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Study Effect of Film Thickness of Articular Cartilage with Couple Stress Fluid on Performance Improvement of the Human Knee Joint

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Abstract

In human knee joint synovial fluid film , covers the surface porosity of cartilage within the joint space .Knee joint acts as journal bearing in mechanical system .In this study determine the characteristic film action with different mechanical lubrication during daily active on the basis modeling thickness of cartilage in the human knee joint to obtain detailed analysis for pressure film that it changed through flow synovial fluid film ,load carrying capacity ,friction force , coefficient of friction and time approach that synovial fluid reduces in it . A theoretical analysis of film thickness in articular cartilage for long partial journal bearing lubrication by synovial fluid with couple stress ,assumed to be non-Newtonian is presented during joint activities and the influences .The model of knee joint has been taken geometrically as surface elastic porous journal bearing under different lubrication during stance phase and swing phase. Typical physical values of the knee joint has been taken from measure values in literature .The problem of layer thickness articular cartilage in knee joint has been solved numerically for various couple stress fluid and film thickness parameters with each other with effect of varying pore size surface on articular cartilage. Increasing values of the couple stress and film thickness parameters increases the pressure film ,load carrying capacity and outfits a longer time to ban cylinder Plan surface contact and reduction coefficient of friction .

Keywords: Knee joint ; synovial fluid ; journal bearing ; elastic ; porous

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1.Introduction:

The synovial human joints surfaces are covered by a film of lubricant of sufficient thickness to separate them. Lubrication synovial human joints have become a concern in recent years since effectively reduces the wear so that the friction becomes the function of the viscosity of the lubricant. The knee joint is a very important since when standing, walking, running or many other movements the knee must support nearly all the weight of the body which doubles several times in stance phase[1].

Though walking patterns can be distinctly individualized and varied all normal walking consists of the same repeating series of event. One full series of events is referred to as a gait cycle ,gait cycle consist of stance phase and swing phase .The stance period of the gait cycle includes initial contact, loading response, mid-stance, terminal stance, and pre-swing. The swing period of the gait cycle includes initial swing Gait cycle is closely linked with the joint lubrication where divided types of lubrication to (hydrodynamic lubrication (HL),squeeze lubrication(SQL) , elaso- hydrodynamic (EHL), weeping (WL)) based on a qualitative gait cycle (stance phase, swing phase)[2].

Articular cartilage is the bearing material that lines the ends of the bones of synovial joints, schematically. Its primary function is to reduce friction and wear at the articulations of the musculoskeletal system. The

Tribological properties of cartilage are intimately related to its structure and mechanical properties. The modes of lubrication in cartilage extend beyond the traditional mechanisms of fluid film or boundary lubrication. Cartilage is a white connective tissue which is synthesized and maintained by cells called chondrocyte. It is a highly hydrated tissue, with a porosity varying from (70% - 80 %) in adult joints .In human joints, the thickness of the articular cartilage layer varies from 0.5 to 1.5 mm in upper extremity joints, such as the hand and the shoulder, and from 4 to 7 mm in lower extremity joints, such as the hip, knee, and ankle. Under normal conditions, articular cartilage provides low friction and wear over a life span [7].

The knee joint is a presentation as cylindrical joint, consists of bones the femur and the tibia (Figure 1). The knee joint is a very strong and complex joint., The knee joint connects the femur, or thigh bone, with the tibia bone of the lower leg. It also connects the femur with the patella or knee cap. There is also a secondary connection between the femur and the fibula. The knee joint connects the femur, or thigh bone, with the tibia bone of the lower leg. It also connects the femur with the patella or knee cap.. The knee is a hinged joint allowing flexion and extension, as well as a slight rotation of the lower leg

It is clear and yellowish substance found in cavity of freely moving joints and interacting with cartilage to provide lubricating action. It occurs in small quantities yet it acts both as a lubricant for the articular surface and as a nutrients for the cartilage . Synovial fluid is secreted by synovial lining cells. It plays a very important role in synovial joints. It occupies the joint cavity and lines the synovial joint, providing nutrients and removing catabolic products. The thin film of synovial fluid that covers the surface of the inner layer of the joint capsule and articular cartilage helps to keep the joint surface lubricated and reduces friction as fluid moves in and out of the cartilage as compression is applied, then released .The composition of synovial fluid also contains hyaluronic acid (HA) and glycoprotein called lubricin .The(HA) component of synovial fluid is responsible for the viscosity of the fluid and is essential for joint lubrication . (HA) reduces the friction between the synovial folds of the capsule and the articular surfaces[4].

Normal healthy synovial fluid is highly non-Newtonian viscous fluid present in small amounts at all synovial joints .However ,when a joint is injured or diseased the volume of the fluid may increase .The synovial fluid ,like all viscous substance ,resists shear loads. The viscosity of the fluid varies inversely with the joint velocity or rate of shear ; that is , it becomes less viscous at high rates of shear.[6]

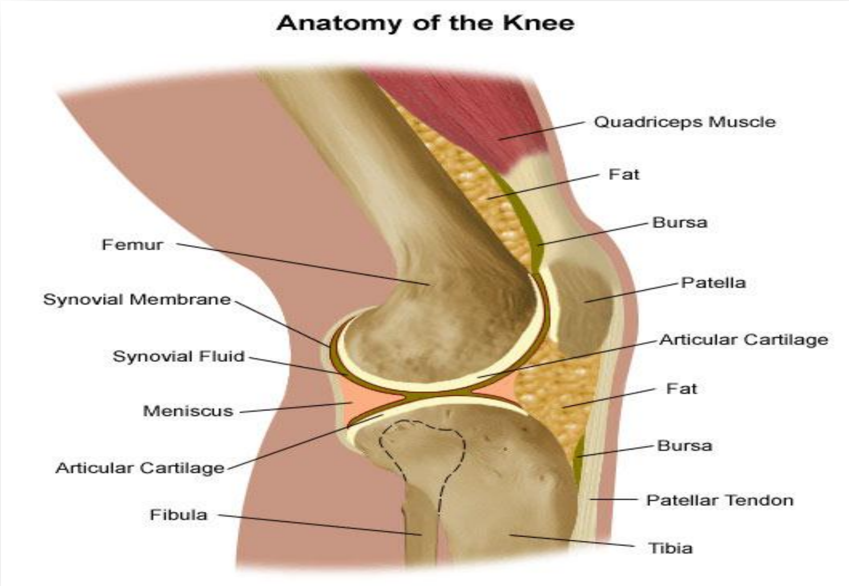

Figure 1 : Human knee joint [2]

*1.1.**Governing Equation***

The physical disposition of a porous journal bearing is shown in Figure 2 .The journal of radius R approaches the bearing surface at any peripheral section θ with velocity V_θ .The film thickness of h is a function of θ ,i.e.$h = \delta - e\ cos\theta$, where δ is the radial clearance and e is the eccentricity of the journal center .Film region H ,film porosity $\emptyset$.

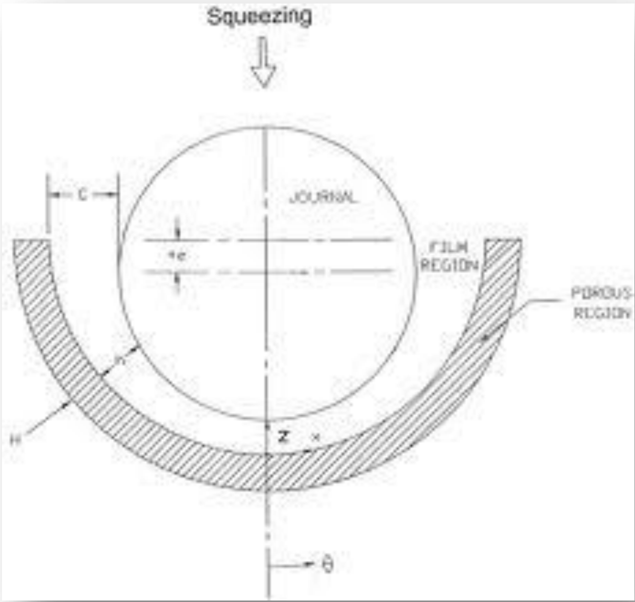

Figure 2 : shows the physical and geometry configuration of the knee joint

The requisite fielded equations of the micro polar fluid were developed by Eringen [3] and Stokes .The basic equations for the flow of synovial fluid from porous matrix

$$\rho \frac{dv}{dt} - H = -\nabla p + \mu \nabla^2 \vec{V} - \gamma \nabla^4 \vec{V} \qquad (1)$$

Where ρ , p , μ and γ represents the density , pressure ,shear viscosity and material constant responsible for couple stress fluid property [4].Under the assumptions of fluid film lubrication applicable to thin films ,the equation of motion of a incompressible couple stress fluid within film and porous regions[6] ,the equation (1) becomes:

$$\frac{\partial p}{\partial x} - H = \mu \frac{\partial^2 u}{\partial y^2} + \gamma \frac{\partial^4 u}{\partial y^4} = 0 \qquad (2)$$

Flow of synovial fluid through porous matrix , described steady laminar and satisfy continuity equation that has form :

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (3)$$

The ratio $\frac{\gamma}{\mu}$ is a dimensional square length therefore characterizes the chain length [1]

$$l = \sqrt{\frac{\gamma}{\mu}} \qquad (4)$$

3. **Modified Reynolds equation**

Integrating Equation (3) with respect to y boundary condition for $u(x, y)$ are:

i.$u(x,0) = 0$ and $\frac{\partial^3 u}{\partial^3 y}$ $(x,0) = 0$ at the bearing surface (5)

ii.$u(x,h) = 0$ and $\frac{\partial^1 u}{\partial^1 y}$ $(x,h) = 0$ at the journal surface (6)

Final form of velocity in Cartesian coordinates as :

$$u(x,y) = \frac{1}{2\mu}\frac{\partial p}{\partial x}[1 - H]\left[-2l^2 Cosh\left[\frac{y}{l}\right] + 2l.Sinh\left[\frac{h}{l}\right]y + y^2 + 2hy + 2l^2\right] \qquad (7)$$

The flow of couple stress fluid in a surface roughness porous is prevailed by the modified Darcy law, which accounts for the polar effects

$$q = (u^*, v^*) = \frac{-\varphi}{\mu(1-\beta)}.\nabla p^* \qquad (8)$$

q is the total discharge , ∇ gradient operator and $q = (u^*, v^*)$ where u^*, v^* components of fluid velocity in x ,y direction respectively in porous region . φ is the permeability of the porous matrix . The parameter (β) represents the ratio of the microstructure size to the pore size. The pressure p* in the porous region ,due to continuity ,satisfies the Laplace equation

$$\frac{\partial^2 p^*}{\partial^2 x} + \frac{\partial^2 p^*}{\partial^2 y} = 0 \qquad (9)$$

$$\frac{\partial p^*}{\partial y} = -\int_e^0 \frac{\partial^2 p^*}{\partial^2 x} \; dy \qquad (10)$$

Eccentricity represent the degree can be expressed by a plus or minus thickness layer of articular cartilage in healthy knee joint degree of eccentricity is high pressure in film region equal to the pressure in porous region .Equation (10) reduces to:

$$\nabla p^* = \frac{\partial p^*}{\partial y} = e\frac{\partial^2 p}{\partial^2 x} \qquad (11)$$

We will focus our attention on squeeze action v^* that change with film thickness of articular cartilage , Thus will ignore the sliding motion u^* and become equation (8) :

$$v^* = \frac{-\varphi}{\mu(1-\beta)}.e\frac{\partial^2 p}{\partial^2 x} \qquad (12)$$

Now integrating the continuity equation (3)

$$\int_0^h \frac{\partial v}{\partial y}\,dy = -\int_0^h \frac{\partial u}{\partial x}\,dy \qquad (13)$$

Applying the boundary condition $v(x,0) = v^*$ at the bearing surface and boundary condition $v(x,h) = -V_\theta$ at the journal surface on continuity equation gives:

$$-V_\theta - \frac{\varphi\, e}{\mu(1-\beta)}.\frac{\partial^2 p}{\partial^2 x} = -\int_0^h \frac{\partial u}{\partial x}\,dy \qquad (14)$$

By replacing the velocity component $u(x,y)$ in equation (14), we obtain the modified Reynolds equation:

$$-2\mu V_\theta = \frac{\partial^2 P}{\partial^2 X}[\frac{2\emptyset e}{(1-\beta)} + (1-H)f(h,l) \qquad (15)$$

Where :

$$f(h,l) = 2l^3 Sinh\left[\frac{h}{l}\right] - 2l^2 Cosh\left[\frac{h^2}{l}\right] - 2l^2.h - \frac{4}{3}h^3$$

3.1 Film pressure of surface roughness journal bearing represent the knee joint

Inserting the following non dimensional quantities of the controlling equation of pressure film :-

$$p^* = \frac{pc^2}{\mu R^2(\frac{d\varepsilon}{dt})} \qquad e^* = \frac{e}{c} \qquad h^* = \frac{h}{c} = 1 - \varepsilon Cos(\theta) \qquad \theta = \frac{x}{R} \qquad \beta = \frac{c}{R}$$

$$l^* = \frac{l}{c} \qquad \emptyset^* = \frac{\emptyset}{c^2} \qquad V_\theta = \mathrm{c}\,\frac{d\varepsilon}{dt}\,Cos\,(\theta) \qquad H = \frac{h}{c} \qquad (16)$$

Where e, c, $\emptyset$, R, and ε represent eccentricity , radial clearance, , permeability, radius Applying the above dimensionless equations in equation (15) .Therefore the final dimensionless form of the modified Reynolds equation becomes:-

$$-2Cos(\theta) = \frac{\partial}{\partial\theta}\{[\frac{\emptyset^*.e^*}{(1-\beta)} + (1-H)f(h^*,l^*)]\frac{\partial p^*}{\partial\theta} \qquad (17)$$

The boundary conditions for the film pressure are:-

$$p^* = 0 \quad \text{at} \quad \theta = \pm\pi \tag{18}$$

$$\frac{dp^*}{d\theta} = 0 \quad at \quad \theta = 0 \tag{19}$$

Equation(18) are the support for the lubricant to be risky to be pressure during stance phase, equation (19) is due to the symmetric distribution of pressure in the θ direction.

Integrating the Reynolds equation with respect to θ with the above conditions (18),(19) and pressing the two limits $(\theta, -\pi)$ the film pressure during gait cycle is:-

$$p^* = \frac{-2\theta^2+\pi^2}{2((1-H)2l^{3*}Sinh\left[\frac{h^*}{l^*}\right]-2l^{2*}Cosh\left[\frac{h^{2*}}{l^*}\right]-2l^{2*}.h^*-\frac{4}{3}h^{3*} \quad +\frac{2\emptyset^*e^*}{1-\beta})} \tag{20}$$

3.2 Load carrying capacity of the elastic porous partial journal bearing represent the knee joint.

The load – carrying capacity of the porous bearing is evaluated by integrating the film pressure equation .The load carrying capacity given by :-

$$\mathrm{W} = \int_{-\pi}^{\pi} p(\theta).R.Cos(\theta) \ d\theta \tag{21}$$

Let the non dimensional load carrying capacity be :-

$$W^* = \frac{Wc^2}{\mu R^{3(\frac{d\varepsilon}{dt})}} \tag{22}$$

Therefore equation (21) can be written in the nondimensional forms as:-

$$\mathrm{W}^* = \int_{-\pi}^{\pi} \frac{(-2\theta^2+\pi^2).Cos(\theta)}{2((1-H)2l^{3*}Sinh\left[\frac{h^*}{l^*}\right]-2l^{2*}Cosh\left[\frac{h^{2*}}{l^*}\right]-2l^{2*}.h^*-\frac{4}{3}h^{3*} \quad +\frac{2\emptyset^*e^*}{1-\beta})} \, d\theta \tag{23}$$

$$W^* = \frac{8\pi}{2((1-H)2l^{3*}Sinh\left[\frac{h^*}{l^*}\right]-2l^{2*}Cosh\left[\frac{h^{2*}}{l^*}\right]-2l^{2*}.h^*-\frac{4}{3}h^{3*} \quad +\frac{2\emptyset^*e^*}{1-\beta})} \tag{24}$$

Although the values of the nondimensional film pressure (p^*) and nondimensional load carrying capacity (W^*) cannot to be obtain by direct integration ,therefore we use numerically evaluated by the method of power series.

3.3 Time –height for journal bearing represent the knee joint :-

The time is most important characteristics of the squeeze film bearings where depended on for determines type of lubrication (hydrodynamic ,squeeze ,elasto- hydrodynamic, weeping) ,where it reduce film thickness (h^*) to minimum film thickness (h_m^*) . Introduction the nondimensional response time:-

$$t^* = \frac{WC^2}{\mu R^3} t \quad (25)$$

The time of approach can be obtained by integrating the equation (23) with minimum film thickness , the initial condition .

$$t^* = 8.37333\,(H-1)(2h^{3*} + 3h^* l^{2*} + 3l^{2*}\,Cosh\left[\frac{h^{2*}}{l}\right] - 3l^{3*} Sinh\left[\frac{l}{h}\right] - 8.37333\,(H-1)(2h^{3*}h_m + 3h^* l^{2*} 3l^{2*}\,h_m Cosh\left[\frac{h^{2*}}{l}\right] - 3l^{3*} h_m Sinh\left[\frac{l}{h}\right] - \frac{25.128 * e^*}{2(\beta-1)} + \frac{25.128 * h_m^2 e^*}{2(\beta-1)} \quad (26)$$

3.4 Coefficient of fiction for journal bearing represent the knee joint :-

The friction force between surface journal and surface bearing can be obtained by integrating the shear stress through journal surface have form :-[19]

$$\tau = \mu(\frac{\partial u}{\partial y})_{y=h} - \gamma\left(\frac{\partial^3 u}{\partial y^3}\right)_{y=h} \quad (27)$$

Substitute for (u) from equation (7) in equation (26) to obtain :-

$$\tau = \mu\left(\frac{U}{h} + \frac{h}{2\mu}\frac{\partial p}{\partial x}\right) \quad (28)$$

Introduce Frication force equation for porous journal bearing:

$$F = \int \tau\,.R.\,d\theta \quad (29)$$

Dimensionless friction force be form $F^* = \frac{Fh}{\mu.U.R}$, therefore , the equation of friction force in a dimensionless form is:

$$F^* = \int_0^1 (\frac{1}{h^*} + \frac{h^*}{2}\frac{\partial p^*}{\partial \theta})\,d\theta \quad (30)$$

Substitute for (p^*) from equation (19) in equation (29) obtain the dimensionless frication force

$$F^* = \frac{h^*\theta^2}{2((1-H)2l^{3*}Sinh\left[\frac{h^*}{l^*}\right] - 2l^{2*}Cosh\left[\frac{h^{2*}}{l^*}\right] - 2l^{2*}.h^* - \frac{4}{3}\,h^{3*} + \frac{2\emptyset^* e^*}{1-\beta})} + \frac{\theta}{h^*} \quad (31)$$

The nondimensional coefficient of friction is given by :

$$C_f = \frac{F^*}{W^*} \quad (32)$$

4. Results and discussion

Depended on Stokes theory , γ is a material constant a counting for couple stress due to polar additives in the lubricant and H film thickness of articular cartilage .Since the dimension of l is of length ,it may be identified as the characteristic length of additives in a Newtonian lubricant .Therefore ,the effects of couple stress , film thickness and pore size are illustrated by the couple stress parameter l^* , film thickness of articular parameter (H) and pore size parameter (β) defined in equation (16) .Different types of lubrication during gait cycle lead to and different definitions of parameters and variables .it is difficult to compare the present results with other existing literatures .therefore ,we relocate Reynold equation to dimensionless non-Newtonian Reynold equation under effect FTA ,when the values l^* approaches zero reduces to the Newtonian Reynold equation with FTA. The numerical computation of all the results are peformed, choosing the parametric values listed in table (1) and for various for the parameters

Table 1. Typical numerical values of the parameters involved [5]

Parameters	Numerical values	Unites
Permeability of cartilage $(\emptyset)$ healthy to diseased cartilage	6×10^{-17} 1.5×10^{-18}	m^2
Dimensionless couple stress length (l^*)	$0.1-0.6$	----------
Film thickness of articular cartilage (H)	$3-7$	m
Pore size of layer articular cartilage (β)	$0.01-0.05$	
Eccentricity ratio parameter (e)	0.1-0.6	

4.1. Squeeze film pressure

"Figure 3" illustrates the dimensionless, film pressure (p*) generated by squeeze film action with angle (θ) for different values of couple stress length parameter l* using equation (20) .During stance phase the effect of couple stresses is to increase the squeeze film symmetrical curves pressure (p*) as compared to the corresponding Newtonian case. Increase in (p*) is more pronounced for larger values of (l*) The percentage rate of increase in pressure distribution was approximately 72% at ($\theta=0$, l*= 0.7) while we find the percentage rate of decrease in pressure distribution was approximately 72% at ($\theta=0$, l*= 0).

"Figure 4" " illustrates the dimensionless, film pressure (p*) generated by squeeze film action with angle (θ) for different values of film of layer articular cartilage (H) .It is observed film of layer in healthy articular cartilage lead to increase the squeeze film symmetrical curves pressure (p*) that was approximately 74% at ($\theta=0$, H= 7) as compared to the corresponding dieses of knee joint where low squeeze film we find the percentage rate of decrease in pressure 36% at ($\theta=0$, H = 4)

"Figure 5" illustrates the dimensionless, film pressure (p*) generated by squeeze film action with angle (θ) for different values of film thickness (h^*) of squeeze lubricant . It is observed in one –cycle require time 1.4 s after end cycle become thickness of film is 0.66 .In two –cycle become time 2.8 s thus decreased film thickness to 0.46, final in three- cycle become time 4.2 s and reach film of lubricant to 0.38 .Table 2 showed relation between gait cycle and film thickness of squeeze lubrication .

"Figure 6" illustrates the dimensionless, film pressure (p*) generated by squeeze film action with angle (θ) for different values of pore size (β) of squeeze lubricant on surface of articular cartilage. It is observed in healthy knee joint when pore size is big in stance phase then synovial fluid that contain particular increases therefore increase film pressure and percentage rate of increases in pressure 74 % at ($\theta=0$, β = 0.05).In swing phase it was find size pore small result that low synovial fluid that pass through pore size of articular cartilage and percentage rate of decrees in pressure 64 % at ($\theta=0$, β = 0.01).

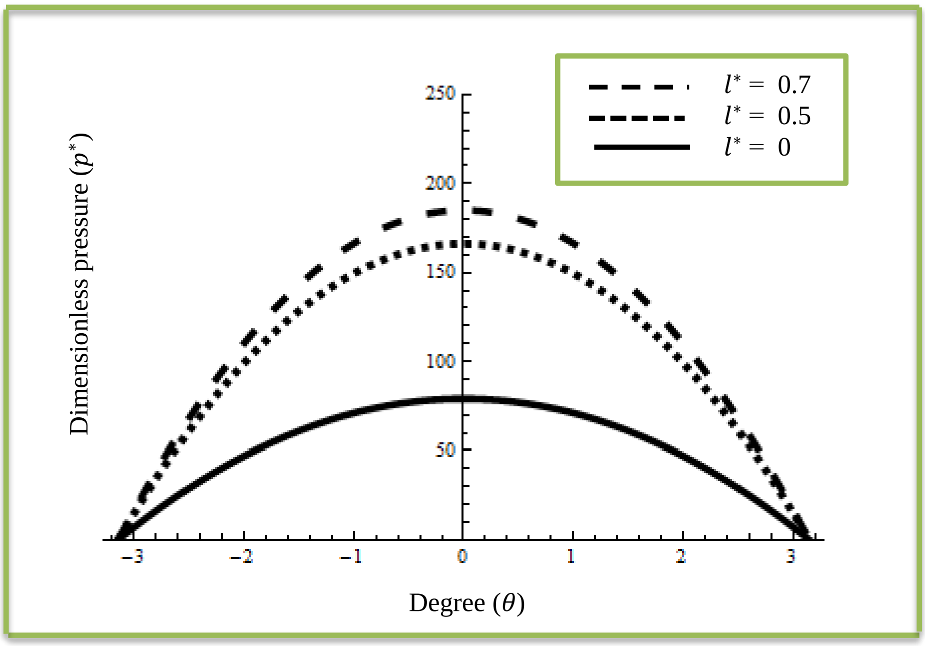

Figure 3 : Shows the variation of dimensionless pressures (p^*) the degree (θ) for different couple stress parameters (l^*)

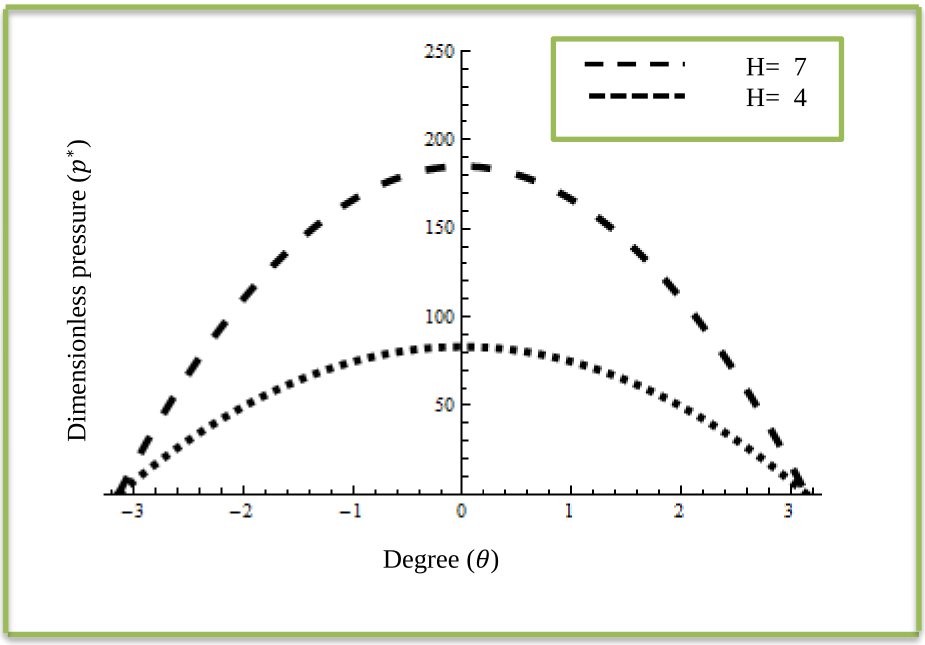

Figure 4 : Shows the variation of dimensionless pressures (p^*) the degree (θ) for different film thickness film parameters (H) of articular cartilage

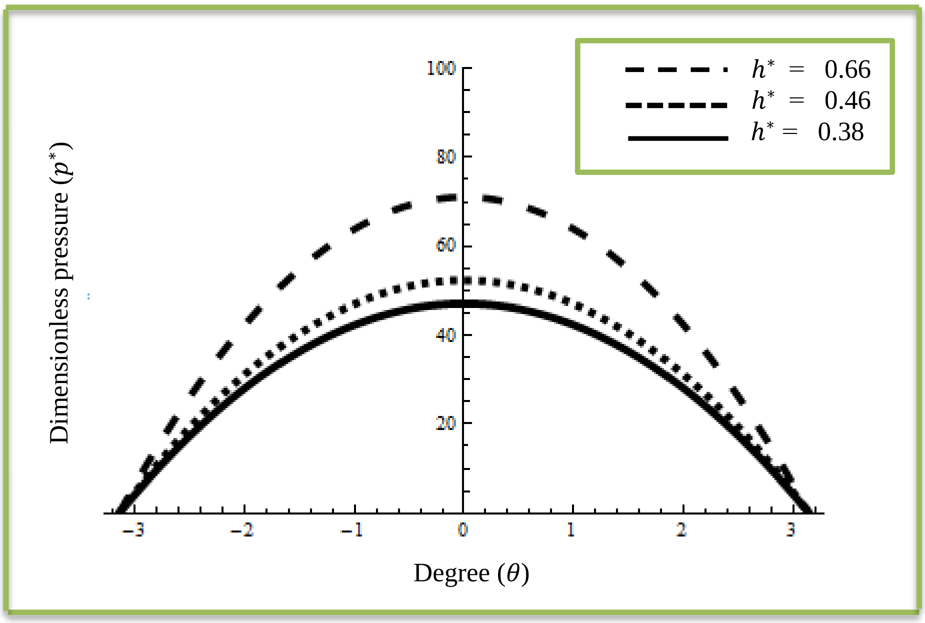

Figure (5) : Shows the variation of dimensionless pressures (p^*) with degree (θ) for different film thickness parameters (h^*) of type of lubricant

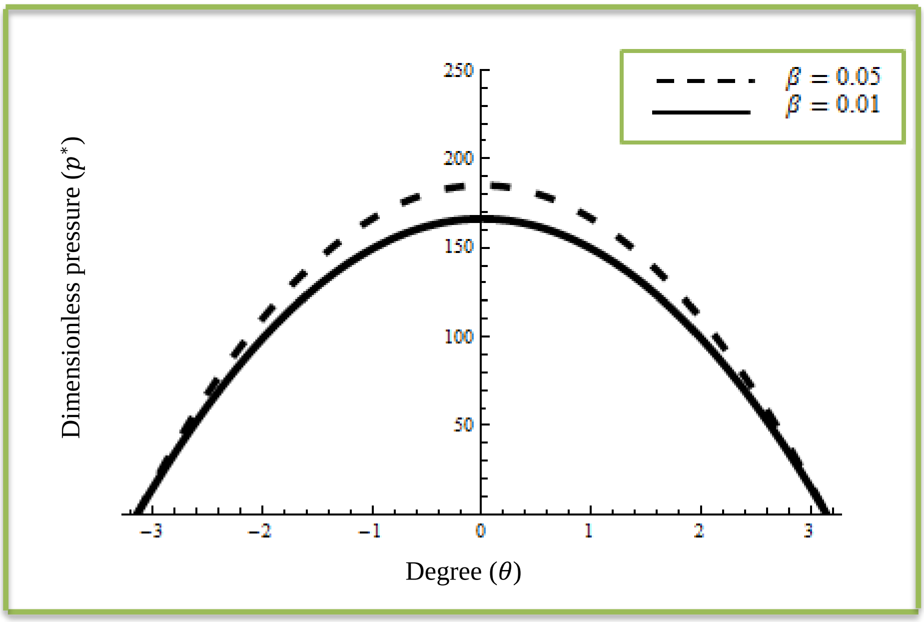

Figure (6) : Shows the variation of dimensionless pressures (p^*) with degree (θ) for different pore size parameters (β) on surface of articular cartilage

Table 2. Relation between gait cycle and film thickness

Gait cycle	Phases	Film thickness	Time of cycle
Initial contact		1.76	0.2
Weight acceptance	Stance phase	1.24	0.4
Mid-stance		1.02	0.6
Toe off		0.83	0.9
Initial swing	Swing phase	0.78	1
Terminal swing		0.69	1.3

4.2. Load carrying capacity

"Figure 7" depicts the dimensionless load carrying capacity (W*) as a function of film thickness (h^*) for different values of couple stress length parameter l* using equation (24) .Since the effects couple stress (l*) result in a increasing pressure film ,similarly affected is applies to load carrying capacity . The rate of increase in pressure distribution was approximately 84 % at ($h,^* = 1$ l*= 0.7) while we find the percentage rate of decrease in load carrying capacity in Newtonian –lubricant case was approximately 32% at $h,^* = 1$ l*= 0). table 3 show that effect couple stress on load carrying .

"Figure 8" illustrates the dimensionless load carrying capacity (W*) as a function of film thickness (h^*) for different values of values of film of layer articular cartilage (H) . It is observed load carrying capacity of body weight during daily active is high when healthy articular cartilage and film thickness is higher where reach approximately 56% at ($h^* = 1$, H= 7) as compared to the corresponding dieses of knee joint where low squeeze film we find the percentage rate of decrease in pressure 28% at ($h^* = 1$, H = 4)

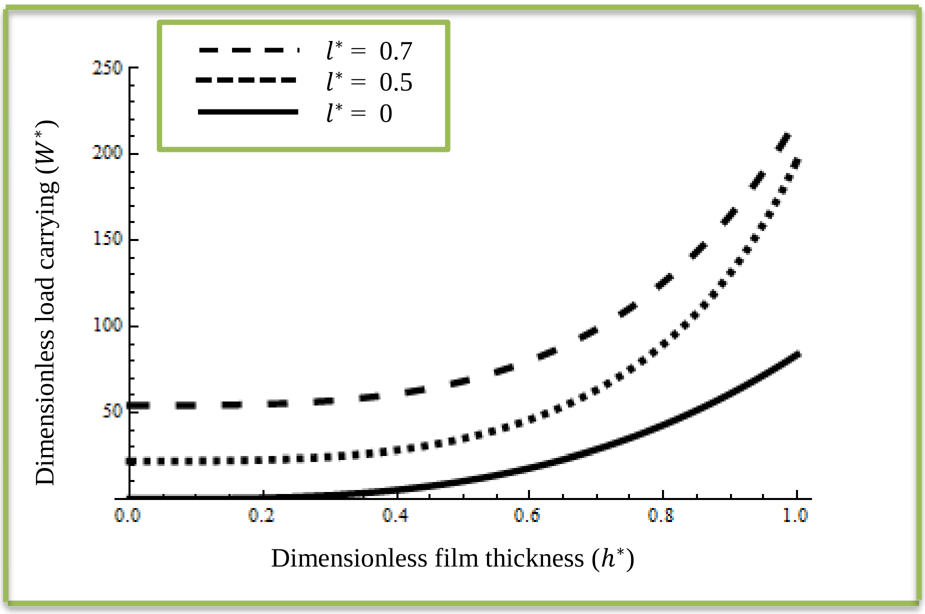

Figure (7) : Shows the variation of dimensionless load carrying capacity (W^*) with dimensionless film thickness (h^*) for different couple stress parameter s (l^*)

"Figure 9" illustrates the dimensionless load carrying capacity (W*) as a function of film thickness (h^*) for different values of pore size (β) on surface of articular cartilage. It is observed the effect of pore size is to increase the load carrying capacity for both type gait cycle (stance phase – swing phase) through squeeze film lubrication

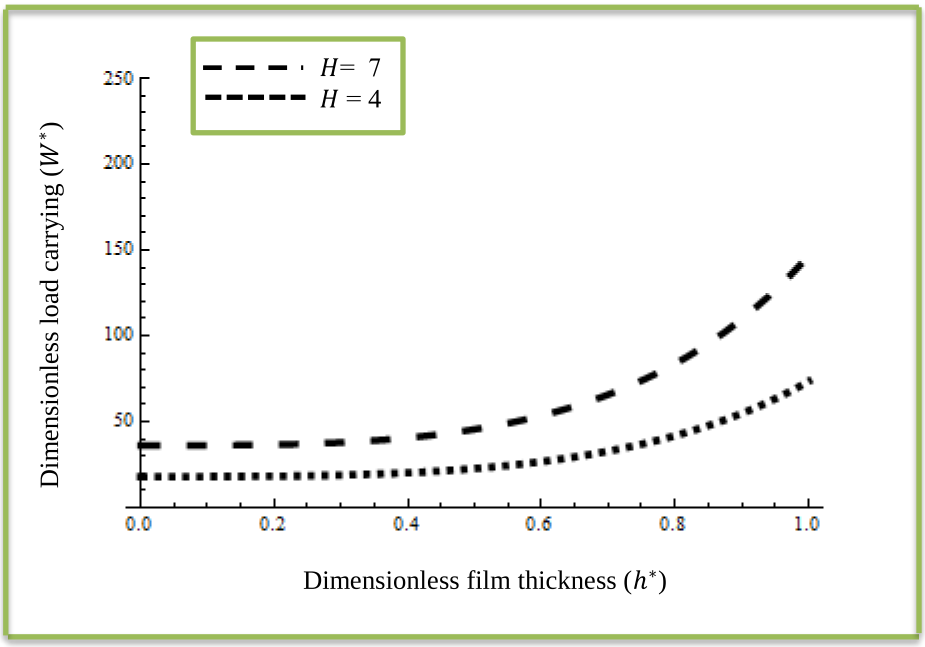

Figure (8) : Shows the variation of dimensionless load carrying capacity (W^*) with dimensionless film thickness (h^*) for different film thickness parameters (H) of articular cartilage

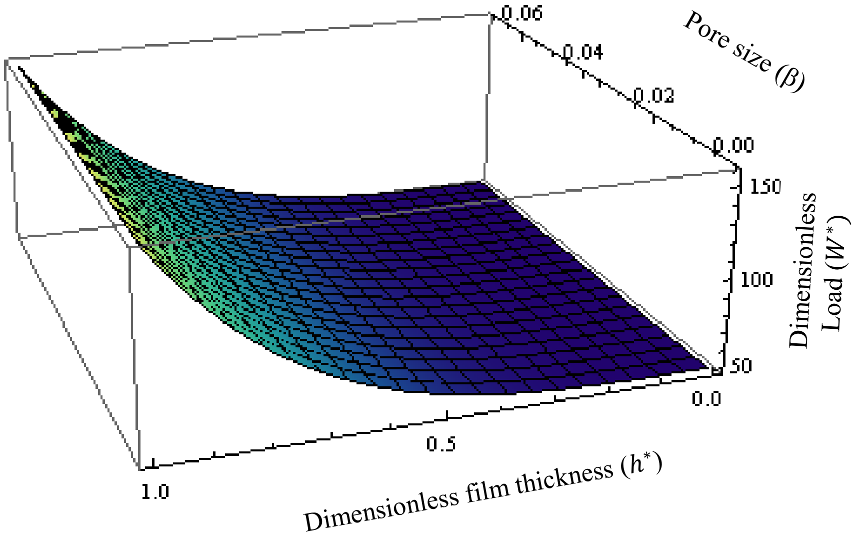

Figure (9) : Shows the variation of dimensionless load carrying capacity (W^*) with dimensionless film thickness (h^*) for different parameters (β) on surface of articular cartilage

Table 3. The variation effect of couple stress and film thickness on load carrying capacity

Couple stress	Load carrying capacity	Film thickness	Load carrying capacity
0.7	235.602	7	235
0.6	220.393	6	196
0.5	214.589	5	157
0.4	211.116	4	117
0.3	199.23	3	78
0.2	180.87	2	39

4.3.Time approach to minimum of load

An important factor in squeeze film characteristics that describe squeeze film in journal bearing represent knee joint is squeeze film time ,where after many of cycle time reduce film thickness to minimum film thickness .Figure (10) depicts the variation of dimensionless squeeze film time (t^*) as a function of dimensionless film thickness (h^*) for different values of couple stress values (l^*) by solving equation (26) in computer program.it is seen that the presence of couple stresses provides an increase in the time of approach .These phenomena can be realized that since the couple stress effects yield a higher load carrying capacity .In other words ,the time of approach for the cylinder –plane surface is lengthened by the use iso-viscosity couple stress fluid camper with Newtonian fluid.

"Figure 11" illustrates the dimensionless time (t*) as a function of film thickness (h^*) for different values of film layer articular cartilage (H). It is observed cylinder required long time approach to plane surface when healthy articular cartilage and film thickness is higher where reach approximately 95% at ($h^* = 1$, H= 7) From here it is clear the importance of the film thickness in healthy articular cartilage where deepened on it increase squeeze time while in older people it was found squeeze time approximately 77 %,relation between squeeze time and film thickness presented in table 4.

"Figure 12" illustrates the dimensionless time (t*) as a function of film thickness (h^*) for different values of permeability ($\emptyset^*$). It is observed healthy knee joint synovial fluid pass surface articular cartilage be few since small pore size that about $\emptyset^* = 10^{-18}$ which makes film thickness required long time to turn into minimum film thickness through squeeze film lubrication, time approach approximately 94.2% while in osteoarthritis it was found pore size become large approximately 37.1 %

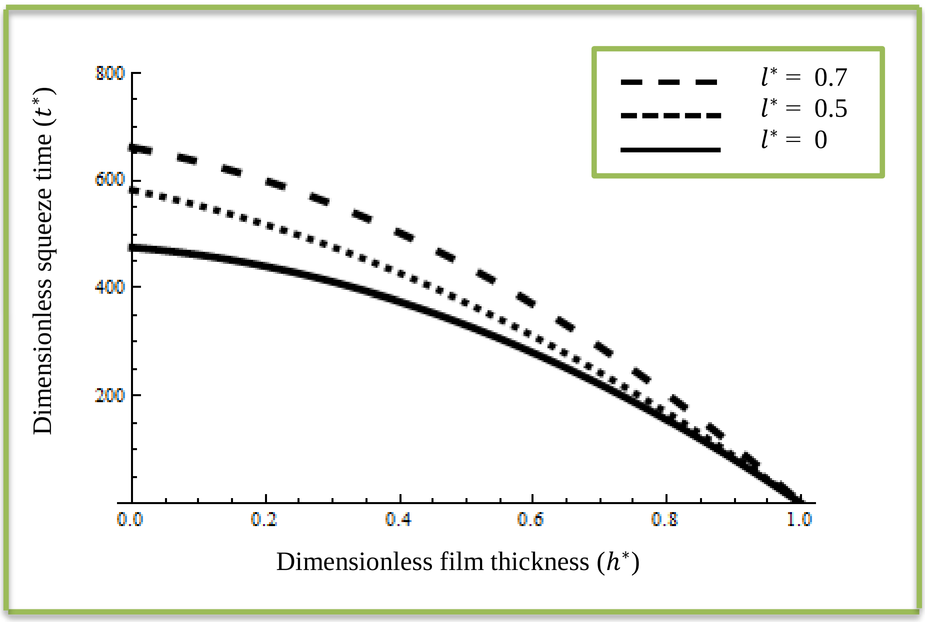

Figure (10) Shows the variation of dimensionless squeeze time (t^*) and dimensionless film thickness (h^*)with different for couple stress parameters (l^*)

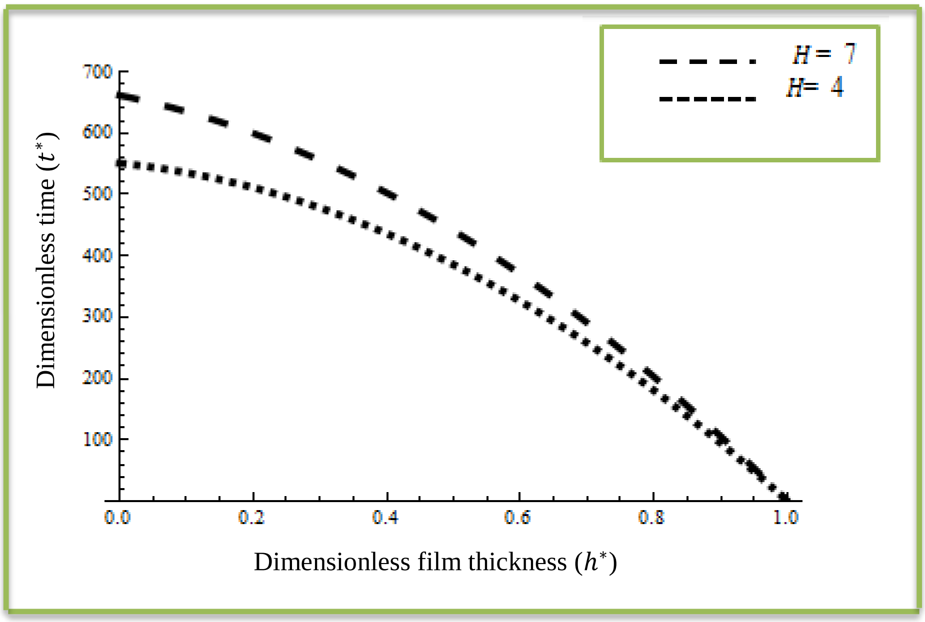

Figure (11) Shows the variation of dimensionless squeeze time (t^*) and dimensionless film thickness (h^*)with different film thickness parameters (H)

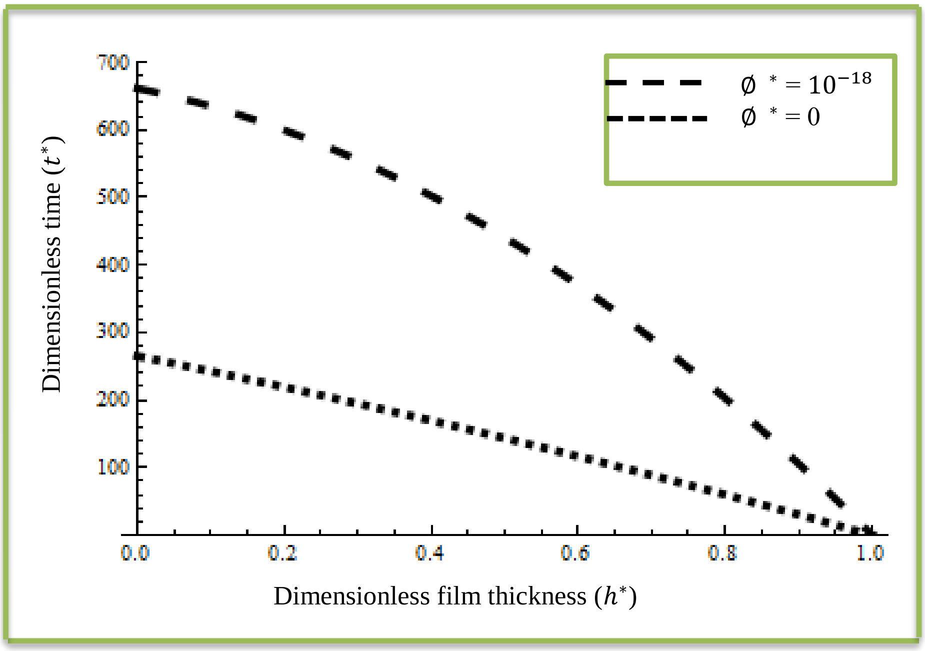

Figure (12) Shows the variation of dimensionless squeeze time (t^*) and dimensionless film thickness $(h^*)$with different permeability $(\emptyset^*)$

Table 4. The different squeeze film time and cycle for different values (H)

Film thickness	squeeze Time	Cycle
7	11.33	485
6	10.33	442
5	9	377
4	8.33	357
3	7.66	328
2	6.66	285

4.4. Frication force

"Figure 13" illustrates the dimensionless friction force (F^*) as a function of couple stress (l^*) for different values of type of lubrication for both phase of gait cycle . It is observed that hydrodynamic lubrication be frication force low since swing phase where stress on joint few when squeeze lubrication start stance phase and increase stress on joint and therefore increase friction force, that reaches its peak in elasto - hydrodynamic lubrication where low elastic which increases the friction between the cartilage

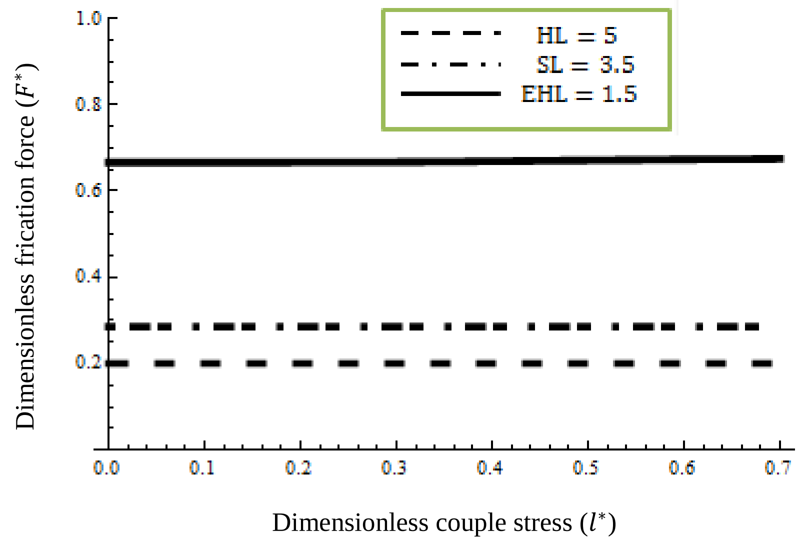

Figure (13) : Shows the variation of dimensionless frication force (F^*)with different dimensionless couple stress (l^*) for different type of lubrication

4.5. Coefficient of friction

"Figure 14" illustrates dimensionless coefficient of frication (μ_s) as a function dimensionless couple stress (l^*) with different for film thickness of articular cartilage (H). It is observed healthy joint coefficient of friction is low since friction force between articular is less but with decrease thickness of layer occur clearly increasing in coefficient of frication .Coefficient of friction in general increase during the gait cycle from (0.001-0.01). It was seen in table (5) relation between coefficient of friction and film thickness

"Figure 15" dimensionless coefficient of frication (μ_s)as a function dimensionless film thickness (h^*) with different for couple stress (l^*) . It is observed decrease in coefficient of friction of the bearing when synovial non- Newtonian fluid flow in thin joint gap rather than that lubricated with Newtonian fluid, using equation (32). Coefficient of friction at ($l^* = 0.7$) for couple stress fluid ,the percentage reduction rate in is approximately 45% as compared with that Newtonian lubricant 99.8% .

Table 5. The effective coefficient of frication (μ_s) and film thickness on friction force

Coefficient of frication (μ_s)	Film Thickness(H)	Frication force (N=60)	Frication force (N=70)
0.004	7	2.35	2.74
0.005	6	2.94	3.43
0.006	5	3.5	4.11
0.008	4	4.7	5.48
0.013	3	7.6	8.91

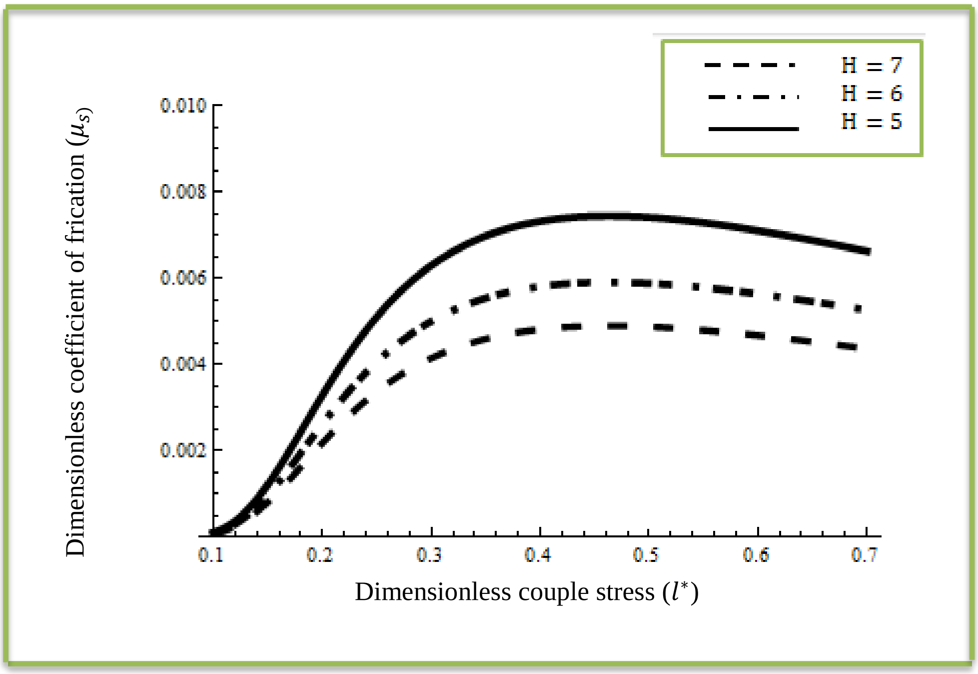

Figure (14) : Shows the variation of dimensionless coefficient of frication (μ_s) with different dimensionless couple stress (l^*) with different for film thickness parameters (H)

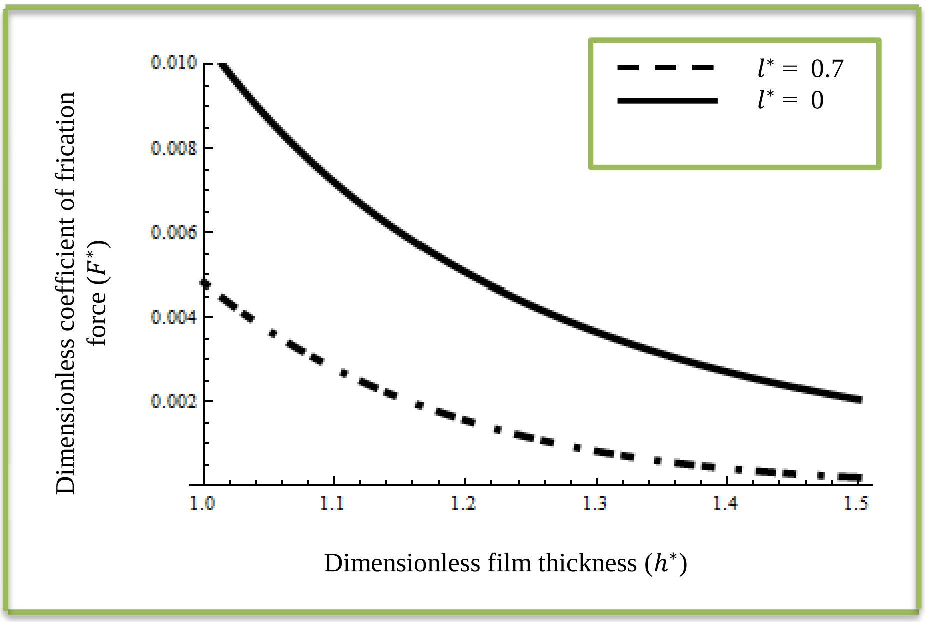

Figure (15) : Shows the variation of dimensionless coefficient of frication (μ_s) with different dimensionless film thickness (h^*)with different for couple stress parameters (l^*)

5. Conclusions

1. The squeeze film characteristics of the journal bearing is significantly affected by the presence of couple stress parameter ,effect of existence particular in synovial fluid make fluid more viscosity, and therefore is increase the film pressure ,load carrying capacity and time in side and decrease in coefficient of friction as compared to the Newtonian case.

2. Another significantly affected by the presence film thickness of articular cartilage where in normal knee joint thickness is high and thus prevent contact between surfaces cartilage during stance phase therefore is increase the film pressure ,load carrying capacity and time in side and decrease in coefficient of friction as compared In the case of osteoporosis, arthritis decreasing film .

3. The effect of pore size parameter on surface articulate cartilage cause causes increasing in pressure film and load carrying capacity during gait cycle.

4. Permeability parameter is important factor to determine features of partial journal bearing of knee joint where in normal case permeability plays role in increasing time approach .

5. Type of lubrication depended on to determine frication force between surface articular cartilage with change from swig phase to stance phase increase friction force .

6. Gait cycle is effected on layer thickness through stance phase bodyweight increase lead to reduce thickness of articular while swing phase high thickness of articular that reach to 7 mm in normal knee joint.

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