MULTIGRID METHOD FOR THE SOLUTION OF COMBINED EFFECT OF VISCOSITY VARIATION AND SURFACE ROUGHNESS ON THE SQUEEZE FILM LUBRICATION OF JOURNAL BEARINGS

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Abstract: *The paper presents, the multigrid method for the solution of combined effect of surface roughness and viscosity variation on the squeeze film lubrication of a short journal bearing operating with micropolar fluid. The modified Reynolds equation which incorporates the variation of viscosity in micropolar fluid is analysed using Multigrid method. The governing modified Reynolds equation is solved numerically for the fluid film pressure and bearing characteristics viz. load carrying capacity and squeeze time. The analysis of the results predicts that, the viscosity variation factor decreases the load carrying capacity and squeeze film time, resulting into a longer bearing life. The results are compared with the corresponding analytical solutions.*

Keywords: *Squeeze film lubrication; micropolar fluid; viscosity variation; surface roughness; multigrid method*

INTRODUCTION

The study of micropolar fluids has attention due to their uses in number of processes that takes place in industries viz. extrusion fluid polymers, liquid crystal solidification, cooling of metallic plate in a bath, animal blood exotic lubricants, colloidal and suspension solutions. The classical Navier-Stokes theory is inadequate in the study of these problems, as the micropolar fluid theory is a subclass of microfluid theory which is obtained by introducing the skew symmetric properties of the gyration tensor with a condition of microisotropy. The squeeze film behaviour takes place from the phenomenon of two surfaces which are lubricated and approaches each other with a normal viscosity. Since the viscous lubricant is resisted to extrusion, a pressure is built up during the interval, and the lubricant film supports the load. Therefore, the squeeze film action analysis focuses mainly on the load carrying capacity and rate of approach. In Gyroscopes, gears, aircraft engines, automotive engines and synovial joint mechanics the squeeze film action applications are commonly seen. Eringen's[1] micropolar fluid theory deals with the fluids which posses some microscopic effects arising from the local structures and micromotion of fluid elements. These fluids supports stress moments and body moments which influences the body inertia. A subclass of these fluids is the micropolar fluids, which exhibit the microrotational effects and microrotational inertia. Eringen's micropolar fluid theory defines the rotation vector, setting up of stress-strain rate constitutive equations.

The applications of different kinds of fluids as lubricants under many circumstances have been given more importance in the development of modern machines. To prevent the viscosity variation with a change in temperature, high molecular-weight polymers are added as a viscosity index improver. Lin[2] studied the static and dynamic behaviours of squeeze films using a couple stress fluids in a short journal bearing. The couple stress fluid model were studied by Lin et al.[3-5], Wang et al.[6], Guha et al.[7] and many researchers have analysed the hydrodynamic lubrication problems with different journal bearing geometries. Spikes[8] showed the behaviour of lubricants in contacts, current understanding and future possibilities. The surface roughness effect on the hydrodynamic lubrication of bearings was studied by many investigators so far. Several researchers used the stochastic theory model to study the surface roughness, developed by Christensen. This model was successfully used by Gururajan et al.[9], Hsiu et al.[10] to study hydrodynamic lubrication of rough surfaces and also many researchers studied the effect of surface roughness on the dynamic characteristics of finite slider bearings. The surface roughness effects on the thermo-hydrodynamic lubrication of journal bearings lubricated by bubbly oil was studied by Butch et al.[11] and effect of oil additives on the performance of a wet friction clutch material studied by Scott et al.[12] predicts that, the effect of surface roughness is to increase the load carrying capacity, stiffness and damping coefficients. In case of Newtonian fluids it is observed that the increase in load carrying capacity, lower coefficient of friction and delayed time of approach by keeping the viscosity constant. Many investigators[13-21] reported that the uses of micropolar fluids in different bearing systems which results in decrease in the load carrying capacity and improve in squeeze time. In general, viscosity of all the fluids decreases with increase in temperature.

Earlier theories were based on the assumption that the viscosity was kept constant although it is a function of pressure as well as temperature. In many practical applications the variation of viscosity and temperature are important, where the lubricants are supposed to function over wide range of temperatures. The viscosity temperature relationship formulae proposed are purely empirical, and for accurate calculations experimental data is required for the lubrication engineers. The viscosity film thickness relationship is replaced by viscosity-temperature relationship which has been verified experimentally. The highest temperature occurs in the zones where the film thickness is minimum[22].

The following assumptions are made in this paper.

1. There exists a thermal equilibrium.
2. The variation of viscosity temperature relation is replaced by viscosity film thickness relationship.
3. Hence the empirical relationship for the viscosity variation can be written as,

$$\mu = \mu_1 \left(\frac{h}{h_1} \right)^Q \tag{1}$$

where μ_1 is the viscosity at the film thickness and Q lies between 0 and 1 according to the nature of the lubricant (Q=0 for perfect Newtonian fluids and Q=1 for perfect gases). The effect of viscosity variation due to lubricant additives in journal bearings were explained by Sinha et al.[23] by employing the relation given in Eqn (1) and Naduvinamani et al.[24] studied the combined effect of viscosity variation and surface roughness on the squeeze film lubrication of journal bearings with micropolar fluids analytically.

In this paper, attempts have been made to solve the modified Reynolds equation using multigrid method. The combined effect of surface roughness and viscosity variation on the lubrication characteristics of journal bearings lubricated with micropolar fluid is analysed numerically and the paper is organised as follows.

The introduction of the proposed problem is described above. Next, the mathematical formulation of the problem, description of the multigrid method, and solution of the problem for the short bearing approximation are given. The longitudinal and transverse roughness patterns are also presented. Then, the results and discussions, and the important conclusions of the proposed work are given.

MATHEMATICAL FORMULATION OF THE PROBLEM

The physical configuration of the journal bearing is shown in Fig. 1. The shaft of radius r approaches the bearing surface with velocity V. The film thickness h is a function of θ, h=c+e cosθ , where c is the radial clearance and e is the eccentricity of the journal centre. The lubricant used in the present configuration is micropolar fluid.

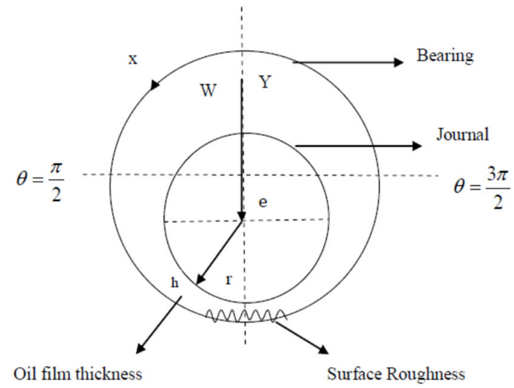

Figure 1. Squeeze film geometry of a journal bearing

The constitutive equations proposed by Eringen[1] for micropolar fluids are same as the equations of hydrodynamic lubrications. The resulting equations under steady state conditions are,

Conservation of linear momentum:

$$\left.\begin{aligned} \left(\mu + \frac{\chi}{2}\right)\frac{\partial^2 u}{\partial y^2} + \chi \frac{\partial v_3}{\partial y} - \frac{\partial p}{\partial x} = 0 \\ \left(\mu + \frac{\chi}{2}\right)\frac{\partial^2 w}{\partial y^2} + \chi \frac{\partial v_1}{\partial y} - \frac{\partial p}{\partial y} = 0 \end{aligned}\right\} \tag{2}$$

Conservation of angular momentum:

$$\left.\begin{aligned} \gamma \frac{\partial^2 v_1}{\partial y^2} - 2\chi v_1 + \chi \frac{\partial w}{\partial y} = 0 \\ \gamma \frac{\partial^2 v_3}{\partial y^2} - 2\chi v_3 + \chi \frac{\partial u}{\partial y} = 0 \end{aligned}\right\} \tag{3}$$

Conservation of mass:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{4}$$

where (u,v,w) are the components of velocity in the x, y and z directions, respectively. (v_1,v_2,v_3) are microrotational velocity components, χ is the spin viscosity coefficient, γ is the viscosity coefficient for micropolar fluids and μ is the coefficient of viscosity of Newtonian fluid. The boundary conditions at the bearing surface are

$$u(x,0,z) = v(x,0,z) = w(x,0,z) = 0\,, \quad \left.\frac{\partial^2 u}{\partial y^2}\right|_{y=0} = \left.\frac{\partial^2 w}{\partial y^2}\right|_{y=0} \tag{5}$$

and at the journal surface are

$$u(x,h,z) = w(x,h,z) = 0\,,\; v(x,h,z) = \frac{dh}{dt},$$

$$\left.\frac{\partial^2 u}{\partial y^2}\right|_{y=h} = \left.\frac{\partial^2 w}{\partial y^2}\right|_{y=h} \quad (6)$$

where h is the fluid film thickness.

MULTIGRID METHOD

The discretized equation can be written in the form $A^h u^h = f^h$, where A is a linear operator, u is the solution, f is the right hand side and h is the mesh size.

The algorithm for V cycle multigrid method as discussed in[25-27] is given as follows.

- Relaxing $A^h u^h = f^h$ 2 times with initial guess u_0^h
- Compute the residual $r^h = f^h - A^h u^h$
- Restrict $f^{2h} = I^{2h} r^h$, $u^{2h} = I^{2h} u^h$
- Relaxing $A^{2h} u^{2h} = f^{2h}$, 2 times with guess u^{2h}
- Compute the residual, $r^{2h} = f^{2h} - A^{2h} u^{2h}$
- Restrict $f^{4h} = I_{2h}^{4h} r^{2h}$, $u^{4h} = I^{4h} u^{2h}$

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- Solve the error equation, $e^H = \left(A^H\right)^{-1} f^H$

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- Interpolate . $e^{2h} \leftarrow I_{4h}^{2h} u^{4h}$
- Correcting the fine grid approximation $u^{2h} \leftarrow u^{2h} + e^{2h}$
- Interpolate $e^h \leftarrow I_{2h}^{h} u^{2h}$
- Correcting $u^h \leftarrow u^h + e^h$

The initial solution is taken on the finest grid. Two times Gauss-Seidel iterations are applied on finest grid for smoothing the errors. To transfer the calculated residual to the next coarse grid level, the half weighting restriction is used. Repeating the procedure till the coarsest grid level reaches the single point. The solution is obtained at the coarsest level. The bilinear interpolation is applied to prolongate the solution obtained from coarsest level to the next fine grid level and then applying two times Gauss- Seidel iterations. Repeating the procedure until the original finest grid level is reached. This is referred to as one V- cycle.

SOLUTION OF THE PROBLEM

The velocity components u and w are solved from Eqns. (2) and (3) subject to the boundary conditions (5) and (6), we obtain

$$u = \frac{1}{\mu}\left(\frac{y^2}{2}\frac{\partial p}{\partial x} + A_{11} y\right) - \frac{2N^2}{m}[A_{21}\sinh(my) + A_{31}\cosh(my)] + A_{41} \quad (7)$$

$$w = \frac{1}{\mu}\left(\frac{y^2}{2}\frac{\partial p}{\partial z} + A_{12} y\right) - \frac{2N^2}{m}[A_{22}\sinh(my) + A_{32}\cosh(my)] + A_{42} \quad (8)$$

$$v_1 = \frac{1}{2\mu}\left(y\frac{\partial p}{\partial z} + A_{12}\right) + A_{22}\cosh(my) + A_{31}\sinh(my) \quad (9)$$

$$v_3 = A_{21}\cosh(my) + A_{31}\sinh(my) - \frac{1}{2\mu}\left(y\frac{\partial p}{\partial z} + A_{11}\right) \quad (10)$$

$$A_{11} = 2\mu A_{21}\ ,\ A_{21} = \frac{A_{31}\sinh(mh) - [h/2\mu][\partial p/\partial x]}{1-\cosh(mh)}\ ,$$

$$A_{12} = -\frac{h}{2\mu}\frac{\partial p}{\partial z}\left\{h\sinh(mh) + \frac{2N^2}{m}[1-\cosh(mh)]\right\}\frac{1}{A_5}$$

$$A_{22} = \frac{A_{12}}{2\mu}$$

$$A_{31} = \frac{h}{2\mu}\frac{\partial p}{\partial x}\left\{\frac{h}{2}[\cosh(mh)-1] + h - \frac{2N^2}{m}\sinh(mh)\right\}\frac{1}{A_5}$$

$$A_{32} = \frac{h}{\mu}\frac{\partial p}{\partial z}\left\{\frac{h}{2}[\cosh(mh)-1] + h - \frac{N^2}{m}\sinh(mh)\right\}\frac{1}{A_5},$$

$$A_{41} = \frac{2N^2}{m}A_{31}, \qquad A_{42} = \frac{2N^2}{m}A_{32}$$

$$A_5 = \frac{h}{\mu}\left\{\sinh(mh) - \frac{2N^2}{mh}[\cosh(mh)-1]\right\},$$

$$m = \frac{N}{l},\ N = \left(\frac{\chi}{\chi+2\mu}\right)^{1/2} \qquad l = \left(\frac{\gamma}{4\mu}\right)^{1/2} \quad (11)$$

where N is the coupling number and l is the Characteristic length of the polar suspension. The modified Reynolds equation is obtained by integrating the Eqn. (4) with respect to y over the film thickness h and replacing u and w in Eqn. (4) by their respective expressions given in Eqns. (7) and (8). Using the boundary conditions for v given in Eqns. (5) and (6) in the form

$$\frac{\partial}{\partial x}\left[\frac{f(N,l,h)}{\mu}\frac{\partial p}{\partial x}\right] + \frac{\partial}{\partial z}\left[\frac{f(N,l,h)}{\mu}\frac{\partial p}{\partial z}\right] = 12\frac{\partial h}{\partial t} \quad (12)$$

where $f(N,l,h) = h^3 + 12l^2h - 6Nlh^2 \coth\left(\frac{Nh}{2l}\right)$ (13)

Short Bearing Approximation

A Short bearing approximation is considered in order to simplify the problem and to get a solution for the fluid pressure. The axial variation of pressure is considered by neglecting the circumferential variation. The Modified Reynolds equation Eqn. (12) reduces to

$$\frac{\partial}{\partial z}\left[\frac{f(N,l,h)}{\mu}\frac{\partial p}{\partial z}\right] = 12\frac{\partial h}{\partial t} \quad (14)$$

Substituting Eqn(1) in the above equation, we get

$$\frac{\partial}{\partial z}\left[\frac{f(N,l,h)}{\mu_1}\frac{h_1^{\,Q}}{h^Q}\frac{\partial p}{\partial z}\right] = 12\frac{\partial h}{\partial t} \quad (15)$$

Including roughness features, taking stochastic expectation of Eqn. (15), we get stochastic Reynolds equation,

$$\frac{\partial}{\partial z}\left\{E\left[\frac{f(N,l,h)}{\mu_1}\frac{h_1^{\,Q}}{h^Q}\right]\frac{\partial p}{\partial z}\right\} = 12\frac{\partial E(h)}{\partial t} \quad (16)$$

where expectancy operator E($\bullet$) is defined by,

$$E(\bullet) = \int_{-\infty}^{\infty} (\bullet)\, f(h_s)\, dh_s \quad (17)$$

where f is the probability density function of the stochastic film thickness h_s. The probability density function is given by,

$$f(h_s) = \begin{cases} \frac{35}{32c^7}(c^2 - h_s^{\,2})^3 & -c < h_s < c \\ 0 & elsewhere, \end{cases}$$

where $c = 3\sigma_1$, σ_1 is the standard deviation. By Christensen stochastic theory for the rough surfaces, the two types of roughness patterns are shown below.

Longitudinal Roughness

In this case, the roughness is assumed in the form of long narrow ridges and furrows running in the z direction and film thickness assume the form,

$$H = h(t) + h_s(z,\xi)$$

Then Eqn. (16) becomes

$$\frac{\partial}{\partial z}\left\{\frac{1}{E(1/F(N,l,H))}\frac{1}{\mu_1}\frac{h_1^{\,Q}}{h^Q}\frac{\partial E(p)}{\partial z}\right\} = 12\frac{\partial E(H)}{\partial t} \quad (18)$$

Transverse Roughness

The roughness is assumed in the form of long ridges and furrows running in the x direction and the film thickness are

$$H = h(t) + h_s(\theta,\xi)$$

Then Eqn. (16) becomes

$$\frac{\partial}{\partial z}\left\{\frac{E(F(N,l,H)}{\mu_1}\frac{h_1^{\,Q}}{h^Q}\frac{\partial E(p)}{\partial z}\right\} = 12\frac{\partial E(H)}{\partial t} \quad (19)$$

For probability density distribution function given by Eqn. (17), we have

$$E(H) = h \quad (20)$$

The modified Reynolds Eqns. (18) and (19) for longitudinal and transverse roughness types of directional structures can be expressed as,

$$\frac{\partial}{\partial z}\left\{\frac{G(F(N,l,H)}{\mu_1}\frac{h_1^{\,Q}}{h^Q}\frac{\partial E(p)}{\partial z}\right\} = 12c\frac{\partial \varepsilon}{\partial t}\cos\theta \quad (21)$$

where

$$G(F(N,l,H) = \begin{cases} \frac{1}{E(1/F(N,l,H))}, & \text{longitudinal roughness} \\ E(F(N,l,H)), & \text{transverse roughness.} \end{cases}$$

$$E(F(N,l,H)) = \frac{35}{32c^7}\int_{-c}^{c} F(N,l,H)\,(c^2 - h_s^{\,2})^3 dh_s,$$

$$E(1/F(N,l,H)) = \frac{35}{32c^7}\int_{-c}^{c} \frac{(c^2 - h_s^{\,2})^3}{F(N,l,H)} dh_s.$$

Introducing the following non dimensional parameters and variables:

$$\lambda = \frac{L}{2r}, \bar{z} = \frac{z}{L}, \bar{l} = \frac{l}{c}, \overline{H} = \frac{H}{c} = \bar{h} + \overline{h_s}, \bar{h} = \frac{h}{c}$$

$$\overline{h_s} = \frac{h_s}{c}, \quad \bar{p} = \frac{pc^2}{\mu_1 r^2 (d\varepsilon/dt)}$$

and $\bar{F}(N,\bar{l},\bar{H}) = c^3\left\{\bar{H}^3 + 12\bar{l}^2\bar{H} - 6N\bar{l}\,\bar{H}^2\coth\left(\frac{N\bar{H}}{2\bar{l}}\right)\right\}.$

The stochastic generalized Reynolds equation Eqn. (21) has to satisfy the following boundary conditions:

$$\bar{p} = 0 \quad at \quad \bar{z} = \pm 1 \qquad and \qquad \frac{d\bar{p}}{dz} = 0 \quad at \quad \bar{z} = 0$$

The Modified Reynolds equation Eqn. (21) can be solved by using multigrid method. Using first order finite difference scheme, Eqn. (21) can be descritised as below

$$\bar{p}_{i+1} - 2\bar{p}_i + \bar{p}_{i-1} = (\Delta z)^2 D_i \qquad (22)$$

where $D_i = \dfrac{48 Cos\,\theta\, E(\overline{H}^Q)\lambda^2}{\overline{G}(N,\bar{l},\overline{H})\, E(\overline{H}_1^Q)}$.

With the fluid film pressure known, the squeeze film characteristics such as load carrying capacity, squeeze time can be evaluated. The load carrying capacity is calculated by integrating the squeeze film action of the negative pressure because the diverging film side is neglected. The load carrying capacity of the bearing operating under the steady load is given by

$$E(W) = -2r\int_{z=0}^{z=L/2} \int_{\theta=\pi/2}^{\theta=3\pi/2} p\cos\theta\, d\theta\, dz \qquad (23)$$

Introducing the nondimensional quantity

$$E(\overline{W}) = \frac{E(W)c^2}{\mu_1 r^2 (d\varepsilon/dt)}$$

(24)

The load carrying capacity can be expressed in dimensionless form as

$$E(\overline{W}) = \frac{4\lambda^2}{(1+\varepsilon)^Q}\int_{\theta=\pi/2}^{\theta=3\pi/2} \frac{(1+\varepsilon\, Cos\theta)^Q}{G(N,\bar{l},\overline{H})} Cos^2\theta\, d\theta \qquad (25)$$

The nondimensional load carrying capacity E ($\overline{W}$) can be numerically evaluated by using Gaussian quadrature method. The time taken by the journal centre to move from from $\varepsilon = 0$ to $\varepsilon = \varepsilon_1$ which can be obtained by integrating eqn. (24) with respect to time at constant load $E(\overline{W})$.

Introducing the nondimensional response time

$$\tau = \frac{E(W)c^2 t}{\mu_1 r^3 L} \qquad (26)$$

The velocity of the journal centre can be expressed

$$\frac{d\varepsilon}{d\tau} = \frac{1}{E(\overline{W})} \qquad (27)$$

Eqn. (24) is a first order nonlinear differential equation, with the initial condition

$$\varepsilon = 0 \;\; to \;\; \tau = 0 \qquad (28)$$

The above differential equation can be solved using fourth order Runge-Kutta method.

RESULTS AND DISCUSSION

The effect of surface roughness pattern considering the viscosity variation on the squeeze film lubrication of short journal bearing lubricated with micropolar fluids is analysed using multigrid method. The results are analysed for various non dimensional parameters such as the coupling number N, the additives length size parameter $\bar{l}$ and the exponent Q of the viscosity variation. In the limiting case as $\bar{l} \to 0$ the effect of microstructures becomes negligible. The roughness parameter $\bar{c}$ characterizes the effect of surface roughness and $\bar{c} \to 0$ the problem reduces to the corresponding smooth case. The following parameters values are used for the numerical computation

$\bar{l} = 0.0,\ 0.2,\ 0.4;\ N = 0.0, 0.2, 0.4, 0.6;$

$\bar{c} = 0.0, 0.1$ and $Q = 0.0, 0.5, 1.0.$

Squeeze film pressure

The variation of nondimensional squeeze film pressure $\bar{p}$ with the angular coordinate θ for different values of Q is shown in Fig. 2. The dotted curves indicate the results of Newtonian case. It is observed that, as the viscosity variation factor increases the squeeze film pressure decreases rapidly for couple stress fluid than Newtonian fluid. Figure 3 presents the variation of $\bar{p}$ with θ for different values of Q with eccentricity ratio $\varepsilon = 0.2$, non-micropolar parameter $\bar{l} = 0.4$ and roughness parameter $\bar{c} = 0.1$ for both longitudinal and transverse roughness patterns.

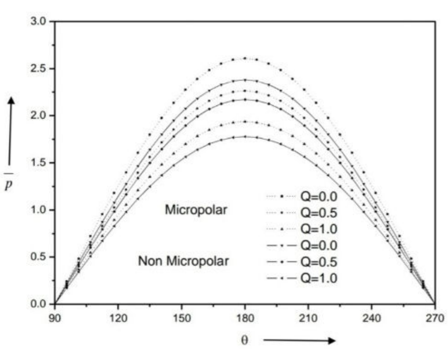

Figure 2. Variation of non-dimensional pressure $\bar{p}$ with θ for different values of Q with $\bar{l} = (0.0, 0.4), N = 0.2, \varepsilon = 0.2$ *and* $\lambda = 0.5$.

Load Carrying Capacity

The variation of nondimensional load carrying capacity $\overline{W}$ with the eccentricity ratio parameter ε is shown in the Fig. 4 for the various values of Q. It is observed that $\overline{W}$ increases for increasing values of ε and decreases for the increasing values of Q. Figure 5 predicts that when λ increases $\overline{W}$ increases. The variation of load carrying capacity $\overline{W}$ with eccentricity ratio ε as a function of $\bar{l}$ with N=0.2, $\lambda = 0.5,\ \bar{c} = 0.1$ is shown in Fig. 6. It is observed that $\overline{W}$ increases rapidly for both longitudinal and transverse roughness patterns, also the effect of transverse roughness pattern on the bearing surface is enhancing the load carrying capacity as compared to the longitudinal roughness pattern.

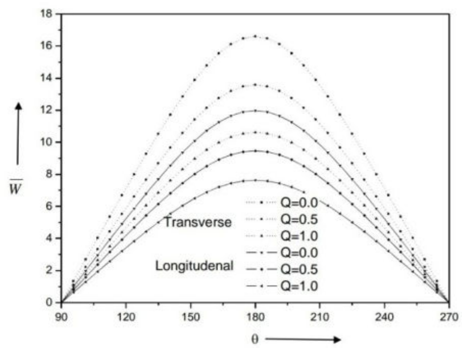

Figure 3. Variation of non-dimensional $\bar{p}$ with θ for different values of Q with $\bar{l} = 0.4, \bar{c} = 0.1,\ \varepsilon = 0.2, N = 0.2, \lambda = 0.5.$

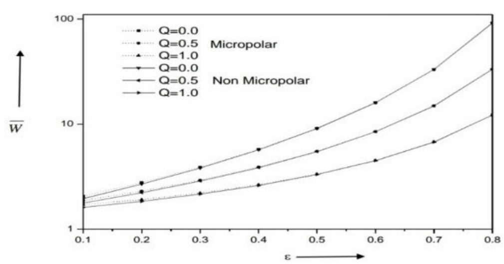

Figure 4. Variation of nondimensional load $\overline{W}$ with ε for different values of Q with $\bar{l} = 0.4, N = 0.2\, and\ \lambda = 0.5.$

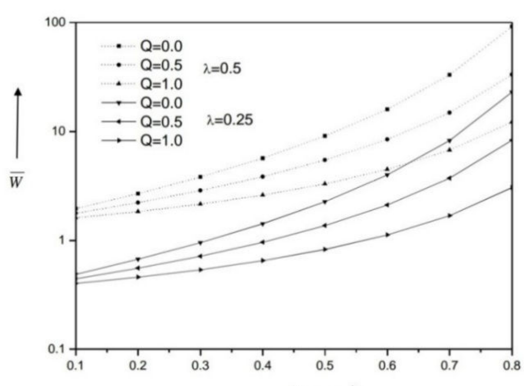

Figure 5. Variation of nondimensional load $\overline{W}$ with ε for different values of Q with $\bar{l} = 0.4, \lambda = (0.5, 0.25), and\ N = 0.2.$

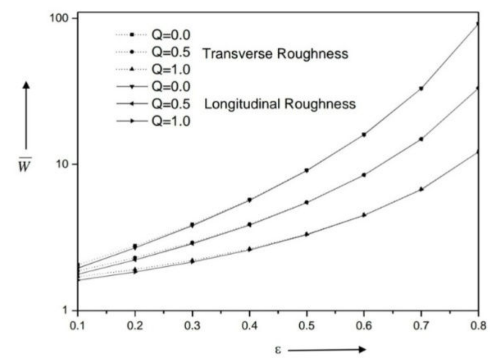

Figure 6. Variation of nondimensional load $\overline{W}$ with ε for different values of Q with $\bar{l} = 0.4, N = 0.2\, and\ \lambda = 0.5.$

Squeeze Film Time

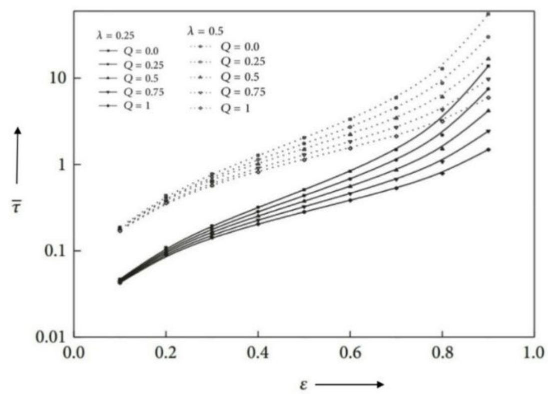

Figure 7. Variation of nondimensional time $\bar{\tau}$ with eccentricity ratio ε for different values of Q with $\bar{l} = 0.4, N = 0.2$ and $\lambda = (0.5, 0.25)$

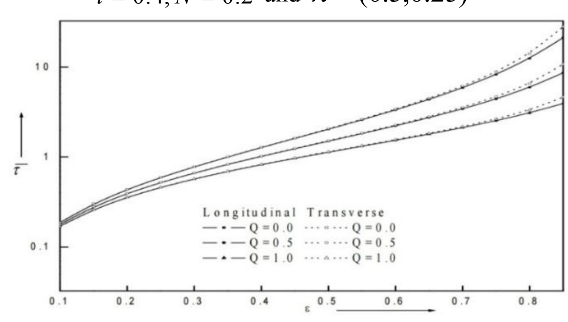

Figure 8. Variation of nondimensional time $\bar{\tau}$ with eccentricity ratio ε for different values of Q with $\bar{l} = 0.4, N = 0.2$, $\lambda = 0.5$ and $\bar{c} = 0.1$.

The variation of non-dimensional squeeze film time as a function of ε for different values of Q is shown in Fig 7. It is observed that the squeeze film time decreases for the increasing values of Q. The presence of couple stress indicates that the increase in response time than the Newtonian fluid. Figure 8 depicts that the variation of dimensionless response time increases with eccentricity ratio parameter in both longitudinal and transverse roughness patterns.

CONCLUSIONS

In this paper, the combined effect of viscosity variations and surface roughness in the pure squeeze film lubrication with additive lubricants in short journal bearing is analysed and conclusions are made as follows

- In both longitudinal and transverse roughness patterns the squeeze film pressure decreases due to the presence of viscosity variation.
- Load carrying capacity increases with increasing values of eccentricity parameter for both longitudinal and transverse roughness patterns.
- When the viscosity variation parameter increases, the squeeze film time decreases in both longitudinal and transverse roughness patterns.

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