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Investigation of Galling In Forming Galvanized Steel Sheet

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The major purpose of the present study is to evaluate the performance of various galvanized (GI) or galvannealed (GA) mild steels and AHSS in stamping applications. Finite Element Analysis (FEA) of selected stamping operations was conducted to estimate the critical pressure boundary conditions that exist in practice. Using this information, laboratory tribotests, e.g. Twist Compression (TCT), Deep Drawing (DDT) and Strip Drawing (SDT) Tests, were developed to evaluate the performance of selected lubricants and die materials/coatings in forming galvanized steels of interest. The sheet materials investigated included mild steels and AHSS (e.g. DP600 GI/GA, DP780 GI/GA, TRIP780 GA and DP980 GI/GA). Experimental results showed that galvanized material resulted in more galling, while galvannealed material showed more powdering and flaking. The surface roughness and chemical composition of galvanized sheet materials affected the severity of galling under the same testing conditions, i.e. lubricants and die materials/coatings.
The results of this study helped to determine the critical interface pressure that initiates lubricant failure and galling in stamping selected galvanized sheet materials. Thus, to prevent or postpone the critical interface conditions, the results of this study can be used to select the optimum combination of galvanized sheet, die material, die coating and lubricant for forming structural automotive components.

Keywords *: galling, galvanized steel, galvanealed steel, coating*

1. Introduction

In forming of galvanized AHSS galling was found to be mainly caused by the zinc-coatings (GI or GA) on the sheet. Furthermore, tool wear is often concentrated at the draw radii or draw beads that are subjected to higher contact pressure and temperature compared to other flat surfaces. At these locations, the specially developed tool materials/coatings are added as inserts to increase die life and reduce the die cost.[1),2)] Several standard ASTM wear tests[3),4),5),6),7),8),9)] were developed to evaluate galling, emulating mechanical rolling and sliding conditions. Twist Compression Test (TCT) was used to estimate the coefficient of friction (COF) for stamping lubricants as a function of time.[10)] However, these tests have limitations in emulating process conditions (temperature, contact pressure and speed) that exist in real stamping operations. Lubricants and tool materials/coatings should be tested in laboratory tests that can emulate production conditions. Deep Drawing Test (DDT) was successfully used for evaluation of lubricants and tool materials/coatings by various European manufacturers. This test was further developed to distinguish the performance of lubricants via systematic evaluation criteria. In addition, Strip Drawing Test (SDT) was derived from DDT for studies on forming of AHSS because of limited formability of AHSS.

2. Objectives

The objective of this study is to determine the critical conditions at the die-workpiece interface which may induce powdering or galling and to reduce galling when possible. The effects of contact pressure at the tool-workpiece interface, surface roughness and hardness of die, die material, die coating and lubricant properties on the Coefficient of Friction (COF) and galling were considered.

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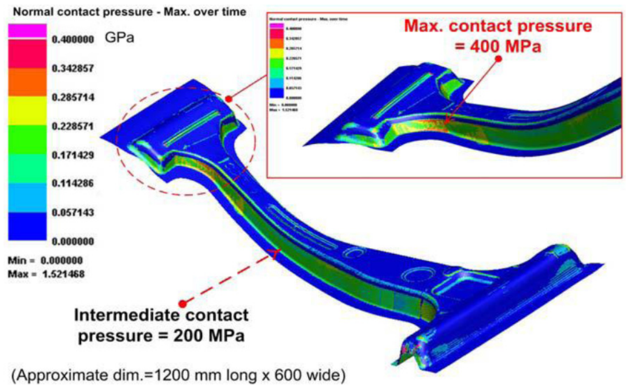

Fig. 1. Contact pressure distribution in the B-pillar part.[11)]

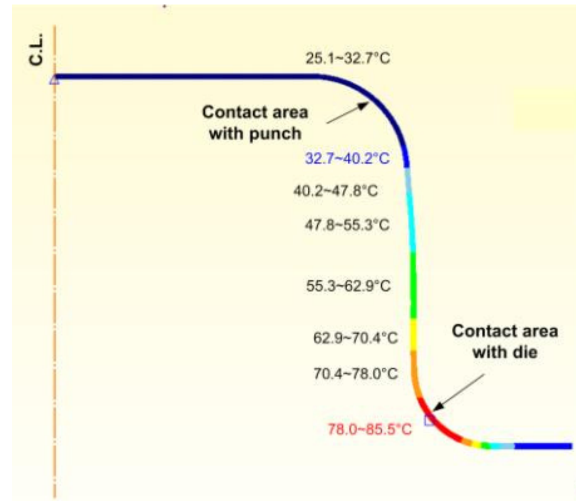

Fig. 2. Temperature distribution at the final drawn cup.[11),10)]

3. Approach

3.1 FE Simulations of forming of AHSS parts

3.1.1 FE Simulation of forming of a B-pillar

FE simulation of forming an ULSAB B-pillar was conducted by using a commercial software, PAM-STAMP 2G. The flow stress of sheet material (TRIP600) was obtained by the tensile test and expressed with the Krupkowsky model, as given in Eq. 1. Normal anisotropy was 1.05. The blank holder force (BHF) of 23 tons was determined by the FEM-based sensitivity analyses to avoid wrinkling and excessive thinning of the part. From the simulation, the contact pressure along the sidewall of the part and the maximum pressure (at the sharp die corner) were predicted to be about 200 and 400 MPa respectively as shown in Fig.1. COF was assumed to be 0.14.

$$\bar{\sigma} = 700\ (0.018 + \bar{\varepsilon})^{0.23} \tag{1}$$

3.1.2 FE Simulation of DDT

The coupled thermo-mechanical simulations of a DDT were conducted by using the commercial code, DEFORM-2D. The purpose is to predict the critical temperature and pressure generated at the tool-workpiece interface. DP 590 GA of 1.24 mm thickness and 305 mm diameter that gave 2.0 Limiting Draw Ratio (LDR) was used. BHF was selected as 30 tons from experimental tryouts and COF was determined to be 0.05 between the tool and workpiece by comparing FE prediction of load-stroke curve with experiments. The sheet material properties were determined by Viscous Pressure Bulge (VPB) test.[12)] The maximum contact pressure and temperature at the die corner radius were predicted to be around 400 MPa and 85.5 °C, respectively at the final stroke of 80 mm as shown in Fig. 2.

3.1.3 FE Simulation of SDT

With preliminary FE simulations of SDT, four different die radii (5, 8, 10 and 12 mm) were determined to change the maximum contact pressure, Pmax, in the range of 110 ~ 260 MPa without any necking of strip that was 356 mm long and 25.4 mm wide. A commercial FEM code, PAM-STAMP 2G, was used. TRIP 780 of 1 mm thickness was used as the strip material and the sheet material properties were determined by Viscous Pressure Bulge (VPB) test.[12)] The sidewall thinning was predicted by FE simulation as shown in Fig. 3. BHF was used as 75 KN. In addition, all these results were carefully analyzed to determine i) the dimensions of initial strip, ii) applicable BHF without any necking of strip, iii) the capacity of load cell to measure the punch force with a reliable resolution.

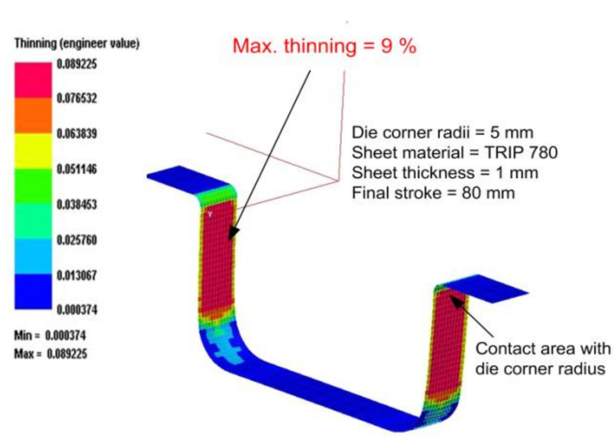

Fig. 3. Thinning distribution on the strip predicted by FEM.[11)]

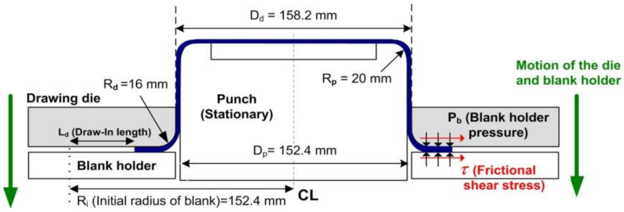

Fig. 4. Schematic of DDT and tool dimensions.[10)]

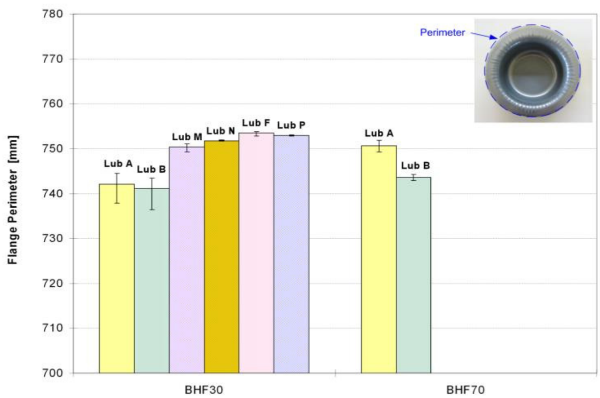

Fig. 5. Comparison of perimeter at the flange of drawn cups coated with different lubes.[10)]

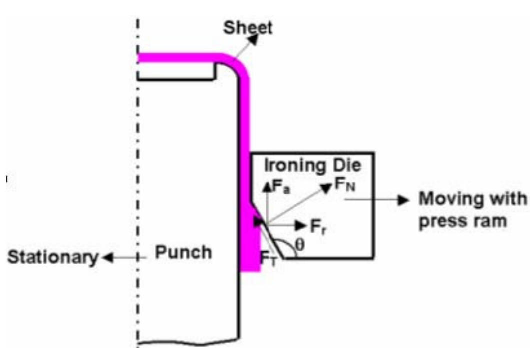

Fig. 6. Schematic of IT.[10)]

3.2 Evaluation of lubricants

3.2.1 Deep Drawing (DDT) and Ironing (IT) Tests

In DDT, the lubrication condition in the flange influences (a) the thinning and, possibly, failure of the side wall in the drawn cup, and (b) the draw-in length, Ld, in the flange, Fig. 4. Therefore, lubricants can be evaluated in DDT by determining the maximum applicable BHF without failure in the cup wall. DDTs were conducted for DP590 GA (initial thickness = 1.24 mm and blank diameter = 305 mm) at two different BHF, 30 and 70 tons, at a constant ram speed, 70 mm/s. D2 tool steel was used as die material. The load-stroke curve was measured in testing various lubricants at BHF 30 and 70 tons. The perimeters of the cups were compared for various lubricants. At BHF 30 tons, while all the lubricants gave fully drawn cups, Lubes A and B showed smaller perimeter than other lubes. When BHF was 70 tons, sheet blanks coated by Lubes A and B were successfully deep drawn while sheet specimens coated by other lubes were fractured, Fig. 5. This fracture was caused by the failure of lubricant film under high contact pressure.

The IT shown in Fig. 6 was also conducted to further evaluate the performance of the same lubricants tested by DDT. The IT provides higher pressures (up to 650 MPa) and temperatures at the tool-workpiece interface than the DDT.[13)] The ITs were conducted at a constant ram speed of 70 mm/s with A2 tool steel as die material. In this test, the maximum punch force and the sidewall thinning change depending on the interface friction between ironing die and workpiece, because the friction increases the tensile stress of side wall during ironing. Therefore, thinning is reduced with good lubrication. The thinning ratio was calculated by measuring the sidewall thickness of ironed cup before and after the test. Lubes A and B showed smaller thinning distribution than other lubricants same as in DDT results.

3.2.2 Strip Drawing Test (SDT)

Various type of stamping lubricants were tested to evaluate their performances with uncoated and coated dies. Two different zinc coatings, GA and GI, on DP590/600 were used for the strip materials. An uncoated and TiCN coated die inserts were selected from the previous evaluation of die coating via SDT, Fig. 7. After experimental trials, BHF was determined respectively as 40 KN for DP600 (thickness=1 mm) and 50 KN for DP590 (thickness= 1.2 mm) to avoid any fracture. Ram speed was set to be 30 mm/sec. 8 mm die radius was selected for experiments.

In SDT, frictional condition at the die and strip changes the sidewall thinning of drawn strip which affects the curvilinear length of strip. The strip elongation was calculated

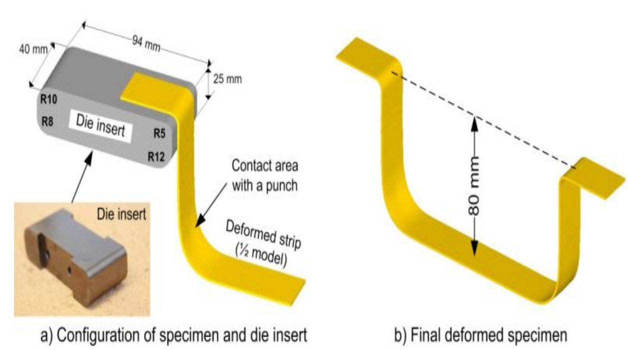

Fig. 7. Schematic of SDT.[11)]

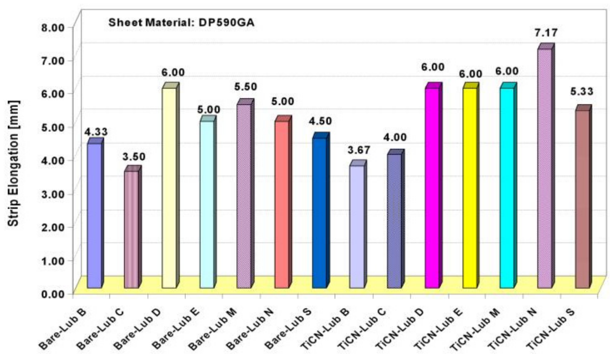

Fig. 8. Strip elongation of DP590 GA specimens after the test.[14)]

Table 1. Tool materials investigated in this study

1. DC53 uncoated (62 HRC, 830 VHN, R_a=0.19 [μm])
2. DC53 with PVD-CrN (62 HRC, 1300 VHN, Ra=0.16 [μm])
3. DC53 with PVD-XNP (62 HRC, 1332 VHN, R_a=0.25 [μm])
4. DC53 with PVD-TiCN (62 HRC, 2500 VHN, R_a=0.34 [μm])
5. Uncoated Graphite Cast Iron (38 HRC, 629 VHN, R_a=0.15 [μm])
6. K340 with PVD-CrN coating (62 HRC, 2195 VHN, R_a=0.16 [μm])
7. K340 with PIN coating (58 HRC, 1577 VHN, R_a=0.06 [μm])
8. Uncoated Vancron40 (61 HRC, 1746 VHN, R_a=0.13 [μm])

by measuring the strip length before and after the test. The strip elongations of GA and GI strips tested with various lubricants and two different die inserts were compared. Overall, the ranks of lubricants based on this criterion showed a good agreement with ranks obtained from the maximum punch force comparison.

3.3 Evaluation of tool materials/coatings

3.2.2 Strip Drawing and Ironing Test (SDT/SIT)

Preliminary tests were conducted to evaluate various tool materials/coatings against galling in forming of DP 980 GI and DP 780 GI by using the SDT/SIT. Galling is difficult to observe by testing a small number of samples. Thus, in our study, 40 specimens in forming of DP 980 GI and 30 specimens in forming of DP 780 GI were tested (one after the other) for each die material/coating without cleaning the die surface under four different test conditions in terms of lubrication (with and without lubricant) and contact pressure (drawing and ironing). Straight oil was applied as a lubricant with a coating weight of 2.0~3.0 g/m^2 by using a draw-down bar. After conducting twenty drawing tests, additional twenty ironing tests were continued with the same die inserts. The die inserts were designed to freely adjust the die-punch clearance that can change the ironing ratio of strip up to 50%. First four tool materials were tested with DP 980 GI at 14% ironing ratio and the rest were tested with DP 780 GI at 10% ironing ratio, Table 1. The ironing area was localized in the middle of strip width because a cylindrical shape punch was used in the test. 5 mm die radius was selected for experiments to create maximum contact pressure. The BHF was selected to avoid excessive thinning or fracture, through experiments and FE simulations in strip drawing and ironing.

To examine the damage on coatings after SDT/SIT, we took the micrograph of critical die surface that experienced high contact pressures during drawing and ironing tests. Before the microscope examination, die inserts were cleaned with Acetone to remove any material pick up and oil contamination that remained after the test. DC53 with TiCN coating and K340 with PVD-CrN coating showed the best effectiveness in reducing galling under all test conditions according to the micrograph examinations.

4. Conclusions

1) Polymer based lubricants A and B gave successfully deep drawn cups while sheet specimens coated by other lubes were fractured during DDT with a BHF of 70 tons.

2) Lub A and Lub B reduced the sidewall thinning compared to other lubricants in IT.

3) In the evaluation of lubricants, a polymer based lubricant with EP additives (Lub B) and a water-soluble DFL (Lub C) was most effective in reducing friction at the tool-workpiece interface, regardless of sheet coatings and tool coatings in SDT.

4) DC53 with PVD-TiCN coating and K340 with PVD-CrN coating showed the best effectiveness in reducing galling in forming DP 980 GI and DP 780 GI compared to other die materials and coatings in SDT/SIT.

5. Future work

In an ongoing study, conducted for a leading steel producer, the anti galling properties of 10 different zinc coatings (GI/GA) will be investigated in forming of mild steel with coated and uncoated spheroidal cast iron die using SDT/SIT. Surface characteristics of sheet materials such as surface roughness, hardness were determined and same measurements are being done on the dies. Actual experiments will be performed based on the test conditions that will be determined by preliminary SDT/SIT. Galling performance will be evaluated considering the changes in surface topography of the dies and sheet materials.

Acknowledgments

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