INTERACTION BETWEEN THE COATING CHARACTERISTICS OF GALVANNEAL STEEL AND FORMING PARAMETERS DURING FLAT DIE DRAWING

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ABSTRACT

Galvanneal steel is considered to be better for automotive applications than its counterpart, galvanized steel, mainly because of its superior coating and surface properties. Galvanneal steel is produced by hot dipping sheet steel in a bath of molten zinc with small, controlled, levels of aluminium, followed by annealing which creates a Fe-Zn intermetallic layer. This intermetallic layer of the coating improves spot weldability and improves subsequent paint appearance. However, if the microstructure of the coating is not properly controlled and forming parameters are not properly selected, wear of the coating could occur during stamping. Frictional sliding of the sheet between the tool surfaces results in considerable amount of coating loss. An Interstitial Free steel with a Galvanneal coating of nominally 60g/m² was used for the laboratory experiments. Flat Face Friction (FFF) tests were performed with different forming conditions and lubricants to simulate the frictional sliding in stamping. Glow-Discharge Optical Emission Spectrometry (DG-OES) was used to measure the change in the coating thickness during sliding. Optical microscopy was considered for imaging the surfaces as well as an optical method to compare the changes in the coating thickness during the forming. The change to the Galvanneal coating thickness was found to be a function of forming parameters.

1. INTRODUCTION

Coated steels are extensively used in the automotive industry, largely due to their high corrosion resistance. Galvanneal is a commonly used type of coated steel in automotive applications and is produced by hot dipping the steel sheets in a bath of molten zinc (with minor aluminium additions) followed by annealing to create an Fe-Zn alloy coating [1, 2]. During annealing three different Fe-Zn layers are formed (Figure 1) and known as γ, δ (High Fe) and ζ (low Fe Al rich). The substrate layer (γ) is hard and brittle, but due to the properties of the steel base, Galvanneal (GA) has proven to have an adequate formability for automotive components [1,2] This intermetallic layer improves the hardness and reduces flaking and cracking during forming [3].

The Galvanneal steel is typically skinpassed to control surface texture and this improves frictional performance [1, 3].

Undeformed Galvanneal samples (Figure 2), shows a relatively rough surface on a micro scale. This crystalline surface structure is ideal for phosphating and painting.

In frictional sliding, if the forming parameters and the lubricants are not properly selected, relative movement between the work and tooling surfaces will result in rubbing and removal of the coating material from the sheet. This will cause deterioration in the coating properties, for example surface roughness, thickness of the coating and also the consistency of the coating over the area, which directly affect the product quality and deterioration of corrosion properties. Removal of coating can also cause severe problems in tooling. The coating particles could be accumulated in dies resulting in surface defects and process difficulties [4]. The powdering depends on several factors; coating weight, composition and chemistry, as well as the microstructure [1, 4, 5]. Therefore, in forming Galvanneal, it is important to consider the reduction of powdering of the brittle alloy coating.

Figure 1: SEM micrograph of Galvanneal cross section

Figure 2: Surface micrograph of Galvanneal
In industrial stamping, frictional sliding and bending and unbending could be considered as the two basic causes for coating damage. The Flat Face Friction (FFF) test is an important and simple method of friction testing in metal forming. Since the FFF test simulates the conditions in frictional sliding, the changes in the coating characteristics due to frictional sliding can be determined.

2. EXPERIMENTAL PROCEDURES

2.1 Flat Face Friction Test

Zincanneal®, which is a proprietary Galvanneal steel, manufactured by BlueScope Steel Ltd at Hastings, Victoria was used for the experimental work. According to manufacturer’s specifications, this product has a nominal coating weight of 60 g/m². To ensure maximum uniformity of the test samples, the edges of the coil were not used for trials [1].

A hydraulically driven, Instron 1341 Testing machine (Serial No: H7047) located at BlueScope Steel Research Laboratories, Port Kembla was used for the FFF test (Figure 3). A specially designed FFF test rig which consists of a pair of flat dies was mounted on the cross head. The dies were made out of K245 tool steel with average roughness (Rₚ) of 0.04μm and 0.06μm in the longitudinal and transverse directions, respectively. The width of each flat face was 45 mm. Therefore the samples have to be wider than 45mm to ensure the clamping pressure is distributed throughout the die surface. A rubber sponge was used for the application of the lubricant, which was identified as the most suitable way to obtain a uniform film thickness. The bottom end of the steel sample was fixed between the flat jaws (Figure 4). The samples (50mm in width, 350mm in length and 0.8mm thick) were drawn between the flat dies by moving the jaws downwards. The clamping force was applied with the aid of the hand operated pneumatic pump and was monitored digitally throughout the test.

![Figure 3: Flat Face Friction test rig mounted in the Instron tensile testing machine](image)

![Figure 4: Schematic diagram of Flat Face Friction test rig](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clamping Force</td>
<td>5, 10, 15 kN</td>
</tr>
<tr>
<td>Speed</td>
<td>50 mm/s</td>
</tr>
<tr>
<td>Lubricant</td>
<td>Lubricant 1: Water Based (High Viscosity)</td>
</tr>
<tr>
<td></td>
<td>Lubricant 2: Water Soluble Poly Alkaline Glycol – PAG (Medium Viscosity)</td>
</tr>
<tr>
<td></td>
<td>Lubricant 3: Low Viscosity Pressing Fluid</td>
</tr>
<tr>
<td>Measurement Length</td>
<td>0.4 mm</td>
</tr>
<tr>
<td>Testing Length</td>
<td>130 mm</td>
</tr>
<tr>
<td>Channel Output</td>
<td>Drawing Force, Clamping Force</td>
</tr>
</tbody>
</table>

The maximum representative value of the coefficient of friction was assumed to be around 0.2, which can be considered as a realistic representation for the given work, tool and lubricant combination. Based on the above approximation of the coefficient of friction, with the maximum clamping force of 15 kN applied, the drawing force would be 6 kN. Then, for a strip with a cross section 50x0.8mm, the normal stress on the strip would be 150 MPa which is below 168 MPa; the yield point of the sheet material. Therefore, it is clear that the deformation is just within the elastic limit and any thinning of the coating is not a result of the longitudinal or transverse plastic deformation of the sheet.
The mean surface roughness ($R_a$) and peak count ($P_p$) values were measured with a Taylor Hobson profilometer before and after drawing. The percentage change in each roughness parameter was calculated.

2.2 Glow Discharge Optical Emission Spectrometry (GD-OES)

Glow Discharge Optical Emission Spectrometry (GD-OES) is a powerful technique which has been successfully applied for zinc coated steels to investigate the elemental depth profiling [2, 6-9]. Once calibrated, GD-OES enables to determine the concentration of each element in the testing media as a function of depth into a sample [2, 7, 8]. In the spectrometer, there are 32 detectors, which have the potential of detecting and analysing 29 elements including most standard metals as well as other common elements like nitrogen, hydrogen, oxygen and carbon [7]. The instrument used in this analysis is LECO GDS 850A spectrometer equipped with a Grimm-type DC lamp for conductive samples and therefore, suitable for Galvanneal steel [7-9]. The instrument consists of a 4mm diameter anode for a sampling area of 12mm². In the analysis, the Galvanneal sample acts as a cathode and the anode and the cathode are separated by an O ring. The plasma current was maintained at 20mA. As sputtering progressed, a variable argon pressure, normally held around 5 torr, controlled the current [7].

![Graph showing elemental depth profiles](image)

Figure 5: GD-OES profile of undeformed Galvanneal G3 with nominal coating mass of 60 g/m²

Samples drawn in Flat Face Friction test were examined with GD-OES and the concentration of each key element was determined as a function of depth. The average zinc coating depth of the samples was determined with the elemental profiles. The coating loss due to frictional sliding was approximated with respect to the zinc iron intercept from the sample surface. Figure 5 shows a GD-OES depth profile of an undeformed Galvanneal coating. The GD-OES technique could be used to distinguish the different phases in the coating based on the pattern of the elemental curves.

3. RESULTS AND DISCUSSION

Despite the various elements present in the coating as well as in the substrate, only the elemental distribution of the iron and zinc was considered in determining the coating thickness. The most realistic representation for the coating thickness was assumed to be the Fe-Zn cross over point in the depth profile. It was observed that there is a clear decrease in the coating thickness with the increase of the clamping pressure in the FFF test as shown in the figure 6. This decrease is considered as a result of the surface wear in the frictional sliding. This occurs when the softer material in the friction couple, i.e. the sheet coating tends to peel off during sliding.

![Graph showing coating thickness variation](image)

Figure 6: The GD-OES representation of the coating thickness variation with the increase of the clamping force

It was observed that the surface roughness and the peak count in the formed Galvanneal samples have been reduced with the clamping force (Figure 7). Therefore, it can be suggested that the flattening of asperities have caused the reduction in roughness parameters and the flattening could result in the reduction of the nominal coating thickness. This result is supported by the GD-OES observations where the Fe-Zn intercept and the reduction of the surface roughness parameters show the same decreasing pattern with the clamping force (Fig. 7).

![Graph showing change in coating parameters](image)

Figure 7: Change in the coating parameters with the clamping force.
In undeformed samples, high concentration of carbon and oxygen was observed (Figure 5) at the extreme surface (1 micron or less). However, the concentrations of oxygen and carbon were seen to be reduced after forming. These reductions could have been the result of the removal of the surface layer due to flattening and peeling in sliding. Wilson [10] has found that under steady state conditions with low interface pressures, partial contact occurs and the adhesion of the friction couple is roughly proportional to the local interface pressure. Therefore, when the adhesion is decreased, the degree of rubbing and peeling of the coating will be increased at high interface pressures, which results in an increased reduction in coating thickness. Hishida et al. [11] have found that Galvanneal has a high tendency for flaking of the coating, and therefore the coating material loss is increased. It was found that the size of the delta grains as well as the iron coating weight has a direct influence on Galvanneal powdering [5]. This result is confirmed by Haynes [1]. In his work, he has found that the iron content in the coating has a significant effect on the powdering behaviour and stamping performance.

Forming lubricant is an important parameter which affects not only the friction conditions but also the removal of the coating due to sliding. The importance of lubricant selection has been highlighted by Haynes [1] as well as in the work by Long et al. [2]. It was observed there that the powdering performance of Galvanneal could be reduced by the effectiveness of the lubricant. As shown in the figure 8, there is a considerable difference in the coating thicknesses when different lubricants were used in the drawing. The smallest change in the coating thickness was observed when a medium viscosity Ploy Alkaline Glycol (PAG) lubricant (Lubricant 2) was used. This thickness change is much less that the thickness reduction when a high viscosity water based lubricant (lubricant 1) was applied. However, the low-viscosity synthetic oil (lubricant 3) showed the poorest result on the coating properties, where the highest change in the coating thickness was observed. Therefore it is clear that the lubricant viscosity is not the most important parameter that influenced coating removal, even though the load carrying capacity of the lubricant is increased with the increase of the viscosity. The behaviour of coefficient of friction has to be considered in determining the effectiveness of the lubricant in relation to the coating-thickness change.

Our previous work [12] shows that the PAG lubricant has the lowest coefficient friction with Galvanneal when the same three lubricants were used. Further, the highest coefficient of friction was observed with the low-viscosity pressing oil. Therefore it is clear that the frictional properties of the lubricant have commanding influence on the reduction in coating mass (equivalent coating thickness) through abrasion with forming dies.

Figure 8: The GDO-ES representation of the coating thickness variation with the forming lubricant

The GD-OES measurements for the coating thickness were compared with the values obtained by the vertical measurement facility provided with the optical microscope. The results show that the GD-OES measurements are considerably higher than the microscopic measurements (Figure 9 and 10). The difference is as high as 15% when the clamping force is increased to 15kN.

In the analysis the coating thickness was obtained as the Zn-Fe crossover point in the depth profile. When the results were carefully investigated, it was found that, in the microscopic measurements, a few microns of zinc were unaccounted. This unaccounted zinc concentration is present within the Fe-Zn cross over depth which is not clearly visible in the optical microscopy. This includes the zinc concentration in γ phase as well as the zinc diffusion in the substrate and leads to a considerable reduction in the microscopic measurements.

Further investigation, a more precise method of comparison of coating thickness with GD-OES has to be considered which enables to quantitatively identify the all the zinc phases in the coating.

Figure 9: Comparison of the coating thickness change with the GDO-ES measurements and the microscopic measurements
4. CONCLUSION

It was observed that the forming lubricant and the tooling pressure have a direct impact on the deterioration of the coating thickness in forming Galvanneal. The reduction in the coating thickness was observed to increase with the increase of the tool pressure. The effectiveness of the lubricant not only determines the frictional properties, but also the changes in mass loss of the coating during forming. Change in roughness parameters have the same pattern as the coating mass loss and the coating thickness in forming.

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