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Prevention of adhesion in forming of stainless steel by using surface coatings

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Abstracts

This research is aimed to study the prevention of adhesion during ironing operation by utilizing surface coatings. Since adhesion is a cause of galling or scratch on the product surfaces; to remove scratches additional cost and time are necessary. In this work, three types of hard-thin surface coatings, i.e. TiCN-CVD, TiCN-PVD and AlCrN are selected. Firstly, Ball-on-Disk typed tribology tests are performed. The balls are made of high strength steel (SKH51) which is the same grade as die materials, while the disks are made of stainless steel (SUS304). Next, strip ironing tests are carried out to study the effectiveness of surface coatings under high contact pressure. From the results of both tests, all surface coating used can reduce adhesion between the workpiece and die surfaces. From ball-on-disk test, AlCrN-PVD provides the lowest coefficient of friction between the contact surfaces. However, the results of strip ironing tests reveal that TiCN-CVD provides the deformed workpieces with the best surface quality, i.e., minimum surface roughness and least number of scratches found on the ironed surface.

Keyword: Strip Ironing/ Tribology Test/ Adhesion/ Surface Coatings/ Stainless steel

1. Introduction

Stainless steel containers that are used widely in beverage and food packaging as well as kitchenware are usually produced by deep drawing and ironing operation. Those processes can produce a large number of parts in a comparatively short time with almost constant product quality. However, the selection of process parameter as well as tool materials and lubrication used are very important. Usually, cold work tool steel always contains high carbon and chromium to improve its properties. Since chromium contents in stainless steel is also quite high, adhesion easily occurs when forming parts made of stainless steel. This is caused by the cohesive force while the tool and product contacting under high contact pressure [1]. Adhesion is a cause of galling or scratch on the product surfaces, which is a major problem for manufacturers that need to remove them. Additional cost and time are necessary for surface polishing process, leading to low competitiveness. In order to solve those problems, surface coatings seems to be effective. Since hard-thin film can prevent direct metal-to-metal contact between the tool and the workpiece, adhesion can be prohibited as long as the film does not crack or peel off.

However, contact pressure between the die and workpiece during forming operation is extremely high; the films that can be applied should have appropriate properties including adequate bonding strength to the substrate or the tool surface. From previous works, AlCrN and TiCN show good tribological properties when contact against stainless steel. Moreover, those films also reveal high peeling resistance [2, 3].

In this work, the authors aim to investigate an ability to prevent adhesion during forming stainless steel by using surface coatings. Three kinds of hard-thin films, i.e., AlCrN (PVD), TiCN (PVD) and TiCN (CVD) are selected because of their superior properties. Ball-on-Disk test and strip ironing test are used to evaluate the performances of those films.

2. Experimental procedure

2.1. Tool and workpiece material

For strip ironing test, cold work tool steel JIS-SKH51 was used as the die material. The tool was hardened to 63±1 HRC prior to coating process. Stainless steel SUS304 (JIS) having thickness of 0.75 mm was used as workpiece material. Chemical compositions of SKH51 (a) and SUS 304 (b) are shown in **Table 1**, while mechanical properties of workpiece material are shown in **Table 2**, respectively.

For ball-on-disk test, the ball was made of the same material as the die, while the disk was made of stainless steel SUS 304 as same as the sheet material. The ball was undertaken hardening and surface coating at the same time as the die to ensure similar properties.

Table 1 Chemical composition of ball and disk materials

a) Ball: SKH51

Element	C	Cr	Mo	V	W	Fe
Content (%wt.)	0.9	4.1	5.0	1.9	6.4	Bal.

b) Disk: SUS304

Element	C	Si	Mn	Ni	Cr
Content (%wt.)	0.07	0.77	0.90	8.01	19.63
Element	S	P	Fe	-	-
Content (%wt.)	0.0003	0.26	Bal.	-	-

Table 2 Mechanical properties of SUS304

Descriptions	Value
Yield Strength	215 MPa
Ultimate tensile strength	505 MPa
Elongation	70%
Posisson's ratio	0.30
Hardness	125 HV

2.2 Ball-on-disk test

Ball-on-Disk test apparatus is shown in **Fig. 1**. The test was carried out using SKH51 balls having diameter of 6 mm and SUS304 disks. Four types of balls were prepared, i.e., non-coated, TiCN (PVD), TiCN (CVD) and AlCrN coated balls. The normal applied load was constant at 7 N which was equivalent to contact pressure of 1,230 MPa. Sliding velocity was determined at 100 mm/s. Sliding distances were 300 m which were the same for all conditions. Testing temperature was varied at two different levels for some cases, i.e.; ambient temperature (25°C) and elevated temperature (80°C). In addition, both dry condition and lubricated condition using commercial forming-oil J77 (viscosity 119.06 cSt at 40°C Thai lubic petroleum Co,Ltd) were performed. The balls and disks were cleaned by acetone to get rid foreign particles. The results of friction coefficient and the depth of wear track were measured and analyzed.

Fig. 1 Ball-on-disk testing equipment

2.3 Strip Ironing Test

Strip ironing setup is shown in **Fig. 2**. The die is made of SKH51 high-speed tool steel with semi die angle of 10° and width of die land 1 mm. Sheet material is stainless steel SUS304 having initial thickness of 0.75 mm. The tests were performed using four different dies, including a non-coated die and the dies coated with three types of hard-thin films mentioned previously. Forming oil J77 was used as the lubricant. Ironing speed was constant at 30 mm/s. The reduction ratio of thickness (ironing ratio) was varies at three different levels; 4%, 11% and 17%, respectively. The die and workpiece were cleaned by acetone before undergoing ironing operation similar to ball-on-disk test. The results of ironing force and surface quality of ironed parts were explored.

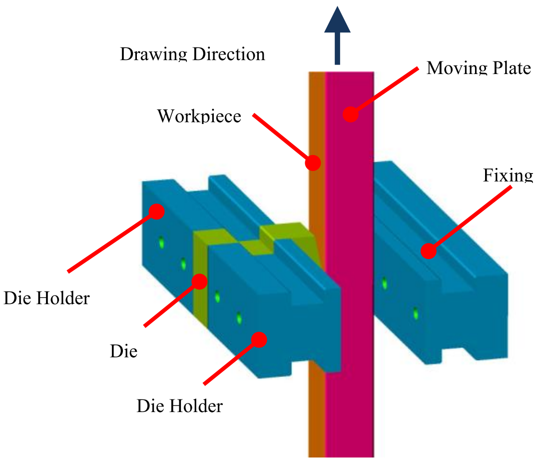


Fig. 2 The setup for the strip ironing test

3. Results and Discussion

3.1 Ball-on-Disk Test

The results of friction coefficient between stainless steel disks against various types of ball are shown in **Fig.3**. The average values of the friction coefficient obtained from each condition are almost the same level.

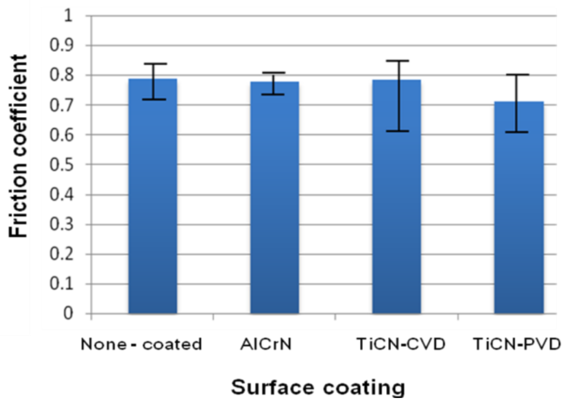
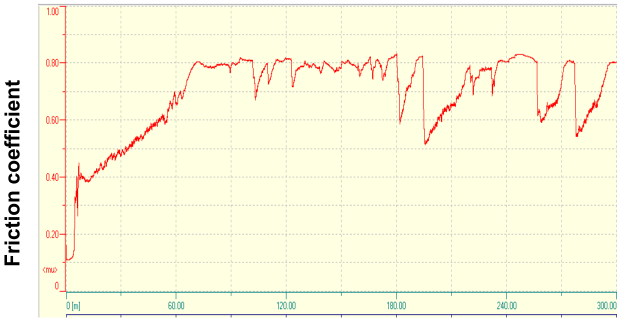


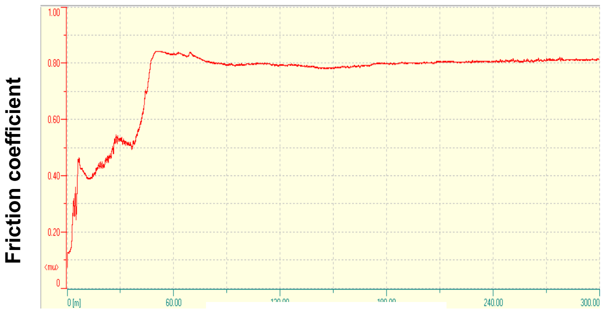
Fig.3 Friction coefficient obtained from ball-on-disk tests for dry condition

However, when focusing on the graph plotted between friction coefficient against sliding distance for the cases of non coating and TiCN (CVD) film, as shown in Fig. 4 (a) and (b), respectively, the value of friction coefficient obtained from TiCN (CVD) is much more stable than non coating condition. The result reveals that adhesion may occurs at the contact surface between the non-coated ball and the disk, leading to noticeably unstable of friction coefficient measured.



Sliding distance (m)

(a) Non-coated



Sliding distance m)

(b) TiCN (CVD)

Fig.4 Friction coefficient obtained from ball-on-disk tests for dry condition

The average values of friction coefficient of various films obtained for the case of lubricated conditions are shown in **Fig. 5**. At room temperature, the average values of friction coefficients are relatively low for all conditions. However, the values obtained scatter in the wide range except for the case of AlCrN. Hence, the tests under elevated temperature (80°C) were carried out to further explore the effectiveness of AlCrN compared to non coating condition. The results obtained are shown in the same figure. In this case, there is no different found from both cases. This may be causes by loading applied that is not as severe as in real forming operation, hence the markedly improvement of friction coefficient for coated condition cannot be observed.

Fig.5 Friction coefficient obtained from ball-on-disk tests in lubricant

However, in order to analyze further, the depth of wear track on the disk surface was measured by roughness measuring stylus. The results obtained are shown in **Fig.6**. All types of film coated used can reduce the depth of wear track compared to that of non coating condition. Especially AlCrN shows noticeably performance which can reduce the depth of wear track up to 50% of the non coated case. The same tendency is also found for the case of elevated temperature. Since the wear depth represents the wear volume of stainless steel disks, the results obtained reveal the potential of the films to reduce adhesion that is the cause of adhesive wear during sliding contact.

3.2 Strip ironing tests

The roughness of the strip-ironed part is measured at the distance 5, 25 and 45 mm from the starting point, respectively. The results of average roughness values (R_a) at each distance obtained from various conditions are shown in **Fig.7**. From the figure, as ironing distance increases, the roughness of the workpiece slightly increases. This might be caused by the adhesion that slightly taken place during ironing the workpiece.

The scratches are evidently found on the surface of the workpieces obtained from the case of using non coated die. However, by using hard-thin coated films, the scratch cannot be visually observed. Since the scratch or galling are caused by the adhesion of the workpiece material on the die surface, those results reveal that film coated are outstandingly important to prevent adhesion in forming stainless steel parts. Thus the defects or unnecessary costs can be minimized.

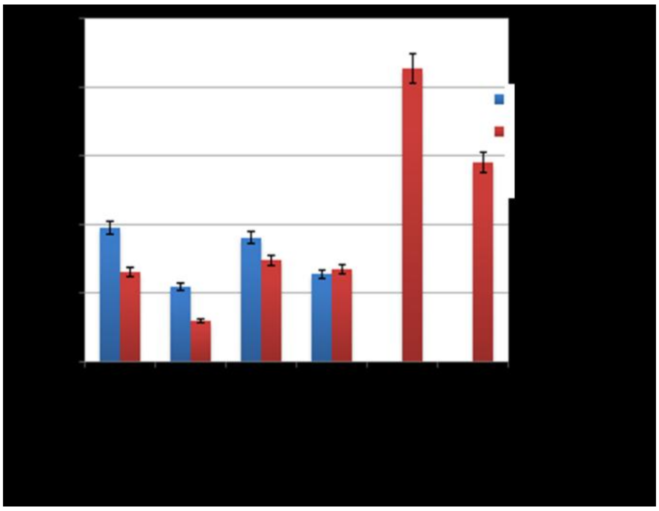


Fig.6 Depth of wear track on disks undergone ball-on-disk tests

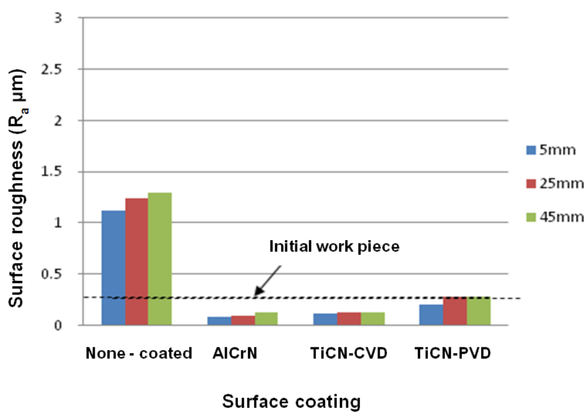


Fig.7 Surface roughness of strip-ironed parts

Moreover, the strip ironing dies were observed by optical microscope after performing ironing experiments. As the results, large amount of adhesion can be found on the die surface for the case of non coated die. For AlCrN and TiCN (PVD) coated dies, some amount of adhesion can be observed, but much more less than the case of non-coated one. On the other hand, there is almost no adhesion found on the surface of TiCN (CVD) coated die. This may be explained that TiCN (CVD) was deposited by CVD process which provided comparatively higher bonding strength to the substrate [4]. Consequently, the film can completely prevent metal-to-metal contact between the substrate and workpiece material without crack or peeling off under extremely high contact pressure during ironing operation.

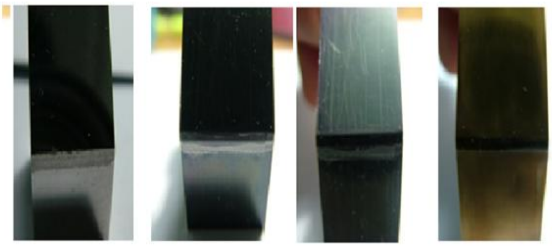


Fig. 8 Testing tools after the steel-strip-ironing-test experiments, from left to right: AlCrN-PVD, TiCN-PVD, Non-coated and TiCN-CVD

4. Conclusions

This research is aimed to study the prevention of adhesion during ironing operation by utilizing surface coatings. The following conclusions can be drawn from this study.

- AlCrN shows the best result from ball-on-disk test, i.e., minimum depth of wear track on the disk and the narrowest scattering range of friction coefficient obtained.
- All surface coatings can reduce adhesion and provide ironed parts with superior surface quality compared to non coating condition. Among those TiCN (CVD) provides the best result since there is no adhesion found on the die surface after performing strip ironing experiments.

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