The Investigation of Zinc Coating Quality with Different Thickness Levels After Forming of Flat Steels

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Abstract. In this study, the deformation performance of galvanized deep drawing steel is investigated depending on coating thickness and forming limit of non-alloy pure zinc coated steel. Regarding to this; 100 and 150 g/m² Zn-coated samples are used to see the relevance with finite element analysis. To determine the deformation condition of Zn coating the samples were prepared at different elongation levels, then the samples are examined with surface views and cross-sectional analyses with scanning electron microscope to observe the amount of deformation at the onset of crack in the zinc coating cross-section. The change of zinc coating with elongation at cross-section region of the material will be investigated via microstructural analyses. It is aimed to determine the most suitable zinc coating level depending on the deep drawing amount in interstitial free (IF) steel usage. Furthermore, the performance of zinc coating will be investigated with finite element analyses with the goal of validating experimental results. Depending on the results of this study, the influence of zinc coating for a physical component will be carried out as a new study.

1. Introduction

The quality of sheet metal forming products commonly depends on the tribological conditions especially in deep drawing analysis since the friction affects the deformation condition. Flat steel products’ elongation can be determined by using finite element analysis with different zinc coating levels. Moreover, the corrosion protection can be developed by applying different coating layers. Even though forming of galvanized steel the zinc coating undergoes large strain without significant damage, there are two major problems in zinc coating performance during forming operation which are the damage of coating and the effect of coating in friction.

The formability of coated flat steel is affected by many factors such as formability behaviour of the uncoated material, existence of an intermetallic layer between the steel substrate and the zinc coating, zinc texture, grain size of zinc grains, as well as quality and quantity of alloying elements in zinc [1]. Different studies in literature including expansion tests for finite element analysis (FEA) have been investigated for galvanized steels and summarized in [2-5].

With the aim of investigating the zinc coating change in thickness at a certain deformation level, different tensile specimens have been prepared. The tests were performed up to different elongations. The change of zinc layer on steel surface a sequence of microstructural analyses was carried out at the cross-section region of the steel. It is aimed to determine the most suitable zinc coating level depending on deformation states. After mechanical characterization tests and microstructural experiments, tensile test simulations with two coating thicknesses (100 and 150 gr/m²) were executed to compare with experimental results.

2. Experimental Setup

The competency in performance of sheet metal forming simulations remarkably rely on the chosen materials’ constitutive models. Thus, material modelling is a field of study which gains increased attention of the scientific community, especially in case of sheet metal forming.
2.1. Mechanical characterization tests

To investigate the performance of zinc coating which will be compared with FEA data, a sequence of tensile tests is performed. To measure mechanical properties DX54D+Z tensile specimens with 100 and 150 gr/m² coating thicknesses were fulfilled. The DX54D+Z material, continuous annealed and hot dip galvanized IF steels, were chosen owing to its wide application range in automotive industry. The nominal thickness of the sheet materials was 0.85 mm, in contrast the individually measured thicknesses both for two different zinc layers were in the range of 0.83 - 0.87 mm. The tests were carried out in rolling direction with Euro-norm test speed. The average values with standard deviation of the test results are figured out in table 1. The average true stress versus true strain curves and the tested specimens are shown in figure 1 and figure 2.

| Amount of coating | t (mm)         | Yield Stress(MPa) | Tensile Stress (MPa) | Aₘₐₓ (%) | n  | r     |
|-------------------|----------------|-------------------|----------------------|----------|----|-------|
| 100 gr/m²         | 0.85 ± 0.02    | 175               | 316                  | 42.4     | 0.22| 1.92  |
| 150 gr/m²         | 0.85 ± 0.02    | 167               | 307                  | 42.4     | 0.22| 1.89  |

Figure 1. True stress-strain curve of DX54D+Z with the thickness of 0.86 mm.

Figure 2. Tensile testing device in Borcelik and test specimens with different deformation levels.

2.2. Microstructural analyses

The microstructural analyses were performed at Zeiss Axio Imager optical microscope and Zeiss EVO 50 scanning electron microscope (SEM). At the very beginning, specimens were cut to a covering 30 mm area in the middle region of the samples. To demonstrate the zinc-coating distribution an undeformed specimen is measured at SEM with 200X magnification. The shorn tensile test specimens were prepared to be measured under the optical microscope. The SEM images are shown in figure 3 and figure 4 both for 100 gr/m² and 150 gr/m² with different elongation levels. To illustrate the coating thickness, shorn samples were investigated under optical microscope (figure 5). The results are going to be assessed in section 4.
Figure 3. SEM measurements in the middle region of deformed tensile specimens for 100 gr/m².

Figure 4. SEM measurements in the middle region of deformed tensile specimens for 150 gr/m².
3. Numerical Modeling
In this study, tensile test simulation was executed with two coating layers. The analyses were performed in Autoform environment. The finite element analyses were conducted with Borcelik material cards. The initial mesh size was 0.06 mm, with 11 layers and 6 refinement levels. Vegter 2017 material model was used as a yield surface model for the sheet material. The mesh size and deformation result of galvanized sheet strip are demonstrated in figure 6. The coating thicknesses of pure zinc were taken from experimentally measured data as 0.0095 mm for 100 gr/m² and 0.015 mm for 150 gr/m².

Coating of pure zinc is modelled using tensile properties which were investigated in [6]. The specimens of pure zinc were used from cast samples and tensile tests were performed at room temperature. The test specimens were manufactured by pouring the molten zinc at a temperature of 430 °C. Mechanical properties used in Autoform simulation are given in table 2.

|                | Yield Stress (MPa) | Tensile Stress (MPa) | Ag (%) | n    |
|----------------|--------------------|----------------------|--------|------|
| Pure Zinc      | 27.5               | 30.0                 | 0.788  | 0.008|

4. Comparison of Results
To figure out a correlation between physical and virtual experiments of galvanized sheet metal in terms of deformation performance on different coating levels, the assessments have been made by using an orthogonal X section profiles on each part as shown in figure 7.
4.1. Results of microstructural analyses

To demonstrate the initial microstructure of zinc coating on sheet material, samples of tensile specimens were investigated in scanning electron microscope. As shown in first picture in figure 8, the surface consists of homogenous zinc layer. According to the figure, as the amount of deformation level increases, the zinc coating on the surface also elongates. However, the zinc coating on the surface does not disappear on material raw surface of steel at fracture.

Moreover, the coating thickness was measured from cross sectional region of the samples via optical microscope. In figure 9, it can be considered that the thickness of the zinc coating decreases, but there is no tearing on steel surface up to rupture.
Even though there is no tearing on material surface, the elongation of the zinc layer at 150 gr/m² coating is notably higher than the 100 gr/m² coated surface.

4.2. Results of FEA
In figure 10, the results of tensile specimen cross sectional measurements are illustrated. The thickness change in coating shows same behaviour as in the experiments.

![Figure 10. FEA results of two different coating levels near fracture.](image)

FEA enables this study of zinc coating with different thicknesses with accurate material model, assuming no effect of measurement errors and supposing ideal mechanical properties of pure zinc.

4.3. Comparison of the results
As the distribution of the zinc layer, the investigation of the coating thickness is performed at only upper surface. The length of the section is 30 mm and the comparison are done at x direction as it is shown in figure 7. The results are presented in figure 11.

![Figure 11. FEA results of two different coating thicknesses with two deformation levels.](image)
One can see from figure 11 the experimental results of maximum elongated specimen agree well with simulation results with a maximum deviation of 3%. On the other hand, the experimental results of 24% elongated specimen differs from simulation results. It should be noted that the thickness of the coating layer is much smaller than steel. Additionally, the difference between the experimental and numerical analysis results might be caused by measurement errors.

5. Conclusion
In this study, the deformation performance of galvanized deep drawing steel is investigated depending on coating thickness of non-alloy pure zinc coated steel. In this context, 100 and 150 g/m² Zn-coated samples are used to investigate the consistency with numerical analysis. With the aim of describing the deformation condition of Zn coating, the samples were tested to different elongation levels, then the samples were examined with surface views and cross-sectional analyses with scanning electron microscope to observe the amount of deformation at the onset of crack at the zinc coating cross-section. The difference in terms of elongation at cross-section region of the steel has been investigated via microstructural analyses. It has been concluded that the experimental results have good agreement at higher deformation levels rather than lower deformation states. Therefore, especially in high formable deep drawing operations it is possible to decide which coating thickness could be offered to end-user with the execution of numerical analysis.

6. Futurework
The experimental tests were performed at rolling direction. With a purpose of investigating the coating thickness effect on anisotropy, the authors will carry out tensile tests at transverse and diagonal directions. According to these results, the effect of coating thickness on drawability will be investigated.

7. References
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