

Friction and Die Wear in Stamping Prephosphated Advanced High Strength Steels

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ABSTRACT

Prephosphated steels have been developed by applying the phosphate coating on zinc coated sheet steels to increase the lubricity in the automotive stamping process and adding extra corrosion protection. The prephosphate coating was also found to be able to further absorb the lubricant, which can reduce the oil migration and excessive amount of lubricant dripping on the die surface and the press floor. Due to its enhanced lubricity characteristic, the applications have been expanded to more-recently developed advanced high strength steels (AHSS). Because of the higher strength of AHSS, it is crucial to understand their performance under more extreme forming conditions such as higher die temperature, contact pressure and sliding speed, etc.

The intent of this study is to investigate the tribological performance and die wear behavior of prephosphated AHSS in the die tryout and production conditions. In this study a typical hot-dip Galvannealed (GA) coated DP600 with and without prephosphate coatings is selected for the tribological performance study. The bending under tension test and strip draw test were used to evaluate the friction behavior. The Marciniak stretch-forming test and the limiting dome height test were also included to evaluate the formability performance of prephosphated AHSS. In addition to the DP600, a hot-dip Galvanized (GI) coated DP980 with the prephosphate coating was also included in the die wear study. The cyclic bend die wear (CBDW) test system based on the modified bending under tension test was used to investigate the effects of the prephosphate coating on the die wear and zinc coating build-up in the production stamping condition. Results indicated that the prephosphate coating has a stable tribological characteristic in reducing the friction coefficient even at the elevated die temperature, higher contact pressure and higher sliding speed conditions. Also, the prephosphate coating can further reduce the die wear, prevent the zinc coating built-up on the die surface and increase the formability.

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INTRODUCTION

Zinc-based coatings have been used in automotive body-in-white components for corrosion protection. Different zinc-based coatings can be applied to a given automotive steel substrate, which affect friction through a more complicated interfacial contact between the sheet metal and the tooling (Hylton *et al.* [1]). The formability of zinc-coated sheet steels depends on both the properties of the sheet and the interactions that occur at the interface between the sheet and the die. In addition to the zinc-based coatings, the phosphate coating can also be applied on the zinc coated sheet steel to improve the formability and adding additional corrosion protection over non-prephosphated steel [2,3]. Research conducted by Kunde *et al.* [4] and Lautensleger *et al.* [5] also found that the prephosphate coating has no disadvantage on the spot weldability.

Conventional automotive mild and high strength steels are being replaced by AHSS due to the demands for vehicle weight reduction and safety performance improvements. Most coated advanced high strength steels (AHSS) are either Hot-Dip Galvannealed (GA) or Galvanized (GI), although Electrogalvanized (EG) coating may also be used over a continuous anneal product. However, AHSS present an increased level of die wear and springback in stamping when

compared to the mild steels and conventional high strength steels, due to their higher surface hardness and high strength levels. During stamping, a higher forming force is often required, which leads to higher contact stresses, pressures, and strain gradients. These, in turn, cause higher panel/die temperatures, wear rates, and steel surface galling. Although various countermeasures have been adopted in production to prevent excessive wear associated with forming AHSS, the stamping die tryout process has not been revised accordingly to ensure that the die surfaces in contact with sheet metal have been treated properly. Therefore, the prephosphate coating can be applied to the zinc-coated AHSS as the short term solution for reducing the manufacturing issues in the die tryout process and the long term resolution for improving the formability in production.

In the present study, the bending under tension (BUT) test and strip draw (SD) test were used to investigate the tribological performance of prephosphated AHSS in the die tryout and production stamping conditions. A cyclic bend die wear (CBDW) test system was used to investigate the die wear in the tryout phase and in production. The stretch-forming test and the limiting dome height test were also included to evaluate the formability performance of prephosphated AHSS.

MATERIAL

Six commercially produced Zinc coated steels were chosen for this study: Two DP600 and two deep drawing steels (DDS grade) with hot-dip Galvannealed (GA) coated, with and without prephosphate coating and two DP980 steels with hot-dip Galvanized (GI) coated, with and without prephosphate coating. The thickness of steels is between 0.81 mm and 1.67 mm, and a light phosphate coating weight ($\sim 0.5 \text{ g/m}^2$) was used. The DDS grade steels are included for the comparison purpose. The as-received mechanical properties of the sheet steels are given in Table 1.

TABLE 1. MECHANICAL PROPERTIES OF TESTED STEELS

Material	Thickness (mm)	Yield Strength (MPa)	Tensile Strength (MPa)
DDS-GA	0.81	152	327
DDS GA-Phos	0.81	151	328
DP600-GA	1.65	399	657
DP600 GA-Phos	1.67	408	600
DP980-GI	1.00	733	1040
DP980 GI-Phos	1.00	710	1026

FRICITION AND DIE WEAR

Friction behaviors in the automotive stamping can be characterized by three typical forming modes as described by Shih *et al.* [6] in Figure 1. The forming mode in zone 1 and zone 2 has the bending effect, while the forming mode in zone 3 does not have the bending effect. In this study, the bending under tension test simulating the forming mode in zone 1 and the strip draw test simulating the forming mode in zone 3 were used to evaluate the friction behavior of the prephosphated AHSS at different die conditions.

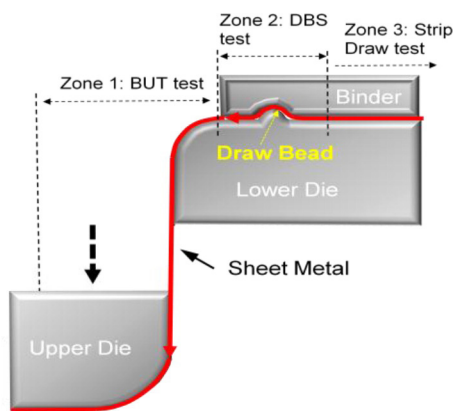


FIGURE 1. DIFFERENT FORMING MODES IN STAMPING

Forming with Bending Effect

Bending under Tension Test

Die surface temperature tends to increase in stamping AHSS due to a higher contact pressure occurred between the sheet steel and the die. To simulate die thermal effect, the heating device was added to the die in the bending under tension test to evaluate friction behavior at

different elevated die temperatures. The BUT test is a system for investigating friction and lubrication in sheet metal forming in which a metal strip is drawn over a fixed cylindrical pin with a pair of independently controlled hydraulic actuators, as shown in Figure 2. The two actuators are offset by 90 degrees. Two load cells, mounted between the actuators and the strip grips, measure the pulling force (F_2) and the back tension force (F_1), independently, as shown schematically in Figure 3.

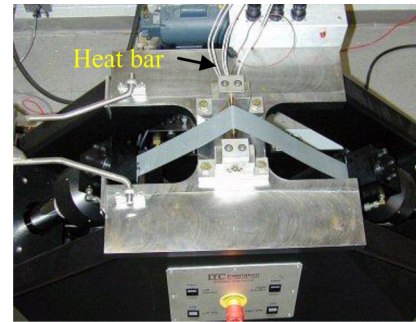


FIGURE 2. BENDING UNDER TENSION (BUT) TEST

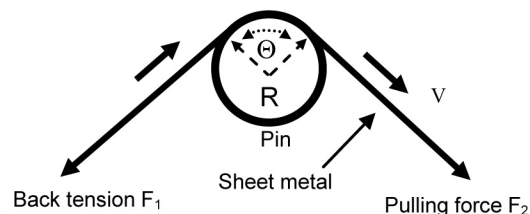


FIGURE 3. SCHEMATIC DRAWING OF BUT TEST

The average friction coefficient is calculated from the equation derived by Wilson, *et al.* [7] with an allowance for bending based on the work of Swift [8]. Thus

$$\bar{\mu} = 2(F_2 - F_1 - F_b) / \Theta(F_1 + F_2) \quad (1)$$

where F_1 and F_2 are the back tension force and pulling forces, respectively, Θ is the angle of wrap, and F_b is the Swift bending and unbending tension given by

$$F_b = \frac{\sigma_y t^2 w}{2R} \quad (2)$$

where σ_y is the yield strength of the specimen, t is the thickness, R is the pin radius and w is the width of the specimen. The details of this methodology were discussed by Saha and Wilson [9]. The test specimen was blanked to 51 mm by 610 mm (along the material rolling direction). All specimens were deburred before the test.

D2 (60RC) steel die with four different die temperatures (22°C, 66°C, 93°C and 121°C) were tested. The elevated die temperatures were controlled by three electrical heat bars, which were inserted into the die base underneath the pin. Two different lubrication conditions, as-received (as) and coated with extra mill oil to be in the flooded condition (mill), were applied to the DP600 steels in the BUT test.

Results in Figure 4 indicate that the DP600 tested with the prephosphate coating has a much lower friction coefficient than that tested without the prephosphate coating regardless of the die temperatures. The friction coefficient slightly decreases at higher temperatures for the prephosphated DP600, while it increases for the GA DP600. Extra mill oil tends to reduce the friction slightly for both steels, while the improvement is limited at higher die temperatures due to the decreasing lubricity of the mill oil. The GA coated AHSS tends to have a higher friction coefficient at the elevated die temperatures, which was previously identified by Shih [10] due to more coating surface flattening at higher temperatures. For the comparison purpose, both DDS steels (with and without prephosphate coating) were carried out at four different die temperatures in the BUT test and the result are compared in Figure 5. A similar trend is observed for the DDS grade steel that the prephosphate coating tends to reduce friction coefficient with increased die temperatures. The difference in friction reduction resulted from the prephosphate coating is smaller for the DDS steel than the DP600, which is due to a lower contact pressure condition for the DDQ material.

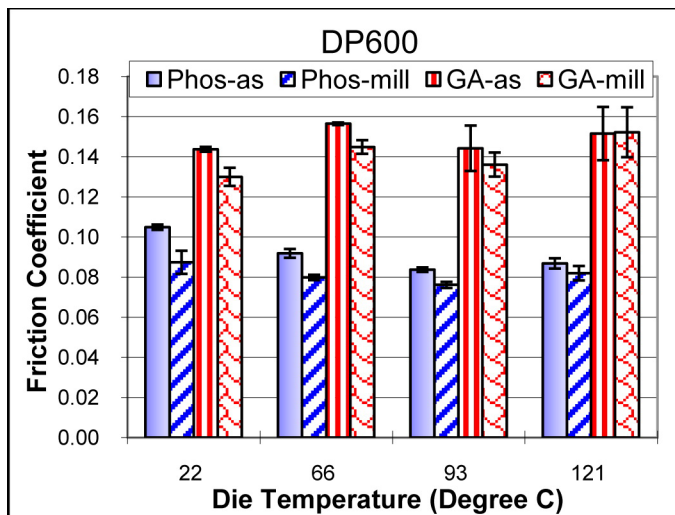


FIGURE 4. EFFECTS OF PREPHOSPHATE COATING ON FRICTION COEFFICIENT IN BUT TEST (DP600)

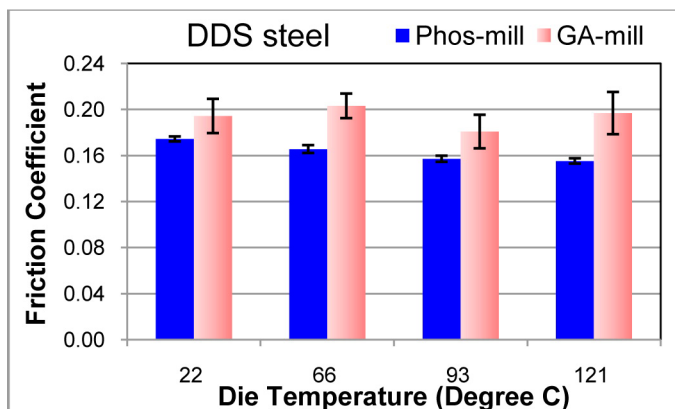


FIGURE 5. EFFECTS OF PREPHOSPHATE COATING ON FRICTION COEFFICIENT IN BUT TEST (DDS STEEL)

Cyclic Bend Die Wear (CBDW) Test

The cyclic bend test was used to evaluate the die wear behavior between prephosphated and non-prephosphated steels. A commercially available GI coated DP980 was used for the wear test. The prephosphated GI DP980 was used to study the effect of the prephosphate coating at a more extreme contact condition. A test program was developed to perform a cyclic bend test on the modified BUT test (Shih [11]). The program runs the test by pulling the specimen from the left-hand side to the right-hand side with the specimen in contact with the die. As one cycle is finished, without releasing the specimen, the actuators reverse direction and pull the same specimen from the right-hand side to the left-hand side, as shown in Figure 6. The specimen gradually elongates from cycle to cycle due to straining. The test has been programmed to compensate for this effect, and the specimen always maintains contact with the die. All specimens were tested in the longitudinal direction with the as-received lubrication condition.

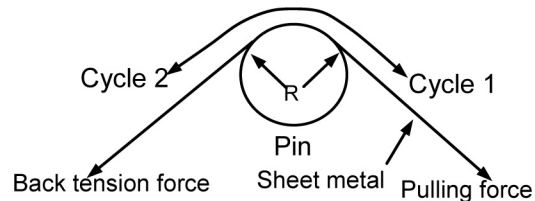


FIGURE 6. SCHEMATIC DRAWING OF THE CYCLIC BEND TEST

The test pin in the cyclic bend test was made of D2 steel with three different surface treatments to represent the die materials in both die tryout and production stages: D2-60RC, D2-Ion Nitride (IN) and D2-Ion Nitride + CrN, which is usually called the Duplex process. The Ion Nitride is a method of surface hardening producing nitrided cases, using the glow discharge technology to generate nitrogen ions at the surface of a metallic part for diffusion. The Duplex is a process also requiring the die surface to be nitrided first before applying the CrN coating. The coating is applied by Physical Vapor Deposition (PVD) to produce metal-based hard coatings on top of the nitrided surface. For each material, ten specimens were tested on the die with 5 cycles of bend testing for each specimen, resulting in 50 total cycles of bend tests. From previous study by Shih [11,12], the die wear tendency was found to be proportional to the friction force. In this study, due to the material hardening effects between each cycle of the test, the load difference between two load cells was used as the friction index and the sum of the total load difference is defined as the friction energy index to distinguish the difference in the resistant force among various die conditions.

Figure 7 shows the comparison of the friction energy among different die materials in the die wear test. The prephosphated steel has an average 26% lower friction energy than the steel without the prephosphate coating regardless of the test die conditions. It also indicates that the Duplex (IN+CrN) coated die, used for production stamping, tends to have the highest friction energy in forming the GI coated DP980, while the lowest for forming the prephosphated DP980. The GI coating tends to built up on the Duplex die surface (Figure 8-A) and results in higher friction energy, while the prephosphate coating acts as a dry lubricant which prevents the build-up of GI coating (Figure 8-B) and reduces the friction energy.