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Effects of Sliding Speed, Surface Extension, Viscosity of Lubricant and Tool Pressure on Material Pick-Up to Tool Surface

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Continuous indentation tests of a flat tool on to a spiral trapezoidal thread shaped around a rotating workpiece are carried out to estimate material pick-up to tool surface by using aluminium as a workpiece material with several lubricants for wire drawing. The effects of sliding speed, extension of surface area, viscosity of lubricant and tool pressure on material pick-up are investigated. An empirical equation representing a critical condition under which material pick-up occurs is presented and the viscosity of the lubricant has the greatest effect on the material pick-up.

1. Introduction

In metal forming, material pick-up to tool surface leads to the increase in frictional stress, tool wear and surface damage of products. Thus, a proper countermeasure should be taken to prevent the material pick-up. There have been developed a number of test methods in the past [1]–[4]. However, it is not possible to estimate quantitatively the effect of various factors — such as tool pressure, extension of surface area, etc. — on material pick-up for general application to metal forming ; or these tests are not suitable for applying to a wide variation of the factors. Recently, an attempt is made to estimate quantitatively the effect of a few factors on the material pick-up in the extrusion [5].

The present authors have already proposed a test method [6] in which a flat tool is indented to a rotating workpiece on a lathe and have presented the results of evaluation of solid lubricants. In the present paper, a test method for estimating the material pick-up is proposed and the effects of factors — such as surface extension, sliding speed, viscosity of lubricant and tool pressure — on material pick-up are investigated by varying the factors widely and independently. Further, an empirical equation representing a critical condition under which material pick-up occurs is presented in terms of factors above.

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2. Experimental Procedure

Fig. 1 shows the principle of the test method and the cross-sectional shape of the workpiece ; a workpiece in the form of a circular rod with a spiral trapezoidal thread (thread angle = 2α) is rotated on a lathe and the thread is continuously indented by a flat surface tool to a depth d. The normal force F_N and the tangential force F_T at the tool-workpiece interface are measured using a tool dynamometer. The mean tool pressure p and the mean frictional stress τ on the tool surface can be calculated from F_N, F_T and the nominal contact area A.

$$p \cong F_N / A \ , \quad \tau \cong F_T / A \qquad (1)$$

where

$$A \cong (2W + W_0)\sqrt{2Rd}\,/\,3 .$$

Thus, using eqn. (1), the mean coefficient of friction μ is simply expressed as

$$\mu = \tau / p = F_T / F_N \qquad (2)$$

The test was carried out at room temperature with the workpiece of commercially pure aluminium (JIS A1100BD, 38 – 45 mm diameter, Hv = 45 – 50). The spiral trapezoidal thread was finished on the lathe. The initial width of the thread W_0 was about 0.5 mm and the surface roughness Ra at the top of the thread which was measured along the axis was 0.5 – 0.6 μm. The material of the tool was tool steel for cold forging (JIS SKD11, Hv = 785 – 807). The tool surface was finished to a roughness of Ra = 0.02 μm.

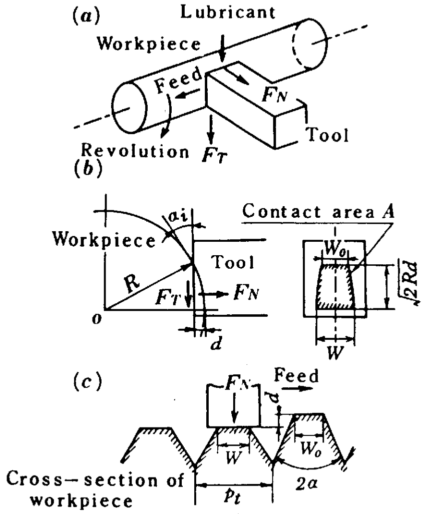


Fig. 1 Principle of test method and shape of workpiece.

Table 1 Lubricants used in the test.

Lubricant	viscosity ν [mm^2/s]	
	20°C	100°C
Spindle oil #60	20.0	2.6
HVI-60	67.0	4.8
Turbine oil #180	185	8.8
F-240	205	9.4
F-280	235	15.6
F-224	480	17.5
HVI-650	1850	30.9

Lubricants used in the test are listed in Table 1. The sliding speed V between the tool surface and the workpiece surface was 1.4 mm/s – 1.4 m/s and the sliding distance in each test was about 1.5 m.

Fig. 2 (a) illustrates the cross-section of the trapezoidal threads before and after test. To find how the surface area of workpiece material which contacts the tool surface increases during the test, two lines of distance W_0' were marked at the top of the thread and then the distance W_0'' were measured after the test. (The apparent width W after the test includes not only the pure expansion of the surface area but also the folding of the side of the thread). Using the measured values of W_0' and W_0'', the expansion of surface area ξ can be determined.

$$\xi = \{(W_0''/W_0') - 1\} \times 100 \qquad (3)$$

The variation of ξ with the indentation depth d for thread angles of $2\alpha = 60°$, $90°$, $120°$, $150°$ and $165°$ is given in Fig.2(b). It is seen that there is a linear relationship between ξ and d for each angle.

Fig.3(a) shows an example of the photogragh of the tool surface after test. It is observed that the workpiece material sticks partially to the tool surface. Fig.3(b) shows the variation of the surface profiles of the tool measured in the direction perpendicular to the sliding direction. From these profiles, the maximum height of adhesion Hmax was estimated.

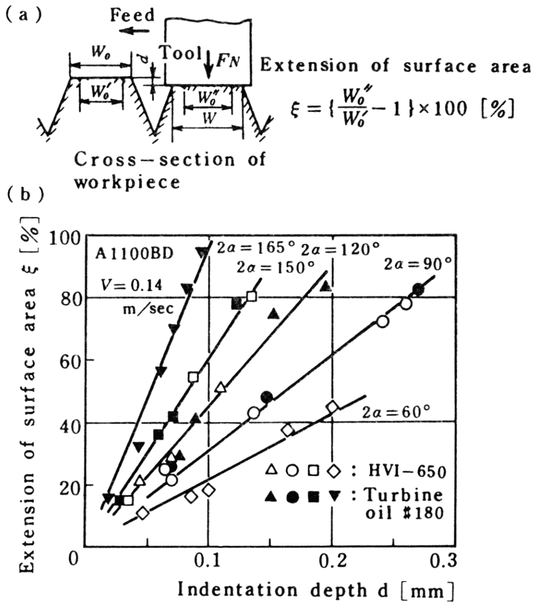
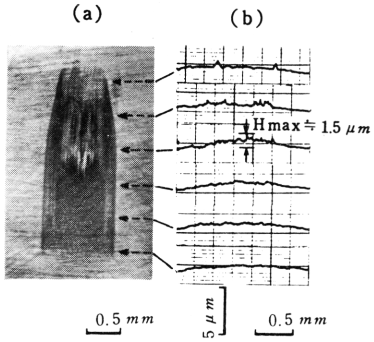


Fig. 2 Relationship between extension of surface area ξ and indentation depth d.

3. Experimental Results and Discussion

Fig.4 shows the relationship between the maximum height of adhesion Hmax and viscosity ν of lubricants. It is clearly seen that the values of Hmax changes sharply at the viscosity ν of about 185 to 235. Therefore, in the following, the degree of material pick-up was judged on the basis of the value of Hmax shown in Fig.4. The terms of "pick-up", "semi-pick-up" and "no-pick-up" correspond to Hmax > 1.5 μm, 0.5 < Hmax < 1.5 μm and Hmax < 0.5 μm, respectively. For Hmax > 1.5 μm, the scratched damage was observed discontinuously on the workpiece surface, but for Hmax < 0.5 μm, it completely disappeared.

Fig.5 shows the relationships between extension of surface area ξ and sliding speed V for both the condition of "pick-up"



Lubricant : F-240
Surface extension : ξ=51%
Sliding speed : V=0.14 m/s

Fig. 3 An example of surface profile after test : (a) appearance of tool surface (b) profiles of tool surface.

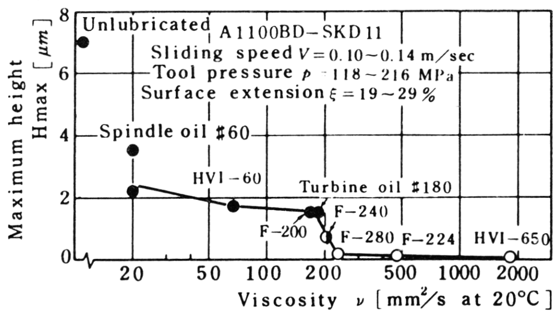


Fig. 4 Relationship between maximum height of adhesion and viscosity of lubricant.

(includes "semi-pick-up") and "no-pick-up". It is seen that for various lubricants the values of ξ at which material pick-up occurs increase linearly with increasing sliding speed V. The critical values of ξ can be given by the following expression.

$$\xi = K_5 \cdot V^{0.6} \qquad (4)$$

where, K_5 depends on the kinds of lubricants and the tool pressure.

Fig.6 shows the relationships between the critical speed V and the viscosity ν for various temperature. It is seen that there are approximately linear relationships between ν and V with a few exceptions ; the results for HVI-650 at 20°C and 37.8 °C. The ν-V relation at 20°C, for instance, is expressed by the following empirical equation.

$$\nu = K_6 \cdot V^{-0.43} \qquad (5)$$

where, K_6 depends on the extension of surface area ξ and the tool pressure p (in this case $K_6 = 85.5$).

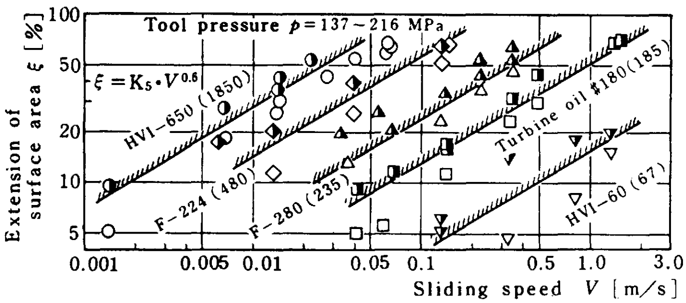


Fig. 5 Relationship between extension of surface area and sliding speed. (Numbers in parentheses represent viscosity of lubricant [mm^2/s at 20°C])

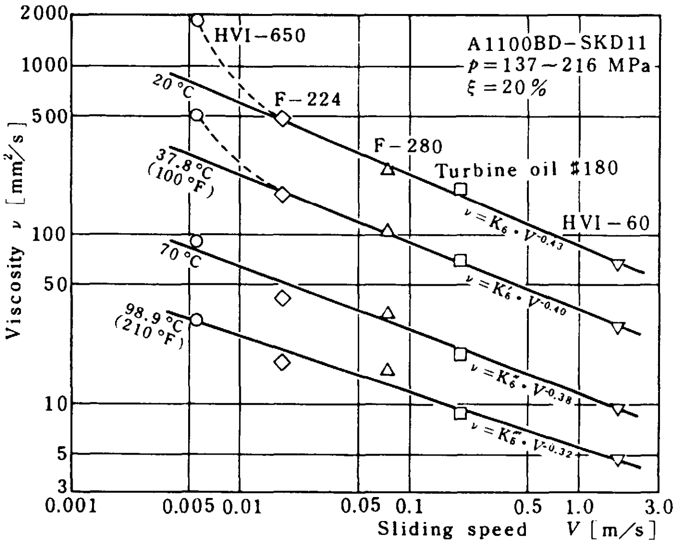


Fig. 6 Relationship between viscosity of lubricant and critical sliding speed at which sticking occurs.

Fig.7 shows the relationships between the mean tool pressure p and the extension of surface area ξ. The critical value of ξ at which material pick-up occurs is also given by a straight line in log-log scale.

$$\xi = K_7 \cdot p^{-1.0} \qquad (6)$$

where, K_7 is a constant which depends on the viscosity ν and the sliding speed V (in this case $K_7 = 4300$). Under the test condition of p = 190 MPa and V = 0.14 m/s, the critical value of ξ is about 22.5%. For $\xi = 22.5$% and V = 0.14 m/s, the viscosity ν of lubricant read from Fig.5 is about 200-210 mm^2/s. This value of viscosity corresponds to that of F-240.

From Figs.5-7, an interrelation between factors which affect material pick-up can be expressed as

$$\xi \cdot V^{-0.6} \cdot \nu^{-1.38} \cdot p = K \quad (7)$$

where, ξ is extension of surface area [%], V sliding speed [m/s] between tool and workpiece, ν viscosity of lubricant [mm^2/s at 20°C], p mean tool pressure [MPa] and K is constant (in this case K = 8.85).

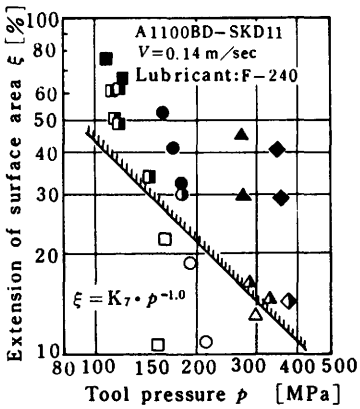


Fig. 7 Effect of tool pressure on critical surface extension.

4. Conclusions

A test method for estimating material pick-up to tool surface was presented and an empirical equation (7) representing a critical condition under which material pick-up occurs was obtained. From equation (7), it is seen that the viscosity of lubricant ν has the greatest effect on the material pick-up of workpiece material to tool surface.

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