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A QUALITATIVE AND QUANTITATIVE INVESTIGATION OF THE SURFACE TRIBOLOGY IN FORMING GALVANNEAL STEEL

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ABSTRACT

In the forming of automotive parts, the sheet metal is forced to slide between die and punch surfaces to obtain the desired geometric shape. During this frictional sliding the coating could be damaged if the forming parameters and the lubricants are not properly selected. This will result in deviations in the coating properties which directly affect the product .quality; for example surface roughness, thickness of the coating and hardness in the final product. Contact pressure, lubricant and speed could be considered as the basic forming parameters which affect the coating characteristics during forming. The effect of lubricant with multiple forming passes was examined in this study.
Galvanneal steel samples were tested using a Flat Face Friction Test in the presence of different forming conditions and lubricants. The samples were re-drawn to analyse the changes of the tribological parameters for the multiple die passes present in most of the industrial stampings. The surfaces were examined with an optical microscope for a qualitative investigation of the surface topography. Surface roughness was measured before and after forming with a Taylor Hobson profilometer.

Keywords: Surface roughness, friction, lubrication

1. INTRODUCTION

Zinc coated steels are commonly used in the automotive industry and enhanced corrosion resistance is one of the main reasons for the increased use of zinc coated steels. Galvanneal steel, which is known as GA, has been recognized to be better for automotive applications compared with galvanized steel or electroplated steels. Because of the satisfactory compatibility with post processes such as spot welding, phosphating and painting, GA steel is typically used in exposed applications such as exterior panels of automotive bodies that require superior painting and joining properties. Among the other advantages, the manufacturing cost of Galvanneal is considerably lower than electroplated steels [1].

Galvanneal is produced by hot dipping the steel sheets in a bath of molten zinc and aluminium followed by annealing to create a Fe-Zn intermetallic layer [1,2]. During the hot dipping process three different Fe-Zn layers are formed, these are known as γ (High Fe), δ and ζ (low Fe Al rich) [1]. The ζ layer is the very thin surface layer which improves the surface hardness. The δ layer is the intermediate layer which contains zinc and aluminium and is comparatively soft. The substrate layer (γ) is hard and brittle, but due to the properties of the steel base, GA has proven to have adequate formability for automotive components compared with the uncoated material [1,2]. The intermetallic substrate layer also improves the hardness and has the potential to reduce the flaking and cracking of the coating [3]. However, it has been found [4] that the GA steel has a higher degree of flaking compared with electroplated steels. The powdering which is common when forming GA can also cause severe problems in tooling. The coating particles could be accumulated in dies resulting in surface defects and process difficulties [5]. The powdering depends on several factors; coating weight, composition and chemistry, as well as the microstructure [1,5,6]. Therefore, in forming GA, it is important to consider the reduction of powdering of the brittle alloy coating.

The skin passing step in the Galvannealing process results in better control in surface texture and this improves frictional performance [1,3]. Undeformed Galvanneal sample show a relatively rough surface on a micro scale. This crystalline surface structure is ideal for lubricant entrapment in metal forming since the flow of lubricant through micro-channels enhances the lubrication conditions. In the forming of automotive parts, the sheet metal is forced to slide between the die and punch surfaces to obtain the desired geometric shape. In such operations, frictional sliding and bending and unbending could be considered as the two basic causes for deterioration of coating properties. In frictional sliding, relative movement between the work and tooling surfaces will result in removal of the coating material from the sheet by rubbing if the forming parameters and the lubricants are not properly selected. This will cause deviations in the coating properties; for example surface roughness, thickness, uniformity of the coating, which directly affect the final product quality. In many industrial forming applications, the sheet is forced to slide between multiple die surfaces and, therefore, the damage to the coating could be accumulated. The Flat Face Friction (FFF) test simulates the conditions of frictional sliding and therefore the changes in the coating characteristics and surface tribology due to frictional sliding can be determined.

2. EXPERIMENTAL PROCEDURE

The Flat Face Friction (FFF) Test is considered as the simplest, but most suitable technique for assessing frictional behaviour and tribological conditions during sliding since it avoids any bending and unbending effects and also the effect of work hardening.

A specially designed FFF rig was mounted to the cross head of the hydraulically driven Instron tensile testing machine located at BlueScope Steel Research Laboratories, Port Kembla. The rig consists of a pair of rectangular flat dies which were made out of K245 tool steel with average roughness of 0.04μm and 0.06μm in the longitudinal and transverse directions, respectively.

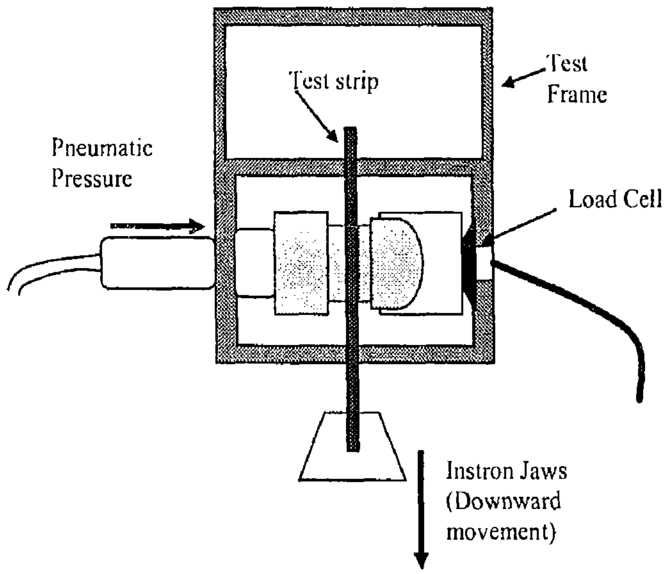


Figure 1: Schematic Diagram of Flat Face Friction Test

Zincanneal® which is the proprietary Galvanneal product manufactured by the BlueScope Steel was used for the experimental work. The properties of the samples are described in Table 1. The prepared samples were in size 350 mm in length, 50 mm in width and the average thickness was 0.8 mm. Sheet samples were lubricated with commercial forming lubricants with different properties and drawn between the flat dies. The specifications of the test parameters are shown in Table 2. The drawing and clamping force were recorded at every 0.4 mm length increment over a testing length of 130 mm and the steady state average was considered as the representative value for each data set.

The coefficient of friction was calculated using Coulombs Law of Friction for each data set. The test strips were redrawn up to three times to investigate the effects of redrawing on the surface roughness and coefficient of friction

Table 1: Sample Description of Galvanneal Steel

Parameter	Description
Quality	ZANEALG3NS-60F60-UNPHOS-NB-OIL-PRIMS
Tensile Strength	295±12 MPa
Coating Mass	60 g/m^2
Nominal Coating Thickness	0.01mm per side

Table 2: Testing Parameters

Parameter	Description
Clamping Force	10 kN
Drawing Speed	50 mm/s
Lubricant	Lubricant 1: Water Based (High Viscosity) Lubricant 2: Low Viscosity Pressing Fluid Lubricant 3: Water Soluble Poly Alkaline Glycol –PAG (Medium Viscosity)
Channel Output	Drawing Force, Clamping Force

A Taylor-Hobson Profilometer was used to measure surface roughness (R_a) and peak count (P_c) after each draw. The measurements were taken in the transverse direction for trace lengths ranging from 2.5mm to 12.5mm at different sections and the profiles were filtered with a 0.8 mm Gaussian Filter. The percentage change in R_a and P_c after each draw was calculated. The surfaces of the drawn samples were examined with the optical microscope at a magnification of 200 for qualitative analysis of the surface.

3. RESULTS AND DISCUSSION

When the high viscosity lubricant (lubricant 1) and the medium viscosity PAG lubricant (lubricant 3) were used, the change in tribological parameters (both surface roughness and peak count) are lower than for the low viscosity lubricant (lubricant 2) (Figure 2). The load carrying capacity of the lubricant increases with the viscosity. Even though the viscosity of lubricants 3 is less than that of lubricant 1, slightly better results were obtained with lubricant 3 which was manufactured using Poly Alkaline Glycol (PAG) technology. Due to the decreased effects on the coating properties and reduction in wear, Poly Glycol Alkaline Lubricants could be ideal for a brittle coating like GA that usually has a high degree of surface wear.

A previous study by the authors [7] showed that this tribological system operates in the mixed lubrication regime where partial metal to metal contact occurs within the experimental pressure and speed conditions. Therefore it is clear that the change in the coefficient of friction in successive draws depended on the change in the surface conditions and also the influence of lubrication. It was observed that the coefficient of friction changed when the strips were re-drawn. This can be explained by the reduction in tribological parameters: surface roughness and peak count due to flattening of the surface asperities. During redrawing, the accumulated flattening of asperities resulted in further drops in surface roughness (Figure 2(a)) and peak count (Figure 2(b)).

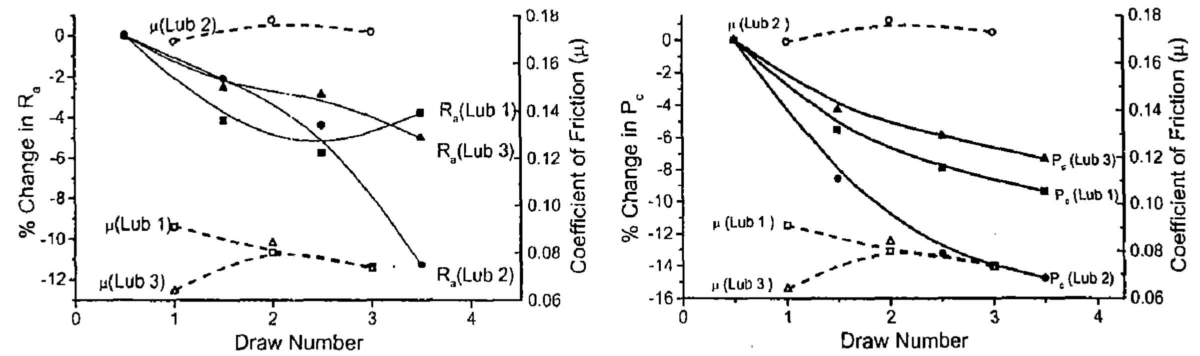


Figure 2: Changes of Surface Parameters and Coefficient of Friction with the Different Lubricants in Flat Face Fiction Test, R_a is Surface Roughness and P_c is the Peak Count. Clamping Force 10kN [7]

The dark surface layer which was visible almost over the Galvanneal surface before the drawing is identified as the ζ layer. This ζ layer is an important component of Galvanneal created during post annealing in the coating process and providing adequate hardness and roughness in the surface of the coating [1,2]. The undeformed surface profile of Galvanneal is shown in Figure 3.

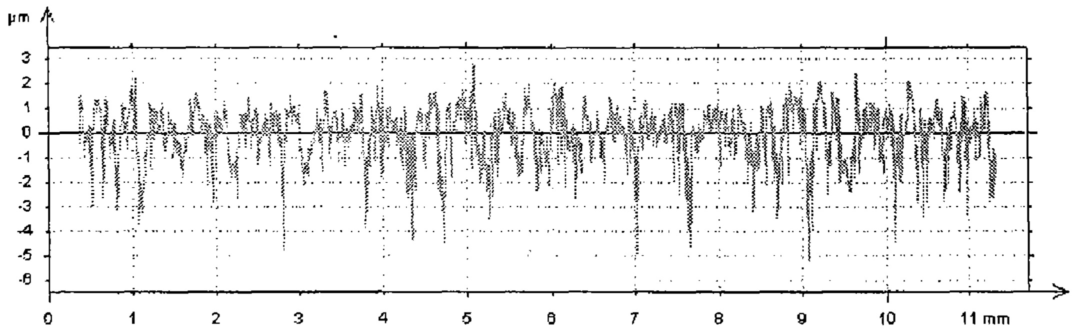


Figure 3: Roughness Profile of Undeformed Galvanneal (R_a =0.765μm) Filtered with 0.8 mm Gaussian Filter

The ζ layer also protects the coating from tooling and other causes of surface damage. However, it was seen that during sliding, flattening of the peak asperities occurred (Figure 4). As this happened, the tool very thin ζ layer in consecutive draws and a shiny δ phase became visible (Figure 5).This soft δ zinc coating is very sensitive to damage by the tooling compared with the ζ phase and it has a high tendency to peel [9,10]. In the first draw for all lubricants, a considerable degree of flattening was observed. This leads to a reduction in the surface roughness and peak count which was observed in the profile measurements. However, due to the high softness of the δ phase, tool scratches are visible in the longitudinal direction (the direction of drawing) after consecutive draws; some of the tool scratches have a considerable depth (Figure 4). This leads to an increase in the surface roughness in the transverse direction.

Low viscosity synthetic oil (Lubricant 2) showed the highest flattening and occurrence of scratches among the three lubricants tested. For the high viscosity, water-based lubricant (Lubricant 1), the flattening, and therefore, the removal of ζ phase is reduced compared with Lubricant 2. For both Lubricants 1 and 2 the micrographs show large areas where the ζ phase has been removed. The micrographs for Lubricant 3 show that removal of the ζ phase has been confined to smaller individual areas of the surface (Figure 5). These micrographs support the results of the roughness measurements (Figure 2) where the sheet with Lubricant 3 was found to be least affected by the sliding wear.

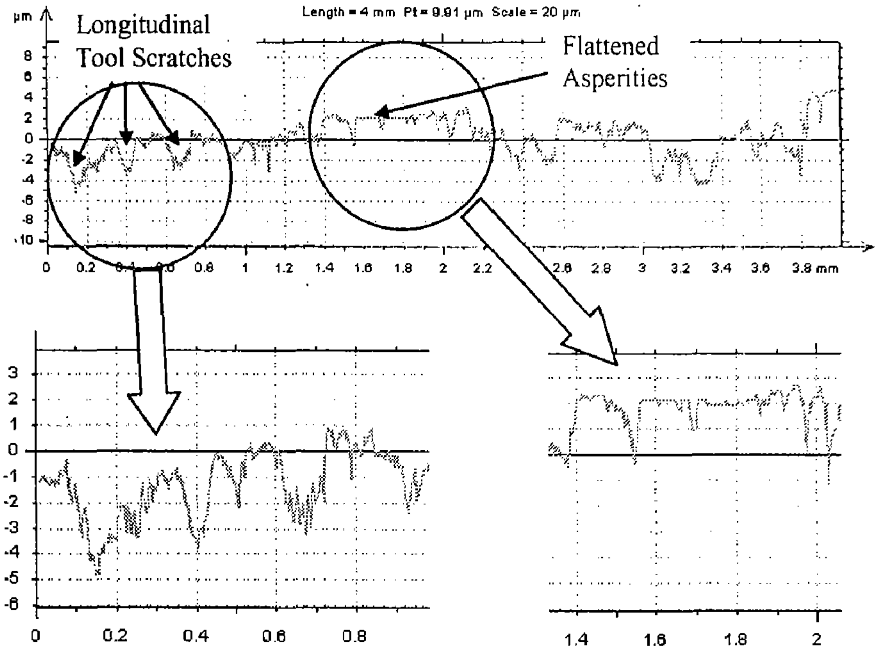


Figure 4: Flattening of Asperities and Tool Scratches in Galvanneal (Third Draw with High Viscosity Water Based Lubricant, Clamping Force 10kN)

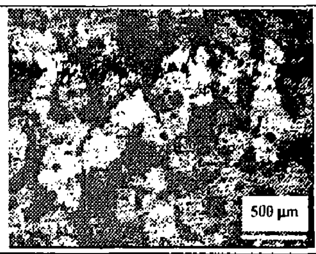
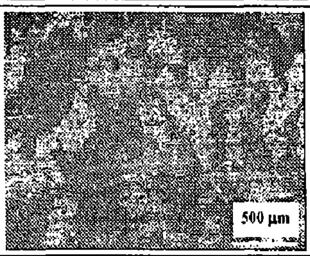
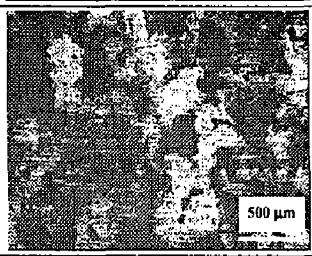
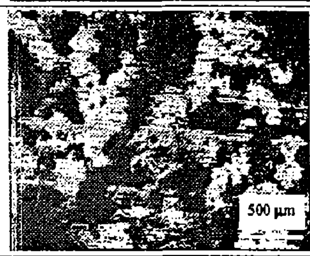
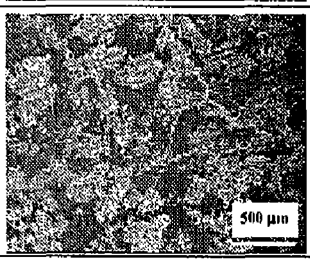
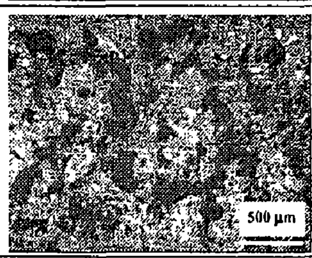
	Draw 1	Draw 2	Draw 3
Lubricant 1			
Lubricant 2			
Lubricant 3			

Figure 5: Changes in the Surface Texture and Appearance of Difference Phases of Zinc Coating with Different Forming Lubricant for Multiple Die Passes: Clamping Force 10kN

With the Draw Bead Test for friction, Dalton et al. [11] have proved that the coating hardness and surface topography of the sheet were important factors in determining the response of the sheet to lubrication conditions. In all of these tests with GA, the coating becomes softer as the hard ζ phase is removed. Flattening of asperities also occurs during this process and the surface becomes smoother. As sliding progresses, scratching of the soft δ phase increasingly contributes to the friction. These changes all contribute to deviations in the frictional conditions.

4. CONCLUSION

The lubricant is an important factor determining the frictional response in forming coated steels. Lubricant 3, a PAG lubricant, showed better frictional properties as well as the smallest change in tribological parameters on the GA surface. In forming GA, the removal of the hard surface layer results in the soft intermediate layer being exposed during sliding. This leads to deviations in the frictional conditions due to the change in the hardness in the friction couple. When the hard ζ layer is present in the friction couple, flattening of asperities occur which results in a smoother surface. However, upon further sliding, longitudinal scratches are created in the newly exposed soft coating layer (δ) which has a negative influence on friction. The resultant change in the coefficient of friction is the combined effect of the flattening creating a smoother surface and the softer phase playing an increasing large role.

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