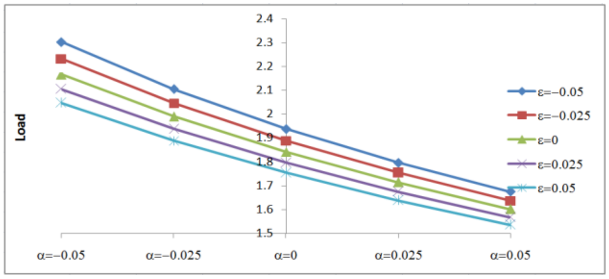

Figure- 18 Variation of Load carrying capacity with respect to ε and α.

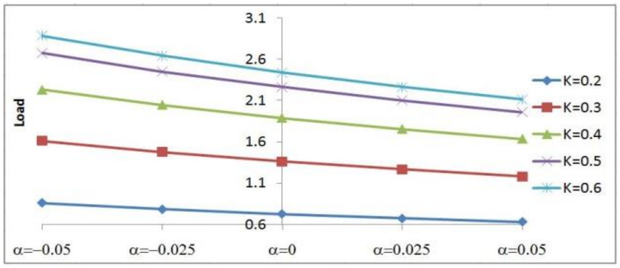

Figure- 19 Variation of Load carrying capacity with respect to K and α.

Figures 16 - 19 describing the load profile with respect to the variance suggest that the variance (+ve) decreases the load carrying capacity while it is opposite for variance (-ve).

Further, the effect of standard deviation on the distribution of load carrying capacity with respect to variance remains negligible. [Figure 17].

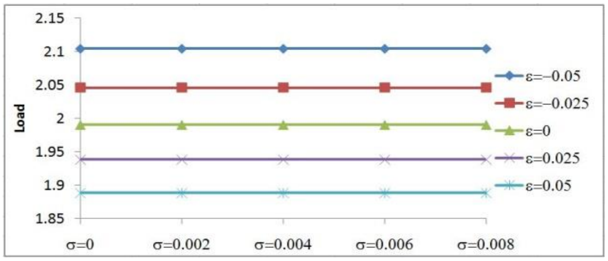

Figure- 20 Variation of Load carrying capacity with respect to ε and σ.

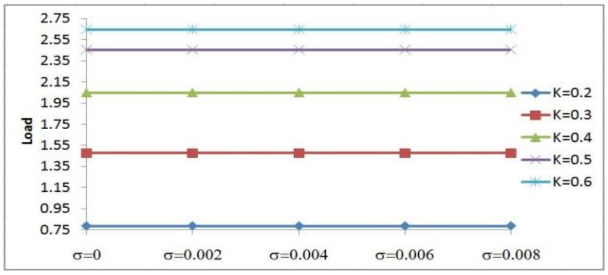

Figure- 21 Variation of Load carrying capacity with respect to K and σ.

From Figures 20 and 21 it is observed that the adverse effect of standard deviation is at the best nominal.

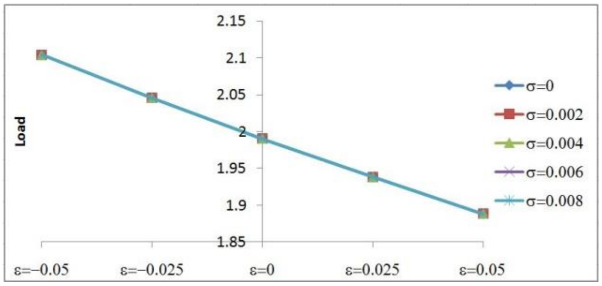

Figure- 22 Variation of Load carrying capacity with respect to σ and ε**.**

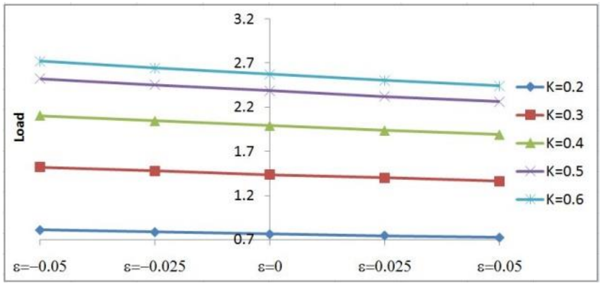

Figure- 23 Variation of Load carrying capacity with respect to K and ε**.**

CONCLUSION

The magnetic fluid lubrication may go a long way in reducing the adverse effect of roughness for moderate to higher values of couple stress parameter However this paper establishes that the roughness must be given due consideration while designing the bearing system even if a suitable magnetic strength is in force.

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