EFFECT OF SURFACE COATING LUBRICITY ON ALUMINUM FIN-STOCK FORMABILITY

Yousuke Ohta, Kenji Noda, Kenichi Kamitani,
Yoshikazu Mukai and Koichi Hatanaka

Aluminum Sheets & Coils Research Department, Moka Plant
Aluminum & Copper Division, KOBE STEEL, LTD., Tochigi, Japan
15 Kinugaoka, Moka-city TOCHIGI pref., 321-4367, JAPAN

Abstract

We studied the effect of surface coating lubricity on aluminum fin stock formability using evaporative lubricants, which are mainly in use recently. Surface treatment decreasing surface friction showed following results :

(1)The limiting ironing ratio improves.

(2)The wear of forming tools is decreased.

(3)The troubles of fin-pitch disorder in the product are decreased.

Keywords: *surface lubricity, surface coating, fin stock, evaporative lubricant, formability*

Introduction

Hydrophilic surface-precoated aluminum fin stock is widely in use for heat exchanger of finned coils in order to remove the condensed water quickly. The fin stock oil should be removed after forming process for keeping the hydrophilic surface. On the other hand, so as to avoid uses of environmentally hazardous organic solvent in manufacture of finned coils, evaporative lubricant has prevailed in Japan. The residue of it on fin stock can be removed by hot blow and thus, degreasing process is saved. Evaporative lubricant does little harm on hydrophilic surface treatment, but it tends to cause inferior formability due to its lower viscosity.

Recently harder and thinner fin stock material has prevailed for efficient heat exchange system. Although drawless type collar forming method which contains ironing process is suitable for this material, the following troubles has emerged : (1)Decreasing limiting ironing ratio ,(2) Fin-pitch disorder of the finned coil(so-called 'avec') .

We studied the effect of surface coating lubricity on aluminum fin stock formability using evaporative lubricants, especially focused on collar formability (limiting ironing ratio), wear of shearing tools(associated with the shearing burr) and 'avec' phenomenon(fin-pitch disorder of the finned coil).

Experimental method

1. Collar formability

1-1 Specimen

Chemical composition and mechanical properties of aluminum material are shown in Table 1-1 and 1-2. Hydrophilic coatings are on both sides of surfaces as shown in Table 1-3. Fin stock oils are shown in Table 1-4, and lubricants A to D are the commercially available evaporative oils.

1-2 Forming conditions and evaluating method

Drawless type of Fin Dies produced by Hidaka Engineering Company is used. The forming process and the die set condition are shown in Figure 1-1 and Table 1-5 respectively. The ironing ratio was varied from 48 to 65% at 260 strokes per minute to evaluate the limiting ironing ratio.

1-3 Erichsen Cupping test

Erichsen cupping test was done and the influence of surface lubricity and lubricant was evaluated.

2. Shearing burr and wear of shearing tools

2-1 Specimen

Chemical composition and mechanical properties of aluminum material are shown in Table 2-1 and 2-2. Silicate type hydrophilic coatings are on both sides of surfaces as shown in Table 2-3. The surface lubricity was varied by the additive water-soluble lubricant in hydrophilic coating. Fin stock oils are shown in Table 2-4, which is commercially available evaporative oil.

2-2 Forming conditions and evaluating method

Drawless type of Fin Dies produced by Hidaka Engineering Company is used and the shearing condition is shown in Table 2-5 and Figure 2-1. Here we particularly focused on burr height which affect the appearance of finned coils. The clearance of tools was varied in three conditions (15 μm, 25 μm and 40 μm) and the relationship between burr height and surface lubricity was evaluated.

Wear of shearing tools was also investigated with no lubricant by one million continuous punches of specimen No.1 and No.3 in Table 2-3 at the clearance 15 μm. It was evaluated as the shape of cutting edge (R) in shearing tools and burr height of workpieces were also measured.

3. 'Avec' phenomenon in expanding copper tube

3-1 Specimen

Chemical composition is shown in Table 2-1. Mechanical properties and the coefficient of friction are shown in Table 3-1. Silicate type hydrophilic coatings are on both sides of surfaces and the surface lubricity was varied by the additive water-soluble lubricant in hydrophilic coating.

3-2 Forming and tube expanding conditions and evaluating method

The condition of aluminum fin stock forming and copper tube expansion for making the finned coil are shown in Table 3-2. The scheme of tube expanding process and the example of 'avec' are

Table 1-1 Chemical composition: wt%

Si	Fe	Cu	Mn	Mg	Ti	Al
0.07	0.30	0.01	0.28	0.01	0.08	Rem

Table 1-2 Mechanical properties

Thickness mm	TS MPa	0.2% Mpa	El. %
0.115	136.3	129.4	19.1

Table 1-3 Surface treatment

No	Surface treatment	Thickness of Film μm	Coefficient of Friction
1	Hydrophilic acrylic resin coating	0.6	0.31
2		0.6	0.15

Table 1-4 Property of lubricant

Test Lubricant	Viscosity (cSt at 40℃)	Additive
A	1.30	Ester
B	1.40	Ester
C	8.83	Fatty Acid

Table 1-5 Test condition of die set

Parts	Diameter mm
Pierce Punch	6.68
1^{st} Ironing Punch / Die	9.40 / 9.55
2^{nd} Ironing Punch	9.80 ($= P$)
2^{nd} Ironing Die	9.88～9.92 ($= D$)

Ironing ratio(%) = $(1 - (D - P) / 2t) \times 100$

t : Material thickness 0.115mm

Table 2-1 Chemical composition: wt%

Si	Fe	Cu	Mn	Mg	Ti	Al
0.08	0.27	0.00	0.27	0.01	0.08	Rem

Table 2-2 Mechanical properties

Thickness mm	TS MPa	0.2% Mpa	El. %
0.110	138	136	13.3

Table 2-3 Surface treatment

No	Surface treatment	Thickness of Film μm	Coefficient of Friction
1	Hydrophilic acrylic resin and silicate combined coating	0.20	0.8
2		0.21	0.15
3		0.22	0.08
4		0.24	0.05

Table 2-4 Property of lubricant

Viscosity (cSt at 40℃)	Additive
1.30	Non Ester

Table 2-5 Test condition of shearing

Operating speed	300spm
Tool material	SKD11(JIS)
Oil spreading amount	1g/m²

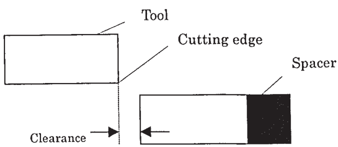

Fig. 2-1 Scheme of shearing test

shown in Figure 3-1 and Photo 3-1 respectively. 'Avec' is evaluated by the appearance in 5 step grades and the most favorable is marked as ' 5 '. The average values of 3 times measurement of this grade for each specimen was figured out.

Results and discussion

1. Collar formability

The relationship between limiting ironing ratio and surface lubricity with evaporative oil A in Table 1-4 is shown in Figure 1-2. Mark ● or ○ indicates that the corresponding coefficient of friction was measured with or without oil A, respectively, and especially mark ○ shows a clear reciprocal curve. This figure shows that the better surface lubricity on fin stock material provides the higher limiting ironing ratio in drawless collar forming method.

Erichsen value of each specimen in Table 1-3 are also schematically shown in Figure 1-3. It indicates that the better surface lubricity on fin stock material is related to the higher Erichsen value and the inferior formability of evaporative oil is compensated by the good surface lubricity of fin stock material.

2. Shearing burr and wear of shearing tools

Shearing burr heights of each specimen in varied clearance are shown in Table 2-6. Photo 2-1 shows the cross section of sheared workpiece observed from vertical direction to the sheared face. Generally the burr height of the surface lubricated material is higher than that of the not lubricated one. But the burr height can be minimized while the clearance is kept narrow enough(about 10 – 15 % of the workpiece thickness) [1] even if the surface lubricated material is used. In this test, the clearance 15μm corresponds to 13.6% of specimen thickness and the burr height was not influenced by the surface lubricity at the clearance.

The cutting edge (R) and burr height in continuous punch of specimen No.1 and No.3 in Table 2-3 is shown in Table 2-7. It shows that both wear of cutting edge and burr height are reduced by using the fin stock material with lower coefficient of friction. Here if we assume that wear of cutting edge corresponds to the increment of clearance, the burr height might easily increase by the usage of the surface lubricated material from Table 2-6 even if we started with a proper clearance due to the wear of cutting edge. But starting with a proper clearance, the wear of shearing tools are lessened by the usage of the fin stock material with lower coefficient of friction. Thus the lower burr height can be kept for a long period by the usage of the surface lubricant material.

3. 'Avec' phenomenon in expanding copper tube

The influence of the surface lubricity on fin stock material on 'Avec' phenomenon is shown in Figure 3-2. Specimen No.2 with lower coefficient of friction was revealed to be better for 'Avec' property. Here we shows the deformed behavior of fin stock in expanding copper tube in Figure 3-3. The fin stock is forced to deformed during tube-expanding process and resume its order after

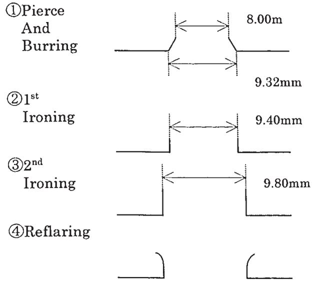

Fig.1-1 Drawless type collar forming process

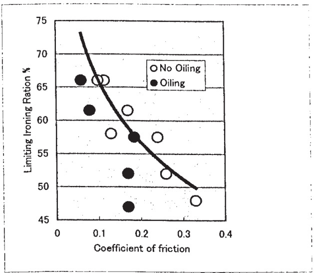

Fig. 1-2 Relation between coefficient of friction and drawless type formability

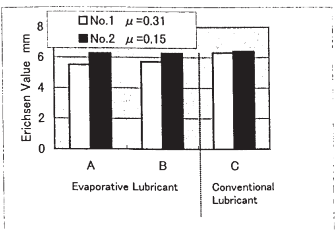

Fig. 1-3 Influence of surface treatment on Erichsen value

Table 2-6 The effect of surface coating on shearing burr height

No	Coefficient of Friction	Shearing burr height μm		
		15μm*	25μm*	40μm*
1	0.8	4.3	7.1	20.8
2	0.15	3.0	8.0	23.2
3	0.08	3.1	8.4	27.1
4	0.05	3.4	10.0	28.3

*clearance

Table 2-7 Cutting edge R and shearing burr height after continuous shearing test

Item	No.	At the beginning	After 0.2million punch	After 1million Punch
Cutting edge R μm	1	4.3	10.0	17.9
	3	4.5	5.3	11.7
Burr height μm	1	4.3	26.3	39.6
	3	3.1	7.9	25.0

Table 3-1 Properties of material(0.11mmt)

No	TS MPa	0.2% Mpa	El. %	μ
1	137	135	15.9	0.8
2	135	132	14.9	0.12

Table 3-2 Test conditions

	Fin stock forming
Fin dies	Drawless type
Lubricant	Evaporative oil (1.28cSt / 40℃)
Collar	Height : 1.25mm, ϕ: 9.80mm
Reflair R	0.4mm
	Tube expanding
Hairpin Tubes	Height : 550mm, ϕ: 9.52 mm
Coil Width	515mm
Expanding Ratio	1.44% (Bullet : ϕ: 8.94 mm)

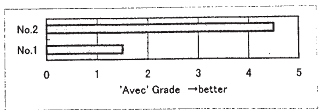

Fig 3-2 The effect of surface lubricity on 'Avec'

expansion. But if the coefficient of friction is higher, then the sliding friction between copper tube and fin stock also increases and the fin stock movement might be restricted. The surface lubricated material is deformed smoothly and this could be the reason of its good 'Avec' property.

Conclusion

By the enhancement of surface lubricity on surface treated fin stock material, the following excellent formability has been obtained.

(1) The limiting ironing ratio in drawless type forming method improved and the Erichsen value of the material is enhanced

(2) The wear of forming tools is decreased and the burr height depressed if the clearance of shearing tools is properly set.

(3) 'Avec' phenomenon which means the fin-pitch disorder of the finned coil is decreased.

Reference

[1] JSTP : Press forming handbook p99～102 (1975)

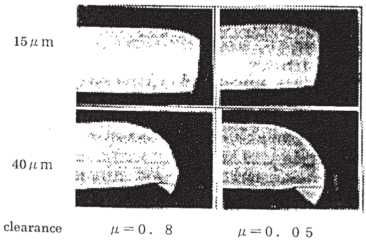

Photo. 2-1 Cross section of sheared face

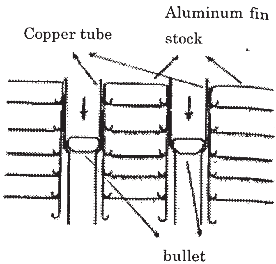

Fig. 3-3 Scheme of tube expansion

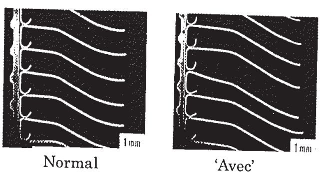

Photo. 2-1 Cross section of finned coil

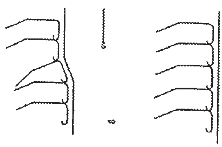

Fig. 3-3 The deformed behavior of fin stock