Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 44 No. 4 (2023)

Lubrication of Squeeze Film Between Porous Rough Circular Plates with Rabinowitsch Fluid Model

Bharati[1], Shivalingappa B. Patil[2], Sharangouda Malipatil[3] & Hanumagowda B. N.[4]

[1]*Department of Mathematics, Faculty of Engineering & Technology (Ex-Women), Sharnbasva University, Kalaburagi, Visvesveraya Technological University, Belagavi – 590018, Karnataka, India.*

[2]*Department of Studies & Research In Mathematics, Govt. College, Kalaburagi, Visvesveraya Technological University, Belagavi – 590018, Karnataka,India.*

[3]*Department of Mathematics, Poojya Doddappa Appa Engineering College, Kalaburagi, Visvesveraya Technological University, Belagavi – 590018, Karnataka, India.*

[4]*Department of Mathematics, School of Applied Sciences, Reva University, Bangalore, Visvesveraya Technological University, Belagavi – 590018, Karnataka, India.*

Abstract : In this paper it is analyzed that the theoretical study of lubrication of squeezing film connecting rough circular porous plates with Rabinowitsch fluid. By using Christensen's stochastic theory for the lubrication of hydrodynamic rough surface modified Reynolds equation is derived. The patterns of roughness of surface are considered in 1-dimensional for two types, which are radial and azimuthal roughness patterns. Squeeze film time, load support and pressure expressions are gained. In both radial and azimuthal patterns the squeezing film time, load carrying capacity and pressure are decreases in porous roughness pattern on the surface.

Keywords : *Rabinowitsch fluid, surface roughness, porous circular plates, squeeze film, azimuthal and radial roughness.*

1. Introduction

In lubrication technology & advancement of science the influence of surface roughness is major role. In recent years analysis of lubrication along rough surfaces had reached many goals. The Rabinowitsch fluid model is best model to study the relationship joining shear stress & shear strain. The different types of bearings with roughness effect has analyses by the many researchers. Christensen [1] has studied the theory of a stochastic process by applying this he derived the modified Reynolds equation to rough bearing surfaces. Hsu and Saibel [2] Wada and Hayashi [3] defined the presentation of journal bearing & slider bearing lubricated along non- Newtonian lubricants respectively. Bearings of Porous are extensively used in industry for a long time. Morgan & Cameron[4] was presented the theoretical research on these porous bearings based on Darcy model. By Bingham fluid Lately Walicka [5] has solved the curve linear bearings with porous walls lubricated problem. In recent years, many researchers are researched the effect of non-Newtonian lubricants of Rabinowitsch on various types of bearings. Singh et al.[6] has presented a squeezing film characteristics to connect a long cylinder & flat plate. Lin[7] presented the non-Newtonian effect results on Rabinowitsch fluid model for parallel annular discs, slider bearings by Lin et al [8], parallel rectular squeeze film plates by Hung et al[9]. Tzeng and Saibel [10] has identified the bearing surfaces on random character of roughness. Usha & Vimala [11] studied the squeezing film lubrication connecting two plane annular on squeezing film lubrication connect porous circular stepped plates the combined effects of surface roughness & couple stresses has found by Naduvinamani et al.[12]. By this theory the investigation is extended and it helps to investigate the performance of various type of bearings fluid film by the effects of couple stresses like, journal bearings by Naduvinamani NB et al.[13,14], slider bearings by Lu Rf & Ramanaiah G. [15,16].

In this paper we analysed the lubrication of squeezing film connecting porous rough circular plates with model of Rabinowitsch fluid. We get the Modified Reynolds type equation by using the Morgan Cameron approximation. Two types of one-dimensional roughness surface patterns are considered for theme of Christensen stochastic theory for the hydrodynamic of rough lubrication surfaces, viz.,radial and azimuthal.

2. Mathematical Formulation

By the consideration of the works one may present the relationship between stress-strain for model of Rabinowitsch fluid in the form

$$\tau_{xy}+k\tau_{ry}^{3}=\mu\frac{\partial u}{\partial y}$$

(1)

Here, μ defines the rate viscosity of zero shear, k defines the non-linear factor which express Non-Newtonian results of the lubricant is called as coefficient of pseudo plasticity. This model can be applicable to Newtonian, dilatants & pseudo plastic lubricants for $k = 0, k < 0$ & $k > 0$ respectively.

Let a lubrication squeezing film connecting two porous circular rough plates which convergent to each other with a normal velocity $v = -\frac{dh}{dt}$& a physical geometry has been manifest in the figure 1. & Rabinowitsch fluid is considered. According to thin film hydrodynamic lubrication theory, the basic equations are as follows:

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

(2)

$$\frac{\partial p}{\partial r}=\frac{\partial \Im_{ry}}{\partial y}$$

(3)

$$\frac{\partial p}{\partial y}=0$$

(4)

Boundary conditions is

At surface upper $y = h$

$$u=0, v=-\frac{dh}{dt}$$

(5a)

At surface lower $y = 0$

$$u=0, v=v^{*}$$

(5b)

Where , u & v are the velocity components of lubricant in the r & y direction respectively & ‘h’ is the film thickness between the bearing plates.

The components of velocity are u^{*} & v^{*} are modified by Darcy’s law, as follows :

$$u^{*}=\frac{\psi}{\mu}\left\{-\frac{\partial p^{*}}{\partial r}+\frac{k\varepsilon_c^{2}}{6}\left(-\frac{\partial p^{*}}{\partial r}\right)^{3}\right\}$$

(6)

$$u^{*}=\frac{\psi}{\mu}\left\{-\frac{\partial p^{*}}{\partial r}+\frac{k\varepsilon_c^{2}}{6}\left(-\frac{\partial p^{*}}{\partial r}\right)^{3}\right\}$$

(7)

where $\psi=\frac{\delta_p\varepsilon_c^{2}}{8}$

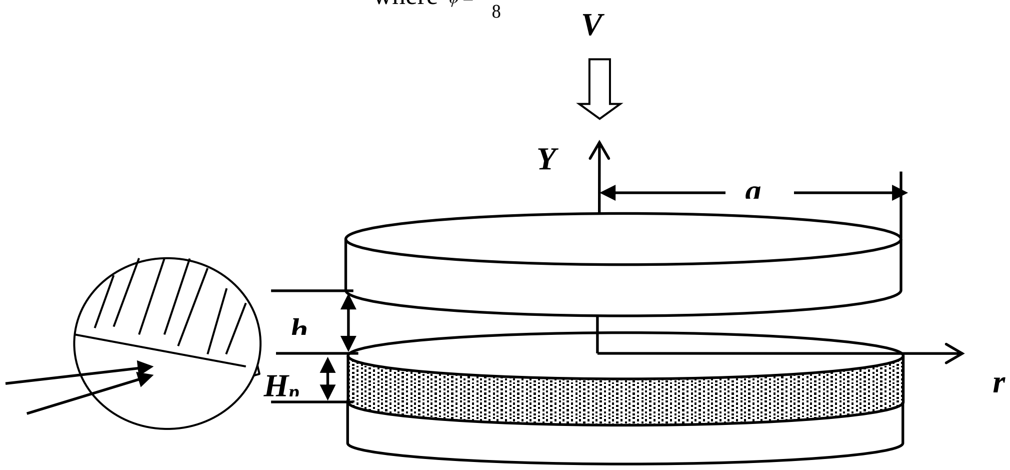

Figure 1. Geoametry and co-ordinate system of rough porous circular plates

Solution of the (3), using the boundary conditions (5a) & (5b) we get

$$u=\frac{1}{\mu}\left\{\frac{1}{2}\left(\frac{\partial p}{\partial r}\right)F_1+k\left(\frac{\partial p}{\partial r}\right)^{3}F_2\right\}$$

(8)

where $F_1=y(y-h), F_2=\frac{y^4}{4}-\frac{y^3h}{2}+\frac{3}{8}y^2h^2-\frac{yh^3}{8}$

Substituting equation (6) in equation (2) and using the boundary conditions (6) and (7) we get

$$\frac{1}{r}\frac{\partial}{\partial r}\frac{r}{\mu}\left[\frac{f}{2}\left(-\frac{h^3}{6}\right)+kf^3\left(-\frac{h^5}{80}\right)\right]=-\left[-\frac{\partial h}{\partial t}-v^{*}\big|_{y=0}\right]$$

(9)

where $f=\frac{\partial p}{\partial r}$

Using Morgan Cameron approximation, we get,

$$v^{*}\big|_{y=0}=\frac{\psi}{\mu}\left\{-\frac{\partial p^{*}}{\partial y}+\frac{k\varepsilon_c^{2}}{6}\left(-\frac{\partial p^{*}}{\partial y}\right)^{3}\right\}\Bigg|_{y=0}=-\frac{\psi}{\mu}\frac{h_p}{r}\frac{d}{dr}\left[r\left\{-\frac{\partial p^{*}}{\partial r}+\frac{k\varepsilon_c^{2}}{6}\left(-\frac{\partial p^{*}}{\partial r}\right)^{3}\right\}\right]$$

(10)

Substituting (10) in (9), obtained the Reynolds type equation to non-Newtonian Rabinowitsch fluid is ,

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left\{G_1\left(h,\delta_p,\varepsilon_c^2,h_p\right)\frac{\partial p}{\partial r}+\frac{3k}{20}G_2\left(h,\delta_p,\varepsilon_c^2,h_p\right)\left(\frac{\partial p}{\partial r}\right)^{3}\right\}\right]=12\mu\left(-\frac{dh}{dt}\right)$$

(11)

$$G_1\left(h,\delta_p,\varepsilon_c^2,h_p\right)=h^3+\frac{3}{2}\delta_p\varepsilon_c^2h_p$$

$$G_2\left(h,\delta_p,\varepsilon_c^2,h_p\right)=h^5+\frac{5}{3}\delta_p\varepsilon_c^4h_p$$

3. Stochastic Reynolds Equation

For stochastic thickness film h_s the function for probability density is $f(h_s)$. By (10) averaged Modified Reynolds type equation is gained w.r.t $f(h_s)$ in the form

Where, $$E(*)=\int_{-\infty}^{\infty}(*)f(h_s)dh_s$$

(12)

Following Christensen [1], we assume that

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

(13)

where $\bar{\sigma}=c/3$ is standard deviation.

Two types of 1-D surface patterns is considered viz. radial & azimuthal in the conditions of Christensen stochastic theory as the hydrodynamic lubrication of rough surfaces.

4.1. Radial roughness pattern on 1-dimensional:

In this type, the structure for roughness forms a long, valleys running & narrow ridges in the radial direction, in case the film thickness takes the form

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

(14)

& the modified stochastic Reynolds equation (11) is of the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left\{E\left\{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\}\frac{\partial E(p)}{\partial r}+\frac{3k}{20}E\left\{G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\}\left(\frac{\partial E(p)}{\partial r}\right)^3\right\}\right]=-12\mu\frac{dh}{dt}$$

(15)

4.2. Azimuthal roughness pattern on 1- dimensional:

This case dfines, in θ-direction the azimuthal roughness on one dimensional, the surfaces bearing is of the form of long valleys running & narrow ridges . In this case the film thickness assumes the form

$$H=h+h_s(r,\xi)$$

(16)

The modified Reynolds type (12) is

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left\{\frac{1}{E\left\{\frac{1}{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)}\right\}}\frac{\partial E(p)}{\partial r}+\frac{3k}{20}\frac{1}{E\left\{\frac{1}{G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)}\right\}}\left(\frac{\partial E(p)}{\partial r}\right)^3\right\}\right]=-12\mu\frac{dh}{dt}$$

(17)

Combining equations (15) and (17)

$$\frac{1}{r}\frac{\partial}{\partial r}\left[r\left\{\xi_1\left(H,\delta_p,\varepsilon_c^2,h_p,c\right)\frac{\partial E(p)}{\partial r}+\frac{3k}{20}\xi_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)\left(\frac{\partial E(p)}{\partial r}\right)^3\right\}\right]=-12\mu\frac{dh}{dt}$$

(18)

where

$$\xi_1\left(H,\delta_p,\varepsilon_c^2,h_p,c\right)=\begin{cases}E\left\{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\} & \textit{For radial roughness}\\ \left[E\left\{\dfrac{1}{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)}\right\}\right]^{-1} & \textit{For azimuthal roughness}\end{cases}$$

$$E\left\{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\}=\frac{35}{32c^7}\int_{-c}^{c}G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)(c^2-h_s^2)^3\,dh_s$$

$$E\left\{\frac{1}{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)}\right\}=\frac{35}{32c^7}\int_{-c}^{c}\frac{(c^2-h_s^2)^3}{G_1\left(H,\delta_p,\varepsilon_c^2,h_p\right)}dh_s$$

$$\xi_2\left(H,\delta_p,\varepsilon_c^2,h_p,c\right)=\begin{cases}E\left\{G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\} & \textit{For radial roughness}\\ \left[E\left\{\dfrac{1}{G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)}\right\}\right]^{-1} & \textit{For azimuthal roughness}\end{cases}$$

$$E\left\{G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)\right\}=\frac{35}{32c^7}\int_{-c}^{c}G_2\left(H,\delta_p,\varepsilon_c^2,h_p\right)(c^2-h_s^2)^3\,dh_s$$

$$E\left\{\frac{1}{G_2\left(h,\delta_p,\varepsilon_c^2,h_p\right)}\right\}=\frac{35}{32c^7}\int_{-c}^{c}\frac{(c^2-h_s^2)^3}{G_2\left(h,\delta_p,\varepsilon_c^2,h_p\right)}dh_s$$

By inserting the following dimensionless quantities in (11)

$$r^*=\frac{r}{a};\ p^*=\frac{E(p)h_0^3}{\mu a^2\left(-\frac{dh}{dt}\right)},\ \beta=\frac{k\mu^2a^2\left(-\frac{dh}{dt}\right)^2}{h_0^4};\ H^*=\frac{h+h_s}{h_0}=h^*+h_s^*,\ H_p=\frac{\delta_p h_p}{h_0},\ R_p=\frac{\varepsilon_c}{h_0}$$

The non-dimensional Raynold's modified equation is

$$\frac{\partial}{\partial r^*}\left[r^*\left\{\xi_1^*(H^*,H_p,R_p,C)\frac{\partial p^*}{\partial r^*}+\frac{3\beta}{20}\xi_2^*(H^*,H_p,R_p,C)\left(\frac{dp^*}{dr^*}\right)^3\right\}\right]=-12r^*$$

(19)

Where, $G_1^*\left(H^*,H_p,R_p\right)=H^{*3}+\frac{3}{2}H_p^2R_p^2$

$$G_2^*\left(h^*,H_p,R_p\right)=H^{*5}+\frac{5}{3}H_p^2R_p^4$$

$$\xi_1^*\left(H^*,H_p,R_p,C\right)=\begin{cases}E\left\{G_1^*\left(H^*,H_p,R_p\right)\right\} & \textit{For radial roughness}\\ \left[E\left\{\dfrac{1}{G_1^*\left(H^*,H_p,R_p\right)}\right\}\right]^{-1} & \textit{For azimuthal roughness}\end{cases}$$

$$E\left\{G_1^*\left(H^*,H_p,R_p\right)\right\}=\frac{35}{32C^7}\int_{-C}^{C}G_1^*\left(H^*,H_p,R_p\right)(C^2-h_s^{*2})^3\,dh_s^*$$

$$E\left\{\frac{1}{G_1^*\left(H^*,H_p,R_p\right)}\right\}=\frac{35}{32C^7}\int_{-C}^{C}\frac{(C^2-h_s^{*2})^3}{G_1^*\left(H^*,H_p,R_p\right)}dh_s^*$$

$$\xi_2^*\left(H^*,H_p,R_p,C\right)=\begin{cases} E\left\{G_2^*\left(H^*,H_p,R_p\right)\right\} & \textit{For radial roughness} \\ \left[E\left\{\dfrac{1}{G_2^*\left(H^*,H_p,R_p\right)}\right\}\right]^{-1} & \textit{For azimuthal roughness}\end{cases}$$

$$E\left\{G_2^*\left(H^*,H_p,R_p\right)\right\}=\frac{35}{32C^7}\int_{-C}^{C}G_2^*\left(H^*,H_p,R_p\right)(C^2-h_s^{*2})^3\,dh_s^*$$

$$E\left\{\frac{1}{G_2^*\left(H^*,H_p,R_p\right)}\right\}=\frac{35}{32C^7}\int_{-C}^{C}\frac{(C^2-h_s^{*2})^3}{G_2^*\left(H^*,H_p,R_p\right)}dh_s^*$$

As (19) is a non linear equation in p^* , by using analytical methods it is not easy to solve. So, to solve it this classical perturbation method is used.

Put $p^*=p_0^*+\beta p_1^*$ in (19) and equating coefficient of the of β^0 and β and neglecting the others,

we get,

$$\frac{\partial}{\partial r^*}\left[r^*\left\{\xi_1^*(H^*,H_p,R_p,C)\frac{\partial p_0^*}{\partial r^*}\right\}\right]=-12r^*$$

(20)

$$\frac{\partial}{\partial r^*}\left[r^*\left\{\xi_1^*(H^*,H_p,R_p,C)\frac{\partial p_1^*}{\partial r^*}+\frac{3}{20}\xi_2^*(H^*,H_p,R_p,C)\left(\frac{\partial p_0^*}{\partial r^*}\right)^3\right\}\right]=0$$

(21)

By solving the above (13) and (14) the squeezing film pressure is obtained&we get

$$p^*=-\frac{3\left(r^{*2}-1\right)}{\xi_1^*(H^*,H_p,R_p,C)}+\frac{81\beta}{10}\frac{\xi_2^*(H^*,H_p,R_p,C)\left(r^{*4}-1\right)}{\xi_1^{*4}(H^*,H_p,R_p,C)}$$

(22)

5. Non Dimensional Load Support:

The dimensionless load support W^* is found by integrating pressure, as follows

$$W^*=2\pi\int_0^1 r^*p^*dr^*$$

(23)

By substituting the non-dimensional pressure p^* in above equation we get,

$$W^*=\frac{3\pi}{2\xi_1^*(H^*,H_p,R_p,C)}-\frac{27\pi\beta}{5}\frac{\xi_2^*(H^*,H_p,R_p,C)}{\xi_1^{*4}(H^*,H_p,R_p,C)}$$

(24)

6. non dimensional squeezing time :

The film thickness is reduced by squeezing time from initial value to final value, is obtained

$$t=\int_{h_f}^{1}\left(\frac{3\pi}{2\xi_1^*(H^*,H_p,R_p,C)}-\frac{27\pi\beta}{5}\frac{\xi_2^*(H^*,H_p,R_p,C)}{\xi_1^{*4}(H^*,H_p,R_p,C)}\right)dh^*$$

(25)

7. result and discussions :

An attempt is made to analyzed that the lubrication of squeezing film between porous circular rough plates based on the mode of Rabinowitsch fluid l. Further Modified Reynolds equation is obtained by using Christensen’s stochastic theory.

7.1. Non dimensional Pressure

Fig.2 shows the dimensionless alteration of P^* along r^* for various roughness parameter C with R_P = 0.3, H_P = 0.3, h^* = 0.8 and β=0.002 for radial & azimuthal patterns. By increasing parameter roughness C it decreases the pressure P^* & increases of radial and azimuthal pattern respectively. By the above result we compare both the patterns and we get the azimuthal pattern is increased much more to the radial pattern. Fig.3. describes the variant of P^* along r^* for separate values of β along C = 0.3, R_P = 0.3, H_P = 0.3 and h^* = 0.8. By extending the value of β it decreases the pressure P^* in both radial and azimuthal pattern. Fig.4. defines about pressure P^* along r^* for H_p = R_p = 0, 0.2, 0.4 with C= 0.3, h^* = 0.8 and β = 0.002 in radial and azimuthal patterns. In both the patterns the pressure P^* decreases.

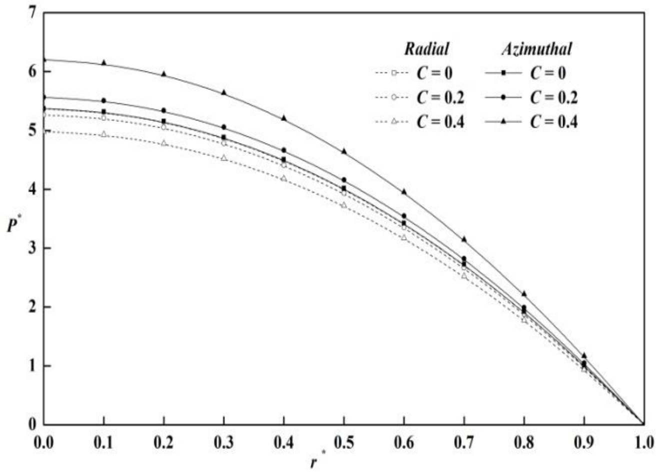

Figure 2. Variation of non-dimensional pressure P^* with r^* for different values of C with R_p = 0.3, H_p = 0.3, h^* = 0.8 and β = 0.002

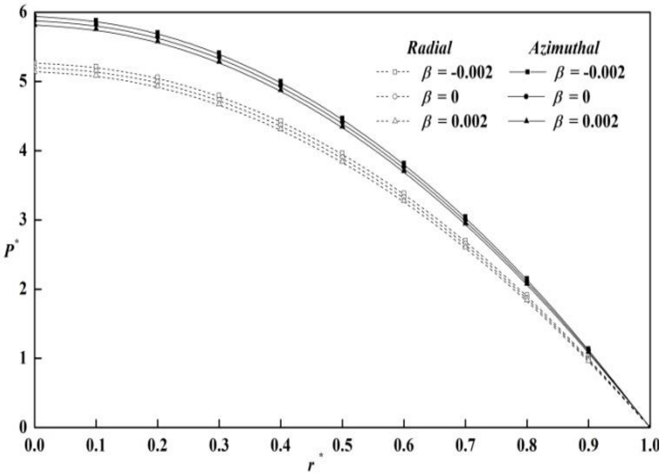

Figure 3. Variation of non-dimensional pressure P^* with r^* for different values of β with C = 0.3, R_p = 0.3, H_p = 0.3 and h^* = 0.8

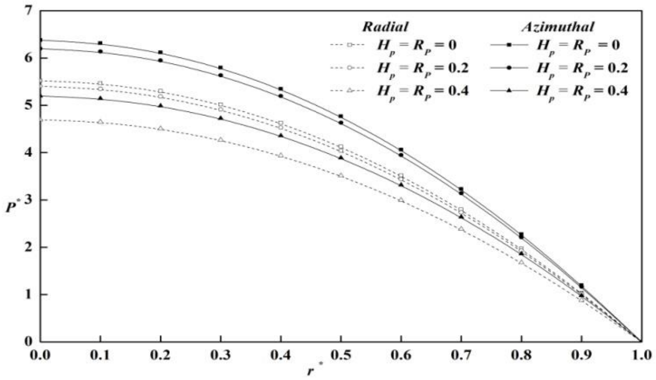

Figure 4. Variation of non-dimensional pressure P^* with r^* for different values of H_p, R_p with $C = 0.3$, $h^* = 0.8$ and $\beta = 0.002$

7.2. Non dimensional Load support :

The alternation of dimensionless Load support W^* along h^* for well defined values of C along $H_P = 0.3$, $R_P = 0.3$ & $\beta = 0.002$ shows in fig.5. The increments in C decreases the W^* in radial and increases the load c support W^* in azimuthal pattern. In fig.6. the alteration of W^* with h^* by differing the values of β along $H_P = 0.3$, $R_P = 0.3$ & C = 0.3. From this we seen that the W^* decreases by increasing the non-linear parameter β in both radial and azimuthal patterns. The alteration of W^* along h^* for distinct values of porous film thickness H_P, porosity R_P in fig.7. The load support W^* decreases with increasing H_P, R_P & h^*.

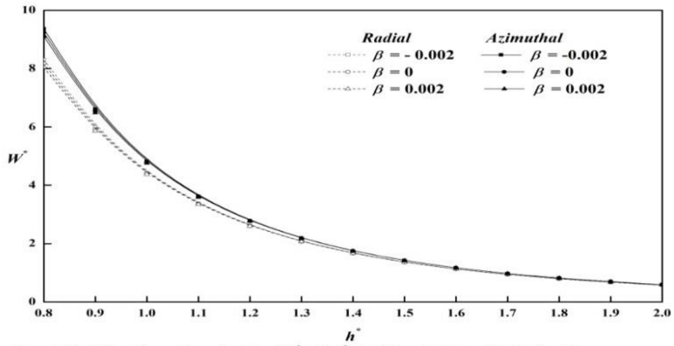

Figure 6. Variation of non-dimensional load W^* with h^* for different values of β with $H_p = 0.3$, $R_p = 0.3$ and $C = 0.3$.

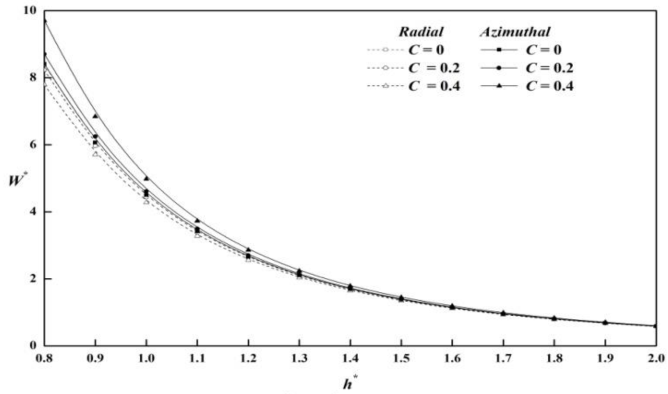

Figure 5. Variation of non-dimensional load W^* with h^* for different values of C with $H_p = 0.3$, $R_p = 0.3$ and $\beta = 0.002$

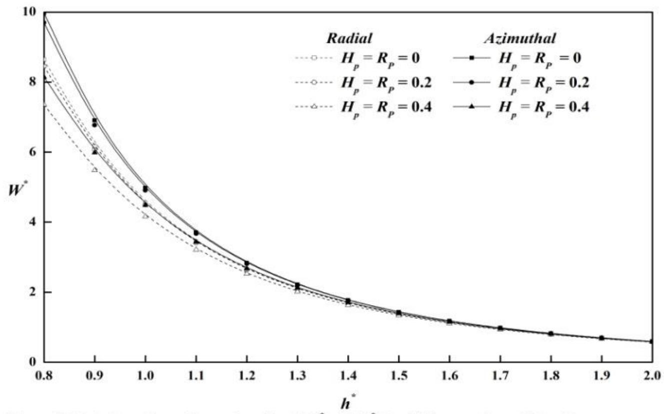

Figure 7. Variation of non-dimensional load W^* with h^* for different values of R_p, H_p with β= 0.002 and C = 0.3.

7.3. Non dimensional Squeeze film time :

Fig.8. explains that the squeezing film time T* against h_f^* for distinct values of C with β = 0.002 , H_P = 0.3 & R_P = 0.3. It is found that the squeezing film time T* falling off in radial and increases in azimuthal pattern by increasing the non dimensional roughness parameter C. Fig.9. illustrate that the squeezing film

time T* with h_f^* by varying the values of β with H_P = 0.3, R_P = 0.3 & C = 0.3. In both radial and azimuthal pattern the squeeze film time T* decreases by increasing the non linear parameter β. By increasing the porous film thickness H_P and porosity R_P with β = 0.002 & C = 0.3 the time T* decreases . The above result we can see in the fig.10.

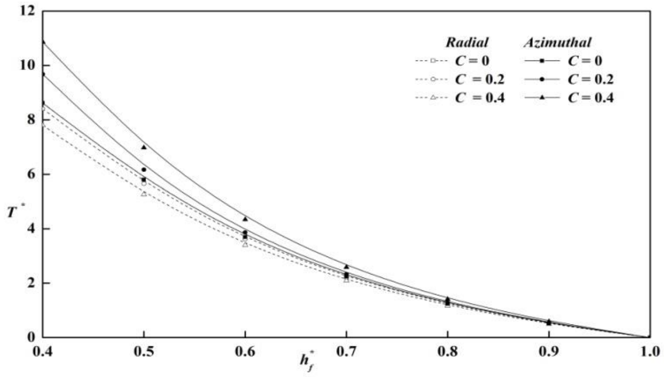

Figure 8. Variation of non-dimensional squeeze film time T^* with h_f^* for different values of C with β = 0.002, H_p = 0.3 and R_p = 0.3

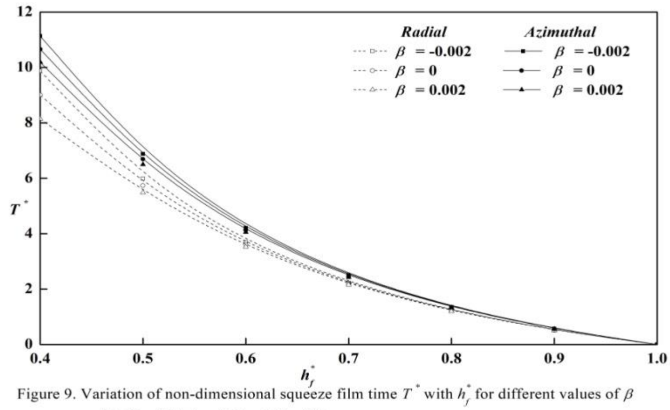

Figure 9. Variation of non-dimensional squeeze film time T^* with h_f^* for different values of β with H_p = 0.3, R_p = 0.3 and C = 0.3

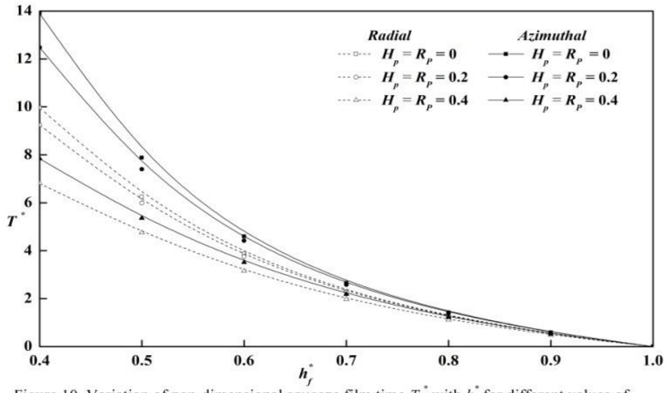

Figure 10. Variation of non-dimensional squeeze film time T^* with h_f^* for different values of H_p, R_p with $\beta = 0.002$ and $C = 0.3$

8. Conclusion

The modified Reynolds equation is theoretically studied for lubrication of squeezing film connecting porous rough circular plates is derived in this paper. From present research work, the conclusions are,

1. The non-dimensional pressure P^*, non-dimensional load support W^*& non-dimensional squeeze film time T^* reduces while rising the roughness parameter C.
2. The Non dimensional pressure P^* Non dimensional load support W^*& Non dimensional squeezing film time T^* declines by increasing the parameter β.
3. Also,the pressure P^* , load support W^*& squeeze film time T^* decreases y increasing the porous film thickness H_P & porosity R_P parameter

Nomenclature :

τ_{xy} - shear stress component

μ - coefficient of viscosity

φ - permeability factor

ε_c - small amplitude of oscillation

u & v - velocity components of lubrication in x & y directions respectively

u^* & v^* - nondimensional velocity components

h - film thickness

h_p - porous pad thickness

E(*) - Expectancy operator

$f(h_s)$ - probability density distribution function

h_s - random part resulting from the surface roughness measured from the nominal level

$\bar{\sigma}$ - standard deviation

$h_s(\theta, \varepsilon)$ - random deviation of film thickness

c - maximum roughness deviation

r^* - non-dimensional radius

p^* - non-dimensional pressure

β - non-linear parameter

H^* - dimensionless film thickness

H_p - porous film thickness $\frac{\delta_p h_p}{h_0}$

R_p - porosity $\frac{\varepsilon_c}{h_0}$

W^* - non-dimensional load carrying capacity

t - time

c^* - non-dimentional roughness parameter

θ - angular co-ordinator

9. References

[1] Christensen H. "Stochastic models for hydrodynamic lubrication of rough surfaces". J Proc Inst Mech Eng. 1969; 184:1013-1026.

[2] Hsu, Y. C. and Saibel, E., "Slider bearing performance with a non-newtonian lubricant", ASLE Transactions, 8, 2, 1965, 191-194

[3] Wada, S. and Hayashi, H., "Hydrodynamic lubrication of journal bearings by pseudo-plastic lubricants", Bulletin of JSME., 14, 69, 1971, 279-286.

[4] Morgan V. T. and Cameron A. " Mechanism of lubrication in porous metal bearings", Proc. Conf. on Lubrication and Wear, Inst. Mech. Eng. London, pp.151-157.

[5] Walicka A., "Pressure distribution in a porous curvilinear squeeze film bearing lubricated by a Bingham fluid" , Int. J. Appl. Mech. Enging, Vol.16, No.4, pp.1215-1224.

[6] Singh UP, Gupta RS, Kapur VK, "On the squeeze film characteristics between a long cylinder and a flat plate: Rabinowitsch model", Proc Inst Mech Eng J Eng Tribol. 2013;227;34-42.

[7] Lin JR. Non-Newtonian squeeze film characteristics between parallel annular disks: Rabonowitsch fluid model", Tribol Int. 2012;52:190-194.

[8] Lin JR. "Non-newtonian effect on the dynamic characteristics of one dimensional slider bearings: Rabinowitsch fluid model", Tribol Lett.2001;10:237-243.

[9] Hung JR, Chu LM, Liaw WL, et al., "Effect of non-newtonian Rabinowitsch fluids in wide parallel rectangular squeeze film plates", Ind Lubric Tribol. 2013;227:34-42.

[10] Tzeng ST, Saibel E. "Surface roughness effect on slider bearing lubrication", ASLE Trans.1967;10:334-348.

[11] Usha, R. and Vimala, P., "Fluid inertia effects in a non-newtonian squeeze film between two plane annuli", ASME Journal of Tribol, 122, 4, 2000,872-875.

[12] Naduvinamani NB, Siddanagouda A. "Combined effects of surface roughness and couple stresses on squeeze film lubrication between porous circular stepped plates",

[13] J Eng Tribol. 2007;221:525-534.

[14] Naduvinamani NB, Hiremath PS, Gurubasavaraj G, "Effect of surface roughness on the static characteristics of rotor bearings with couple stress fluids", Comput Struct,

[15] 2002;80:1243-1253.

[16] Naduvinamani NB, Hiremath PS, Gurubasavaraj G, "Squeeze film lubrication of a short porous journal bearing with couple stress fluids", Tribol Int.2001;34:739-747.

[17] Lu Rf,Ho MH. Lin JR, "A steady of steady-state performance and dynamic characteristics for wide Rayleigh step slider bearings", J Sci Technol.2005;14:205-211.

[18] Ramanaiah G., "Squeeze films between finite plates lubricated by fluids with couple stress", Wear.1979;54:315