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The Effect of Couple Stress Fluid on the Squeeze Film Lubrication in Human Synovial Hip Joint

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ABSTRACT: In this paper a study of the squeeze film characteristics in the synovial human hip joint is presented, on the basis of the Stokes micro continuum fluid theory. To take into account the couple stress effects due to the lubricant containing additives or suspended particles , the modified Reynold's equation governing the fluid film pressure was derived. The modified Reynold's equation's is solved analytically, and closed form expressions for the squeeze film pressure, and load carry capacity was presented. The influence couple stresses on the squeeze film characteristics was discussed. It has been found that the effect of couple stresses increased the pressure distribution, load carry capacity and squeeze film time, and decreased the friction coefficient, as compared to the Newtonian lubricant case.

KEYWORDS: Couple stress fluid; Articular cartilage; Synovial fluid; Micro continuum theory; Hip joint .

I. INTRODUCTION

The hip joint is one of the most important joints in the human body. It allows us to walk, run, and jump. It bears our body' and the hip joint is also one of our most flexible joints and allows a greater range of motion than all other joints in the body .The squeeze film phenomenon is observed in several engineering application such as gears ,bearings ,machine tools, dampers and human joints [1] .It arises when two lubricating surface move towards each other in normal direction so pressures are generated and in normal circumstances surface contact does not occur until a long time has elapsed .Squeeze film lubrication is capable of carrying the heavy loads during the walking process even though the velocity was very low at this time [2].The hip joint is a spherical joint between the femoral head and acetabulum in the pelvis .It is a synovial joint ,since it is wrapped in a capsule that contains the synovial fluid ,a biological lubricant that acts also like a shock absorber . The hip bone is formed by three bones; ilium, ischium and pubis. At birth, these three component bones are separated by hyaline cartilage. They join each other in a Y- shaped portion of cartilage in the acetabulum as shown in Fig. (1).

The synovial fluid ,the inner lining ofthe capsule, the synovial member secretes a viscous, non-Newtonianfluid called synovial fluid . It is believed to be the deadliest of blood plasma with the addition of long chain hyaluronate molecules (hyaluronic acid). The thin film of synovial fluid that covers the surfaces of the inner layer of the joint capsule and articular cartilage help to keep the joint surfaces lubricated and reduces friction [3].The fluid nourishment for the hyaline cartilage covering the articular surfaces ,as fluid moves in and out of the cartilage as compression is applied ,then released. The composition of synovial fluid also contains hyaluronic acid component of synovial fluid is responsible for the viscosity of the fluid and is essential for joint lubrication Hyaluronate reduces the friction between the synovial fluid in the capsule and the articular surface .Lubricin is the component of synovial fluid thought to be responsible for cartilage on cartilage lubrication.Many experiments have confirmed that the articular coefficient of friction in synovial joints is far lower than created with manufactured lubricants. The lower the coefficient of friction is, the lower is the resistance to movement. The synovial fluid ,like all viscous substances ,resists shear loads. The viscosity of the fluid varies with the joint velocity or rate of shear ; that is, it becomes less viscous at high rates.

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II. RELATED WORK

In [4] authors showed the hip joint is one of the most important joints in the human body, it allows us to perform many of the movements as jumping, running and walking so it bears our body weight and the hip joint is also one of our most flexible joints and allows a greater range of motion (Flexion Extension, Abduction, Adduction) than all other joints. Lubrication synovial hip joint is a necessary process in order to reduce friction and wear between the surfaces of cartilage during daily activities, lubrication process depended on synovial fluid. It has three main functions : lubrication, absorption and nutrition of the cartilage of the joint. In a healthy hip joint synovial fluid appear non-Newtonian, result in the relationship between viscosity and shear rate.In [5] authors based on the theory of micropolar lubrication the first application of the theory was presented by himself for the steady motion of micropolar fluids in a circular channel in which the profiles for the velocity, micro rotational velocity, shear stress difference and the couple stress on the fluid surface adjacent to the wall were presented graphically. The velocity profile was found to lose its parabolic nature and was smaller than that of classical Navier-Stokes fluid. Though the shearing stress remained the same as that determined by classical theory. The surface shear was found to be reduced by an amount equivalent to the effect of the distributed couples aroused on the fluid surface in a thin layer adjacent to the surface, thus indicating the development of a boundary layer phenomenon not present in the Navier-Stokes theory.In [6]authors studied the hydrodynamic squeeze film lubrication of the human ankle joint, by modeling the joint by a partial porous journal bearing lubricated with a non-Newtonian couple stress fluid .Under squeeze film lubrication .The governing equations were solved numerically and showed increase in pressure ,load capacity ,and friction factor with a decrease in the time of approach.

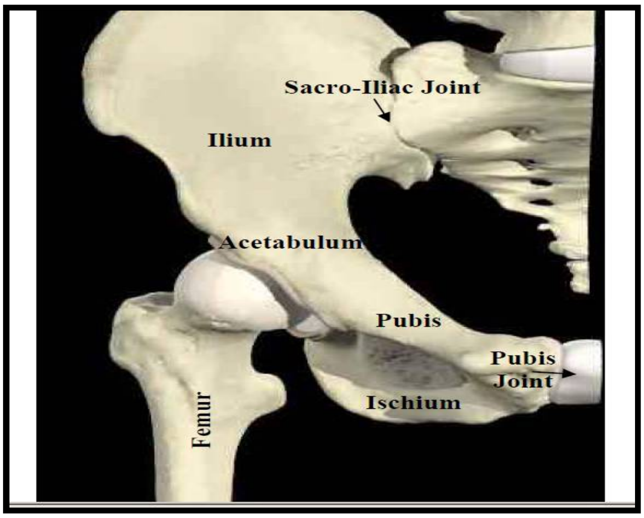

Fig.(1) Shows The nature Human Hip Joint

III. ANALYSIS

The squeeze film mechanism as represents a rigid sphere of radius (R) approaching an infinite plate with a velocity $V = \frac{\partial h}{\partial t}$ under applied load on the synovial human hip joint. The lubricant is taken to be a Stockes couple stress fluid. The geometry and coordinates of the flow domain in the present problem are shown in Fig. (2). Using momentum equations and continuity equation expresses the synovial fluid flow

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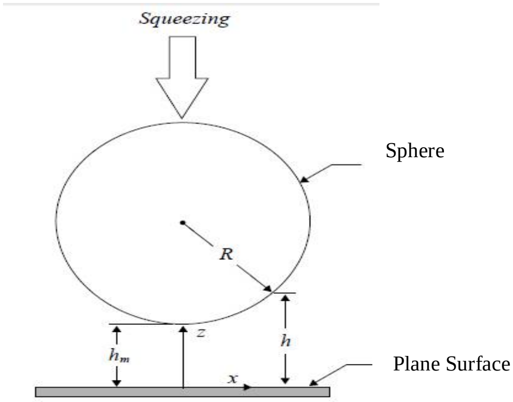

Fig. (2) Squeeze Film Action Between a Sphere and a Flat Plate[4]

$$\rho(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+w\frac{\partial u}{\partial z})=X-\mu\frac{\partial^2 u}{\partial z^2}-\frac{\partial p}{\partial r}-\eta\frac{\partial^4 u}{\partial z^4} \quad \text{eq.(1)}$$

$$\frac{\partial p}{\partial z}=0 \ \text{eq.(2)}$$

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial (r\rho u)}{\partial r}+\frac{\partial (\rho w)}{\partial z}=0 \ \text{eq. (3)}$$

Where ρ density , X body force , (u,w) are the velocity components of the lubricant in r and z directions respectively , p is pressure , μ dynamic viscosity , ηis a material constant accounting for couple stresses due to polar additives in the lubricant. Under the assumptions hydrodynamic lubrication theory the fluid film is thin, the fluid inertia is small and body forces are absent,

then the momentum equations and the continuity equation governing the flow of lubricant in polar coordinates reduces to the form

$$\frac{\partial p}{\partial r}=\mu\frac{\partial^2 u}{\partial z^2}-\eta\frac{\partial^4 u}{\partial z^4} \qquad \text{eq.(4)}$$

$$\frac{\partial p}{\partial z}=0 \qquad \text{eq. (5)}$$

$$\frac{1}{r}\frac{\partial (ru)}{\partial r}+\frac{\partial w}{\partial z}=0 \ \text{eq. (6)}$$

The Boundary conditions for the velocity component at the surfaces of the plate and spheres are:

$$u(r,0)=\frac{\partial^2 u(r,0)}{\partial z^2}=0 \qquad , \mathrm{w(r,0)}=0 \qquad \text{eq.(7)}$$

$$u(r,h)=\frac{\partial^2 u(r,h)}{\partial z^2}=0 \qquad , \mathrm{w(r,h)}=\frac{\partial h}{\partial t} \qquad \text{eq.(8)}$$

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If a lubricating exists between the spherical and plane, h_m is minimum film thickness and R is a curvature radius ,then the film thickness h can be written as follows :

$$h = h_m + \frac{r^2}{2R} \quad \text{eq.(9)}$$

The velocity can be obtained by integrating equation (4) subject to the boundary conditions (7) and (8). Divide the equation (4) by (μ) to get:-

$$\frac{\partial^2 u}{\partial z^2} - l^2 \frac{\partial^4 u}{\partial z^4} = \frac{1}{\mu}\frac{\partial p}{\partial r} \quad \text{eq.(10)}$$

The ratio ($\frac{\eta}{\mu}$)is about of dimensional square length and hence characterizes the Chain length of the polymer additives.

$$l = \sqrt{\frac{\eta}{\mu}} \quad \text{eq.(11)}$$

Solving equation (4) with the above boundary condition one can obtain the expression for u as

$$u(r,z) = \frac{1}{2\mu}\frac{\partial p}{\partial r}\left\{ z(z-h) + 2l^2[1-\cosh(\frac{2z-h}{2l})/\cosh(\frac{h}{2l})] \right\} \quad \text{eq.(12)}$$

Now integrating the continuity equation (6) with respect to y with the boundary conditions of you (r, z). Then the modified Reynolds equation governing the film Pressure is derived as

$$12\mu\frac{\partial h}{\partial t} = \frac{\partial}{\partial r}\{ f(h,l)\ \frac{\partial p}{\partial r}\} \quad \text{eq.(13)}$$

Where the function $f(h,l)$is given:

$$f(h,l) = h^3 - 12l^2 h + 24l^3 \tanh[\frac{h}{2l}] \quad \text{eq.(14)}$$

Introducing the non-dimensional parameters in the governing equations for .The pressure is of importance for both theoretical and computational purposes. It is also of importance to present the various parameters in the lubrication system, in non dimensional form .

$$\left.\begin{array}{l} r^* = \frac{r}{R} \quad , \quad p^* = -\frac{p h_0^2}{\mu R\,\partial h/\partial t} \quad , \quad h^* = \frac{h}{h_0} = h_m^* + \frac{r^{*2}}{2\beta} \quad , \quad l^* = \frac{l}{h_0} \\ \beta = \frac{h_0}{R} \quad , \quad \mathrm{h}^*_{\mathrm{m}} = \frac{h_m}{h_0} \end{array}\right\} \quad \text{eq.(15)}$$

Where r ,h_0 , β , h_m , l are the radial ,film thickness at $t = 0$,a represents the ratio of the microstructure size (particle) to the pore size of surface cartilage ,minimum film thickness, couple stress length . Apply equation (4.32) into equation (4.30) it was obtained the final form of dimensions modified Reynolds equation as:-

$$\frac{\partial}{\partial r^*}\left\{ f(h^*,l^*).r^* \right\}\frac{\partial p^*}{\partial r^*} = -\frac{12}{\beta}.r^* \quad \text{eq.(16)}$$

Where $f(h^*,l^*)$ is represented by:-

$$f^*(h^*,l^*) = h^{*3} - 12l^{*2}h^* + 24l^{*3}\tanh(\frac{h^*}{2l^*}) \quad \text{eq.(17)}$$

It can easily be seen that when $l \rightarrow 0$,the modified Reynolds equation reduces to that in the Newtonian lubrication case .The boundary conditions for the fluid film pressure and radial in the human gap joint are:-

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2016

$$\left.\begin{aligned} p^* &= 0 \quad \text{at} \quad r^* = 1 \\ \frac{dp^*}{dr^*} &= 0 \quad \text{at} \quad r^* = 0 \end{aligned}\right\} \qquad \text{eq. (18)}$$

To find the solution to the modified Reynolds equation. We integration equation (16) one with respect to r^* ,and thus we obtain from following:

$$r^*\frac{\partial p^*}{\partial r^*} = -\frac{12}{\beta\,(h^{*3} - 12l^{*2}h^* + 24l^{*3}\tanh(\frac{h^*}{2l^*})}\int r^* dr^* + A \qquad \text{eq.(19)}$$

Where A is the integration constant, by using the boundary condition, it was obtained the integration constant $A = 0$,then the squeeze film pressure is given by

$$p^* = \frac{6}{\beta(h^{*3} - 12l^{*2}h^* + 24l^{*3}\tanh(\frac{h^*}{2l^*})}\int_{r^*}^{1} r^* dr^* \qquad \text{eq.(20)}$$

$\beta \neq 0$ .With the film pressure known, the squeeze film characteristics can now be calculated.

IV. SQUEEZE FILM CHARACTERISTICS

The load carrying capacity is obtained by integrating the film pressure acting on the sphere

$$W = 2\pi\int_0^R p\,\mathrm{r}\,\mathrm{dr} \qquad \text{eq.(21)}$$

Introducing the dimensionless quantity [24]

$$W^* = -\frac{Wh_0^2}{\mu R^3 \partial h/\partial t} \qquad \text{eq.(22)}$$

Then dimensionless load – carrying capacity is given by

$$W^* = 2\pi\int_0^1 p^* r^* dr^* \qquad \text{eq.(23)}$$

Although the values of the dimensionless film pressure (p^*) and the dimensionless load- carrying capacity (W^*) in equations (20) and (23) cannot be calculated by direct integration ,they could be numerically evaluated by the methods of (power series, Gaussian Quadrature and Simpson method). In this study the power series was used and both terms have been substituted with the well fitting approximate function which has been substituted with power series, then integrating the output result from power series to get the dimensionless load. All mathematical analyses and output resulting curves were carried out by “wolfram Mathematica (9. 0)”. This is a computational software program used in scientific, engineering, and mathematical fields and other areas of technical computing. The equation (23) becomes:-

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$$W^* = \frac{3\pi}{2\,\beta\, h^{*3} - 24\,\beta\, l^{*2} h^* + 48\, l^{*3} \beta \tanh(\frac{h^*}{2l^*})} = g(h^*, \beta, l^*) \qquad \text{eq.(24)}$$

The most important characteristics of the squeeze film action are the squeeze film time, i. e., the time required for reducing the initial film thickness (h^*) to (h_m^*) (minimum film thickness) in different regime lubrication . The response time of the squeeze film is one of the significant factors in the understanding of biological synovial hip joint. The response time is the time that will elapse for a squeeze film to be reduced to some minimum permissible level. The film thickness at any time (t) can be obtained by the integration equation (24) for the given load. Now introduction dimensionless response time depended on load carrying capacity and film thickness as well as viscosity and radial :

$$t^* = \frac{W h_0^2}{\mu R^4} t \qquad \text{eq.(25)}$$

Time – film thickness was depended on load carrying capacity only . In this case we obtain the function of time by the integration equation (24) with respect to h_m^*.

$$\frac{dh_m^*}{dt^*} = -\frac{1}{6\pi \int_0^1 g(h^* \beta, l^*)\ dr^*} \qquad \text{eq.(26)}$$

If the dimensions time approach tends to zero, then the minimum film thickness is high. Equation (26) is a highly non-linear differential with initial condition, $h_m^* = 1$ at $t^* = 0$.

$$t^* = \frac{4\pi(1-\beta)}{H^* \beta \phi^*}(1-h_m^*) - (\frac{4\pi}{5H^{2*} l^* \phi^{2*}} - \frac{2\pi}{5H^{2*} l^* \phi^{2*} \beta} - \frac{2\pi\beta}{5H^{2*} l^* \phi^{2*}})(h^{5*} - h^{5*} h_m^*) - (-\frac{17\pi}{210 H^{2*} l^{4*} \phi^{2*}}$$

$$+ \frac{17\pi}{420 H^{2*} l^{4*} \phi^{2*} \beta} + \frac{17\pi\beta}{420 H^{2*} l^{4*} \phi^{2*}})(h^{7*} - h^{7*} h_m^*) - (-\frac{31\pi}{3780 H^{2*} l^{6*} \phi^{2*}} - \frac{31\pi}{7560 H^{2*} l^{6*} \phi^{2*} \beta}$$

$$- \frac{31\pi\beta}{7560 H^{2*} l^{6*} \phi^{2*}})(h^{9*} - h^{9*} h_m^*) - (-\frac{3\pi}{25 H^{3*} l^{4*} \phi^{3*}} + \frac{\pi}{25 H^{3*} l^{4*} \phi^{3*} \beta} + \frac{3\pi\beta}{25 H^{3*} l^{4*} \phi^{3*}}$$

$$- \frac{\pi\beta^2}{25 H^{3*} l^{4*} \phi^{3*}})(h^{10*} - h^{10*} h_m^*) \qquad \text{eq.(27)}$$

Coefficient of friction between surface spherical and surface plane is a very important factor in synovial hip joint ,to find coefficient of friction depended on shear stress action on the ball surface.

$$\tau = \mu(\frac{U}{h} - \frac{h}{2\mu}\frac{\partial p}{\partial r}) \qquad \text{eq.(28)}$$

The frictional force is given by :

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2016

$$F=\int_0^1 \tau.\ R.\ dr \qquad \text{eq.(29)}$$

$$F=\int_0^1 \mu\left(\frac{U}{h}-\frac{h}{2\mu}\frac{\partial p}{\partial r}\right).\mathrm{R}^2.\mathrm{dr}^* \qquad \text{eq.(30)}$$

Where U is sliding motion , μ is dynamic viscosity . Introduce non- dimensional frictional force by form:

$$F^*=\frac{Fh}{\mu R^2 u} \qquad \text{eq.(31)}$$

Hitting the two parties by the formula above to convert the equation (4.46) to the following formula:

$$F^*=\frac{Fh}{\mu R^2 U}=\int_0^1\left(\frac{1}{h^*}-\frac{h^*}{2}\frac{\partial p^*}{\partial r^*}\right)dr^* \qquad \text{eq. (32)}$$

Substitute dimensionless pressure (p^*) from equation (20) in equation (32) to obtain the final dimensions friction force in the synovial fluid pass through the synovial hip joint.

$$F^*=\frac{3.h^*}{2\beta\, h^{*3}-24\,\beta\, l^{*2}h^*+48\,\mathrm{l}^{*3}\tanh(\frac{h^*}{2l^*})}+\frac{1}{h^*} \qquad \text{eq.(33)}$$

Coefficient of friction is given by

$$C_f=\frac{F^*}{W^*} \qquad \text{eq.(34)}$$

Substituting for (F^*) and (W^*) from equation (24) and equation (33) respectively in equation (34) to get the final expression of non dimensional coefficient of friction :-

$$C_f=\frac{2\beta\, h^{*3}-24\beta\, h^*l^{*2}+48\beta\, l^{*3}\tanh(\frac{h^*}{2l^*})}{3\pi h}+\frac{3h^*(2\beta\, h^{*3}-24\beta\, h^*l^{*2}+48\beta\, l^{*3}\tanh(\frac{h^*}{2l^*}))}{3\pi((2\beta\, h^{*3}-24\beta\, h^*l^{*2}+48\beta\, l^{*3}\tanh(\frac{h^*}{2l^*}))}$$

V. RESULTS AND DISCUSSION

In the present paper, the effect of couple stress on the squeeze film characteristics between a sphere approaching a flat plate is theoretically examined. The effect of couple stress on the performance of the sphere approaching a flat plate is observed with the aid of dimensionless parameters. The dimensionless ratio of $(\eta/\mu)^{1/2}$ may be identified as chain length of the polar additives in the lubricant . The numerical computation of all the results are performed, choosing the parametric values listed in table (1) and for various for the parameters (l, ϕ, h)

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2016

Table (1) Typical numerical values of the parameters involved [1,6]

Parameters	Numerical values	Units
Film thickness	1.5- 4	μm
Dimensionless couple stresses length (l^*)	0.1-0.5	-------
Thickness layer of cartilage (H)	3-7	M
Radius of curvature	0.1-1	M
Viscosity of synovial fluid	$10^{-2} - 10^{-5}$	Pa.s

VI. SQUEEZE FILM PRESSURE

The variation of the dimensionless squeeze film pressure (p*) generated by the squeeze film action as a function of dimensionless radial (r^*) for different values of couple stress length parameters (l^*) is shown in Fig. (3) with using equation (20) . It is observed that the effect of the couple stress fluid ($l^* \neq 0$) is to increase film pressure , especially in the vicinity of the position ($r^* = 0$) than those of the Newtonian case ($l^* = 0$) ,see table (1) ,this result appears important lubricant (synovial fluid) for about increase pressure distribution . The effect of film thickness parameter (h^*) on the variation of (*p**)with (r^*) is shown in Fig.(4). It is observed that the pressure film (*p**) increases with decreasing values of (h^*) in different stage lubrication (hydrodynamic, squeeze and elastohydrodynmic). The effect of the ratio of microstructure size to the pore size parameter (β) on the variation of (*p**) with (r^*) is shown in Fig.(5) with the parametric (h*=2) and (l^*=0.7). It is observed that the pressure film (*p**) increases with decreasing values of (β)in healthy joint inversely in disease joint .

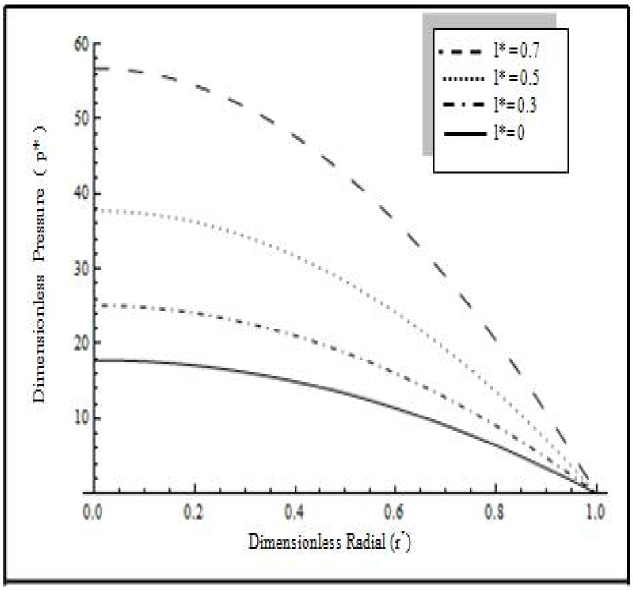

Fig.3. Shows The Variation of Dimensionless Pressure (p^*) with Dimensionless Radial(r^*) for Different Couple Stress Length Parameters (l^*) (β= 0.05 and h^*=3)

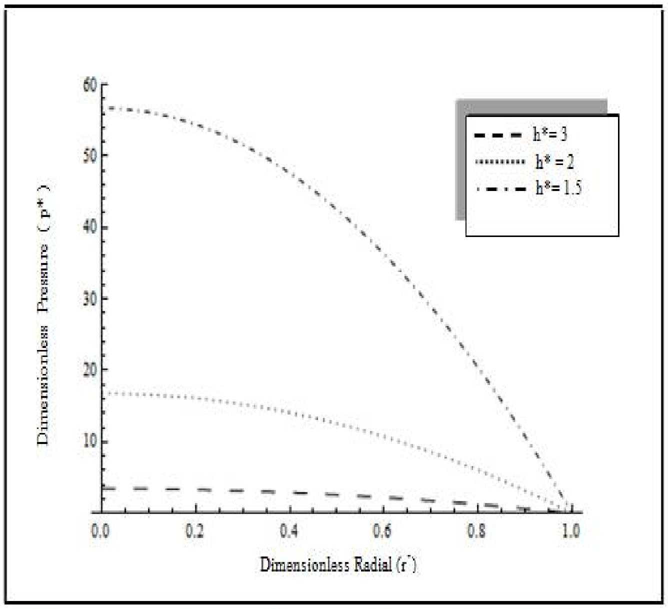

Fig. 4. Shows the Variation of Dimensionless Pressure (p^*) with Dimensionless Radial (r^*) for Different Film Thickness Parameters (h^*) (l^*=0.7 and β=0.05)

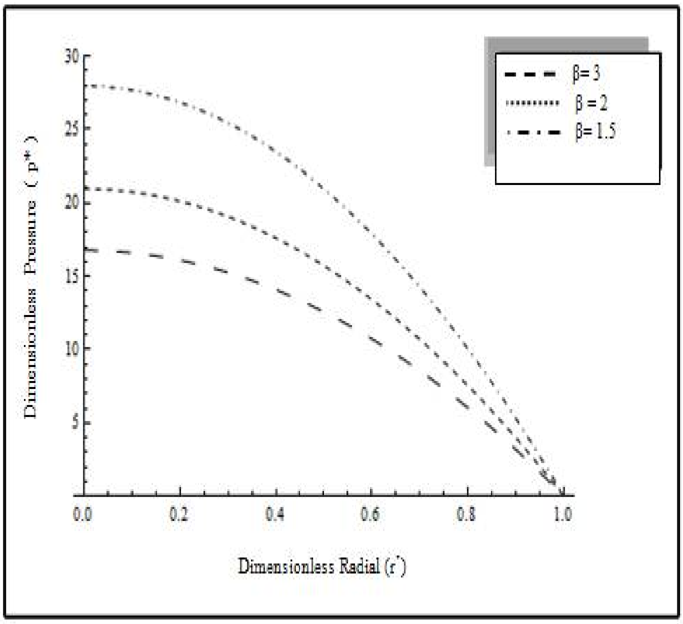

Fig. 5. Shows the Variation of Dimensionless Pressure (p^*) with Dimensionless Radial (r^*) for Different ratio of Microstructure Size to Pore Size β (l^*=0.7 and h^*=3)

VII.**LOAD CARRYING CAPACITY**

The dimensionless load carrying capacity (W*) as a function of dimensionless film thickness (h*) with different dimensions couple stress (l*) is shown in figure (6). After applying equation (24) in the computer program. It is observed that the effect of the couple stress fluid (l^* (0) is to increase load carrying capacity, especially in the vicinity of the position (h* = 1) than those of the Newtonian case (l^*= 0) . It is observed in figures (7) dimensionless load as a function of couple stress at various dimensions, a film thickness large increase of the load is obtained with increasing values of (l*) or decreasing values of (h*)

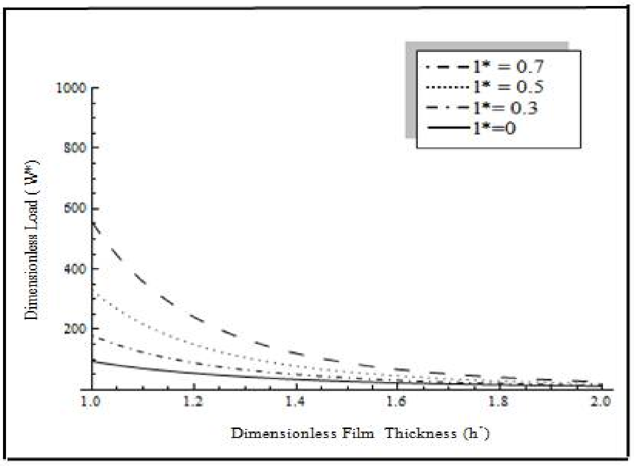

Fig.6.Shows The Variation of Dimensionless Load Carrying Capacity (W^*) with and Dimensionless Film Thickness h^* for Different Couple Stress Length Parameters (l^*) ,(h^*=2 β=0.05)

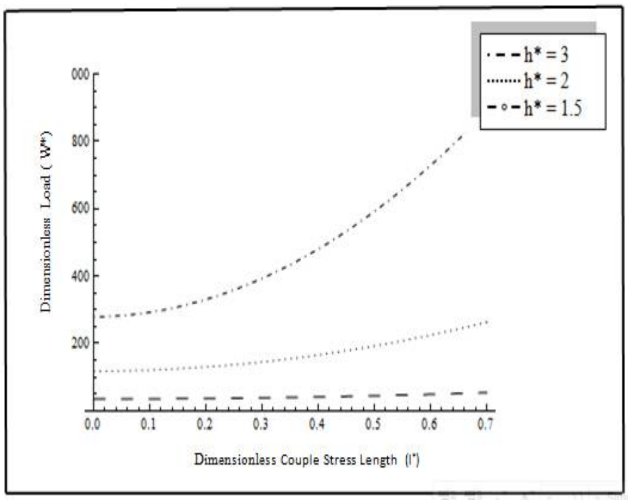

Fig.7. Shows the Variation of Dimensionless Load Carrying Capacity (W^*) with Dimensionless Couple Stress Length (l^*) for Different Film Thickness Parameters (h^*) and β=0.05

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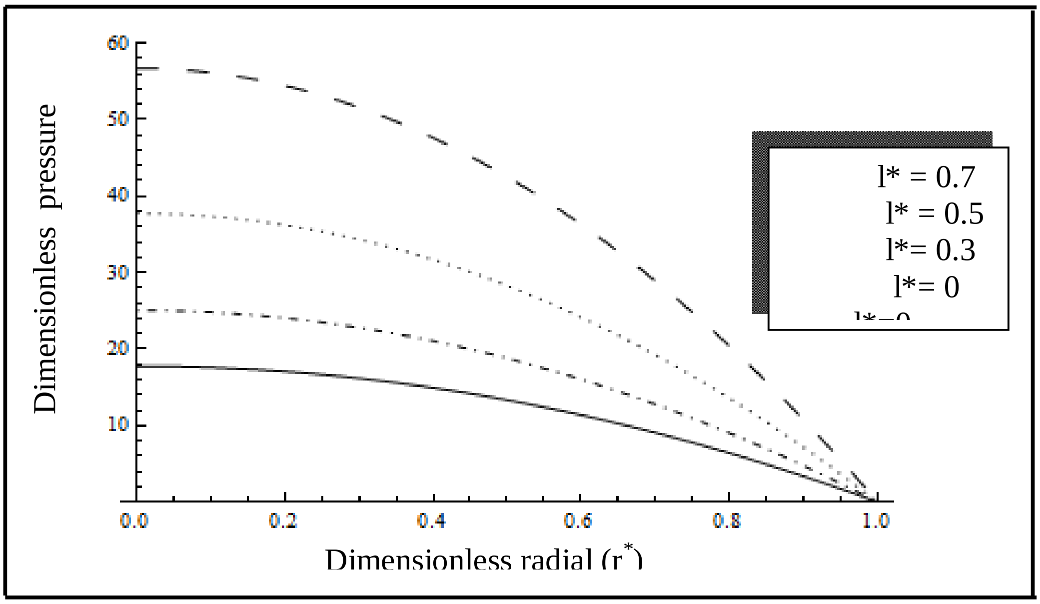

Figure (3) shows the variation of dimensionless pressure (p^*) with dimensionless radial(r^*) for different couple stress length parameters (l^*) (β= 0.05and h^*=3)

in figure (8) show that dimensionless load as a function of film thickness at various (β) dimensionless load decrease with increasing values of (β) and thus decreasing in () is more accentuated for larger values of (β) .

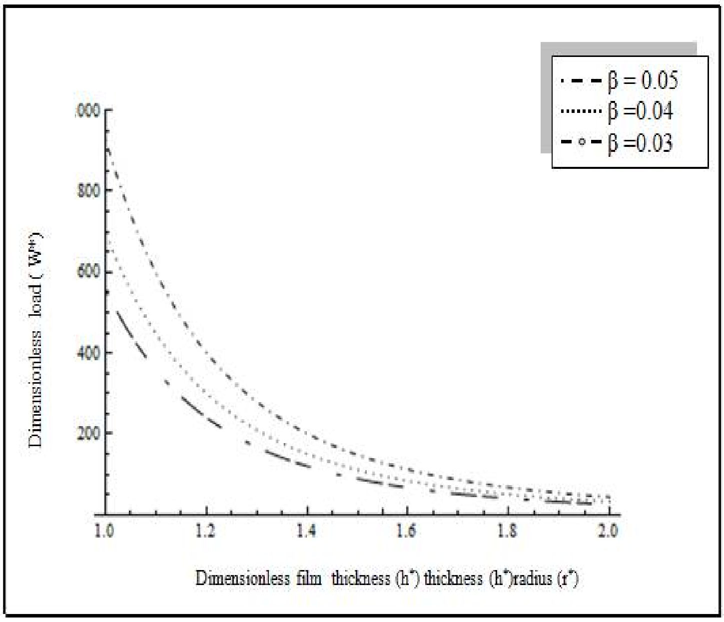

Figure (8) shows the variation of dimensionless load carrying capacity (W^*) with dimensionless film thickness (h^*) for different (β) and $l^* = 0.7$

ISSN(Online): 2320-9801
ISSN (Print): 2320-9798

International Journal of Innovative Research in Computer and Communication Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2016

VII.SQUEEZE TIME –FILM THICKNESS

The response time of the squeeze film is an important factor in describing squeeze film bearings. This is the time elapsed to reduce the initial film thickness to the minimum permissible squeeze film height. The variation of the in the dimensionless response time (t) for the different values of couple stress (l^*) is shown in figure (9) by solving equation (27) in computer program. The approaching time of the film thickness to minimum film thickness for the couple stress fluid lubricant ,see table (4.3) which was greater than the approaching time for the case of a Newtonian lubricant. Therefore couple stress fluid as lubricant have longer response times as compared to the Newtonian. The figures (10) and (11) explain the effect of film thickness and pore size on the dimensionless response time (t) with a fixed value of (l^*) , The response time of the squeeze film (t*) decrease with increasing values film thickness and pore size .This is due to decrease film pressure (p*) with increasing (h*) and (β).

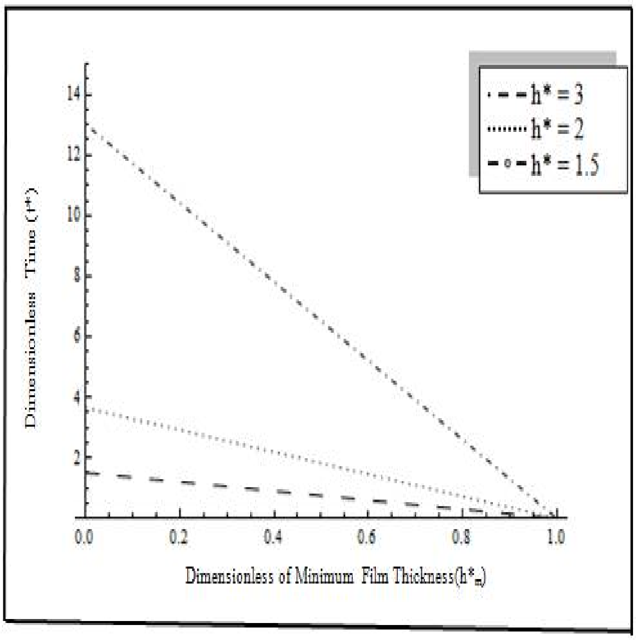

Fig.10.Shows The Variation of The Dimensionless Squeeze Time (t^*) with Dimensionless Minimum Film Thickness (h_m^*) for Fifferent Film Thickness (h*) and $\beta = 0.05$

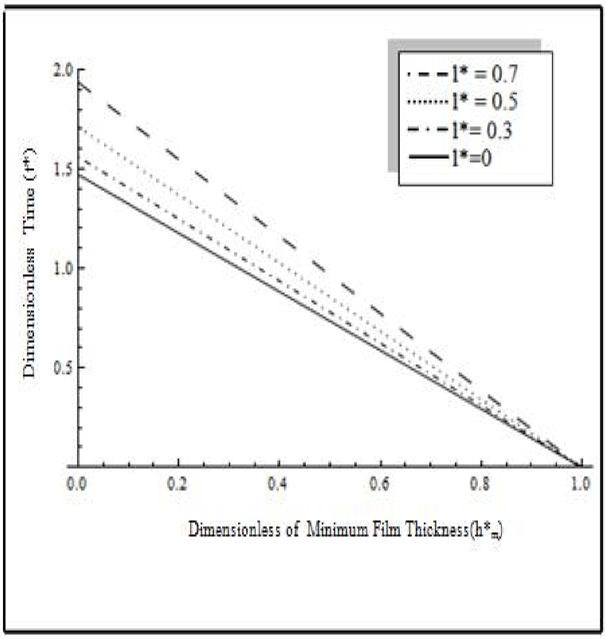

Fig.(9). Shows The Variation of The Dimensionless Squeeze Time (t^*) with Dimensionless Minimum Film Thickness (h_m^*) for Different Couple Stress Length and $\beta = 0.05$

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2016

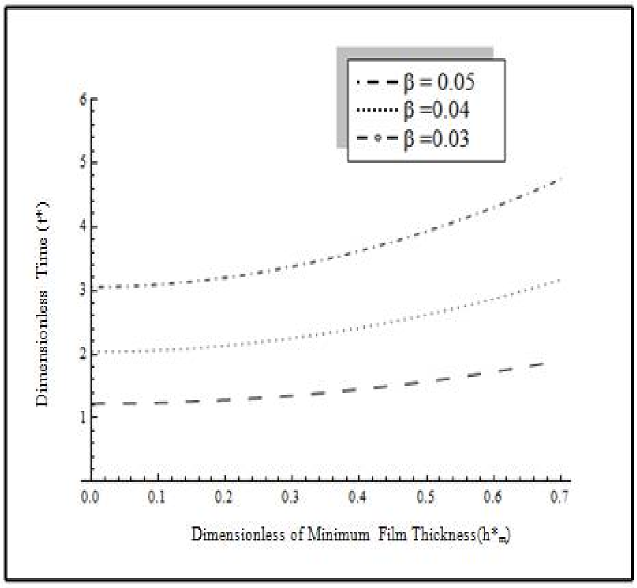

Fig. 11. Shows The Variation of The Dimensionless Squeeze Time (t^*) with Dimensionless Minimum Film Thickness for Different Values β and $l^* = 0.7$

VIII. COEFFICIENT OF FRICTION

Figures (12) – (14) shows the variation of dimensionless friction force (F^*) as a function of dimensionless film thickness (h^*) for various values of couple stress parameters (l^*) and a ratio of microstructure size to pore size. After applying equation (35).The effect couple stress is to increase the dimensionless friction force which is more significant than microstructure size to pore size. It is observed that the effect of couple stresses is to reduce the dimensionless friction force as compared to Newtonian case .Figure (13) shows the variation of dimensionless frictional force (F^*) as a function of dimensionless couple stress (l^*) for various values of film thickness parameters . It is observed that effect of film thickness is to increase the dimensionless friction force in case Elastohydrodynamic lubrication as compared squeeze and hydrodynamic lubrication

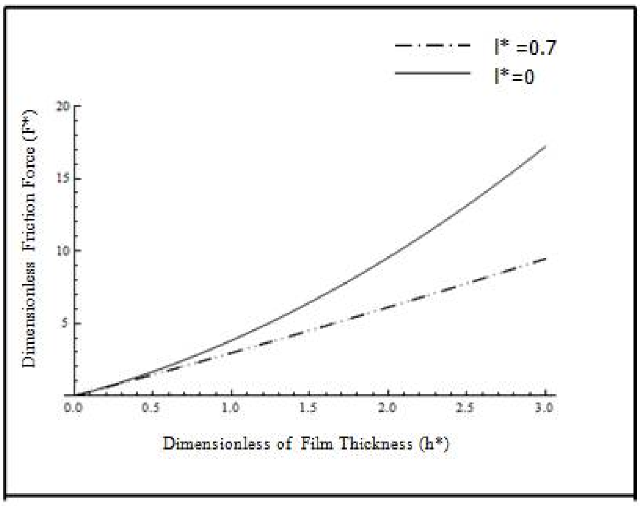

Fig.12.Shows The Variation of The Dimensionless Friction Force with Dimensionless Film Thickness Parameter (h^*) for Different Values of Couple Stress (l^*)

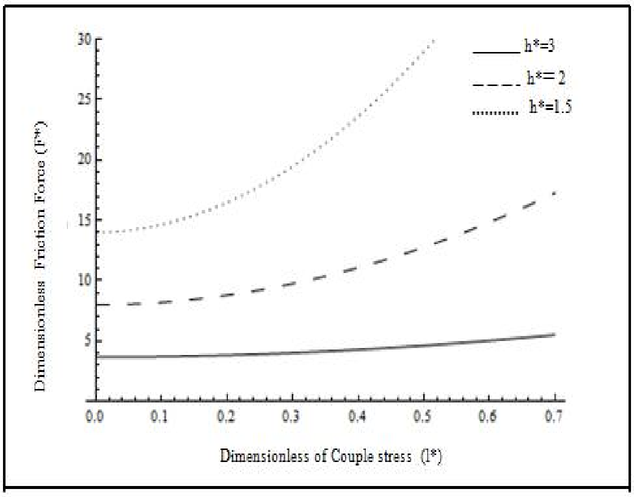

Fig.13.Shows The Variation of The Dimensionless Friction Force with Dimensionless Couple Stress (l^*) for Different Values of Film Thickness Parameter (h^*)

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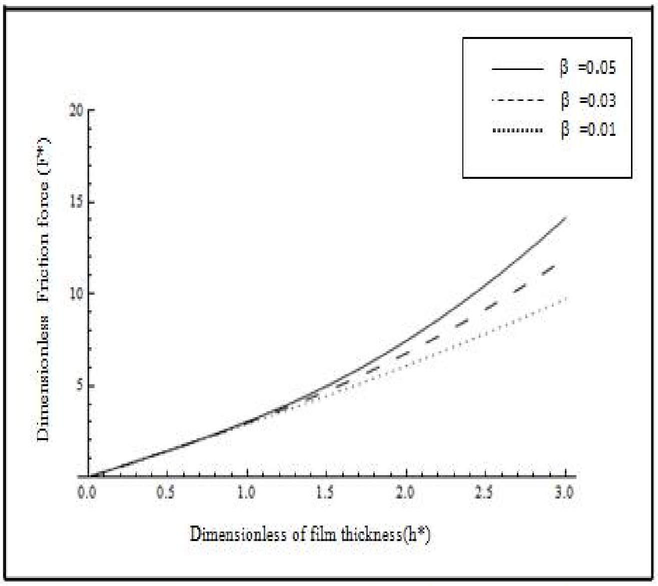

Fig.14 .Shows the Variation of the Dimensionless Friction Force with Dimensionless film Thickness (h^*) for Different Values of (β) and $l^* = 0.7$

IX.CONCLUSIONS

The effects of couple stresses on the squeeze film between a sphere and a permeable flat plate are presented on the basis of Stockes micro continuum theory . The modified Reynolds equation, governing the squeeze film pressure is derived using the Stockes constitutive equation and is solving numerically using (Wolfram Mathematic 9) .According to the results obtained the following conclusions :

(1) The effect of couple stress is increase the film pressure ,load carrying capacity and time in side and decrease in coefficient of friction in other side significantly as compared to the Newtonian case.

(2) The effect of the ratio of the microstructure size (particle) to the pore size of surface cartilage parameters(β) causes decrease the film pressure ,load carrying capacity and time and increase in coefficient of friction in disease joint.

(3) The effect of film thickness parameters causes reduction in film pressure ,load carrying capacity , time and coefficient of friction in squeeze lubrication ,and increase in film pressure ,load carrying capacity time and coefficient of friction in elas to hydrodynamic lubrication .

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BIOGRAPHY

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