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Development of Self-lubricating Steel Sheet "RIVER ZINC（R） FS"

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The body can be viewed from the next page.

Development of Self-lubricating Steel Sheet "RIVER ZINC® FS"*



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1 Introduction

Electro-galvanized steel sheet is used as corrosion-resistant member material in applications such as electric appliances, construction materials, and automobiles. It is frequently subjected to press forming work in the manufacturing process for various member parts. Such processing typically involves the sequence of applying a press forming lubricant coating or decasting solid lubricant → press working → degreasing → phosphating → coating. With such a sequence, the following problems have been found in the past:

(1) Since press oil is sprayed in most cases, scattered oil deteriorates the working environment.
(2) If degreasing after pressing is insufficient, the subsequent phosphating and coating processes will be adversely affected, resulting sometimes in the generation of blotching.
(3) The organic solvent used for degreasing after pressing is liable to become an environmental contaminant.
(4) In rigorous press forming work, cracking and galling due to insufficient lubrication may result.

To solve these problems, the development of pre-coated steel sheets that can improve both the working environment and manufacturing efficiency has been explored, and Kawasaki Steel has particularly been studying self-lubricating steel sheets coated with a thin film of organic resin.[1]

During the development of self-lubricating steel sheets, the authors examined a method for experimentally reproducing and evaluating the powdering and cracking which occurs in practical press forming, and studied the effects of an organic resin coating and lubricating agent on press formability. As a result, the self-lubricating steel sheet RIVER ZINC® FS was developed

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which can be press-formed without using any press oil. This steel sheet is made by applying a chromate conversion coating and a resin top-coat containing an organic lubricant to an electro-galvanized steel sheet as the base, and offers excellent corrosion resistance.

This paper reports the evaluation method for powdering and cracking, the effects of the resin characteristics and coating conditions on press formability, and the product characteristics of RIVER ZINC FS.

2 Method for Evaluating Powdering and Cracking

2.1 Problems with the Conventional Method

Previously, the press formability of coated steel sheets was evaluated by the limiting drawing ratio (LDR) of the steel sheet measured with a cup drawing machine (**Fig. 1**). In the practical press forming process, debonding of the resin layer, which is referred to as powdering, sometimes occurs. Since practical press forming is performed continuously at high speed, the temperatures of the die and punch rise instantaneously due to friction with the steel sheet to several hundred degrees, and maintain 70 to 80°C as an average.[2,3] "Powdering" is a phenomenon in which the resin and lubricating agent are scraped off by the friction and heat build-up arising from pressing, and then adhere to the press-formed part in the form of black powder. This not only lowers the quality of press-formed products, but the powder is also deposited on the metallic mold and causes cracking. Since the reproduction of the metal temperature rise during continuous press forming is difficult by the conventional cup drawing test, powdering resistance cannot be evaluated. In order to simulate powdering, therefore, a friction test, in which the metal temperature is raised to nearly the level reached during practical press forming, and a continuous drawing test at high speed were conducted.

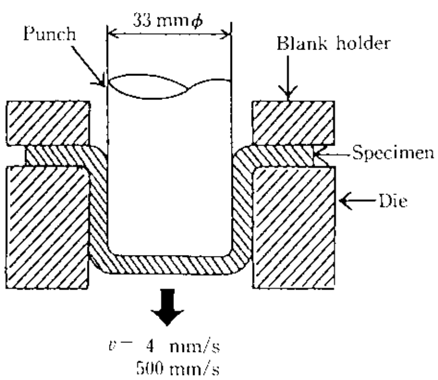


Fig. 1 Cup drawing test

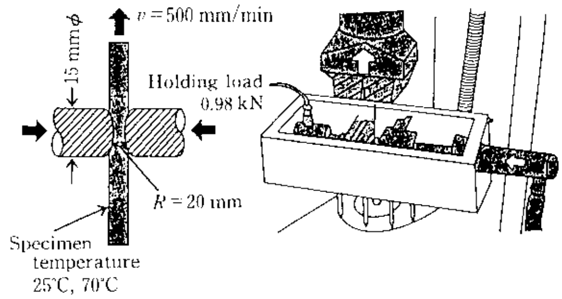


Fig. 2 Friction test

2.2 Testing Method

A self-lubricating steel sheet was used for the sample which had been made first by depositing a chromate conversion coating on a 1.0 mm-thick electro-galvanized steel sheet (SPCC raw material) with a zinc coating weight of 20 g/m^2, and then by coating it with 1.0 g/m^2 of a lubricant-containing resin on the roll coating line. Ten pieces of other materials were also selected as samples for some of which developed and other which did not develop powdering in practical press forming. The experimental reproduction of powdering by the friction tester and cup drawing tester was then examined, together with an evaluating method for powdering. For the friction test, the friction tester shown in **Fig. 2** was used. The temperature of each specimen was set at the two levels of 25°C room temperature and 70°C mean temperature of the metallic mold during press forming, and the specimens were drawn at a holding load of 0.98 kN and a drawing speed of 500 mm/min. For the continuous cup drawing test, 10 specimens were continuously drawn by the cup drawing tester shown in Fig. 1 at a low drawing speed of 4 mm/s and at a high drawing speed of 500 mm/s (equivalent to the speed of a practical forming press) without trimming the die, and LDR and the quantity of powder generated on the side wall were evaluated by a visual inspection.

2.3 Results and Discussion

2.3.1 Friction test

The results of measuring the drawing load for 20 specimens by the friction tester are shown in **Fig. 3**. Both the powdering-resistant material indicated by the solid line (good) and the non-powdering-resistant material indicated by the broken line (poor) show the same drawing load, the metal temperatures being equal, and the drawing load progressed at nearly a constant value of the initial load. When the metal temperature was raised to 70°C, the drawing load decreased. This was due to the lubricating agent added to the resin being melted or softened at the higher temperature, thereby enhancing the lubricity. The measured result of the fric-

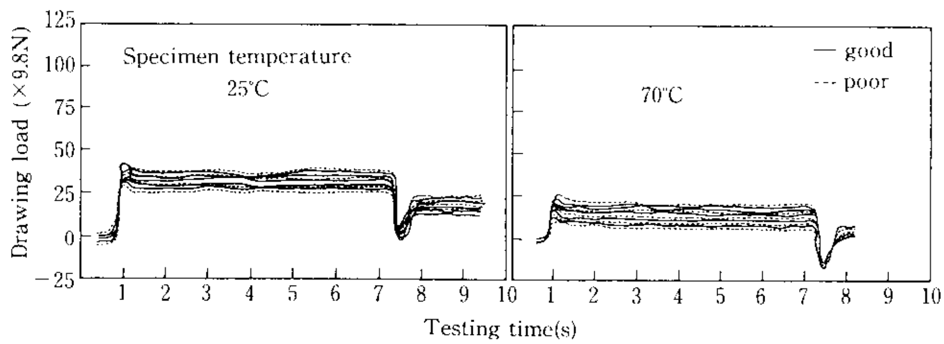


Fig. 3 Drawing load of several specimens

tion coefficient showed the same trends as that of the drawing load.

Consequently it was impossible to evaluate powdering resistance by the friction test under these conditions.

2.3.2 Cup drawing test

Ten samples each of poor materials which had developed powdering during practical press forming were subjected to cup drawing tests under drawing speeds of 4 mm/s and 500 mm/s, the results of the test to investigate the presence/absence and quantity of powder on the drawn part being shown in **Fig. 4**. In order to set press forming conditions ranging from mild to rigorous, the blank holding force was varied from 4.9 to 39.2 kN, and the drawing ratio was set at 2.30, which was nearly equivalent to LDR, in the continuous test. When drawn at 4 mm/s, no powdering occurred, even when the blank holding force was increased. However, at a drawing speed of 500 mm/s, which is equivalent to the drawing speed during practical press forming, stripped powder due to low-level powdering began to adhere to the top of the drawn part starting with the ninth or tenth specimen, when the blank holding force was set to 9.8 kN. Furthermore, when the blank holding force was raised to 19.6 kN, stripped powder in the same quantity as that during practical press forming adhered, starting with the fifth or sixth specimen. In contrast, the powdering-resistant material during practical press forming generated no powdering, even when the blank holding force was raised and the sample was drawn at high speed. From these results, the adoption of continuous drawing at high speed made it possible to reproduce the powdering that occurs during practical press forming.

After measuring each specimen temperature immediately after the test, it was observed, as shown in **Fig. 5**, that low-speed drawing did not increase the metal temperature even when blank holding force was increased, whereas high-speed drawing increased the metal temperature when the blank holding force was increased, the metal reaching a maximum temperature of 70°C at 19.6 kN. With a blank holding force above 19.6 kN, the specimens cracked, and a great deal of powdering occurred; hence it is considered that high-speed drawing caused a temperature rise in the metallic mold and thermal decomposition of the resin.

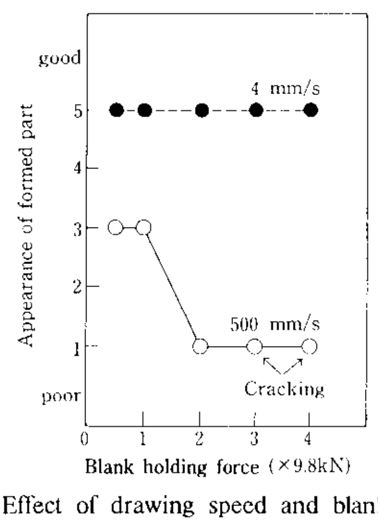


Fig. 4 Effect of drawing speed and blank holding force on appearance of formed part

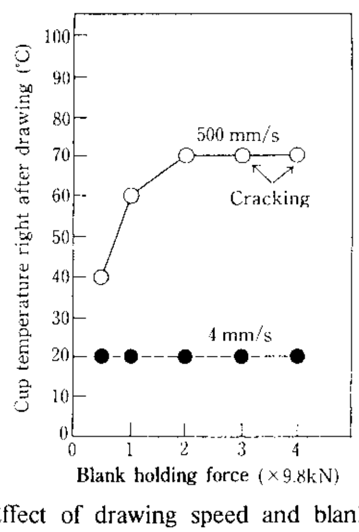


Fig. 5 Effect of drawing speed and blank holding force on cup temperature right after drawing

After considering the value of this testing method, press formability has been evaluated by the limiting drawing ratio (LDR), using the high-speed drawing process at a drawing speed of 500 mm/s, and the powdering effect assessed when 10 samples have been continuously drawn under such conditions.

3 Effects of Resin Characteristics and Coating Conditions on Press Formability

3.1 Testing Method

Using a chromate conversion-coated steel sheet based on the electro-galvanized steel sheet used in Sec. 2.2, the effects of the resin system, lubricating agent, resin coating weight, and baking temperature on press formability were investigated. The lubricating resin was coated on the sheet by a barcoater at a coating weight of 0.4 to 2.0 g/m^2, and baked in an oven at 100 to 220°C to produce the specimens. The press formability was evaluated by the above-mentioned high-speed cup drawing test.

3.2 Results and Discussion

3.2.1 Examination of resin types

To select the best resin system for press formability, five types of resin possessing high adhesion to electro-galvanized steel sheet, i.e., acrylic, acrylic-epoxy, epoxy, vinyl-acetate, and urethane-epoxy, were supplemented with polyolefin wax at a rate of 10% of the resin solid fraction, and a high-speed cup drawing test was carried out. It was found that all the LDR values for these resin types were equally as high as 2.30 to 2.33, but there was a difference in the powdering resistance. After examining the characteristics of the five types of resin, it was found, as shown in **Fig. 6**, that the powdering resistance increased with increasing T_g, the vinyl-acetate and urethane-epoxy resins having the highest powdering resistance among those tested. From the fact that specimens with same LDR value had different powdering resistance, it was concluded that the type of resin had more effect on powdering resistance than LDR did. Namely, the resin should have a high T_g value, should not thermally decompose when in contact with the hot metallic mold, and should effectively coat the steel sheet and alleviate friction during forming work.

From the tests, it was found that the vinyl-acetate resin and urethane-epoxy resin had satisfactory press formability, and for the present study, the vinyl-acetate resin, which provided high corrosion resistance, was used in the subsequent tests.

3.2.2 Examination of the lubricating agent

To find an effective lubricating agent for press formability, 10%-fraction lubricants of various types were added to the vinyl-acetate resin, and the high-speed cup drawing test was performed. The results in **Fig. 7** show that the lubricating agent with the highest LDR of 2.33 and with satisfactory powdering resistance was polyolefin wax. Others such as the fluoro resin, graphite, boron nitride and molybdenum disulfide are known to be excellent lubricating agents.[4,5] However, they were vulnerable to coagulation and sedimentation, and it was difficult to form a uniform lubricating film when they were added to the resin; consequently it was difficult to enhance their LDR value and powdering resistance.

To enhance lubricity and, hence, press formability, it is most effective to form a lubricating oil film on the friction surface that will separate the two metallic surfaces of the mold and steel sheet from each other. Lubricating states can be broadly classified, depending upon how the metallic mold and steel sheet are separated, into three kinds, that is, hydrodynamic lubrication, mixed lubrication, and boundary lubrication.[6,7] As shown in **Fig. 8**, hydrodynamic lubrication is the most ideal condition in which the die and the steel sheet are completely separated by a lubricating film. Boundary lubrication may cause metallic contact by the rupture of the lubricating layer, and a temperature rise and wear of

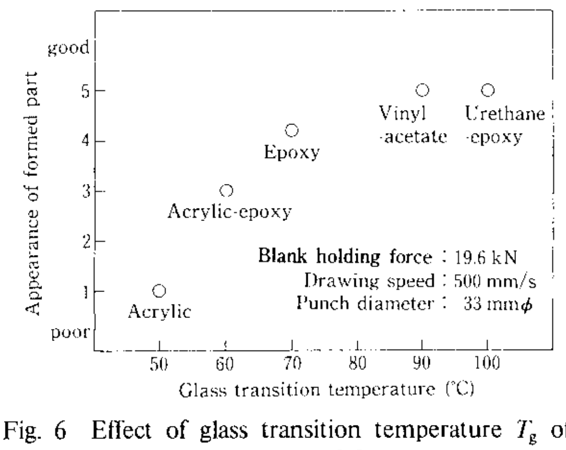


Fig. 6 Effect of glass transition temperature T_g of resin on appearance of formed part

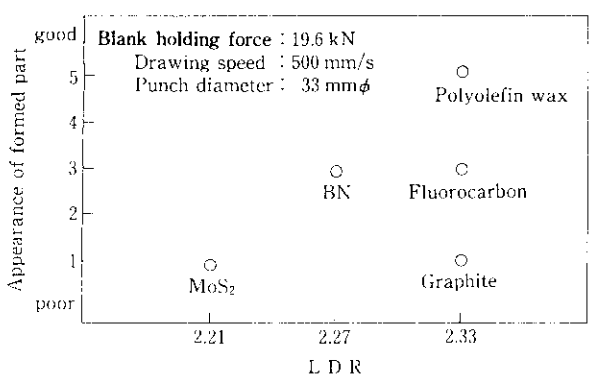


Fig. 7 Effect of lubricating agent on press formability

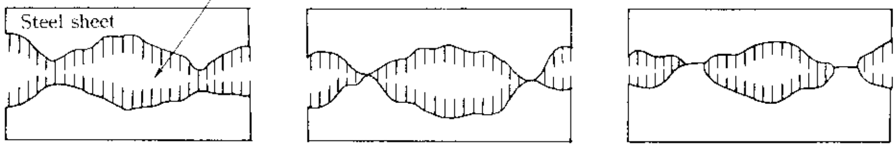


Fig. 8 Schematic diagram of lubrication

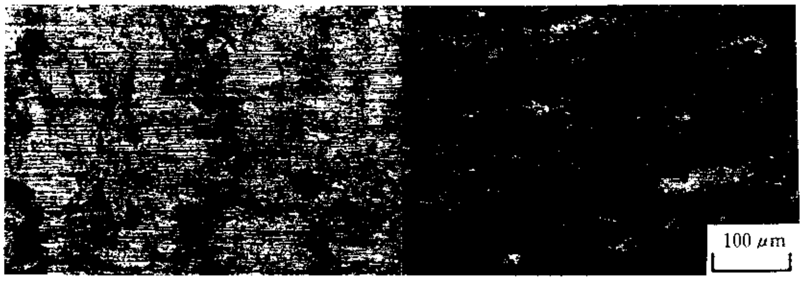


Photo 1 Surface morphology of formed parts after cup drawing test (by microscope)

the friction surfaces are generated, thereby making this state liable to cause lubricating trouble. Mixed lubrication is a combination of the other two types of lubrication. **Photo 1** shows the outside appearance of the side wall after a press-oil-coated electro-galvanized steel sheet and a self-lubricating steel sheet had been press-formed. Despite the coating with press oil, minute flaws are apparent in the press-forming direction, and damage to the surface of the electro-galvanized steel sheet can be observed. This was caused by contact between the metallic mold and the steel sheet, and indicates that press forming had involved mixed lubrication near the boundary condition. On the other hand, the self-lubricating steel sheet shows hardly any surface damage. This confirms that the resin had covered the irregular surface of the steel sheet, and in addition, the polyolefin wax had reached its melting point and melted as the temperature rose during pressing. Consequently, pressing was in the mixed lubrication condition near the hydrodynamic state in which the steel sheet and metallic mold would not touch each other. This is the main reason why the newly-developed self-lubricating steel sheet has excellent press formability.

3.2.3 Effect of resin coating weight

To investigate the effect of resin coating weight on press formability, a high-speed cup drawing test was carried out with various resin coating weights. The results are shown in **Fig. 9**, and indicate that LDR increases as

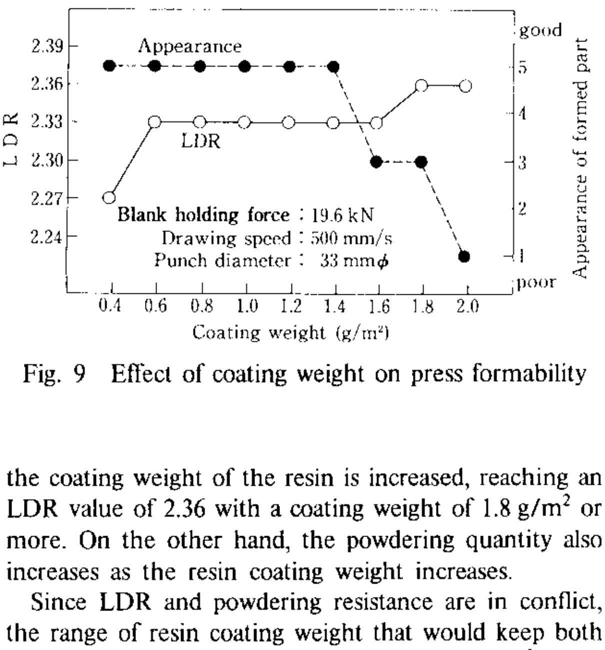


Fig. 9 Effect of coating weight on press formability

the coating weight of the resin is increased, reaching an LDR value of 2.36 with a coating weight of 1.8 g/m^2 or more. On the other hand, the powdering quantity also increases as the resin coating weight increases.

Since LDR and powdering resistance are in conflict, the range of resin coating weight that would keep both these characteristics consistent is 0.6 to 1.4 g/m^2.

3.2.4 Effect of baking conditions

To investigate the effect of the baking temperature for the lubricating resin on press formability, a high-speed cup drawing test was conducted on samples baked at various temperatures. The result shown in **Fig. 10** indicates that the range of baking temperature for

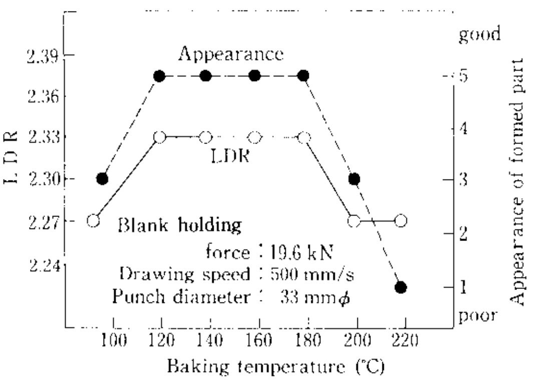


Fig. 10 Effect of baking temperature of resin on press formability

which LDR is the highest without powdering occuring was 120 to 180°C. The reason for this is that a baking temperature below 120°C was insufficient for complete curing of the resin, so that sufficient cohesion and adhesion of the lubricating film could not be obtained. Conversely, a baking temperature of 200°C or above is near the thermal decomposition temperature of 220°C[8] for the vinyl-acetate resin, so that the resin partially decomposed, thereby lowering the cohesion and adhesion of the lubricating film.

4 Performance of RIVER ZINC FS

4.1 Testing Method

RIVER ZINC FS, produced by coating and baking the vinyl-acetate polyolefin-wax-based lubricating resin under the appropriate conditions, and an electro-galvanized steel sheet with a chromate conversion coating (Cr coating weight of 50 mg/m^2) were tested for press formability, corrosion resistance, anti-fingerprinting, and weldability. Press formability was evaluated by the high-speed cup drawing test, and the corrosion resistance was evaluated by a salt spray test on the flat sheet and press-formed part according to JIS Z 2371. Anti-fingerprinting was evaluated by coating the steel sheet with white vaseline and measuring the color difference (ΔE) before and after coating. Weldability was evaluated by the tensile strength of a 1.2-mm thick specimen welded under a pressing force of 2.94 kN with a welding cycle of 14 at various values of electric current.

4.2 Results

Table 1 summarizes the results of the performance investigation. It can be seen that the self-lubricating steel sheet has, compared with the electro-galvanized steel sheet, a higher LDR value and better press formability. **Photo 2** shows the samples after continuous cup drawing. The press-formed part from the electro-galvanized steel sheet shows excessive powdering, while the self-lubricating steel sheet shows no powdering. **Photo 3** shows the results of the corrosion resistance test on the press-formed part, the self-lubricating steel sheet having no white rust even after 48 h, indicating excellent corrosion resistance. The value for ΔE in Table 1 is lower with the self-lubricating steel sheet than with the electro-galvamized steel sheet, indicating better anti-finger-

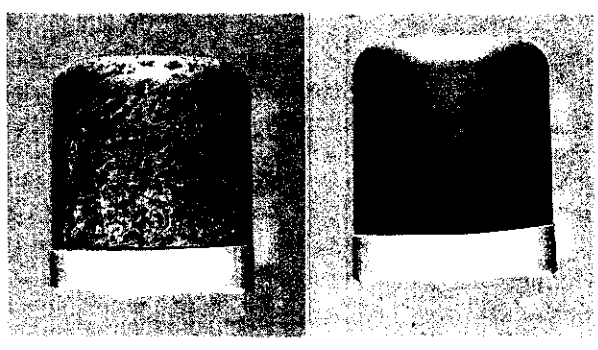
Table 1 Performance of RIVER ZINC FS

		Electro-galvanized steel	RIVER ZINC FS
Press formability	LDR	2.15*	2.33
	Appearance of formed part	Poor*	Good
Corrosion resistance (Salt spray test)	Flat part (240 h)	White rust 100%	No corrosion
	Formed part (48 h)	White rust 100%	No corrosion
Anti fingerprint		ΔE=3.45	ΔE=0.87

* With lubricating oil

Electro-galvanized steel (with lubricating oil) RIVER ZINC FS

Photo 2 Appearance of formed parts after continuous cup drawing test



Electro-galvanized steel (with lubricating oil) RIVER ZINC FS

Photo 3 Appearance of formed parts after salt spray test (after 48 h)

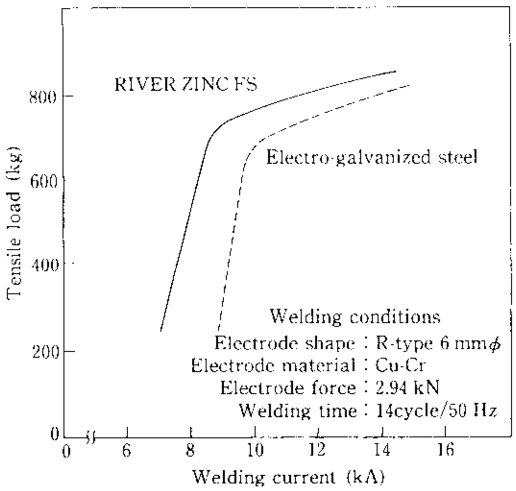


Fig. 11 Spot weldability of electro-galvanized steel and RIVER ZINC FS

printing characteristics in the former than in the latter. **Figure 11** shows the results of the weldability test. While the self-lubricating steel sheet required a higher electric current, it could be welded in the same manner as that for the electro-galvanized steel sheet.

5 Conclusions

Studies have been made on the self-lubricating steel sheet RIVER ZINC FS, concerning a press formability evaluation method which can simulate practical press forming and the optimum coating conditions for resins and lubricating agents which affect press formability, and the following points have been clarified:

(1) The powdering which occurs in practical press forming was experimentally reproduced by the continuous cup drawing test at a drawing speed of 500 mm/s. This method has made it possible to evaluate powdering resistance.

(2) The resin system of polyolefin wax added to vinyl acetate has been found to provide the best lubricating qualities. The high-T_g resin is effective for coating the steel sheet without thermally decomposing, and alleviates friction during press-forming, even after coming into contact with the hot die and punch. As a lubricating agent, polyolefin wax melted as the die temperature rises, thereby alleviating friction with the metallic mold in the manner of hydrodynamic lubrication.

(3) With this resin system, the optimum coating weight range and baking temperature range to provide a compatible LDR value and powdering resistance are 0.6 to 1.4 g/m^2 and 120 to 180°C, respectively.

(4) This self-lubricating steel sheet has outstanding press formability, corrosion resistance, and anti-fingerprint qualities. It also has similar weldability to electro-galvanized steel sheet after setting up the most appropriate welding conditions.

This newly-developed self-lubricating steel sheet RIVER ZINC FS permits the omission of oiling and degreasing processes, through the selection of the resin system, lubricating agent, resin coating weignt, and baking conditions, thereby shortening the press forming process and improving the work environment. RIVER ZINC FS is being inereasingly used in the manufacture of electrical appliances.

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