Combined Effect of Pressure-Dependent Viscosity and Micropolar Fluids on Squeeze Film Circular Stepped Plates

Hanumagowda B. N[*1]., H. M. Shivakumar[#2], Raju B. T[*3], J. Santhosh Kumar[*4]
* Department of Mathematics, REVA University, Bangalore - 560064, India.
# Department of Mathematics, East West Institute of Technology, Bangalore - 560091, India

Abstract:

The theoretical investigations made in this paper are to study the combined effect of pressure-dependent viscosity (PDV) and micropolar fluids on squeeze film circular step plate. The modified Reynolds equations in both the regions accounting for the pressure-dependent viscosity of micropolar fluids are mathematically derived. From the analysis, it has been found that the non dimensional pressure, non dimensional load carrying capacity, and non dimensional squeeze film time decreases with increasing value of non dimensional step distance (K) and increases as compared with iso-viscous lubricant case.

***Keywords**: Squeeze film, Circular stepped plates, micropolar fluids, pressure-dependent Viscosity.*

1 Introduction

Numbers of theories have been proposed to explain the peculiar behaviour of fluids which contain microstructures such as additives, suspension of granular matter. The theory of micropolar fluids introduced by Eringen[1-2] deals with a class of fluids which exhibits certain microscopic effects arising from the local structures and micro motion of fluids elements. These fluids can support stress movements and body movements and are influenced by the spin inertia. A subclass of these fluids is the micropolar fluids which exhibits the micro rotational effects and micro rotational inertia. Eringen's micropolar fluid theory defines the rotation vector called micro rotation vector, setting up of stress-strain rate constitutive equations. The study of micropolar fluids has received considerable attention due to their applications in a number of processes that occur in industries such as the extrusion of polymer fluids, Solidification of liquid crystal, animal bloods, Exotic lubricants and Colloidal solution.

Several researchers used the micropolar fluid for the study of several bearing systems. The properties of micropolar lubricant were examined by Maiti[3] in reference to composite and step slider bearing. The lubrication theory for micropolar fluids and its applications to a journal bearing is presented by Prakash and Sinha[4]. In their study, the orders of magnitude arguments are used to reduce the governing balance equations to a system of coupled ordinary differential equations and are solved subject to appropriate boundary conditions. Micropolar fluid lubrication of one-dimensional journal bearings is presented by Isa and Zaheeruddin[5]. It is found that the load carrying capacity increases as the micropolar parameter increases and decreases as the step height increases. Agarwal *et al.*[6] made a theoretical study of a porous pivoted slider bearings lubricated with micropolar fluid and proved that their load capacity is greater than with Newtonian fluid. Sinha and Singh[7] applied in Eringen theory the study of lubrication of an inclined stepped composite bearing with additives in lubricant. Their results were in good agreement with experimental observations. Prakash and Tiwari[8] presented an analysis of the squeeze film between porous rectangular plates including the surface roughness effects. These authors shown that, the nominal geometry as characterized by the aspect ratio of the plates has a profound effect on the system. The analytical solution of the problem of squeeze film lubrication of micropolar fluid between two parallel plates is given by Bujurke *et al.*[9]. The performance of finite journal bearings lubricated with micropolar fluids is analyzed by Khonsari and Brewe[10]. The finite Reynolds equation for micropolar fluids is solved by applying central finite difference scheme. It is shown that although the frictional force associated with micropolar fluid is in general higher than that of a Newtonian fluid, the friction co-efficient of micropolar fluids tends to be lower than that of Newtonian. Huang and Wang [11] studied the dynamic characteristics of finite width journal bearings with micropolar fluid and have analyzed the dynamic characteristics of finite width journal bearings lubricated with a micropolar fluid by linear stability theory. The stiffness and damping coefficients and the critical stability parameter for the micropolar fluid are obtained and it is reported that the normal stiffness coefficient is larger while the damping coefficient is smaller for micropolar lubricants.

Khonsari[12] studied the effect of viscous dissipation on the lubrication characteristics of micropolar fluids and shown that the heat generation due to viscous dissipation plays an important role on the load carrying capacity of a journal bearing lubricated with micropolar fluids. On the conical whirls instability of hydrodynamic journal bearing lubricated with micropolar fluids is presented by Das *et al.* [13]. It is found that, for any micropolar lubrication condition, the bearing is always stable as the ratio of the moment of inertia approaches the value of conical whirl ratio. Naduvinamani and Marali[14] presented the dynamic Reynolds equation for micropolar fluids and the analysis of plane inclined slider bearings with squeezing effect and have shown that the micropolar fluids provide an improved characteristics for both steady state and the dynamic stiffness and damping characteristics. It is found that, the maximum steady load carrying capacity is a function of the coupling parameter. Naduvinamani and Siddanagouda[15] studied the porous inclined stepped composite bearings with micropolar fluid. It is observed that the micropolar fluid lubricants provide an increased load carrying capacity and decreased coefficient of friction as compared to the corresponding Newtonian case. Naduvinamani and Santosh[16] studied the micropolar fluid squeeze film lubrication of finite porous journal bearing. It is observed that the micropolar fluid effect significantly increases the squeeze film pressure and the load carrying capacity as compared to the corresponding Newtonian case.

Abdallah and Al-Fadhalah[17] analysed a squeeze film characteristics between a sphere and a rough porous flat plate with micropolar fluids and reported that lubrication by a micropolar fluid will increase the load-carrying capacity and lengthen the squeeze film time, regardless to the surface rough and porosity of the flat plate. It is also found that excessive permeability of the porous layer causes a significant drop in the squeeze film characteristics and minimises the effect of surface roughness. For the case of limited or no permeability, the azimuthal roughness is found to increase the load-carrying capacity and squeeze time, whereas the reverse results are obtained for the case of radial roughness.

Lin at. al.,[18] analysed the Effects of non-Newtonian micropolar fluids on the squeeze-film characteristics between a sphere and a plate and it is analysed that the results, the effects of non-Newtonian micropolar fluids provide an increase in the load capacity, and therefore lengthen the response time to prevent the contact of sphere with plate. Furthermore, the non-Newtonian effects on the squeeze-film characteristics are more emphasized under lower squeeze-film heights with larger coupling numbers and smaller interacting parameters. Syeda Tasneem Fhatima at. al.[19-20] analysed the effects of MHD and couplestress fluids on rectangular plates. It is found that MHD and couplestress fluids provide an increase in pressure, load carrying capacity and squeeze film time.

Present analysis is a first attempt to report the effects of Pressure-dependent viscosity and Micropolar fluids on squeeze film Circular stepped plates. The existing studies on pressure dependent viscosity mainly concentrate on circular plates with micropolar fluids. Hence, the present works is mainly motivated, since in earlier works the viscosity is treated as constant.

The relation between viscosity and pressure is analysed by Barus[21] and Bartz and Ether[22] and is given by the relation

$$\mu = \mu_0 e^{\beta p} \qquad (1)$$

where β denotes the coefficient of pressure-dependent viscosity (PDV) and μ_0 is the viscosity at ambient pressure and a constant temperature. Equation (1) indicates the lubricant viscosity is increasing exponentially and it could alter the predicted performance of squeeze film bearings.

Naduvinamani et. al.[23] analysed the effect of surface roughness and viscosity-pressure dependency on the couple stress squeeze film characteristics of parallel circular plates. It is reported that the effects of couple stresses and viscosity-pressure dependency are to increase the load carrying capacity and squeeze film time for both azimuthal and radial roughness patterns. Lu and Lin[24] studied a theoretical study of combined effects of non-Newtonian rheology and viscosity-pressure dependence in the sphere-plate squeeze-film system. It is observed that the combined effects of couple stresses produced by the spin of microelements and viscosity-pressure dependence provide an enhancement in the load-carrying capacity and lengthen the response time as compared to the classical iso-viscous Newtonian-lubricant case

Naduvinamani and Archana[25] analyzed the effect of viscosity variation on the micropolar fluid squeeze film lubrication of a short journal bearing. Sinha *et al.*[26] studied the variation in viscosity with temperature in journal bearing lubricant with additives using the micropolar theory. They established that, the additives in lubricant increase the temperature in journal bearing. Jaya Chandra Reddy at. al.[27] analysed that the Effect of viscosity variation on the squeeze film performance of a narrow hydrodynamic journal bearing operating with couple stress fluids and reported that the couple stress fluid as a lubricant improves the squeeze film characteristics and results in a longer bearing life. Whereas the viscosity variation factor decreases the load carrying capacity and squeeze film time.

The effect of pressure-dependent viscosity and micropolar fluids in squeeze film circular plate is analysed in this paper and the results are compared with iso-viscous lubricant case given in appendix A. The results are presented in table 1. The results are in excellent agreement with the iso-viscous lubricant case given in appendix A.

2 Mathematical Formulation and solution of the problem

The basic equations governing the flow of micropolar lubricants [1] under the usual assumptions of lubrication theory for thin films [28] are

Conservation of linear momentum

$$\left(\mu+\frac{\chi}{2}\right)\frac{\partial^2 u}{\partial y^2}+\chi\frac{\partial v_1}{\partial y}-\frac{\partial p}{\partial r}=0 \qquad (2)$$

Conservation of angular momentum

$$\gamma\frac{\partial^2 v_1}{\partial y^2}-2\chi v_1+\chi\frac{\partial u}{\partial y}=0 \qquad (3)$$

Conservation of mass

$$\frac{1}{r}\frac{\partial}{\partial r}(ru)+\frac{\partial v}{\partial y}=0 \qquad (4)$$

where u, v are the velocity components of the lubricant in the r and z directions, respectively, v_1 is the microrotational velocity component, χ is the spin viscosity, γ is the viscosity coefficient for micropolar fluids, and μ is the Newtonian viscosity coefficient.

The relevant boundary conditions for the velocity and microrotational velocity components are

At the lower surface (y = 0)

$$u=0,\ v=0 \qquad (5a)$$
$$v_1=0 \qquad (5b)$$

At the upper surface (y = h)

$$u=0,\ v=\frac{\partial h}{\partial t} \qquad (6a)$$
$$v_1=0 \qquad (6b)$$

The solution of equations (2) and (4) subject to the corresponding boundary conditions given in the equations (5a), (5b), (6a), and (6b) is obtained as

$$u=\frac{1}{\mu_0 e^{\beta p}}\left(\frac{y^2}{2}\frac{\partial p}{\partial r}+A_1 y\right)-\frac{2N^2}{m}\left(A_2\sinh my+A_3\cosh my\right)+A_4 \qquad (7)$$

$$v_1=A_2\cosh my+A_3\sinh my-\frac{1}{2\mu_0 e^{\beta p}}\left(y\frac{\partial p}{\partial r}+A_1\right) \qquad (8)$$

where,

$$A_1=2\mu_0 e^{\beta p}A_2$$

$$A_2=\frac{A_3\sinh mh-\dfrac{h}{2\mu_0 e^{\beta p}}\dfrac{\partial p}{\partial r}}{1-\cosh mh}$$

$$A_3=\frac{h}{2\mu_0 e^{\beta p}}\frac{\partial p}{\partial r}\left\{\frac{h}{2}(\cosh mh-1)+h-\frac{N^2}{m}\sinh mh\right\}\frac{1}{A_5}$$

$$A_4=\frac{2N^2}{m}A_3$$

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

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

where, the symbols have their usual meaning as given in nomenclature.

The micropolar parameters N and l are assumed to be independent of viscosity variation for mathematical simplicity. It is assumed that χ and γ varies in the same way as μ varies.

The modified Reynolds equation for the pressure in the film region is obtained by using equations (7) in the continuity equation (5) and then integrating over the film thickness and also using the boundary conditions for v given in equations (5a) and (6a) in the form.

$$\frac{\partial}{\partial r}\left\{g\left(N,l,h\right)e^{-\beta p}r\frac{\partial p}{\partial r}\right\}=12r\frac{\partial h}{\partial t} \qquad (9)$$

where, $g(N,l,h)=h^3+12l^2h-6Nlh^2Coth\left(\frac{Nh}{2l}\right)$ (10)

The volume flow rate of the lubricant is given by

$$Q=2\pi r\int_0^h udy \qquad (11)$$

Substituting the expression for u from equation (7) in equation (11) the volume flux is obtained in the form

$$Q=\frac{\pi re^{-\beta p}}{6\mu_0}\frac{\partial p}{\partial r}g\left(N,l,h\right) \qquad (12)$$

Using the non-dimensional quantities

$$r^*=\frac{r}{R},h^*=\frac{h}{h_2},p^*=\frac{ph_2^3}{\mu_0R^2(-\partial h/\partial t)},l^*=\frac{l}{h_2},$$
$$G=\frac{\beta\mu_0R^2(-\partial h/\partial t)}{h_2^3},Q^*=\frac{Q\mu_0R^2}{h_2^3}$$

In equations (9) and (12) the non-dimensional modified Reynolds equation and the non-dimensional volume flow rate are obtained in the form

$$\frac{\partial}{\partial r^*}\left\{e^{-Gp^*}f^*(N,h^*,l^*)r^*.\frac{\partial p^*}{\partial r^*}\right\}=-12r^* \qquad (13)$$

$$Q^*=\frac{\pi r^*e^{-Gp^*}}{6}\frac{\partial p^*}{\partial r^*}f^*(N,h^*,l^*) \qquad (14)$$

where

$$f^*(N,h^*,l^*)=h^{*3}+12l^{*2}h^*-6Nl^*h^{*2}Coth\left(\frac{Nh^*}{2l^*}\right) \qquad (15)$$

Reynolds equations in region I: $(0\le r^*\le K)$

$$\frac{\partial}{\partial r^*}\left\{e^{-Gp_1^*}f_1^*(N,h_1^*,l^*)r^*.\frac{\partial p_1^*}{\partial r^*}\right\}=-12r^* \qquad (16)$$

where

$$f_1^*(N,h^*,l^*)=h_1^{*3}+12l^{*2}h_1^*-6Nl^*h_1^{*2}Coth\left(\frac{Nh_1^*}{2l^*}\right) \qquad (17)$$

Reynolds equations in region II: $(K\le r^*\le 1)$

$$\frac{\partial}{\partial r^*}\left\{e^{-Gp_2^*}f_2^*(N,l^*)r^*.\frac{\partial p_2^*}{\partial r^*}\right\}=-12r^* \qquad (18)$$

Where $f_2^*(N,l^*)=1+12l^{*2}-6Nl^*Coth\left(\frac{N}{2l^*}\right)$ (19)

The pressure boundary conditions are

$$\frac{dP_1^*}{dr^*}=0 \quad \text{at } r^*=0 \qquad (20)$$

$$P_2^*=0 \quad \text{at } r^*=1 \qquad (21)$$

$$P_1^*=P_2^* \quad \text{at } r^*=R \qquad (22)$$

$$Q_1^*=Q_2^* \quad \text{at } r^*=R \qquad (23)$$

where Q_1^* and Q_2^* are the nondimensional volume flow rates in region I and region II respectively.

Solving equations (16) and (18) using the boundary conditions (20), (21), (22) and (23) gives

Pressure in region I: $(0\le r^*\le K)$

$$p_1^*=-\frac{1}{G}\ln\left\{\frac{3G(r^{*2}-K^2)}{f_1^*(N,h_1^*,l^*)}+\frac{3G(K^2-1)}{f_2^*(N,l^*)}+1\right\} \qquad (24)$$

Pressure in region II: $(K\le r^*\le 1)$

$$p_2^*=-\frac{1}{G}\ln\left\{\frac{3G(r^{*2}-1)}{f_2^*(N,l^*)}+1\right\} \qquad (25)$$

The load carrying capacity W is obtained in the form

$$W=2\pi\int_0^{KR}rp_1dx+2\pi\int_{KR}^1 rp_2dx \qquad (26)$$

The non-dimensional load carrying capacity is obtained in the form

$$W^*=\frac{Wh_2^3}{\mu_0R^4\left(-dh/dt\right)}$$
$$=-\frac{2\pi}{G}\int_0^K\ln\left\{\frac{3Gr^{*2}}{f_1^*(N,h_1^*,l^*)}-\frac{3G}{f_2^*(N,l^*)}+1\right\}r^*dr^*$$
$$-\frac{2\pi}{G}\int_K^1\ln\left\{\frac{3G(r^{*2}-1)}{f_2^*(N,l^*)}+1\right\}r^*dr^* \qquad (27)$$

The squeezing time for reducing the film thickness from an initial value $h_2^* = 1$ to a final value h_f^* is given by

$$T^* = \frac{Wth_0^2}{\mu_0 R^4}$$
$$= -\frac{2\pi}{G}\int_{h_f^*}^{1}\int_{0}^{K} \ln\left\{\frac{3Gr^{*2}}{f_1^*(N,h_2^*,h_3^*,l^*)} - \frac{3G}{f_2^*(N,h_2^*,l^*)} + 1\right\} r^* dr^* dh_2^*$$
$$-\frac{2\pi}{G}\int_{h_f^*}^{1}\int_{K}^{1} \ln\left\{\frac{3G(r^{*2}-1)}{f_2^*(N,h_2^*,l^*)} + 1\right\} r^* dr^* dh_2^* \qquad (28)$$

where

$$f_1^*\left(h_2^*,h_3^*,N,l^*\right) = \left(h_2^*+h_3^*\right)^3 + 12l^{*2}\left(h_2^*+h_3^*\right) - 6Nl^*\left(h_2^*+h_3^*\right)^2 Coth\left\{N\left(h_2^*+h_3^*\right)/2l^*\right\}$$

$$f_2^*(h_2^*,N,l^*) = h_2^{*3} + 12l^{*2}h_2^* - 6Nl^*h_2^{*2}Coth(Nh_2^*/2l^*)$$
$$h_2^* = h_2/h_0,\ h_3^* = h_3/h_0,\ h_f^* = h_f/h_0,\ l^* = l/h_0$$

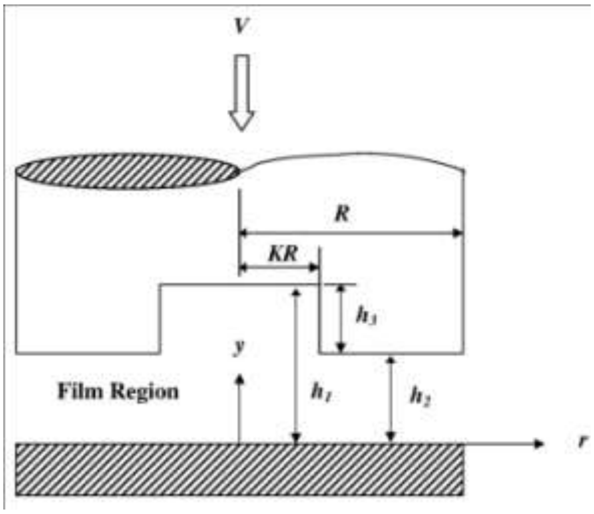

Figure 1 Squeeze film between circular stepped plates with viscosity-pressure dependency and Micropolar fluids.

3 Results and Discussions

The lubricating effect of the micropolar fluids, on the circular step plate squeeze films is studied through the parameters N and l^* respectively. The parameter $N = \left\{\chi/(\chi+2\mu)\right\}^{1/2}$ is the coupling number and it characterizes the coupling of linear and rotational motion arising from the micro motion of the fluid molecules or the lubricant additives. Thus N signifies the coupling between the Newtonian and rotational viscosities. As χ tend to zero, N also tends to zero, and the expressions for the bearing characteristics obtained in this paper reduce to their counter parts in classical Newtonian theory. The second non-dimensional couplestress parameter $l^* = (l/h_2)$ with $l = (\gamma/4\mu)^{1/2}$, characterizes an interaction between the bearing geometry and the fluid. The effect of pressure dependent viscosity on the circular stepped plates is analyzed through the pressure dependent viscosity parameter $G\left\{= \beta\mu_0 R^2(-dh/dt)/h_2^3\right\}$. In the limiting case $G \to 0$, the modified Reynolds equations (16) and (18), non dimensional pressure equations (24) and (25), non-dimensional load carrying capacity equation (27) and non-dimensional squeeze film time equation (28) reduce to the iso-viscous case given in the Appendix(A1 to A4).

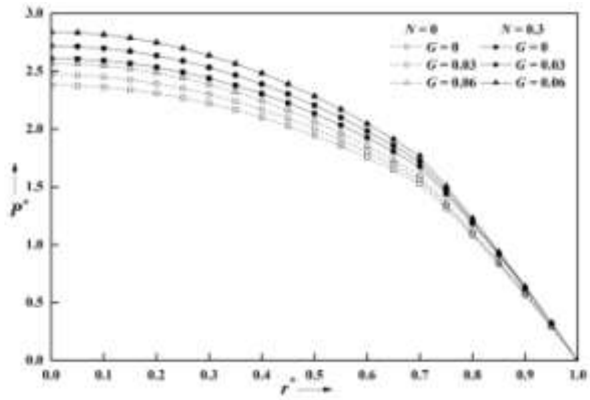

Figure 2 Variation of non-dimensional pressure P^* with r^* for different values of N and G with $l^* = 0.3$, $h_1^* = 1.2$, $K = 0.7$.

The following range of parameters is used for the discussion of squeeze film characteristics
N = 0, 0.2, 0.3, 0.4, 0.6, l^* = 0, 0.3, G = 0, 0.2, 0.03, 0.4, 0.06, K = 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9.

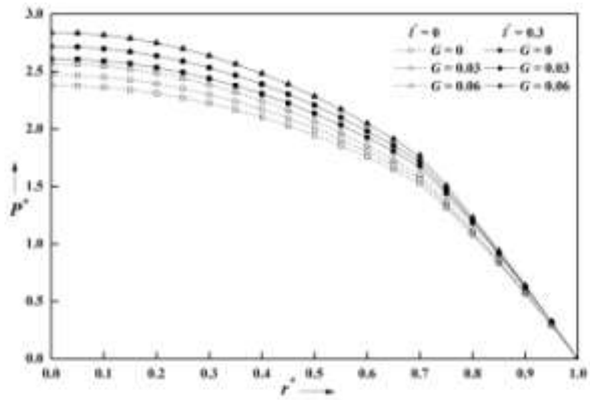

Figure 3 Variation of non-dimensional pressure P^* with r^* for different values of l^* and G with $N = 0.3$, $h_1^* = 1.2$, $K = 0.7$.

3.1 Pressure

Figure 2 shows the variation of non dimensional pressure P^* with r^* for different values of coupling number (N) and viscosity parameter(G) with

$l^* = 0.3$, $h_1^* = 1.2$, $K = 0.7$. It is observed that P^* is maximum at $r^* = 0$ further P^* decreases for increasing values of r^*. It is also observed that P^* increases for increasing values of N and G. The effect of l^* on the variation of non dimensional pressure is depicted in figure 2. It is observed that non dimensional pressure increases with increasing values of l^*. The effects of dimensionless parameters N and G with $h_1^* = 1.2$ on the variation of non dimensional maximum pressure $P^*_{\max}$ with K is depicted in figure 4. It is observed that maximum pressure is decreases for increasing values of K. Further maximum pressure $P^*_{\max}$ increases for increasing values of N and G.

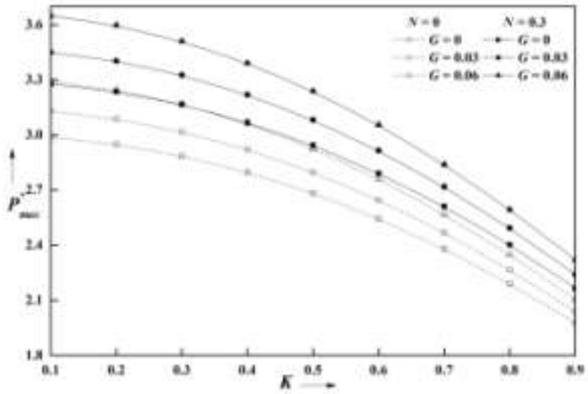

Figure 4 Variation of non-dimensional maximum pressure P^*_{max} with K for different values of N and G with $l^* = 0.3$, $h_1^* = 1.2$.

3.2 Load Carrying Capacity:

The variation of non-dimensional load carrying capacity with h_1^* for different values of N and G is shown in figure 5. It is observed that the non-dimensional load carrying capacity W^* decreases with increasing values of h_1^*. It is also observed that the non-dimensional load carrying capacity increases with increasing values of N and G. Figure 6 depicts the non dimensional load carrying capacity varies as the a function of the couple stress parameter l^*, for different values of N and G. It is observed that the non-dimensional load carrying capacity increases with increasing values of l^*. Figure 7 shows the variation of non-dimensional load carrying capacity with K. It is observed that non-dimensional load carrying capacity decreases with increasing value of K.

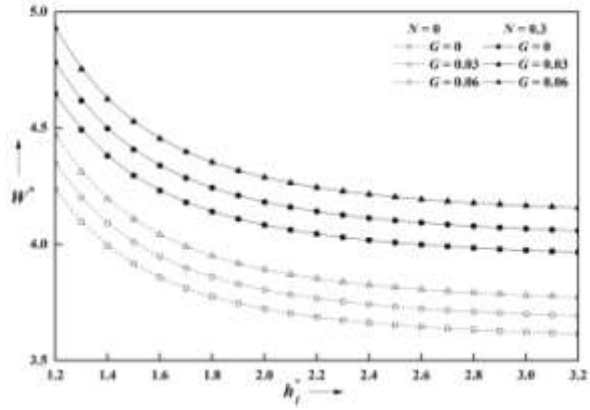

Figure 5 Variation of non-dimensional load carrying capacity W^* with h_1^* for different values of N and G with $l^* = 0.3$, $K = 0.7$.

The relative percentage increase in the non dimensional load carrying capacity R_{W^*} is defined by $R_{W^*} = \left\{\left(W^*_{PDV} - W^*_{Non-PDV}\right)/W^*_{Non-PDV}\right\} X\ 100$. Table 2 shows the values of R_{W^*} for different values K and G with $h_1^* = 1.2$. It is observed that an increase of nearly 4.03% in W^* for $K = 0.6$, $G = 0.04$, $N = 0.2$ and $l^* = 0.3$.

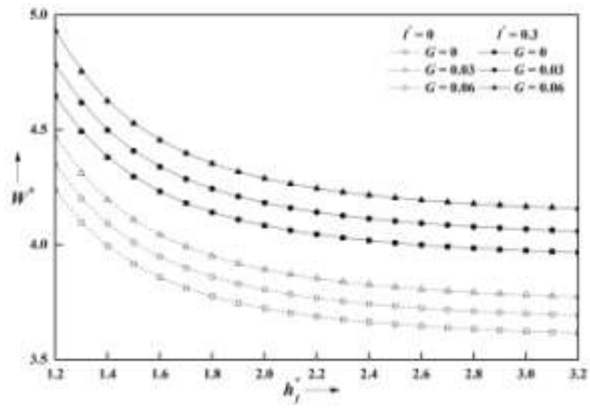

Figure 6 Variation of non-dimensional load carrying capacity W^* with h_1^* for different values of l^* and G with $N = 0.3$, $K = 0.7$.

Table 1 Viscosity and couple stress characteristics W^*, T^* and comparison with the iso-viscous lubricant case (Appendix) with $l^* = 0.3$, $K = 0.6$, $h_f^* = 0.6$.

		Iso-viscous case (Appendix A)		Present analysis					
				$G = 0$		$G = 0.03$		$G = 0.06$	
	N	$h_l^* = 1.5$	$h_l^* = 2$	$h_l^* = 1.5$	$h_l^* = 2$	$h_l^* = 1.5$	$h_l^* = 2$	$h_l^* = 1.5$	$h_l^* = 2$
W^*	0	4.282619	4.178004	4.282619	4.178004	4.397551	4.285999	4.521983	4.402515
	0.2	4.459629	4.350691	4.459629	4.350691	4.584457	4.467979	4.72008	4.594944
	0.4	5.069588	4.94579	5.069588	4.94579	5.231788	5.09817	5.410181	5.265033
	0.6	6.460937	6.304171	6.460937	6.304171	6.727721	6.554682	7.029565	6.836671
	N	$h_s^* = 0.5$	$h_s^* = 1$	$h_s^* = 0.5$	$h_s^* = 1$	$h_s^* = 0.5$	$h_s^* = 1$	$h_s^* = 0.5$	$h_s^* = 1$
T^*	0	3.762572	3.688864	3.762572	3.688864	4.049557	3.961994	4.43427	4.324019
	0.2	3.918615	3.841854	3.918615	3.841854	4.2317	4.139765	4.658517	4.540971
	0.4	4.464404	4.377043	4.464404	4.377043	4.879497	4.771753	5.483097	5.336598
	0.6	5.756504	5.644814	5.756504	5.64482	6.486572	6.337975	7.79737	7.540514

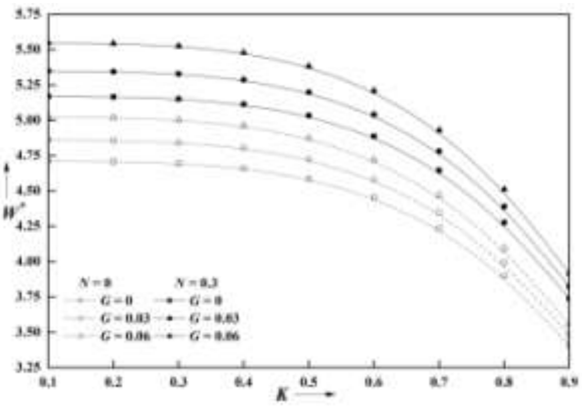

Figure 7 Variation of non-dimensional load carrying capacity W^* with K for different values of N and G with $l^* = 0.3$, $h_1^* = 1.2$.

3.3 Squeeze Film Time:

The variation of non-dimensional squeeze film time T^* with h_f^* for different values of N and G is presented in figure 8. It is observed that the increasing values of h_f^* decreases the non-dimensional squeeze film time. Further it is observed that the non-dimensional squeeze film time increases with the increasing values of N and G respectively. Figure 9 shows the variation of non dimensional squeeze film time with couple stress parameter l^*. It is observed that the non-dimensional squeeze film time increases with increasing values of l^*. Figure 10 depicts the variation of non-dimensional squeeze film time with K for different values of N and G. It is observed that the non-dimensional load carrying capacity decreases with the increasing values of K. $R_{T^*} = \left\{ \left(T^*_{PDV} - T^*_{Non-PDV} \right) / T^*_{Non-PDV} \right\} X\ 100$. Table 2 shows the values of R_{T^*} for different values K and G with $h_f^* = 0.6$. It is observed that an increase of nearly 25.12% in T^* for $K = 0.6$, $G = 0.06$, $N = 0.4$ and $l^* = 0.3$.

Table 2 Variation of R_W^* and R_T^* for different values K and G with $l^* = 0.3$, $h_l^* = 1.2$, $h_s^* = 0.2$, $h_f^* = 0.6$.

K	G	R_W^*	R_T^*	R_W^*	R_T^*
		$N = 0.2$		$N = 0.4$	
0.2	0.02	2.147383	6.16328	2.452651	7.143932
	0.04	4.440572	14.03206	5.096975	16.70797
	0.06	6.898531	25.16137	7.962044	32.11715
0.4	0.02	2.106818	5.999626	2.406081	6.949174
	0.04	4.353037	13.57392	4.994985	16.11834
	0.06	6.755744	23.99062	7.793466	30.07176
0.6	0.02	1.958527	5.417179	2.235493	6.260721
	0.04	4.035154	12.03895	4.625381	14.19355
	0.06	6.242881	20.59015	7.190152	25.12656
0.8	0.02	1.647909	4.2356	1.878298	4.876109
	0.04	3.377834	9.150894	3.863904	10.67682
	0.06	5.197512	15.00883	5.968257	17.84547

4 Conclusions:

On the basis of micropolar fluids theory introduced by Eringen[1-2] and Bartz and Ehert[22] analysis for pressure-dependent viscosity the theoretical study is presented in this paper. On the basis of the theoretical results presented, the following conclusions are drawn:

1. Non-dimensional pressure, load carrying capacity, squeeze film time are functions of viscosity parameter G, coupling number N, and couple stress parameter l^*.
2. The non dimensional pressure, non dimensional load carrying capacity, and non dimensional squeeze film time decreases with increasing

value of non dimensional step distance (K) and increases as compared with iso-viscous lubricant case.

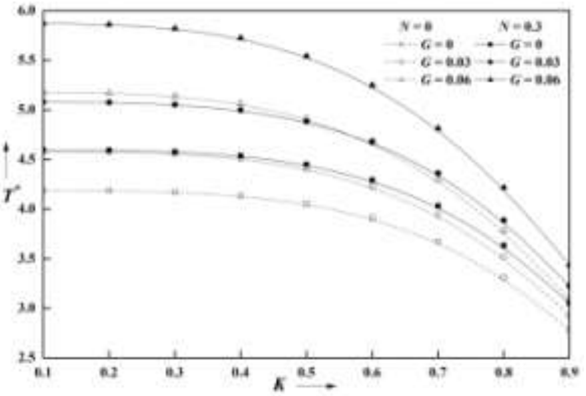

Figure 10 Variation of non-dimensional squeeze film time T^* with K for different values of N and G with l^* = 0.3, h_s^* = 0.2, h_f^* = 0.6.

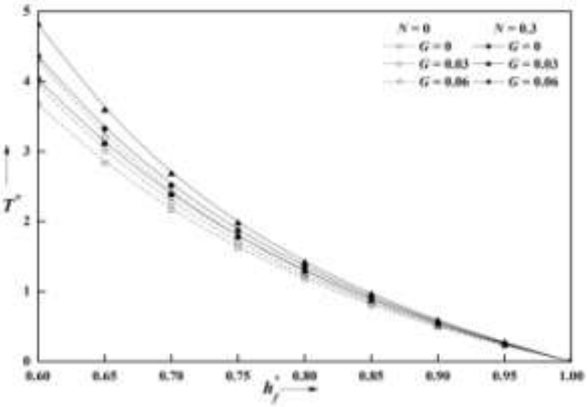

Figure 8 Variation of non-dimensional squeeze film time T^* with h_f^* for different values of N and G with l^* = 0.3, h_s^* = 0.2, K = 0.7.

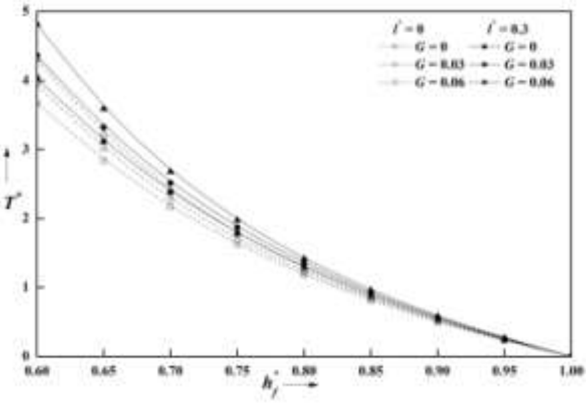

Figure 9 Variation of non-dimensional squeeze film time T^* with h_f^* for different values of l^* and G with N = 0.3, h_s^* = 0.2, K = 0.7.

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Nomenclature

G viscosity parameter
h^* non-dimensional film thickness
h_1 maximum film thickness
h_2 minimum film thickness
h_s^* step height ratio $(= h_s/h_2)$
KR the position of the step $0 < KR < R$.
l couplestress parameter $(\gamma/4\mu)^{1/2}$
l^* non-dimensional couple stress parameter (l/h_2)
N Coupling number
p pressure in the film region
p_1 fluid film pressure in the region $0 \le r \le KR$
p_1^* non-dimensional fluid film pressure in the region $0 \le r^* \le K$
p_2 fluid film pressure in the region $KR \le r \le R$
p_2^* non-dimensional fluid film pressure in the region $K \le r^* \le 1$
Q volume flow rate.
Q_1 volume flow rate in the region $0 \le r \le KR$
Q_1^* non-dimensional volume flow rate in the region $0 \le r^* \le K$
Q_2 volume flow rate in the region $KR \le r \le R$
Q_2^* non-dimensional volume flow rate in the region $K \le r^* \le 1$
R radius of the circular plate
R_T^* relative time of approach
R_W^* relative load carrying capacity
r, y radial and axial coordinates
T time of approach
T^* non-dimensional time of approach $\left\{Wth_2^2/\mu_0 R^4\right\}$
u, v velocity components in r and y directions
W load carrying capacity
W^* non-dimensional load carrying capacity $\left\{Wh_2^3/\mu_0 R^4(-dh/dt)\right\}$

Greek Symbols

β coefficient of pressure-dependent viscosity
η material constant responsible for couple stresses
μ dynamic Viscosity
μ_0 viscosity at atmospheric pressure

Appendix A:

The squeeze film characteristics for the lubrication between circular step bearings are obtained as:
The dimensionless Pressure is obtained as

Pressure in region I: $(0 \le r^* \le K)$

$$p_1^* = \frac{3(K^2 - r^{*2})}{f_1^*(N, h_1^*, l^*)} + \frac{3(1-K^2)}{f_2^*(N, l^*)} \quad \text{(A1)}$$

Pressure in region II: $(K \le r^* \le 1)$

$$p_2^* = \frac{3(1 - r^{*2})}{f_2^*(N, l^*)} \quad \text{(A2)}$$

The dimensionless load-carrying capacity is obtained as

$$W^* = \frac{3\pi K^4}{2 f_1^*(N, h_1^*, l^*)} + \frac{3\pi(1-K^4)}{2 f_2^*(N, l^*)} \quad \text{(A3)}$$

The dimensionless time-height relationship is obtained as

$$T^* = \int_{h_f^*}^{1} \left\{ \frac{3\pi K^4}{2 f_1^*(N, h_2^*, h_3^*, l^*)} + \frac{3\pi(1-K^4)}{2 f_2^*(N, h_2^*, l^*)} \right\} dh_2^* \quad \text{(A4)}$$