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Effect of ductile cast iron tool with grooved polishing and die coatings on friction behaviour in flat strip drawing of A7075-T6 alloy strip with quick heating

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Abstract. A7075 aluminium alloy, a heat-treatable aluminium alloy, is expected to be applied to automobile frame parts from the viewpoint of high strength and light weight. To form this aluminium alloy, hot stamping using quick contact heating with a hot plate has been developed. To prevent seizure caused by hot stamping, the frictional properties of different tool coatings under warm and dry conditions were investigated by drawing tests of aluminium alloy strips using quick contact heating. Diamond like carbon (DLC) showed a low coefficient of friction and prevented seizure. The warm forming process allows the use of liquid lubricants. The frictional properties of cast iron and a simple surface texturing technique, grooved polishing, were investigated under warm and liquid lubrication conditions. The cast iron with grooved polishing showed the reduction in friction equivalent to DLC and prevented seizure as well.

Introduction

The weight of vehicles has been increasing due to improved collision safety and environmental performance. Therefore, it is important to improve fuel efficiency. Reducing the weight of the automobile body is effective for low fuel efficiency. Conventionally, increasing the strength of steel strips and reducing their thickness have been considered. Among them, high-strength steel strips are widely used. However, reducing the strip thickness reduces rigidity and reduces collision safety and driving performance. Therefore, it is important to replace the material with one that has a lower specific gravity without reducing the strip thickness. Especially, A7075 aluminium alloy, a heat-treatable alloy, has particularly high strength and is expected to be used for automobile frame parts.

Forming of heat-treated aluminium alloys under heated conditions has been investigated, and hot stamping (HFQ® (Hot Form Quench)) with die quenching has been developed [1]. For HFQ, the blank is heated to above the solution treatment temperature in the furnace and is stamped and simultaneously held at the bottom dead centre for quenching of solution heat treatment. Heating not only improves the formability but also eliminates the solution heat treatment process after forming. However, artificial ageing after stamping is required for precipitation hardening and is reduces a productivity.

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To omit not only solution heat treatment but also artificial ageing after forming, warm hot stamping using quick heating was developed [2]. Although high temperature or long heating reduces the strength of age-hardened aluminium alloy by over ageing and re-solid solution, the precipitation hardening is maintained by quick heating such as contact or Joule heating.

Since even cold stamping of aluminium alloys easily causes adhesion, friction is more essential in hot stamping of aluminium alloy. For high-temperature hot stamping of aluminium alloys such as HFQ, the properties of solid lubricants and tool coatings have been investigated [3]. For warm hot-stamping, liquid lubricants can be used because the heating temperature is around 200°C. In addition, a combination of surface textures of tools and lubricants can also be considered. Spherical graphite cast iron has been confirmed to exhibit friction-reducing effects using liquid lubricants [4]. In addition, surface dimples have been confirmed to function as micro reservoirs for lubricant retention using liquid lubricants [5].

In this study, we investigated the frictional properties of A7075-T6 aluminium alloy in a drawing test using quick contact heating at warm temperatures. Under warm (200 to 300°C) dry conditions, the effects of heating temperature and heating time on friction properties were researched. Under the same conditions, the friction properties of tool surface coatings were also researched. 200°C liquid lubricant was used to investigate the friction properties of spheroidal graphite cast iron and a grooved polishing proposed as a simple surface texturing method.

Warm and hot flat strip drawing test using contact heating and tool polishing

Fig. 1 shows the sequence of the aluminium alloy flat strip drawing test with quick contact heating. The system is composed of hot plates, a fixed tool, and a movable tool by a pneumatic cylinder and is installed in a universal testing machine. The shoes imitate a stamping tool. The A7075-T6 aluminium alloy strips having 2 mm in thickness are cut into 20×300 mm and clamped with the chuck. The aluminium strip is sandwiched with the hot plates and is heated to target temperature for almost 30 s. The strip is ascended by immediately moving the crosshead when reaching target temperature. When the heated area of the strip reaches the shoe position, the strip is caught between shoe tools by a pneumatic cylinder and is drawn.

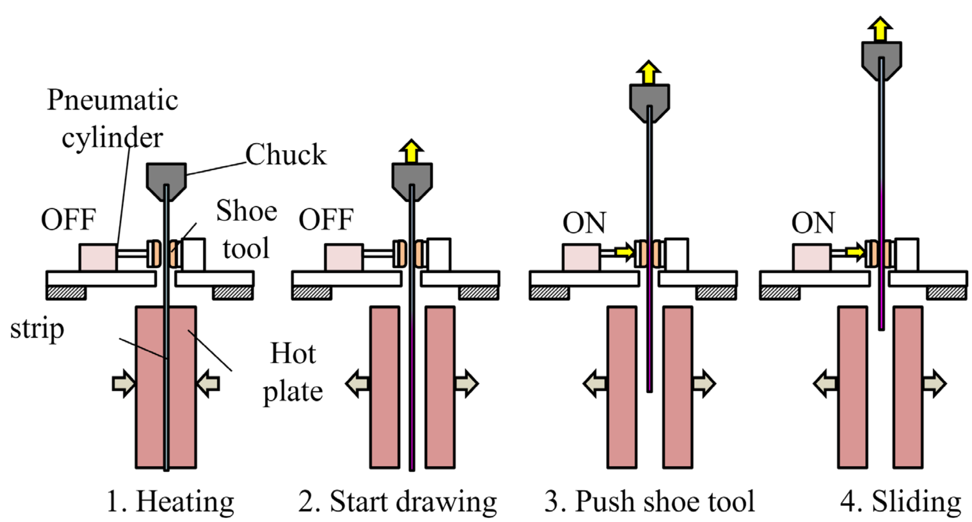

Fig. 1. Sequence of warm and hot flat strip drawing test using quick contact heating.

The drawn force is measured as frictional force. The coefficient of friction μ was determined by Eq. 1.

$$\mu = F/2N \quad (1)$$

F is a drawing load of a strip and N is a vertical load of the shoe by the pneumatic cylinder. The vertical load of the shoe was measured in advance by a load cell, and the universal testing machine measured the drawing load. Since the frictional force is generated on both sides of the strip, the drawing force of strip F is double the frictional force on each side.

The detailed layout of aluminium alloy strip in the warm and hot flat strip drawing testing machine is shown in Fig. 2(a). The temperature of the hot plates were set at 50 °C higher than the target temperature. The temperature of the strip was measured by a K-type thermocouple inserted into a hole on the thickness side of the strip. Since the temperature within the centre 110 mm of the hot plates is uniform, the bottom 110mm of the strip is uniformly heated to the target temperature. This part is caught between shoes, and the friction is evaluated. The shoe dimensions is illustrated in Fig. 2(b). The flat area slidden with the strip is 36×20 mm and the length in drawn direction is 20 mm. The appearance of shoe is shown in Fig. 2(c).

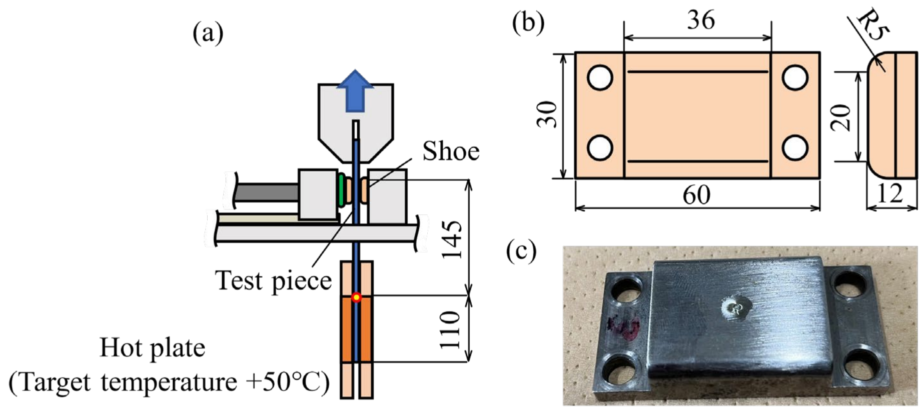

Fig. 2. (a) Detailed layout of aluminium alloy strip in warm and hot flat strip drawing testing machine, (b) shoe dimensions and (c) used shoe.

Table 1 shows the test conditions for the hot flat strip drawing test. The shoe materials used were SKD61 (hot work tool steel in JIS) and FCD600 (spheroidal graphite cast iron in JIS). For SKD61, tests were conducted with and without surface coatings. The coatings were AlSiCrN, vanadium carbide (VC), and DLC. The AlSiCrN and DLC were formed by the PVD process, VC was formed by thermo-reactive deposition and diffusion process. The coatings were processed after miller polishing and heat treatment for SKD material shoe.

The "conventional polishing" is composed of rough polishing (#600), intermediate polishing (#1000), and finish polishing (#3000). In contrast, the intermediate polishing is omitted for "grooved polishing". To keep the lubricant, grooves are formed with rough polishing and remained by omission of intermediate polishing. Finish polishing smooths the sharp surface edge. The grooved polishing was performed only for FCD600 shoe. Shoe was polished 90° angle to drawing direction. Experiments were investigated mainly at heating temperatures of 200°C. To compare the heating effects of furnace heating and quick heating, 30 s and 600 s were used. The average contact pressure between the shoe and the strip is 0.75 MPa. The liquid lubricant was an insoluble oil with a kinematic viscosity of 40 mm^2/s and was applied with a micro-pipette, the film thickness to be 1.5 μm. The drawing distance after the catching with the shoe tools was 80 to 96 mm, and drawing speed is 8.3 mm/s.

Table 1. Experimental conditions for hot flat strip drawing test.

Parameter	Value
Die Materials	SKD61(tool steel) FCD600(ductile cast iron)
Die Coatings (for SKD61)	None, AlSiCrN, VC, DLC
Polishing method	・conventional polishing ・ grooved polishing
Polishing direction [°] (0° is parallel to the drawing direction)	90（0, 45）
Heating temprature T [°C]	200, 300
Heating time [s]	20 - 30, 600
Average contact surface pressure [Mpa]	0.75
Drawing distance s[mm]	88±8
Lubricant film thickness [μm]	1.5
Drawing speed [mm/s]	8.33

Fig. 3(a) and (b) show the tool surface profiles of only the rough polished and the grooved polished ones, respectively. In the case of grooved polishing, the plateau area is flatter, and the corners of that are rounded compared to that of only rough polishing. This surface shape is less scratching against to aluminium alloy sheet during friction.

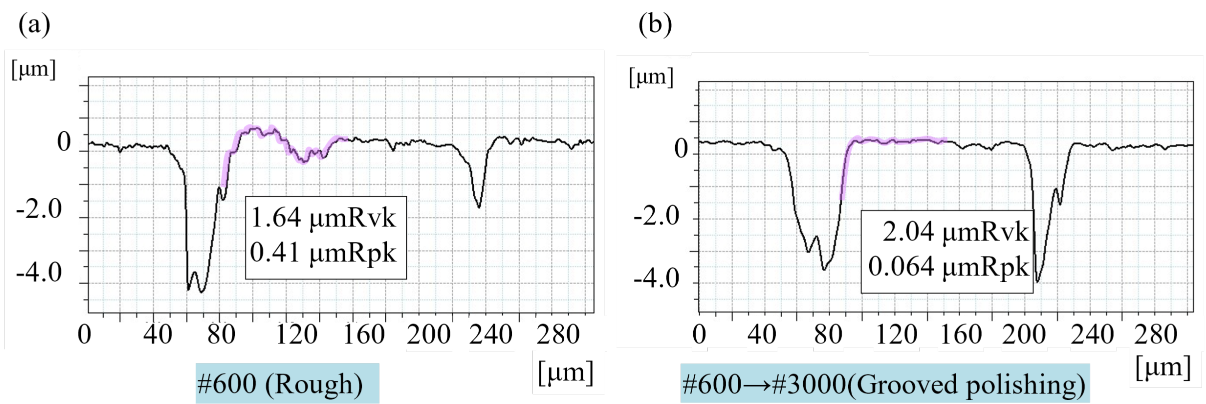

Fig. 3. Surface profiles of (a) only rough polished and (b) grooved polished tools.

Influence of heating temperature and time on frictional behaviour

Aluminium alloy flat strip drawing tests were conducted using quick contact heating at heating temperatures of 200°C, and 300°C and a heating time of about 20-30 s. For comparison, contact heating at 200°C for 600 s is also performed, which simulates long-time heating in a furnace. Fig. 4(a) shows the relationship between an average coefficient of friction and an average contact pressure of shoe at T = 200°C and 300°C for quick heating. The friction at 200°C is approximately half that of 300°C, and a difference of only 100°C significantly reduces friction. Fig. 4(b) shows the friction coefficient-stroke curves for different heating time for flat strip drawing test of contact heated aluminium alloy strip for dry condition at 200°C. The coefficient of friction increased with heating time, indicating that quick heating is better for friction. This is thought that during quick heating, the slight amount of pollution such as oil remaining on the surface of the strip acted as a lubricant.

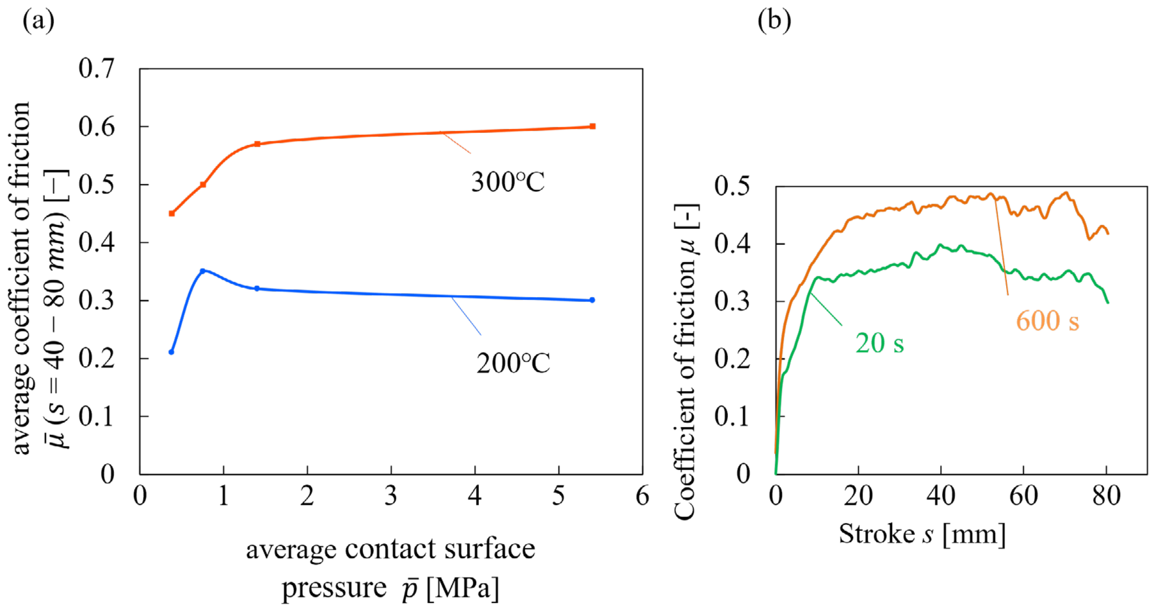

Fig. 4. (a) Relationship between average coefficient of friction and average contact pressure of shoe in flat strip drawing test of aluminium alloy strip for dry condition, (b) Friction coefficient-stroke curve for different heating time for flat strip drawing test of contact heated aluminium alloy strip of T = 200 °C for dry condition.

Influence of tool surface coating on friction behaviour

Fig. 5 shows the friction coefficient-stroke curves obtained by the flat strip drawing test using coated shoe for dry condition. Each coating exhibited lower friction in the initial stage of drawing than the without coating. However, the friction coefficients of AlSiCrN and VC increased with an increase in stroke, and AlSiCrN reached to that of no coating at s = 80 mm. This is thought to be because the Al contained in AlSiCrN easily reacts with the strip specimen, causing adhesion to occur. DLC exhibited stable low friction despite warm sliding.

Fig. 6 shows the seizure on the surface of each shoe. The degree of seizure is severe for the case with no coating. For AlSiCrN and VC, seizures are also observed, although more moderate than without coating. There is no seizure for DLC-coated shoe.

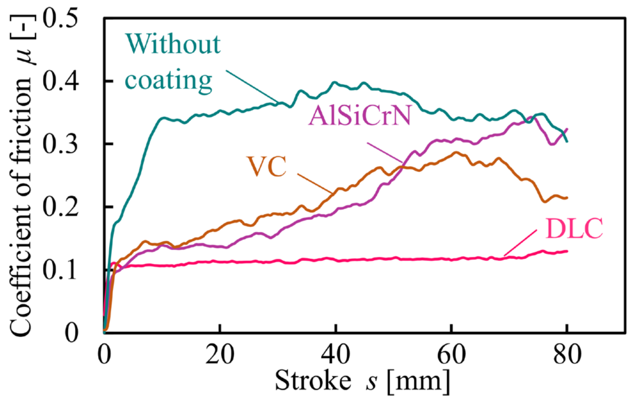

Fig. 5. Friction coefficient-stroke curve for different tool surface coatings for flat strip drawing test of contact heated aluminium alloy strip of T = 200°C for dry condition.

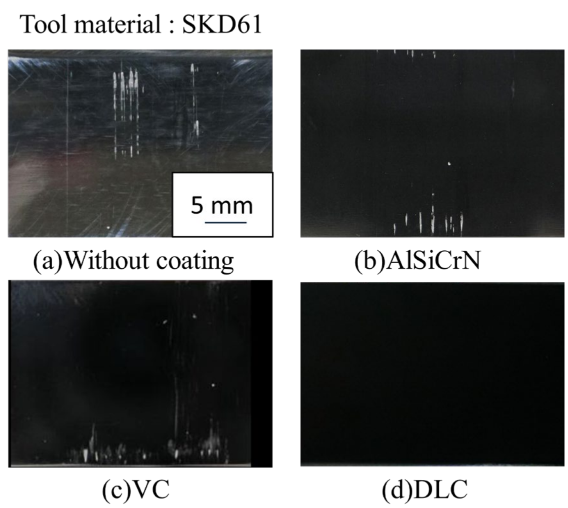

Fig. 6. Surface appearances of tools after flat strip drawing test of contact heated aluminium alloy strip of T = 200 °C for dry condition.

Influence of tool material and grooved polishing of shoe surface on friction behaviour

Although the DLC coating has low friction and prevents seizures, the coating process costs. Applying spheroidal graphite cast iron to warm hot-stamping of aluminium alloy is attractive as an inexpensive tool. A reduction of friction by the spheroidal graphite as a lubricant and holding of liquid lubricant at the graphite escaped pit are expected. Fig. 7 shows the friction coefficient-stroke curves of an aluminium alloy strip drawing test using quick contact heating with a conventional polished SKD61, a conventional polished FCD600 and a grooved polished FCD600 shoe using a liquid lubricant. Both SKD61 and FCD600 showed low friction in the initial stage of drawing. However, the friction coefficient for conventionally polished SKD61 and FCD600 increased at $s = 20$ mm and $s = 40$ mm, respectively. When conventional polished, FCD600 showed lower friction for a longer distance than SKD61 when liquid lubricant was used, but both were finally seized.

The friction coefficient for groove polishing of FCD600 is constant, equivalent to that of DLC for dry. Fig. 8 shows that no seizure was observed for the groove-polished FCD600, whereas seizure occurred when the FCD600 was conventionally polished.

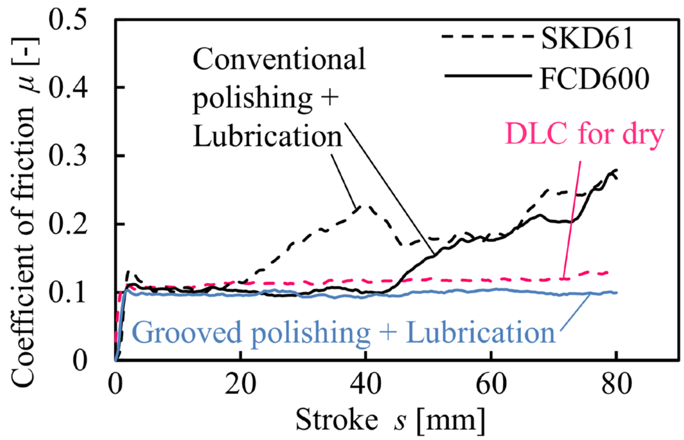

Fig. 7. Friction coefficient-stroke curves for conventionally polished SKD61 and FCD600 and grooved polished FCD600 in flat strip drawing test at T = 200°C with liquid lubricant.

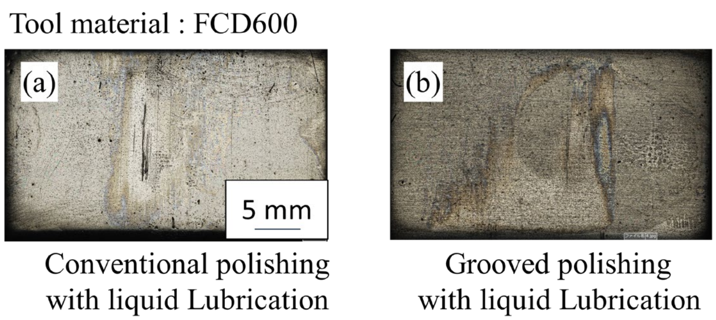

Fig. 8. Surface appearances of the FCD600 shoes of conventionally polished and grooved polished, after flat strip drawing test at T = 200°C with liquid lubricant.

Rvk of the surface roughness parameter was used to represent the value of the valley's depth on the shoe surface. The relationship between an area of adhesion on the strip and Rvk of the shoe is shown in Fig. 9. The area of adhesion decreased with increasing Rvk, indicating that seizure scratches did not occur when Rvk ≈ 2 μm. This suggests that for a given drawing distance, Rvk represents a threshold value for the occurrence of a seizure.

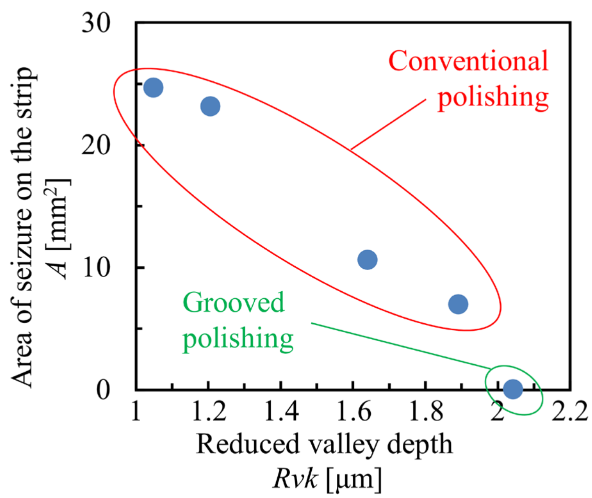

Fig. 9. Area of adhesion on aluminium strip for different Rvk with liquid lubricant obtained by flat strip drawing test using FCD600 shoe for T = 200°C.

Influence of groove polishing direction on friction behaviour

It has been shown that the combination of groove-polished FCD600 of spheroidal graphite cast iron and liquid lubricant keeps low friction and prevents the occurrence of seizures. Next, the optimal polishing direction was investigated. Fig. 10 shows the coefficient of friction-stroke curves for a spheroidal graphite cast iron tool surface polished in three different directions. The difference in the polishing direction on the friction coefficient is slight. Whereas the effect on the occurrence of seizures is observed. Although no seizure was observed at 90°, as the polishing direction was closer to the direction parallel to the drawing direction, the stroke without seizure became shorter.

We expect the phenomenon shown in Fig. 11 to occur. The left figure shows the case where the polishing direction of the tool surface is orthogonal to the drawing direction, and the right figure shows the case where it is parallel to the drawing direction. In the case of drawing direction and groove's direction are orthogonal, the liquid lubricant accumulated in the groove leaches into the boundary lubrication area as the strips draw, preventing contact between the material and the tool. On the other hand, if the grooves are parallel, the liquid lubricant does not leach into the boundary lubrication area, and tool and material contact at the boundary lubrication area, resulting in a seizure.

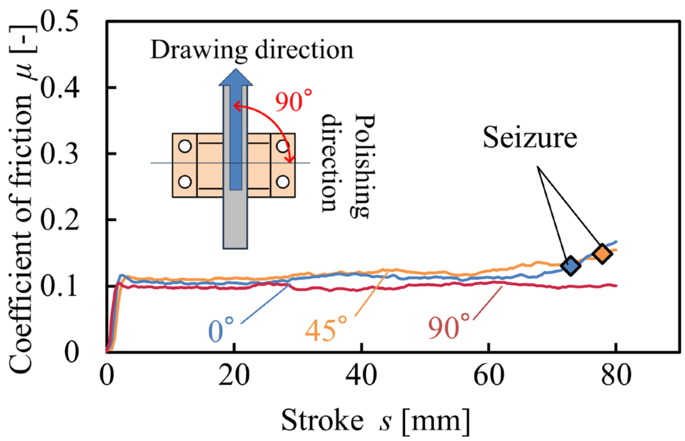

Fig. 10. Friction coefficient-stroke curves for different Grooved polishing directions of ductile cast iron tool obtained by flat strip drawing test.

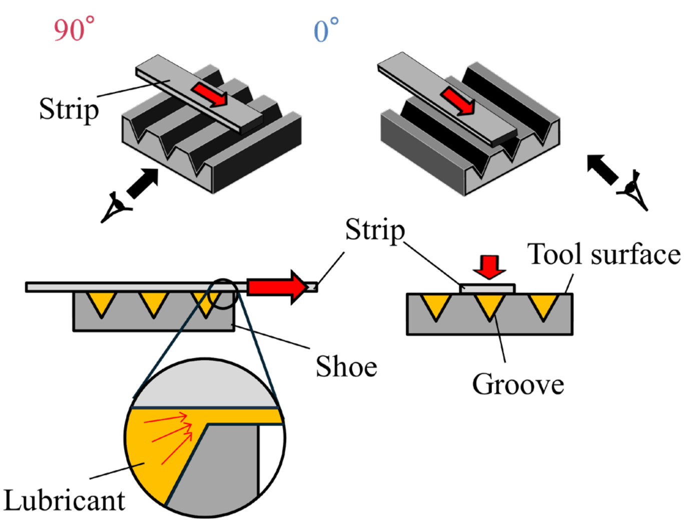

Fig. 11. Consideration of liquid lubricant behaviour in different polishing directions.

Summary

A strip drawing test was conducted under warm conditions to investigate the frictional properties of an age-hardened A7075 aluminium alloy strip during warm heating using quick contact heating. The following results were obtained.

Friction for quick heating at 200°C becomes mild compared with the high-temperature and long heating time. Therefore, warm stamping using quick heating has the advantage of friction against to hot stamping including solution heat treatment and warm stamping with a furnace.

A DLC coating showed very stable and small friction without a seizure, even in dry conditions. The DLC coating is very suitable for hot and warm stamping of aluminium alloy although the price is high cost.

Conventional-polished ductile cast iron showed superior low friction compared to tool steel under liquid lubrication. However, it was not enough against the seizure. By combining the ductile cast iron and grooved polishing, lubricant is kept and seizure was prevented. The friction was small and stable like that of a DLC coating. A combination of ductile cast iron tool and grooved polishing is ideal for the warm forming of aluminium alloy, where liquid lubricants can be used. In addition, Rvk was also shown to be a useful parameter for expressing the frictional properties of the surface using grooved polishing.

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