DEVELOPMENT OF EVALUATION METHOD FOR FRICTIONAL CHARACTERISTICS OF ZINC COATED STEEL SHEET

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Abstract

The frictional characteristics of Zn-Ni coated steel sheets were investigated by draw bead test and strip draw test. In strip draw test, the frictional characteristics were evaluated by the drawing force ratio (T_c/T_s) for half coating-stripped specimens. It is clarified that the drawing force ratio obtained by strip draw test is a convenient parameter compared to coefficient of friction obtained by draw bead test to evaluate the frictional characteristics of Zn-Ni coated steel sheets.

1. Introduction

The recent needs of the automotive industry to improve corrosion resistance of automobile body have led to extensive use of various kinds of zinc coated steels up to 50~60% of body-in-white materials ; pure zinc coated steel, galvannealed steel, zinc alloy coated steel (Zn-Fe, Zn-Ni), zinc-organic coating and others.

However, the change from the traditional bare, cold-rolled steels to the zinc coated steels has caused several problems in press forming, for example the damage of coating layer (peel off into powdering) and the variation of the frictional characteristics. The frictional characteristics of zinc coated steel depend on the nature of the coating layer such as phase composition in coating, micro-hardeness, morphology of the coating surface and other factors [1,5,10]. Moreover actual press performance of zinc coated steel was found to be quite different from that of cold-rolled steel. In general, the press formability of zinc coated steel depends on both the mechanical properties of the substrate and the frictional characteristics on the coating surface as discussed in Meuleman et al. [2] and Kimoto et al. [10].

It is often said that one of the forming defects - fracture - occurred in stamping process of the zinc coated steel sheets is mainly contributed by the change of frictional characteristics due to existence of zinc coated layer, but not by the change of mechanical properties in coating process.

Many studies [4,5] have been focused on the evaluation of frictional characteristics of zinc coated steels and several evaluation methods [6,7] were proposed. Draw bead simulation test (DBS) developed by Nine [8] is the most widely used method to evaluate the frictional characteristics by measuring quantitatively frictional coefficient.

Pure zinc coating, electro Zn-Fe and Zn-Ni alloy coated steels are mainly used for both exterior body panels and underbody or structure panels of the automobile. Among these Zn-Ni coated steels have been reported to have excellent anti-corrosion property while retaining good formability, weldability and paintability because of their high melting point [9]. The Zn-Ni coated steels are normally produced with 20~40g/m^2 coating weights and nickel contents in a narrow admissible range of 11~14% Ni compared to wide range 14~20% Fe in Zn-Fe coating. The nickel content in coating layer is very sensitive to the various plating parameters - current density, solution flow, electrolyte concentration, PH and temperature - thus it is difficult to control the Ni content within the admissible range of 11~14%.

Several papers [3,9,10] have reported that Zn-Ni coated steel containing below 11% Ni exhibits high frictional resistance in friction test and poor press formability compared to that of above approximate 11% Ni. From the X-ray diffraction analysis of the Zn-Ni coating, it was clarified that the Zn-Ni coating below 11% Ni content shows a composite phase of η (Zn), δ(Ni_3Zn_{22}), and γ (Ni_5Zn_{21}). Owing to its low hardness of η phase, η phase contributes to easy galling tendency and high friction coefficient.

Due to its difficulty in control of Ni content within the admissible range, it is necessary to estabilish an appropriate method of evaluation for frictional characteristics of Zn-Ni coated steel sheet in order to avoid the possible fracture during press forming and improve its press perfomance.

In this paper the surface properties of Zn-Ni coated layer for various Ni contents were investigated by Scanning Electron Microscopy (SEM), X-ray diffraction (XRD) and micro-hardness test. The draw bead simulation test for as-received coated specimen and the strip draw test with circular bead for half coating-stripped specimen were performed respectively to evaluate the frictional characteristics of the Zn-Ni coated steels containing various Ni contents. As a parameter to evaluate the frictional characteristics of Zn-Ni coated steel in the strip draw test, the ratio of drawing force at coated part versus drawing force at stripped part was compared with the coefficient of friction obtained by DBS.

2. Experimental Procedure

2.1 Tested Materials

Twenty seven Zn-Ni alloy coated steel sheets manufactured from POSCO were used in this experiment. These coatings contain various Ni contents in coating layer and therefore are suitable to investigate the influence of Ni content on frictional characteristics. Table 1 shows the mechanical properties of typical samples among these coatings. Tensile tests were performed at 10mm/min speed using 20 ton Instron universal testing machine for ASTM standard E-8 tensile specimens. At each Ni content, the values of 1st row are for the case of as-received coated specimen and the 2nd row for coating-stripped specimen after chemical removal of coating layer. The coating layer was removed by submerging about 60 seconds in a solution of 30% hydrochloric acid (HCl) and 1~2 drops of hexamine as a inhibitor. The difference of mechanical properties between 1st and 2nd rows gives the constraint effect of coating layer to the deformation of substrate under tensile testing.

The Vickers micro-hardnesses of these coatings were measured by applying a 10g load on the surface for 15 seconds. The surface morphologies and the phase composition for these coatings were observed by Scanning Electron

Microscopy (SEM) and X-ray diffraction (XRD), respectively.

2.2 The Method of Evaluation for Frictional Characteristics

The frictional characteristics of these coatings were evaluated by draw bead simulation test (DBS) for as-received coated specimens and strip draw test for half coating-stripped specimens. Fig.1 shows a schematic view of DBS to measure the coefficient of friction. All tests were performed by Nine standard test procedure. The test specimens were 45mm wide by 400mm long strips. Two identical specimens were used to obtain a single coefficient of friction. Before test, the beads and specimens were coated with reference lubricant, washing oil used in press shop. At this test the specimen was pulled through beads at constant speed of 200mm/min, relatively low speed compared to actual press forming condition. Two sets of tests were conducted. First, a set of fixed beads was used to determine the drawing and normal forces representing the repeated bending and unbending deformation plus the friction. Second, a set of frictionless roller beads was used to determine only the bending and unbending deformation. During the test, the drawing force, normal force, and the drawing length are continuously recorded on an X-Y recorder. These data were then used to calculate the coefficient of friction as follows

$$\mu = \frac{\text{Drawing force}}{\text{Normal force}} = \frac{T_{d+f} - T_d}{\pi N_{d+f}} \qquad (1)$$

Where T_{d+f} is the drawing force through the fixed beads, T_d is the drawing force through frictionless roller beads, and N_{d+f} is the normal force generated by the fixed beads. It is needed that the male bead interleaf distance remains constant value of 9.53mm during two sets of tests.

A schematic view of strip draw test with circular bead is shown in Fig.2. This tester has been designed to simulate a bead portion of die face in actual press forming. The specimen is same size of DBS specimen except stripping off the half part of the coating layer at as-received coated specimen in longitudinal direction as shown in Fig.3 (a) and (b).

After setting the specimen between male and female beads under constant clamping force, the specimen is pulled through beads. The drawing force (T_c) for the coated part is followed to the drawing force (T_s) for the stripped part. The ratio of drawing force T_c to T_s (T_c/T_s) is taken as an parameter to evaluate the frictional characteristics of Zn-Ni coated steel. As the ratio (T_c/T_s) becomes large, the frictional characteristics become worse and the reverse is true. The test was carried out at constant clamping force of 250kgf and speed of 200mm/min. The reference lubricant was also used in this test.

3. Results and Discussion

Figure 4 shows the surface morphologies for various Ni contents. It is clarified that the surface morphology of Zn-Ni coated sheet varies depending upon Ni content. The Zn-9.8% Ni coated sheet exhibits rough and smooth areas on the overall observed surface. This surface property contributes to an increase of surface roughness. However as the Ni content increases, the crystals of coating become growing into nodule shape and their size decreases, thus the surface roughness decreases. Above 11.6% Ni content the coating has much smoother surface.

Figure 5 represents the effects of Ni contents on the Vickers micro hardness. The micro hardness of coating layer significantly decreases below than 11% and increases smoothly above 11% Ni content. This is due to relative increasement of hard γ (Ni_5Zn_{21}) phase in coating layer above 11% Ni content. Below 10% Ni content the coating layer contains relatively much soft η (Zn) phase. This smooth surface property and high hardness above 11% Ni content give lower coefficient of friction.

Figure 6 denotes the effects of Ni contents on the coefficient of friction obtained by draw bead simulation test. From Fig.6 it is said that the coefficient of friction is very sensitive to Ni content in coating layer. Moreover the Zn-Ni coated steels have higher or lower coefficients of friction than that of stripped cold-rolled steels. The coefficient of friction increases rapidly as Ni content decreases. Especially the coefficient of friction near 9.5% is high and approximately double value compared to that of 11~14% Ni content. Also the coefficient of friction for Zn- (11~14%) Ni coated steel is similar to that of the stripped cold-rolled steel.

The drawing force versus drawing length curve for half coating-stripped specimen in strip draw test is shown in Fig.7. In the case of Zn-9.8%Ni coated steel, the drawing force for the coated part increases suddenly after passing the coated/stripped boundary with initial load spike at the boundary. This is due to the relative poor frictional characteristics of the coated part compared to that of the stripped part. However in the case of Zn-11.6% Ni coated steel there is no initial load spike at the boundary and a transition from the stripped part to the coated part occurs smoothly, and drawing force for the coated part is a little lower than that of the stripped part. This means that as expected from Fig.6 the frictional characteristics for the coated part is almost similar to that of the stripped part.

Figure 8 shows the drawing force ratios (T_c/T_s) for all Zn-Ni coated steels. In comparision with coefficient of friction in Fig.6 good correlation between coefficients of friction and drawing force ratios is shown. The drawing force ratio increases very sharply as the Ni content decreases below 11%. But above this content the drawing force ratio converges nearly to constant value of 1.0. Therefore it is deduced that the coated steels containing 11~14% Ni content have similar frictional characteristics compared with stripped cold-rolled steels.

Due to the simplicity of test procedure, the strip draw test with circular bead for half coating-stripped specimen is a simple and good method to evaluate the frictional characteristics in actual press forming. This appropriate test method can be used to check the press formability of Zn-Ni coated steel sheets in respect of friction characteristics.

4. Conclusions

Draw bead simulation tests for as-received coated specimen and strip draw test for half coating-stripped specimen were performed respectively to investigate the frictional characteristics of Zn-Ni coated steel. The drawing force ratio obtained by strip draw test for the half coating-stripped specimen was compared with the coefficient of friction obtained by draw bead simulation test for as -received coated specimen. It is concluded that drawing force ratio (T_c/T_s) by strip draw test is a convenient parameter and can be used as an alternative with coefficient of friction by draw bead simulation test to evaluate the frictional characteristics of Zn-Ni coated steel sheets.

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Table 1. Mechanical properties of tested materials

Material	Coating Weight (g/m²)	Alloy Content (Wt.%)	Thick-ness (mm)	YP (kg/mm²) 0.2% offset	TS (kg/mm²)	El(%) over 50 mm	R value	n value	K (kg/mm)
EGN	35/35	Ni: 9.8	0.796	15.7	29.3	47.2	1.99	0.230	50.2
	-	-	0.794	14.3	28.7	48.2	2.16	0.246	49.4
EGN	35/35	Ni:10.6	0.792	15.7	29.0	44.1	1.70	0.232	49.3
	-	-	0.788	15.0	28.8	46.6	2.00	0.247	49.0
EGN	35/35	Ni: 11.0	0.781	17.0	31.1	43.8	1.71	0.224	54.1
	-	-	0.778	16.6	30.7	44.9	1.79	0.232	53.4
EGN	30/30	Ni: 11.6	0.695	16.3	29.8	44.0	1.71	0.214	51.6
	-	-	0.692	15.3	28.9	47.2	2.02	0.223	49.2
EGN	30/30	Ni: 13.0	0.746	17.0	29.9	45.0	1.64	0.235	50.8
	-	-	0.744	15.2	28.9	49.2	1.92	0.236	48.4

* EGN : Electro Zn-Ni alloy coated steel sheet.

* 1st row : coated steel, 2nd row : stripped steel

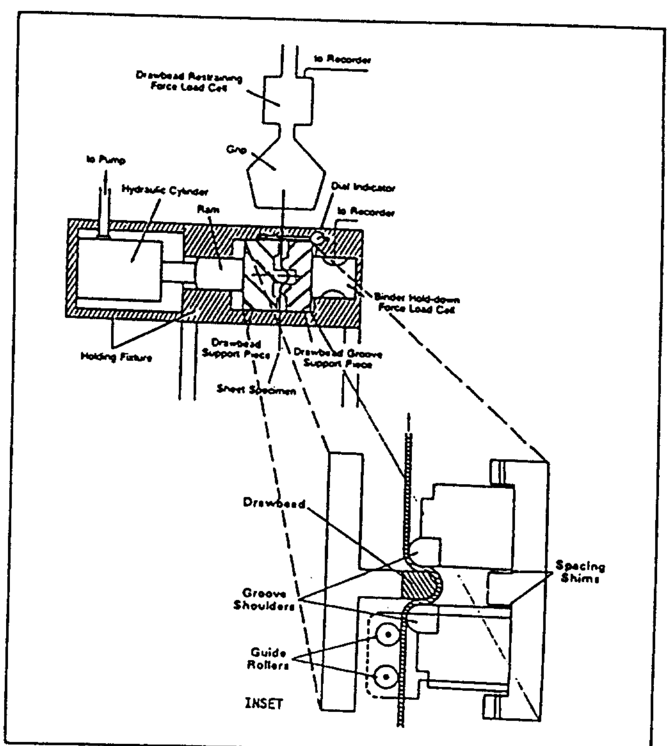

Fig.1 Schematic view of draw bead simulation test

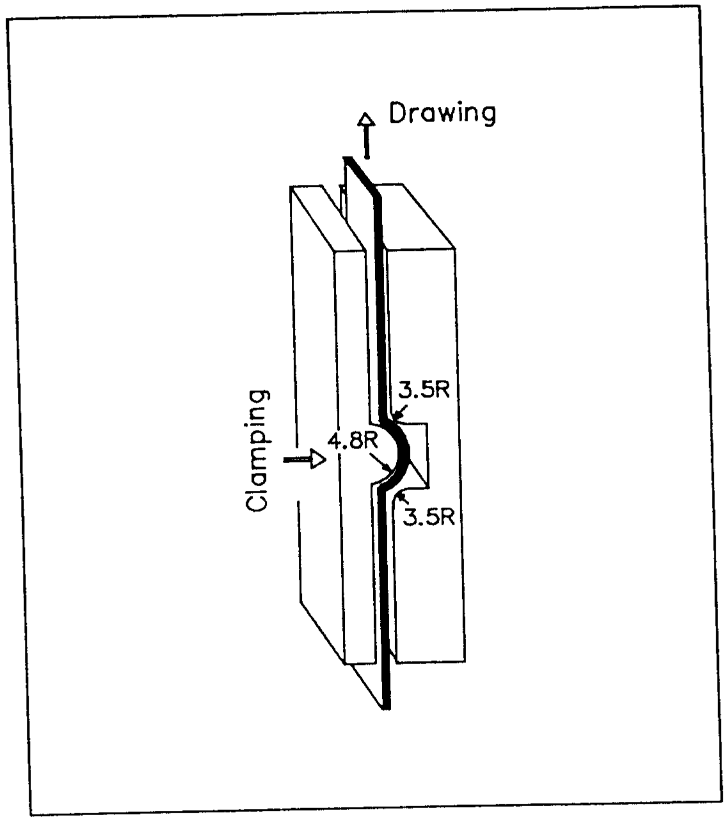

Fig.2 Schematic view of strip draw test with circular bead

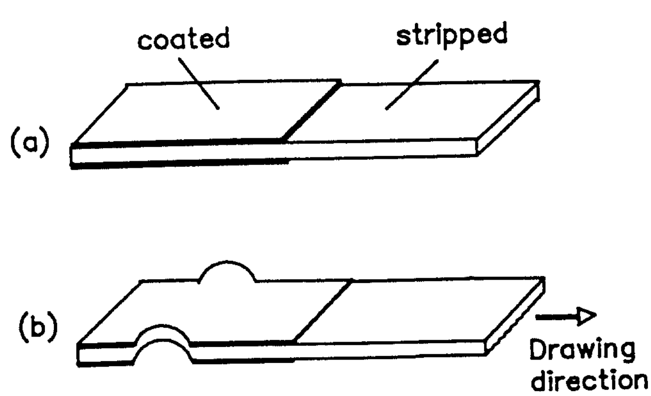

Fig.3 Specimen shape stripped off the half part of the coating layer at as-received coated specimen in longitudinal direction
(a) before test, (b) after test

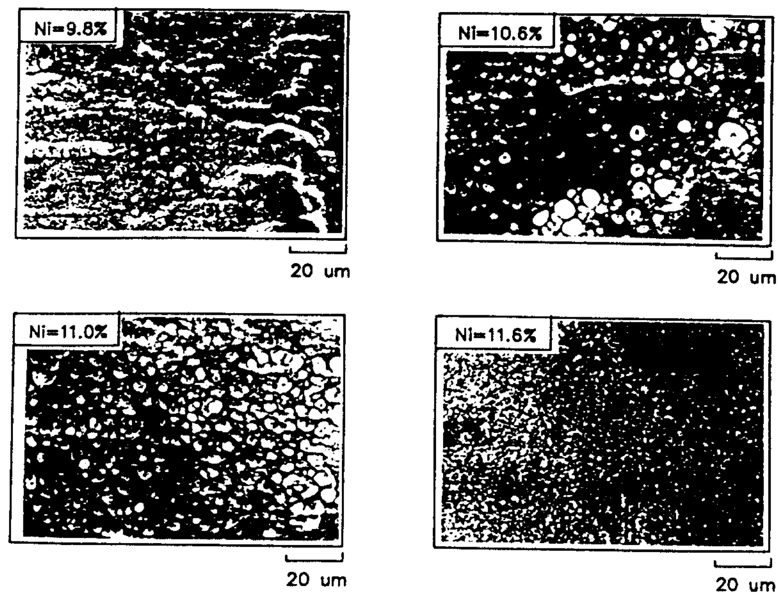

Fig.4 Surface morphologies for Zn-Ni coated steel sheets with various Ni contents

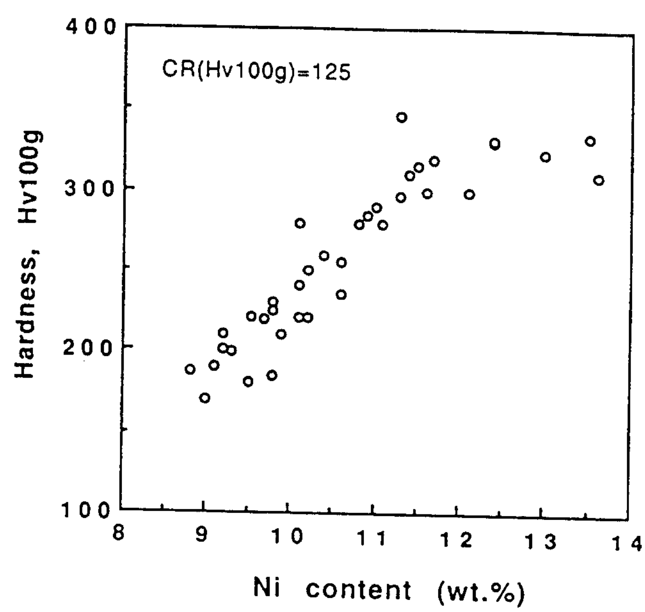

Fig.5 Effect of Ni content on the Vickers micro hardness of coating layer

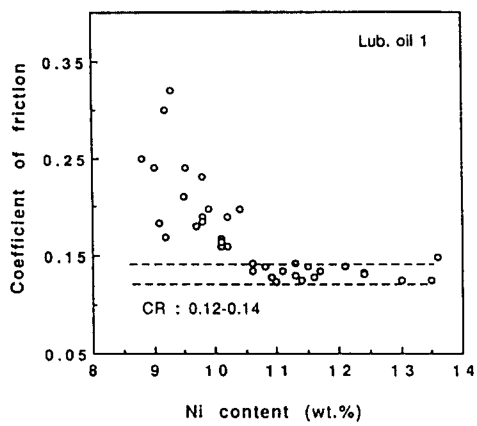

Fig.6 Effect of Ni content on coefficient of friction obtained in draw bead simulation test

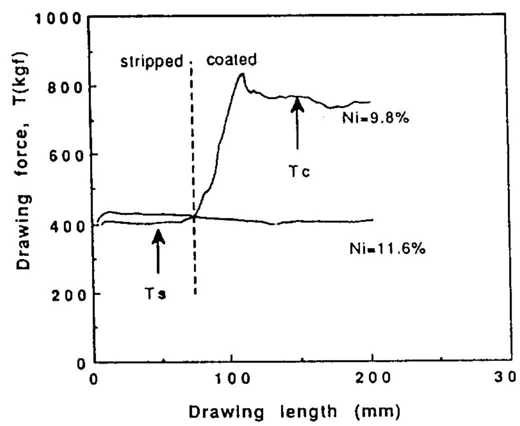

Fig.7 Drawing force versus drawing length for Ni = 9.8 % and Ni = 11.6 % obtained in strip draw test

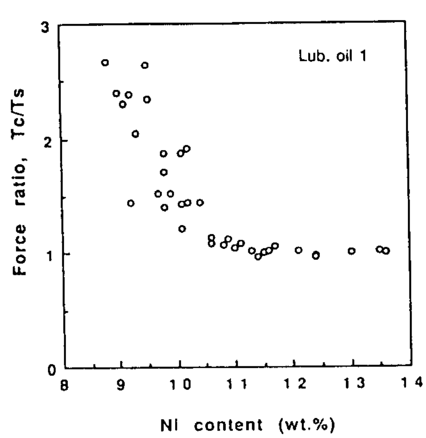

Fig.8 Effect of Ni content on drawing force ratio (T_c/T_s) obtained in strip draw test