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Micro-Pits Effectiveness for Controlling Friction In Planestrain Extrusion

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ABSTRACT

In metal forming process for controlling lubricant film thickness is a one critical parameter because the decrease or absent in lubricant layer can cause severe wear. In this present study, we will further investigate effectiveness of micro-pits in maintaining lubricant film. Therefore, this research will work on to acquire the possibility surface texture of using die with micro-pits patterns were produced by an electrical discharge machine (EDM) as a case study. Usually to control the friction engineer use the various kind of lubricating oil withdifferent viscosity. The experiment used a cold work plane strain extrusion apparatus consist of a pair of taper die and perfectly symmetrical work piece. The lubricant is additive free paraffinic mineral oil. P1is a represent low viscosity lubricant while P3 represented high viscosity lubricant. All the experiments were conducted at room temperature. The experimental results are focusing on the extrusion load, billet surface roughness, billet surface, grid pattern observation and micro pattern sized observation. The distribution of velocities and effective strain were analyzed by using the visioplasticity method. From the result micro-pit affected on surface roughness if the lubricant high viscosity but low viscosity lubricant would give high extrusion load.

Keywords: Extrusion, Micro-pits, Surface roughness, Paraffinic mineral oil, Velocity, Effective strain

1.0 INTRODUCTION

The importance of tribological considerations in metal forming processes have been generally recognized as affecting tool and die life, material flow during forming,workpiece integrity and surface finish, the relationship of the lubricant to the machine elements, cost considerations and energy conservation. Much knowledge and expertise alreadyexists in the application of tribological principles so that an acceptable end product can be manufactured.

On the other hand, whether or not these applications have been optimized for each particular case or process is open to some doubt. In fact, the extent of the literature published every year suggests that this is not the case and that, as in other disciplines, there is a constant effort to improve our understanding of this subject. This has particularly become important with the continuing development of new materials and processes, especially as they pertain to high-precision components at high rates of production, to aerospace applications, and to the overall economics of metal forming operations.[5].

In metal forming process, friction between tool and workpiece surface is one of the most importantfactor which control the quality of the product. The ability to control this parameter could help us to produce a product with specified finishing surface quality. To control the friction, usually we use different kind of lubricating oil with different viscosity.

In this research, we found the existance of micro-pattern on the tool or workpiece surface could improve the lubrication mechanism, and because of that, we prefer to say that we could control the friction. One of the advantages of this method, we could produce a product with smooth or coarse surface with one type of lubricating oil, by changing the parameter of micro-pattern.

One of the most successful applications in engineering is the improvement of tribological performance. Observations of the surface topography of some engineering surfaces have suggested that systematic patterning could lead to optimized behavior, as a logical development of the more random texturing achieved through processes such as abrasive finishing and honing. Different mechanisms may contribute towards better tribological performance.

2.0 EXPERIMENTAL PROCEDURE

2.1 Experimental apparatus

Figure 1 shows the cross sections of rig in cold forward in plane strain extrusion process. There are taper die and billet (workpiece) as main component of this experiment, and others as an equipment to complete the process as dummy block, outer cover, end plate and punch. The taper die is made from tool steel SKD 11 and heat treatment were done before run the experiment. After heat treatment taper die was polished with abrasive paper to obtain clean contact between billet and taper die during the experiment. The lubricant applied on the interface between the taper die and billet.Dimension on the figure in millimetres (mm).

Billet is made from aluminium A1100 was shape used NC wire cut electric discharge machining device, and the grid pattern made by NC milling machining device. The grid lines were V-shaped grooves with 0.2 mm deep, 0.1 mm wide and 1.0 mm interval length. The grid lines are using for analysis the visioplasticity method to obtain the flow of the extrusion and through that will generate the velocity and effective strain. The billets were annealed before set up the experiments. The Vickers hardness of the billet is 36 Hv.

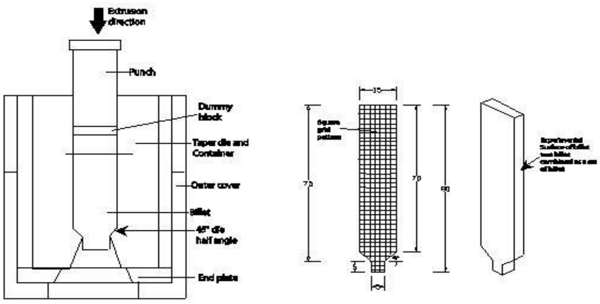


Figure 1: Schematic sketch of plain strain extrusion process

2.2 Lubricants

There are three kinds of lubricants were used in these experiments are RBD palm stearin (ps) as a case study, paraffinic mineral oil VG460, and paraffinic mineral oil VG95. Refer on the table 1 below there are shows that the density of the RBD palm stearin is very higher than paraffinic mineral oil, but then the kinemaric viscosity is very lower than paraffinic mineral oil. There two categories are density and viscosity, if based on order of the density RBD palm stearin is most higher, paraffinic mineral oil VG460 in the middle and paraffnic mineral oil VG95 is lower. If based on order of the viscosity, paraffinic mineral oil VG460 is higher, paraffinic mineral oil VG95 in the middle and RBD palm stearin is lower. In these experimental, the parameter changes are quantity, density and viscosity. The lubricants were applied on the interface between the taper die and billet follow the order of the quantities as 0.1mg, 1mg, 5mg and 20mg.

Properties/ Types	RBD Palm Stearin	Paraffinic Mineral Oil VG 460	Paraffinic Mineral Oil VG 95
Density @ 15°C , (kg/m^3)	1074.3	0.9035	0.8725
Kinematic viscosity, μ_k	16.66	455.1	90.12

Table 1: Properties of the lubricants

2.3 Experimental condition

The plane strain extrusion apparatus was assemble and located on the press machine. The extrusion load and the displacement were recorded by software used in the computer. The extrusion process was running and stops at extrusion length of 35 mm. The experiments were run in the room temperature, and the ramp speed for every single of the experiment can be measured by time and displacement of the experiment, where the time were carried out from computer software. The next experiments were repeated as first follow the order of the quantity and types of the lubricants.

2.4 Velocities distribution.

The visioplasticity method is used to find the complete velocities distribution in the deformation zone, according to the deformation of grid lines marked on the surface of the workpiece as Figure 7. Figure shows that the V_o is the velocity of the press ram speed in mm/s and $Z_i$is the distance in mm from the y-coordinate axis (X=0) of the i-th flow line in the region where deformation does not occur. The flow line in the deformation zone clearly influenced of velocity on each flow line. The flow lines were analyses with digitizes every single of the element of 1mm x 1mm after experiment is done.

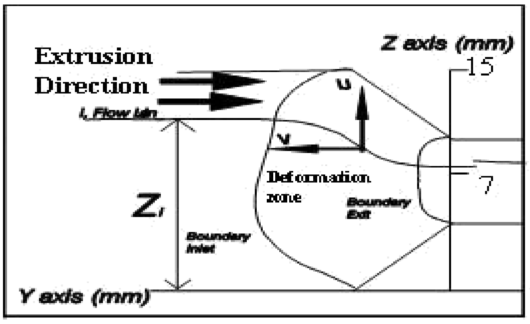


Figure 7: Visioplasticity analysis

From the experimental data (the values of the flow function for plane-strain extrusion), the velocity on the surface between taper die and plane of billet was calculated to know the velocities distribution for each times of experiments. For incompressible material, the velocity field of plane strain can be expressed by the stream function φ(y, z) as follows:

Stream function;

$$\varphi_i = Z_i|V_0|$$

Velocity Component; (z-direction: u, y-direction:v)

$$u = \frac{\partial \varphi}{\partial Y}, v = -\frac{\partial \varphi}{\partial Z}$$

To plot the results of the velocity the resultant velocity was calculated to get a single velocity as below:

$$V = v_r = \sqrt{u^2 + v^2}$$

2.5 Effective Strain distribution

The effective strain distribution also used the visioplasticity method as figure 7. The same as velocities distribution, this effective strain was calculated for each times of experiments based on the experimental data were obtained.

The strain rate component (s^{-1})

$$\dot{\varepsilon}_z = \frac{\partial u}{\partial Z}, \dot{\varepsilon}_y = \frac{\partial v}{\partial Y}, \dot{\gamma}_{zy} = \frac{\partial u}{\partial Y} + \frac{\partial v}{\partial Z}$$

The effective strain rate (s^{-1})

$$\dot{\varepsilon}_z = \frac{2}{3}\sqrt{3\dot{\varepsilon}_z^{2} + \frac{3}{4}\dot{\gamma}_{zy}^{2}}$$

The effective strain (time integration value of the effective strain rate along the flow line)

$$\varepsilon = \int \dot{\varepsilon}\, dt$$

3.0 RESULT AND DISCUSSION

3.1 Extrusion Load

The extrusion load vs extrusion length curves shown in figure 2. There are represent of quantities of the lubricants, (a) 0.1mg, (b) 1mg, (c) 5mg, (d) 20mg. In condition 0.1mg, the extrusion load of RBD palm stearin (ps) is higher than paraffinic mineral oil pr(460) and pr(95), then both mineral oil shows that the orientation of extrusion load issimilarly. For the second condition is 1mg, the orientation of ps was changes compared to the first one, the extrusion load for ps shown in the middle of pr(460) and pr(95), it can be stated the load of the ps decrease as the quantity become higher. The third condition is 5mg, the load of ps is lower than paraffinic mineral oil pr(460) and pr(95). And the last condition with 20mg is again repeated the result of 5mg, but it so is clearly can seen the load of ps is lower than both mineral oil. Based on this explanation there are several things related influence of extrusion load, there are viscosity, density and quantity. This figure is clearly shows that the density, viscosity and quantity respectively very needed to produce a better lubricant to obtaina minimum load and minimum quantity in the extrusion process. There are shows that in the less quantity, the load of ps is higher than paraffinic mineral oil, but as the quantity increased the load of ps would be decreased and the paraffinic would be increase. Between 5mg and 20mg the load changes just for paraffinic mineral oil, but the ps still in the same condition and not many changes.

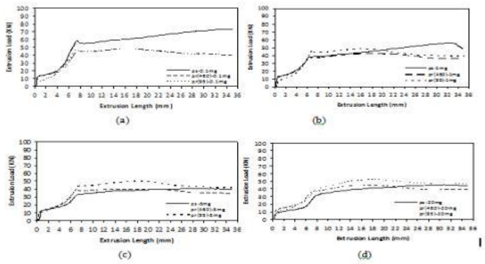
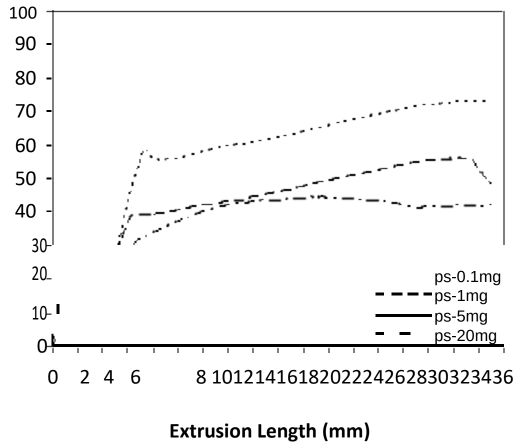
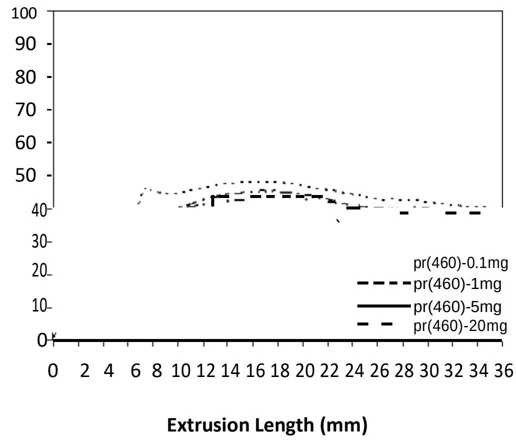


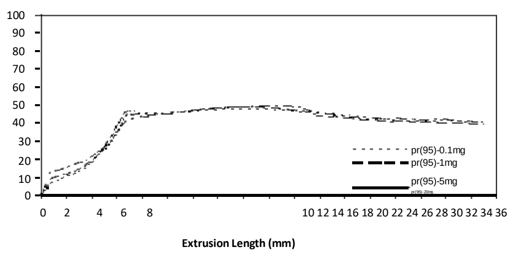
Figure 2: Extrusion load vs extrusion length, (a)-0.1mg,(b)-1mg, (c)-5mg, and (d)20mg



(a)



(b)



(c)

Figure 3: Extrusion load vs extrusion length, (a)-RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)- Paraffinic Mineral Oil (VG95)

Figure 3 shows the curves of extrusion load vs extrusion length in (a), (b), and (c). There are represent of (a) RBD palm stearin, (b) Parffinic mineral oil (VG460), and (c) Paraffinic mineral oil (VG95). The figure shows that in the quantity 5mg and 20mg the load of ps are similar but lower than 0.1mg and 1mg, then for pr(460) the load in condition of 5mg is lower , and the last one for pr(95) not conclusion be there because the orientation of the load shows the similarity. For ps is clearly if the quantity of lubricant increased, the load of ps cannot be changes anymore, but the interesting is for pr(460) where the load of 1mg is lower than 0.1mg, and then the load of 5mg are lower than 1mg and 0.1mg, but when the quantity increase to 20mg, the load become increase again. There are interesting to study why it can happen. It look may have some of quantity as transition point to load increase again.

Based on figures, the ps in condition 5 mg achieve a minimum quantity lubricant (MQL) to obtain a minimum load, then the higher density will give a lower load, and for pr(460) achieve a minimum quantity lubricant (MQL) also in condition 5 mg and need further research why when the quantity increase, the load what as expected to be decrease not be happen otherwise increase again. In this experiment as a proved the previous experiment [1] is correct because the result in condition 5mg, the ps is lower than pr460.

3.2 Surface Roughness

Figure 5 shows the surface roughness distribution measured perpendicular to the direction of extrusion on the sliding plane of billet after the experimental have done as reference infigure 4. The figure shows that there are levels of the quantity of the lubricant, (a)-0.1mg, (b)-1mg, (c)-5mg, (d)-20mg. The result was shows that in the fourth level all of the surface roughness, ps always lower than paraffinic mineral oil. There are shows that the higher of density and viscosity of the lubricants will contribute a lower of surface roughness. The ranges of the surface roughness for three kind of this lubricant, can be conclude that at 0.1mg the ranges is 0.5-0.8, at 1 mg and 5mg the ranges is about 0.4-0.6, then another one at 20mg the ranges is 0.3-0.8. Therefore the smaller quantity and the bigger quantity will give larger ranges, but at 1 mg and 5 mg the ranges of surface roughness will become small.

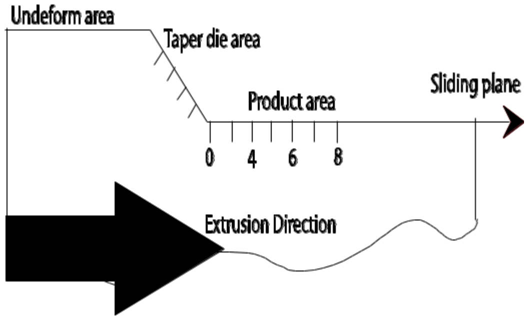


Figure 4: Sketch of the position of the measurement of surface roughness

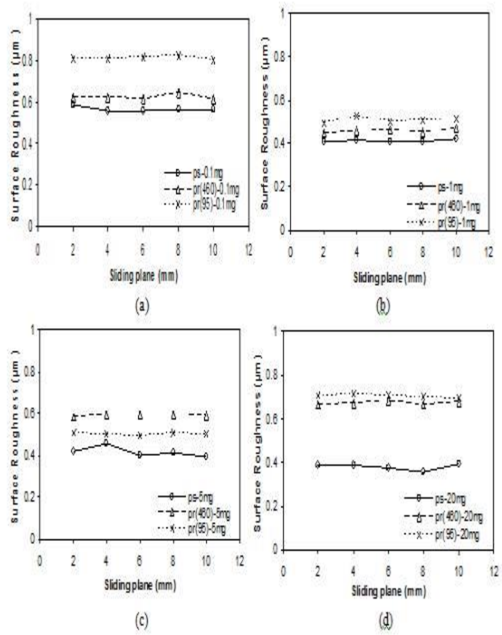
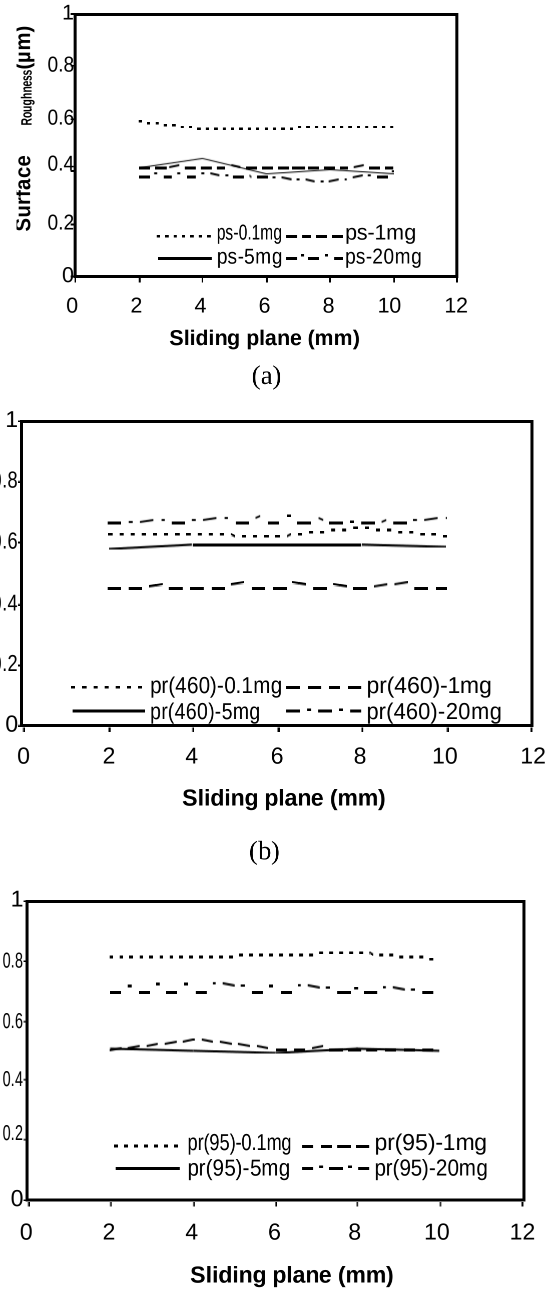


Figure 5: Surface roughness distribution along on the sliding plane of the billet, (a)-0.1mg,(b)-1mg, (c)-5mg, and (d)20mg

The distribution of the surface roughness based on kinds of the lubricant shown in figure 6. In figure 6(a) for RBD palm stearin, there shows that at condition 0.1mg give a higher of surface roughness, at 1mg and 5mg is similarly, and another one at 20 mg the surface roughness is lower, so that there are shown the lesser quantity will become higher roughness. For paraffinic mineral oil VG460 in figure 6(b) at the condition 20mg give a higher surface roughness and 1mg is lower, so that can be conclude here a greater quantity of the lubricant would be increase the surface roughness. And the last one for paraffinic mineral oil VG95 in figure 6(c) the result shows that the higher of surface roughness at condition 0.1mg, and there are lowers at 5mg and 1mg, so that no conclusion can be conclude for pr(95). The overall observation the quantity lubricant at 5 mg shows that the surface roughness for ps, pr(460) and pr(95) looking more stable based on the orientation of the surface roughness if compared to others three condition. Therefore it support the statement was stated in the figure 11 where at 5mg, the surface roughness based on the ranges is smaller, and the orientation also is lower.

Therefore from study just the only of the surface roughness result was show that the minimum quantity lubricant (MQL) for three kind of lubricant to obtain a lower of surface roughness is 5 mg. And the results also shows the ps would be a lower surface roughness compared to paraffinic mineral oil and it is agree with the previous experimental [1] where the surface roughness of ps is lower than paraffinic mineral oil. Therefore is prove it in this experimental after considering by density, viscosity, condition and the ranges of the surface roughness based on each quantity condition.

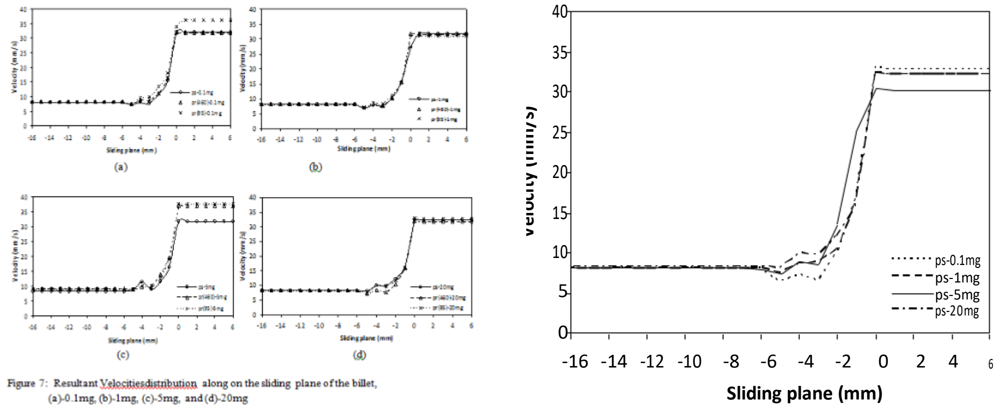


(c)

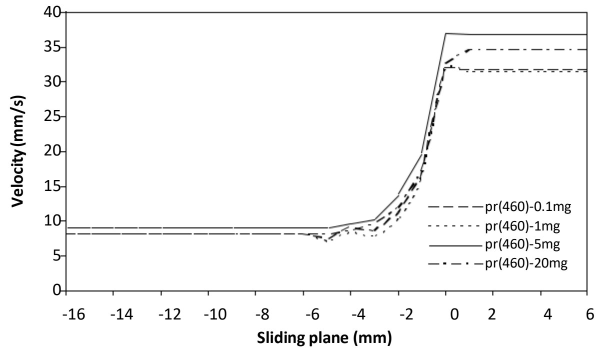
Figure 6: Surface roughness orientation along on the sliding plane of the billet, (a)-RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)- Paraffinic Mineral Oil (VG95)

3.3 Velocities Distribution

Figure 7 shows the distribution of the resultant velocities of billet on along the sliding plane in four level of quantity of lubricant, there are (a) 0.1mg, (b) 1mg, (c) 5mg, (d) 20mg. the results were obtain and analyses show that the velocities are no changes along undeformed area and a bit changes at taper die area, and the changes of the velocities could be seen start after deformation happen on the billet. In condition 0.1mg the result shows that pr(95) is higher than ps and pr(460), so that can be conclude that the higher density and viscosity of the lubricant can be reduce the velocity. For 1mg there aren't result can be conclude because there have similar orientation of the velocities distribution. Then the velocities for 5mg, ps is lower velocity and pr(95) is most higher, so that in this condition the conclusion still support for 0.1mg, but the orientation most clearly could be seen. And the last condition is 20mg, there are also haven't result could be discuss because like similar orientation of the velocities distribution.Therefore for this figure, at 5mg the ps shown a lower velocities compared to the paraffinic mineral oil, it can be related on the surface roughness result where the ps also is lower than paraffinic mineral oil, with that could be say the lower velocity can produces a lower roughness. It's also proved with other three condition the ps velocity is quite similar than three condition, its means that the statement above is relevant.



(a)



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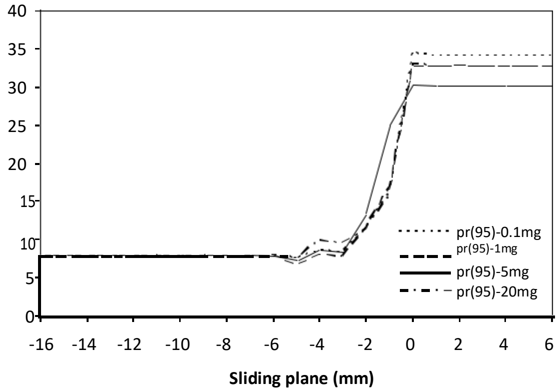


(c)

Figure 8: Resultant Velocities orientation along on the sliding plane of the billet, (a)-RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)- Paraffinic Mineral Oil (VG95)

Figure 8shows that the orientation of the velocities of the lubricant on the the sliding plane of the billet dividing in (a)-RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)- Paraffinic Mineral Oil (VG95). There are shows the velocities is lower at

5mg for ps, but it is contra with the pr(460) at 5mg is higher compared to other quantity condition of the lubricant. And another lubricant pr(95) there couldn't make it the conclusion because the result is not show something relevant, but the result can be used to support figure 14(c) where the surface roughness at 5 mg is lower same as velocity at 5mg also lower compared to other condition.

Therefore based on the figures of velocities distribution 5mg for ps support the result of the surface roughness because velocity of ps is lower than pr(460) and pr(95). Then also support the result based on the condition for pr(95) at 5 mg. so that can be conclude that on this figures the velocities proportional with the surface roughness, its means that when the velocity is lower there will be impact lower of surface roughness.

3.4 Effective Strain Distribution

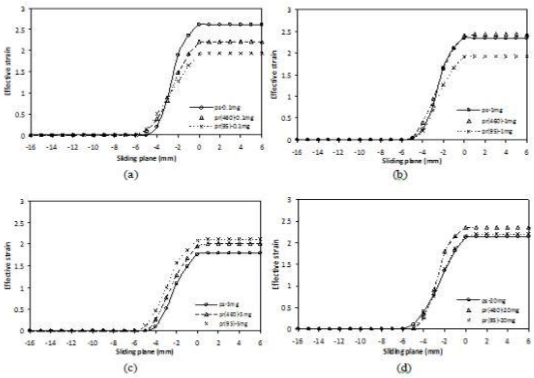
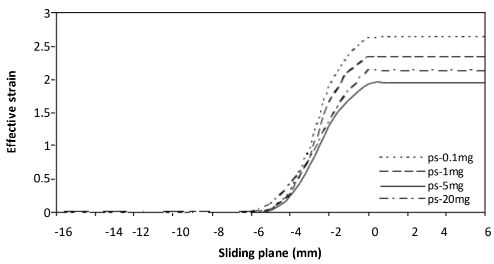


Figure 9: Effective strain distribution along on the sliding plane of the billet, (a)-0.1mg, (b)-1mg, (c)-5mg, and (d)-20mg

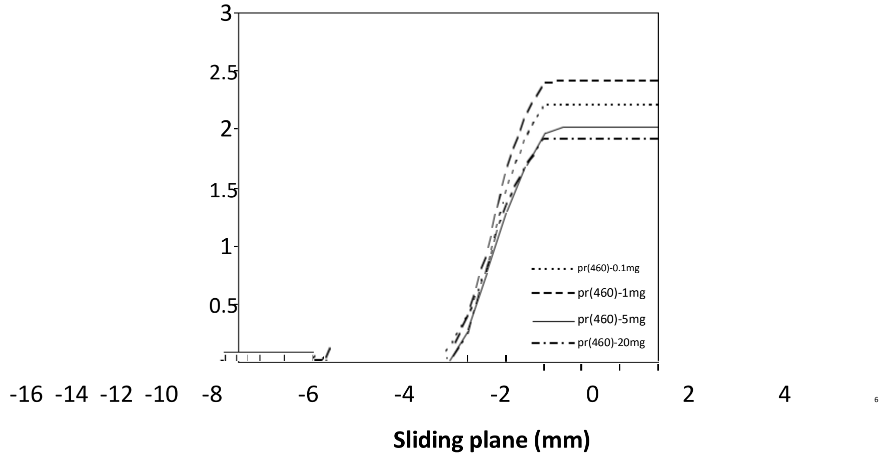
The figure 9 shows theEffective strain distribution along on the sliding plane of the billet for (a)-0.1mg, (b)-1mg, (c)-5mg, and (d)-20mg. For 0.1mg the results show that ps is most higher, then pr(460) is lower than ps but higher than pr(95), so that if the density and viscosity increased the effective strain become smaller. When the quantity of the lubricant increased to 1 mg, there are shows that the effective strain for ps starting down in the middle of the pr(460) and pr(95). Then at the condition of 5 mg, the distribution of effective strain of ps is lower than pr(460) and pr(95), in this condition look that the effective strain for pr(460) become lower than pr(95). Therefore the orientation of the effective strain of ps is quite similar with the orientation of the extrusion load of ps. There are shows that in the less quantity, the effective strain of ps is higher than paraffinic mineral oil, but when the quantity increase the effective strain of ps will be decrease and the paraffinic will be increase. Between 5 mg and 20 mg the position of ps still lower than paraffinic but the position of pr(460) and pr(95) was changes. Then the effective strain also can be concluding that it depends on the extrusion load, where the viscosity and quantity is the most important things to get a lower effective strain..

Figure 10shows the orientation of effective strain for (a)RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)-Paraffinic Mineral Oil (VG95). As discussed above the orientation of effective strain of ps is similar the orientation of the load of ps. For pr(460) the effective strain at 20mg is lower than 5 mg, therefore for this pr(460) means that to get a lower effective strain the more quantity is needed. Then another paraffinic mineral oil pr(95) the results shows that at 5 mg the effective strain is higher than others lubricant.

Therefore for this study of effective strain for three kind of lubricant with different quantity of the lubricant, it can be conclude that for RBD palm stearin the position or the orientation of the effective strain follow the extrusion load. For paraffinic mineral oil, some of the condition follow the extrusion load, but there also have some different. However for ps and pr(460) the minimum quantity of the lubricant (MQL) based on the effective strain to get a lower effective strain is 5mg, and for another one is difficult to get the conclusion.



(a)



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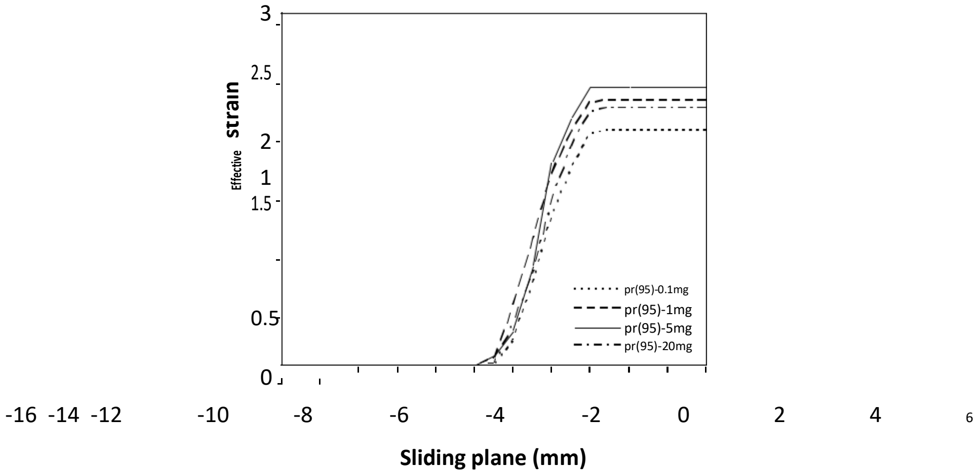

(c)

Figure 10: Effective strain orientation along on the sliding plane of the billet, (a)-RBD Palm Stearin, (b)-Paraffinic Mineral Oil (VG460), and (c)- Paraffinic Mineral Oil (VG95)

3.5 Discussion

The results of the extrusion load, surface roughness, velocities distribution, effective strain distribution for three kinds of lubricants with different density and viscosity could be proved it with the previous experimental and theory.

Based on this experimental we found that the RBD palm stearin(ps) are lower of extrusion load, surface roughness, velocity and come out with a lower of effective strain compared to paraffinic mineral oil. These results could say that it is relevant because the extrusion load and surface roughness already proved it with the experimental of the performance of RBD palm stearin as lubricant [1] shows that the extrusion load and surface roughness of ps is lower than pr(460) as figure 1. The velocity is lower could be related it as figure 3 where the sliding velocities were measured between two contact, the results was shows that the lower velocities could make a lower friction coefficient [3]. Therefore the relationship of friction with the surface roughness could be stated by friction theory, where surface roughness is one of the parameter can influence the sliding friction.The lower of surface roughness could be reduced the friction coefficient, therefore the lower velocities are lower of friction coefficient and surface roughness. The effective strain also lower, it is could be looking on the relationship between effective strain and velocity, section 2.5 clearly can seen the effective strain is integral of strain rate and the strain rate is differentiation of the velocities. Therefore the generated formula shows that the effective strain it is depends on the velocity, if the velocity increased means that effective strain also would be increased too. Another reason can include in this experimental why ps is lower than paraffinic at 5 mg, it is depends on the higher density of the ps compared to mineral oil.

The results for paraffinic mineral oils at 5mg, between pr(460) and pr(95) were obtained the pr(460) are lower of extrusion load, it can proved that based on the previous experimental the higher viscosity was reduced the extrusion load as figure 2 [2]. And most of the condition, surface roughness of the pr(460) is lower than pr(95) except at 5mg, there are prove it with the previous experimental the higher viscosity were reduced the surface roughness too. However velocity and effective strain is lower at 5mg for pr460. Therefore at 5mg for pr(460) still relevant could be as minimum quantity lubricant (MQL)

There are need more study between 5mg and 20mg of extrusion load of ps and pr460, where the relationship for conditions 0.1mg,1mg, and 5mg, the results shows more lubricant could reduced the extrusion load, but when it move to 20mg, the lubricant look as increased again, its may have some transition point between 5mg and 20mg. The expectation have a transtition points is relevant, because if refer the stribeck curve as figure 5 at mixed friction there are shows that when the film thickness become more higher the friction would be increase again. If friction increase means that the surface roughness also increased cause of the load also increase.

4.0 CONCLUSION

The minimum quantity of the lubricant (MQL) for three kind of the lubricants in plane strain extrusion process were clarified by cold forward extrusion equipment. The experimental were analysis through extrusion load, surface roughness distribution, velocity distribution and effective strain distribution. The experimental results and analytical results could be summarized as below:

1. In the extrusion load the minimum quantity lubricant (MQL) is 5mg for RBD palm stearin and paraffinic mineral oil VG460, this point could be expected as the transition quantity because the expectation if the quantity increased the load could be increased again. It is clearly from 0.1mg, 1mg, 5mg, the result show more lubricant couldreduced the extrusion load, but at 20mg the load no changes for ps and for pr(460) the load is higher than condition at 5mg. And comparison between RBD palm stearin with paraffinic mineral oil there shows that RBD palm stearin is lower than paraffinic mineral oil, its means that the higher density of the lubricantcould reduced the load. For paraffinic mineral oils it’s depend on the viscosity, the results also show the higher viscosity could reduced the load, and it is proved with previous experiment [2].
2. The surface roughness analysis also choose the minimum quantity lubricant (MQL) is 5mg for three kinds of lubricants were testing, the result based on the ranges of surface roughness at 5mg and 1mg there are a smaller ranges, then the greater density toocould reduced the surface roughness so that the surface roughness of RBD palm stearin is lower than paraffinic mineral oil, it is proved that the previous experimental [1] and the condition of 5mg is not many changes compared to others three condition of the quantity of the lubricant.
3. The velocities analysis shows that at 5mg is the minimum quantity lubricant for RBD palm stearin and Paraffinic mineral oil VG95 its because there are lower compared to others condition. The results proved that the velocities are proportional with the surface roughness, because the lower surface roughness has come out lower velocities. This relationship already proved with the previous experimental of the sliding velocities between two contacts [3], and it also could be clearly explain through stribeck curve [4].
4. Study of the effective strain shows that at 5mg is the minimum quantity lubricant for RBD palm stearin and paraffinic mineral oil VG460, the results looking depends on the velocity, because the analytical formula shows that the effective strain is proportional to velocity, its means that if the velocity higher, the effective strain supposedly higher. Therefore the theoretical is relevant because most of the results were obtain could be clarified.

Based on the all of the conclusion by each analysis, there are shows that for RBD palm stearin and Paraffinic mineral oil (VG460) the minimum quantity lubricant (MQL) is 5mg. For Paraffinic mineral oil (VG95) the minimum quantity lubricant cannot be predict because the result not stable and didn’t give a accurate results.

NOMENCLATURE

ps	RBD palm stearin
pr(460)	Paraffinic mineral oil VG460
pr(95)	Paraffinic mineral oil VG95
F	Pushing force
F_r	Friction force
MQL	Minimum quantity lubricant

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