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Influence of area ratio on pressure distribution for dimple structure

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ABSTRACT – Dimple structure has been known to act as a lubricant reservoir, generating hydrodynamic pressure and load-carrying capacity to help reducing friction for sliding surface. In this paper, a three-dimensional CFD analysis was done on a simplified model resembling a piston skirt surface textured with dimple. The influence of dimple area ratio ($\boldsymbol{\alpha_r}$) on pressure distribution in hydrodynamic lubrication was investigated. Largest contribution can be seen for $\boldsymbol{\alpha_r}$of 8.1% by which an increase of 102% in load carrying capacity was obtained as compared to untextured surface with 0% area ratio.

1. INTRODUCTION

Various studies have been done by researchers to highlight the benefit of surface texturing. Experiment using test rig shown that texturing help in reducing friction up to 30% for either plane or ring surface [1]. Another experiment by the same group also obtained a friction reduction up to 40% [2]. Meanwhile, experiment using a pin on a disk test discovered that for all loads tested, textured surface was found to help avoid the transition from hydrodynamic to mixed or boundary lubrication, leading to friction reduction up to 75% [3].

To clarify on how surface texturing improves friction and lubrication performance, numerical simulation was also done. A two-dimensional CFD analysis on parallel sliding surfaces was studied by Sahlin et al. [4]. By introducing micro groove on one of the surfaces, a net pressure buildup and positive load carrying capacity were obtained thus increasing the separation between surfaces. A three-dimensional analysis was later conducted involving hemispherical dimple [5]. Pressure curve was shown to be asymmetric across the domain, with peak pressure at the dimple periphery which results in net pressure build up to help the separation and friction reduction between surfaces.

Surface texturing come in various sizes and shapes, in which different parameter is opted for different condition. According to review by Gropper et al. [6], texture density also known as α_r are one of the most influencing parameter in designing dimple texture. It is given by the ratio of dimples to surface area. The optimum area ratio of surface texturing in a reciprocating automotive component was analytically explored by Ronen et al. [7], and found to be between 5% to 20%. Review on previous researches by Wang et al. [8] suggested that for oil lubricated component, α_r is between 5% to 13%. However, the area ratio is highly operation dependent, and need to be study according to specific condition.

In this study, CFD method will be used to understand the effect of α_r towards pressure distribution and load carrying capacity for textured piston skirt surfaces. As the study will focus on the fluid mechanic effect of different dimple parameter, other effect including cavitation and body forces are not yet considered.

2. METHODOLOGY

Numerical simulation using CFX 15.0 was used to solve the incompressible, steady, laminar and isoviscous Navier-Stokes as well as continuity equation which can be given by Equation (1) and Equation (2) respectively.

$$\rho(\mathbf{u}.\nabla)\mathbf{u} = -\nabla p + \nabla\nabla^2\mathbf{u} \quad (1)$$

$$\nabla.\mathbf{u} = 0 \quad (2)$$

Whereby ρ is fluid density which is 883 kg/m^3, u is fluid velocity which follows sliding speed of 0.39 m/s, p is fluid pressure and μ is the viscosity of lubricant which is 0.01298 Pa.s. All fluid properties are based on real engine lubricant. Due to small film thickness relative to cylinder radius, effect of curvature can be neglected [9]. The surfaces of piston and cylinder is thus approximated as two parallel planes with no slip condition which is shown in Figure 1.

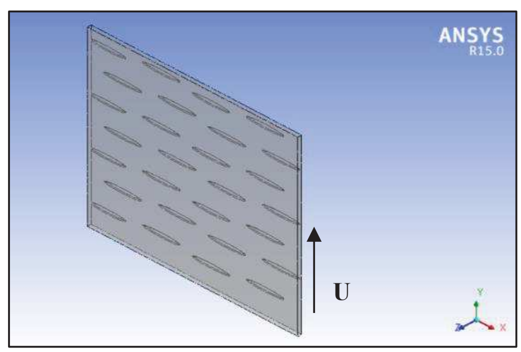


Figure 1 Schematic of fluid model.

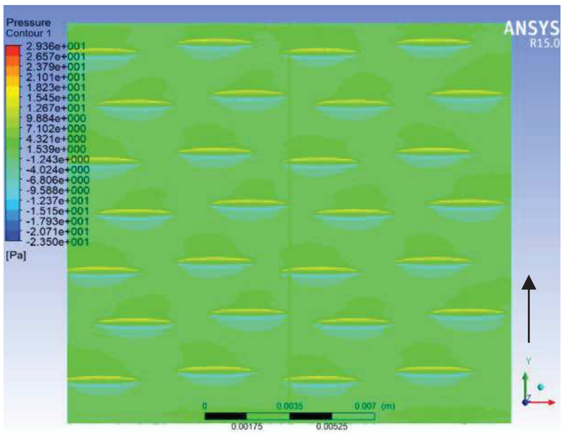
Following real skirt parameter in the symmetrical, fluid model was set to 18.25mm and 15.5mm of length in x and y direction respectively while film thickness was 0.34mm. Dimple parameter was based on a machining process by Dali et al. [10] which was proven viable to be fabricated on piston surfaces. The dimple was simplified to ellipse shape with major axis of 3.2616mm, minor axis of 0.3968mm and depth of 63.43μm.

Grid study was done on single dimple with maximum $\boldsymbol{\alpha_r}$ of 9.5% and projected to the multiple dimples. Mesh of 584981 element was found sufficient to capture pressure generation with error below 5% with respective mesh. Projected to multiple dimple, the maximum mesh size is around 4.5million element.

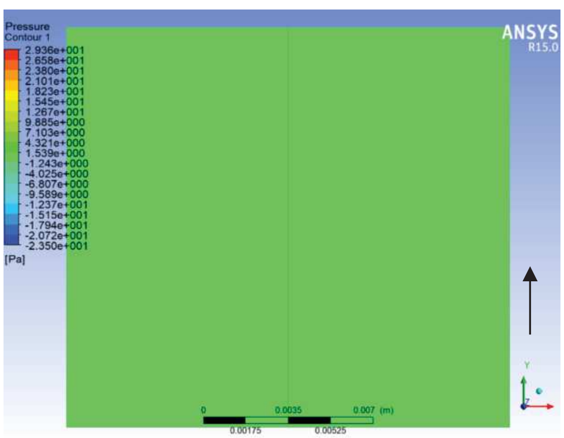
For this simulation, 5 cases will be simulated, which involve α_r of 0% (untextured), 5.4%, 7.5%, 8.1% and maximum of 9.5% for case 1-5 respectively. The pressure distribution on the upper liner wall was then compared. Load carrying capacity, F_z was obtained directly by CFD solver. It was solved by area weight integral of pressure on the upper wall [5].

3. RESULTS AND DISCUSSION

Figure 2 shows the pressure contour on piston surfaces for cases 5 and 1 respectively.



(a)



(b)

Figure 2 Pressure contour for (a) $\boldsymbol{\alpha_r}$ = 9.5% and (b) $\boldsymbol{\alpha_r}$ = 0%.

From Figure 2, higher pressure contour can be seen for textured surface as compared to untextured surface, especially at the dimple periphery. This is in accordance with the study by Jing et al. [5]. To give better visual on influence of area ratio towards pressure generation, pressure distribution on the midplane of sliding wall was plotted along y-direction for all cases simulated as shown on Figure 3. For convenient presentation, pressure on the inlet and outlet was set to 0 Pa [4].

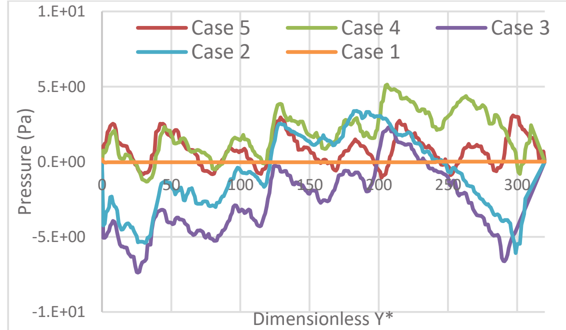


Figure 3 Pressure distribution for different area ratio.

From Figure 3, it can be observed that all cases with dimple generate asymmetric pressure distribution. Case 4 ($\boldsymbol{\alpha_r}$ = 8.1%) shown the highest positive net pressure compared to other cases. This indicate that there exists an optimum area ratio which not need to be the maximum $\boldsymbol{\alpha_r}$ possible. For case 2 and case 3, negative pressure is dominant compared to positive pressure, showing how surface texturing may be detrimental, if designed wrong. Table 1 present the effect of these pressure distribution towards load carrying capacity on the upper liner wall.

Table 1 Load capacity related to area ratio.

Case	α_r (%)	Load Capacity
1	0	-1.1907e-5 N
2	5.4	-2.0463e-4 N
3	7.5	-7.7924e-4 N
4	8.1	5.8503e-4 N
5	9.5	2.3497e-4 N

From Table 1, it was observed that for Case 1 with untextured surface, load capacity was the lowest as a result of linear pressure distribution indicating no positive load support. Similar result was obtained for case 2 and 3, in which negative load support was obtained, as a result of negative pressure distribution. Meanwhile, case 4 with 8.1% area ratio shown the highest load carrying capacity from all cases.

4. CONCLUSION

CFD simulation study on the effect of the dimple area ratio towards pressure distribution and load carrying capacity for sliding surfaces resembling piston skirt found that the a_r of 8.1% resulted in the largest positive net pressure distribution and the highest load capacity, which is the optimum value of the area ratio within the simulation range in the present study.

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