Formability of AlSi and Zn coating during hot stamping

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Abstract. Hot stamping is widely used in the automotive industry due to the combination of high strength (±1500 MPa), low springback and good formability. The sheet is austenitized in a furnace transported to a press and formed at high temperatures (600-800ºC). Forming at lower temperatures could be interesting with respect to multi-step hot stamping. Coatings are used to prevent scaling during the austitisation. AlSi is the most common protection. Zn coatings are also applied but are susceptible to microcracks. These microcracks can be avoided by using pre-cooling. In this investigation the formability and fracture of AlSi and Zn coating at several temperatures are investigated. Cross dies are formed and extensively analysed. At low temperatures the AlSi coating is very brittle and results in large amount of tool pollution. With respect to fracture and formability the Zn coating is stable in the whole temperature range and could be suitable for multi step hot stamping process.

1. Introduction

Hot stamping is mainly used to produce passive safety components such as A- and B pillars, bumper beams, side impact beams and different types of reinforcement components. With hot stamping high strength can be combined with good formability and tight geometrical tolerances. The process steps are as follows: austenitization in a furnace (900-930 ºC for 5 to 6 min), transported to the press (4-13 s), formed at high temperature (600-800 ºC) and directly quenched inside the press (> 27 K/s) resulting in a high strength product (1500 MPa).

To overcome scaling and decarburization during the austenitization and to provides corrosion protection the sheet is often coated. Hot dip aluminium coatings are commonly used in hot stamping and have several advantages such as good barrier corrosion resistance [1] and good spot weldability [2]. Unfortunately the AlSi coating have no cathodic corrosion protection [1] and suffers from brittleness [1] which causes severe adhesive wear [3-4] and abrasive wear [5-6] of tools and dies.

To achieve better corrosion protection steel producers are working on the development of zinc based coating systems [7-10]. However they are less applied in industry mainly due to the risk of propagation of microcracks in the coating layer into the substrate material [1,9,11]. Microcracks can be avoided by using pre-cooling. Zn coatings have some other advantages such as relative low friction [3,12-14] and wear [13].

In case of Zn coatings a so called multi step hot stamping process is proposed [7] so that more geometrical challenging products can be produced. In a multi step hot stamping process, multiple forming steps at high temperature occurs after the heat treatment, while still offering the dimensional accuracy and high strength. To be able to perform a multi step hot stamping process the formability of
the coating needs to be sufficient in the whole temperature range. In this investigation the formability
and fracture of AlSi and Zn coating at several temperatures are investigated.

2. Experimental method

In order to investigate the formability and fracture of Zn and AlSi coatings in hot stamping, cross dies
are pressed. The dimensions of the AlSi and Zn coated press hardening steel (PHS) blanks are 260 x
260 x 1.5 mm. The cross die tools are made of tool steel 1.2311.

The products are analyzed using imaging, morphology and chemical analysis techniques after the
tests to unravel the effect of temperature on the formability and fracture of AlSi and Zn coatings.

2.1. Test equipment and procedure

The blank is heated for 6 minutes (AlSi) or 5 minutes (Zn) in the roller hearth furnace up to 930 ºC
(AlSi) or 900 ºC (Zn). The furnace heat treatment is necessary to austenitize the substrate and to achieve
the required diffusion process between substrate and coating. Both coatings undergoes their own
favorable heat treatment.

After the heat treatment the sheet is transported to the pre cooling unit, where it is cooled upon a
certain temperature with forced air. The blank is then transported to the press (~7 seconds) where the
blank is formed. The spacer distance between die and blankholder is 0.15 mm during forming. No
lubrication is applied on the sheet or die.

The inlay temperature is measured by a pyrometer. The tests are performed with four different blank
temperatures between ~740 ºC and ~440 ºC with an interval of 100 ºC. At each specific temperature the
maximum height before fracture is determined. At this maximum height a strain measurement is
performed.

2.2. Analysis.

In order to analyse the fracture and formability of the coating a number of analysis is performed. Cross
sectional analyses were conducted using optical microscopy (Leica DM-LM microscope with a
motorised stage (Prior) and a camera (Leica DFG 420 C)).

Three dimensional optical (nanafocus µsurf mobile) topographical measurements are performed to
investigate the surface.

To obtain a first indication of the amount of tool pollution (after 1 strike), dust is removed from the
tool by a scotch tape. Thereafter the light intensity of the scotch tape is measured. A lower light intensity
represents more tool pollution.

For some products the dust on the tools is collected by tissues. After chemically removing the tissue,
the mass fraction of the metallic elements is determined with ICP OES.

Strain measurements are performed with Argus strain measurement system.

Figure 1; Press hardening line at Tata Steel R&D and cross die with position of analysis indicated.
Results and discussion

2.3. Formability

The maximum height of the cross die is determined by increasing the drawing height by steps of 1 millimeter until failure occurs. With Zn PHS, cross dies with the same maximum height (31 mm) can be drawn in the whole temperature range, see Figure 2.

With AlSi PHS, an increase in formability (from 28 mm to 31 mm) is observed for a decrease in temperature (from 740 °C to 440 °C). The increase in formability is combined with a huge amount of tool pollution at lower temperatures. The fractured particles probably result in a decrease in coefficient of friction (COF). This decrease in COF at lower temperatures is not observed in the hot friction draw tests [16]. However in a hot friction draw test no deformation takes place and thus not the same amount of dust occurs.

![Figure 2: Maximum height versus temperature for AlSi (blue squares) and Zn (red circles) coated PHS.](image)

2.4. Fracture of coating

Due to stresses (thermal and mechanical) the coating fractures. The AlSi coating is brittle and the fracture is very severe at low temperatures, see Figure 3. In the flange, die radius, wall and nose fracture is visible. It is known that the AlxFe y intermetallics are very brittle and have a high hardness [5].

The Zn coating has also fracture, however a high amount of coating remains on the surface, see Figure 3.

![Figure 3: Cross section in radius for Zn coating and AlSi coating for several inlay temperatures.](image)

Confocal measurements reveals the fracture texture on the surface, which is related to the stress state, see Figure 4. In the wall horizontal lines of fracture are visible. With the AlSi coating the fracture propagates through the coating and large cracks are visible. At the nose of the product the stress state is more complex and a different fracture texture is revealed.
With the Zn also cracks are visible, there are pieces out of the coating, however they don’t propagate so much as the AlSi coating, see Figure 4.

2.5. **Tool pollution**

After each draw the tools are cleaned by a tissue. Drawing at low temperature results in a huge amount of tool pollution for AlSi coated PHS, see figure 5.

Figure 6 shows the light intensity versus temperature for products with several heights. Light intensity gives a first indication of amount of dust. Lower light intensity represents more dust. The tool pollution is temperature dependent for both coatings. AlSi and Zn coated PHS shows opposite trends. AlSi coated PHS has significant more dust on the tool at low temperature, see Figure 6 and 7. With Zn coated PHS more dust is observed at higher temperatures, which is unexpected. It is most likely related to higher stresses measured at the higher temperatures, see Figure 8.

Analysis of the dust revealed that abrasive wear occurs for AlSi PHS material, since an significant amount chromium is measured. Abrasive wear during hot stamping is mentioned in several publications [3,5-6, 15] and caused by the very hard intermetallics [5].
In case of Zn PHS the chromium amount is in all cases lower than 0.1 mg/filter and thus (almost) no abrasive wear occurs due the relative low hardness of the Zn coating.

![Figure 7: Analysis of content of tool pollution after 1 draw at maximum height for AlSi (left) and Zn (right).](image1)

2.6. Strain distribution

Strain measurements are performed on the critical (max height) products. The grid is damaged (Zn) or removed (AlSi) at the die radius. The maximum strains measured at plane strain state are between 0.3 and 0.6, see Figure 8. The plane strain value of 0.6 corresponds to necking (Zn: 636 ºC height 31 mm and AlSi 544 ºC 30 mm). Some wrinkling is also visible for some products.

![Figure 8: Strain measurements for Zn and AlSi PHS at several temperatures and heights.](image2)
3. Conclusions
The effect of formability and fracture is investigated for Zn and AlSi PHS. The main conclusions are:

- Zn coating PHS could be suitable for multi step hot stamping since the coating does not fracture severely and formability is good in the whole temperature range investigated.
- AlSi PHS is most likely less suitable for multi step hot stamping since the coating fracture is severe at low temperature and tool pollution is very high.
- AlSi PHS result in abrasive tool wear, which is even more severe at lower temperatures due to even higher hardness of the AlFe intermetallic at lower temperatures.
- Almost no abrasive tool wear occurs with Zn coating due to the relative low hardness of the Zn coating.
- Both coatings fractures, however the propagation of cracks in Zinc coating is less severe than in AlSi coating.
- Strain measurements can be performed with a grid, however the grid is damaged (Zn) or removed (AlSi) at the die radius.

Acknowledgements
The author would like to thank Richard Stegeman, Menno de Bruine, Mary Roelofsen for assistance with the measurements.

References
[1] Fan D and De Cooman B 2012 State-of-the-knowledge on coating systems for hot stamped parts, SteelRes.Int. 83 (5) 412–433
[2] Suehiro M, Kusumi K, Miyakoshi T, Maki J and Ohgami M 2003 Properties of Aluminum-coated Steels for Hot-forming, Nippon Steel Technical Report No. 88 16-21
[3] Vilaseca M et al. 2014 Wear measurement methodology and test facility to increase the efficiency of hot stamping for high performance component production(TESTTOOL) ISBN 978-92-79-53615-1
[4] Pelcastre L, Hardell J and Prakash B 2013 Galling mechanisms during interaction of tool steel and Al-Si coated ultra high strength steel at elevated temperature, Tribology International 67 263-271
[5] Windmann M, Röttger A, Hahn I and Theisen W 2017 Mechanical properties of AlXFeY intermetallics in Al-base coatings on steel 22MnB5 and resulting wear mechanisms at press-hardening tool steel surfaces, Surface & Coatings Technology 321 321-327
[6] Hardell J, Kassfeldt E and Prakash B 2008 Friction and wear behaviour of high strength boron steel at elevated temperatures of up to 800 C, Wear 264 788-799
[7] Hamamoto S, Omori H, Asai T, Mizuta N, Jimbo N and Yamano T 2017 Steel sheets for highly productive hot stamping, Kobelco technology review No.35
[8] Belanger P, Lopez Lage M, Romero Rulz L and Isaksson K 2017 New Zn Multi Step Hot Stamping Innovation at Gestamp, Proc. of the 6th Int. Conf. on Hot Sheet Metal Forming of High-Performance Steel, CHS2 2017 Atlanta, USA 327-335
[9] Genderen M, Verloop W, Loiseaux J and Hensen G 2011 Zinc-coated Boron Steel, ZnX®: Direct hot forming for automotive applications, Proc. of the 3rd Int. Conf. on Hot Sheet Metal Forming of High-Performance Steel, CHS2 June 13-17 2011, Kassel, Germany
[10] Kondratuiuk J, Kuhn P, Labrenz E and Bischoff C 2011 Zinc coating for hot sheet metal forming: Comparison of phase evolution and microstructure during heat treatment, Surface & Coatings Technology 205 4141-4153
[11] Hensen G, Beentjes P, Abspoeil M and Loiseaux J 2015 Unlocking the potential of zinc coated steel for hot forming by innovative process modifications Proc. of the 5th Int. Conf. on Hot Sheet Metal Forming of High-Performance Steel, CHS2 2015 Toronto, Canada
[12] Ademaj A, Weidig U and Steinhoff K 2013 Phenological thermos-physical approach on process
monitoring in hot stamping of coated boron steel. Proc. of the 4th Int. Conf. on Hot Sheet Metal Forming of High-Performance Steel, CHS2 2013, Luleå, Sweden, pp.239-248

[13] Kondratiu k J and Kuhn P 2011 Tribological investigations on friction and wear behaviour of coatings for hot sheet metal forming. Wear 270 839-849

[14] Ghiotti A, Bruschi S, Sgarabotto F and Bariani P 2014 Tribological performances of Zn-based coating in direct hot stamping. Tribology International 78 142-151

[15] Venema J, Matthews D, Hazrati J, Wörmann J and van den Boogaard A 2017 Friction and wear mechanisms during hot stamping of AlSi coated press hardening steel, Wear 380-381 137-145

[16] Venema J, Hazrati J, Matthews D, Stegeman R and van den Boogaard A 2018 The effects of temperature on friction and wear mechanism during direct press hardening of Al-Si coated ultra high strength steel, Wear 406-407 149-155