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PAPER C

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Evaluation and comparison of surface defects on a simplified model for the area around the fuel filler lid by simulation and experiments

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ABSTRACT: There is a serious need in the automotive industry to predict surface defects in outer panels. Measures to prevent these defects can not be taken until a test part has been manufactured. This costs a lot in time and money. Within the present project stamping tools for a model part resembling the area around the fuel filler lid was developed. This is an area of the outer surface of a car, which is particularly sensitive for surface defects. Based on this model both experiments and sheet-metal-forming simulations were performed and the results were compared. The result showed that the simulations were able to predict the location of the defects but the magnitudes of the defects were not sufficiently accurate. The defects that occurred were more like waves than small localised defects at the corners, “teddy bear ears”. These defects could be seen in both the experiments and the simulations.

1 INTRODUCTION

Sheet-metal-forming simulations have become more common in the automotive industry during the last decade and are efficient tools for many applications. The most significant advantages compared to try-out methods are the time and cost reduction.

Makinouchi (1996) and Makinouchi et al. (1998) have described various uses of sheet-metal-forming simulations in the automotive industry. Today it is possible to predict thinning, cracks and forces with high accuracy, but there are still challenges to overcome.

One of these is prediction of surface defects. Surface defects are small deviations from the nominal surface of an automotive panel, and can be of varying sizes and depths. Defects with relatively large depths (wrinkles) are visible in an ocular check while small defects are detected by a method where a specialist manually examines the panel. The small defects do not become visible until the panel has been painted. Today there are methods to detect small defects by using interference of light. These methods are able to visualise the defects but are limited in efficiency and repeatability.

Surface defects often appear on relatively flat panels with some kind of embossment, e.g. on doors in the area of the door handle, and on rear fenders with fuel filler lid. The areas around the corners of the embossments will be subjected to compressive stresses. Since the panels usually have rather low stiffness in these areas, and the plastic strains are insignificant, they are very sensitive for springback which results in some kind of surface defects. Since the surface defects are detected at a late stage in the process, they cost a lot of time and money to repair. Therefore it is urgent to find a way to predict these problems already in the design phase in order to increase the quality of the manufactured parts. A very useful tool for predicting the forming behaviour of a part is to use sheet-metal-forming simulations. Unfortunately, the simulation technique has not yet been developed fully as a reliable tool for prediction of surface defects.

The objective of this study is to suggest a method for comparing simulation results and experimental results by using a simple tool, which generates surface defects that typically appear around the fuel filler lids and door handles of a car. Another important issue is to evaluate the accuracy in the simulation results.

2 METHODOLOGY

One area where surface defects often appear on a car is the area around the fuel filler lid. These defects appear as small dents in the corners, Figure 1, and are called “teddy bear ears”. It was, thus, suitable to study this kind of panel closer.

In order to verify and detect surface defects, an experimental tool was manufactured, which corresponds to the area around the fuel filler lid and generates parts with the desired defects. The tool consists of a double curved panel with an embossment in the centre. The embossment has different corner radii to make it possible to study the effect of the shape of the embossment.

The forming process was then simulated with a finite element method and the results were compared with the experimental results.

Since it is very difficult to detect and measure surface defects, different measurement systems were tested in order to reach results, which were comparable with the simulation results.

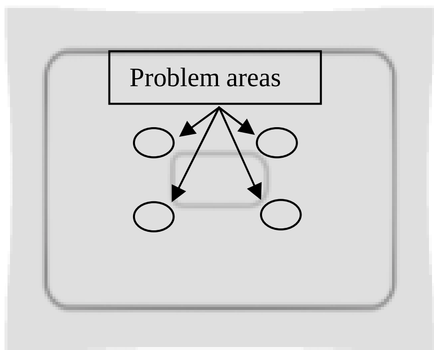

Figure 1. Areas with surface defects, “teddy bear ears”.

3 MECHANICAL PROPERTIES

3.1 Material

In this study two different materials were analysed: steel (FeP04) and aluminium (AA6016-T4, also called AC121-T4). The properties of these materials are shown in table 1. $\overline{R}$ is calculated according to equation (1):

$$\overline{R} = \frac{R_0 + 2R_{45} + R_{90}}{4} \quad (1)$$

3.2 Friction coefficient

Friction coefficients in the sheet-metal-forming simulations were determined by fitting draw-in along the blank edges from simulations to experimental results. This yielded a friction coefficient of 0.07 for FeP04 and 0.10 for AC121-T4.

4 EXPERIMENTS

4.1 Experimental setup

The experiments were performed in a hydraulic single action press with cushion. Different setups were tested in order to achieve defects, which were similar to defects that could be detected in real automotive parts. The clearance in the tool was 1.75 mm. The list below shows the setups that were tested.

- Plane and leaning embossment.
- 20mm distance between the draw depth and the depth of the embossment.
- Blank holder force of 500kN.

The forming depth was set to maximum depth without cracks in the material. Corresponding depths are shown in table 2.

Table 2. Drawing depths.

Material	Leaning/plane embossment	Depth (mm)
AC121-T4	Plane	28
AC121-T4	Leaning	34
FeP04	Plane	31
FeP04	Leaning	39

Process parameters for the experimental procedure can be found in table 3.

Table 3. Process parameters.

Parameter	
Blank dimension	550x750 mm
Rolling direction	Along the short side
Lubricant	Aral Ropa 4093LN, viscosity = 22 mm^2/s at 40°C
Lubricant amount	2-3 g/m^2

The results were evaluated along a line at co-ordinate y=-58. The position of the line can be seen in figure 2.

Table 1. Material characteristics.

Material	Thick-ness (mm)	$R_{p0.2}$ (MPa)	R_m (MPa)	R_0 (15%)	R_{45} (15%)	R_{90} (15%)	$\overline{R}$ (15%)	N (10%, 15%)
AC121-T4	1.0	134	246	0.64	0.42	0.77	0.56	0.272
FeP04	0.79	149	300	1.83	1.29	2.13	1.63	0.23

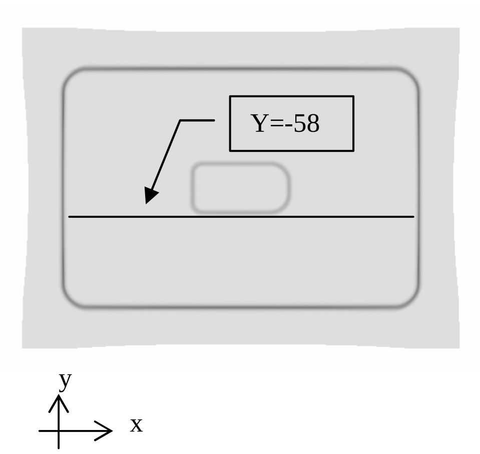

Figure 2. Position of evaluation line.

4.2 Sources of variations in experimental results

In order to decrease the error all the reported experimental results are the mean value from three different samples with the same process parameters. In the experimental procedure the scatter in the following parameters contribute to variations in the results.

- Amount and distribution of the lubricant.
- Material properties.
- Orientation of the blank.
- Blank holder force.
- Distribution of blankholder pressure.

5 SURFACE MEASUREMENTS

In order to measure the surface defects on the experimental parts, several different systems were evaluated. Two systems were chosen for analysis. One is based on projected lines, see Huntley & Saldner (1997), Saldner & Huntley (1997), and the other is based on fotometric stereo, Hansson (1999) and Horn (1986). These systems were able to present values which made it possible to compare the simulation and experimental results. The systems mentioned above are also capable of visualising the pattern of the surface defects. In order to have reference values the panel were also measured in a co-ordinate measuring machine.

6 SIMULATION

Since the release of stresses in the panel, which occurs after removal of the work piece from the tool, does influence the appearance of surface, the results from the simulations were studied both after forming and after springback. Studies by Mattiasson et. al. (1995) showed that springback simulations require low punch speed during the forming simulation, small elements and good tool description. Therefore the convergence with respect to these parameters was tested in a parameter study.

6.1 Forming simulation

The forming simulations were performed in the explicit FE-code LS-DYNA, Hallquist (1997). The blank was modelled by Belytschko-Lin-Tsay quadrilateral shell elements, Belytschko (1984). The material model introduced by Barlat-Lian (Barlat & Lian, 1989) was used.

6.2 Springback simulation

The springback simulations were performed in the implicit FE-code LS-NIKE3D, Hallquist (1998). The forming simulation in LS-DYNA generated the input deck to NIKE3D, containing geometry description and residual stresses. The shell formulation was switched from a one point integrated to be a fully integrated element, which was proved to give the same result as using a fully integrated element during both forming and springback simulation. The material model was also switched to an elastic material model.

6.3 Parameter study

6.3.1 Tool description

Two ways of describing the tool geometry were tested. The first way was to describe the tool in the traditional way by discretisising the model using nodes and elements. The other way was to describe the tools using VDA-surfaces. The use of VDA-surfaces yields smooth, continuos contact surfaces in contrast to the use of finite elements, which give rise to a faceted surface.

The results showed a strain concentration at the nodes in the draw radius for the model built by nodes and elements. This phenomenon could not be seen in the model with VDA-surfaces. The strain concentration is probably caused by the non-smooth representation of the tool surfaces. This generates errors in the solution. Therefore all tools were described with VDA surfaces in the simulations.

6.3.2 Element size

In order to evaluate the discretisation error, different element sizes in the blank were tested. Convergent results were obtained for an element size of 3 mm.

6.3.3 Punch velocity

Convergent results were obtained for the punch speed of 3 m/s.

7 RESULTS

The results from the simulations showed that the springback gave rise to a significant wave in the panel surface.

7.1 Analysis of the global surface

A comparison between the defects obtained in the simulations and the ones obtained in the experiments shows the same shape but different magnitudes. The difference in magnitude is difficult to determine in exact values since the measurements of the experiments were performed without any fixed reference point. Therefore the curves were fitted to two reference points (x=-175, y=-58; x=175, y=-58). The curves from the simulations and experiments were fitted to the z-value for the tool with compensation for the sheet thickness.

A conclusion is that the difference between the results from experiments and simulation were larger for AC121-T4 than for FeP04. This could be seen in the results for the evaluated cut in y=-58 where AC121-T4 showed more deviance than FeP04. The results from both experimental tests and simulation are shown in figure 4-7.

7.2 Analysis of the local surface defects

The panel was evaluated both by measuring the surface and by manual inspection by a specialist. The evaluation methods showed that the surface is very unstable and it is difficult to detect local defects such as “teddy bear ears”. This can also be seen in figure 3-7. Figure 3 shows the results from the method based on projected lines. The blue area in the middle is the embossment.

In figure 3 the depression in the middle of the panel can easily be seen by the change from blue to red and the back to blue. This depression can also be found in the measurements along the evaluation line y=-58 (see figure 4). It can also be seen that there are heights in the area beside the embossement. It is, however, very difficult to detect small areas with depressions such as “teddy bear ears”.

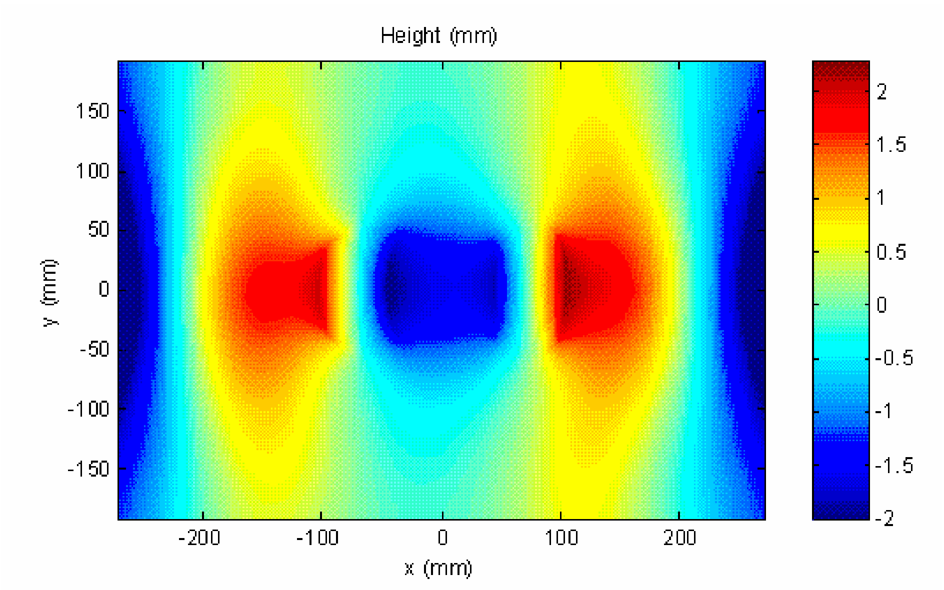

Figure 3. Evaluation of local surface defects with projected lines method. The picture shows results from panel with plane embossement of material AC121-T4. The scale shows the deviance in mm from a reference surface. Since the panel is double curved, a continuous colour change from blue to red indicate the form of the panel.

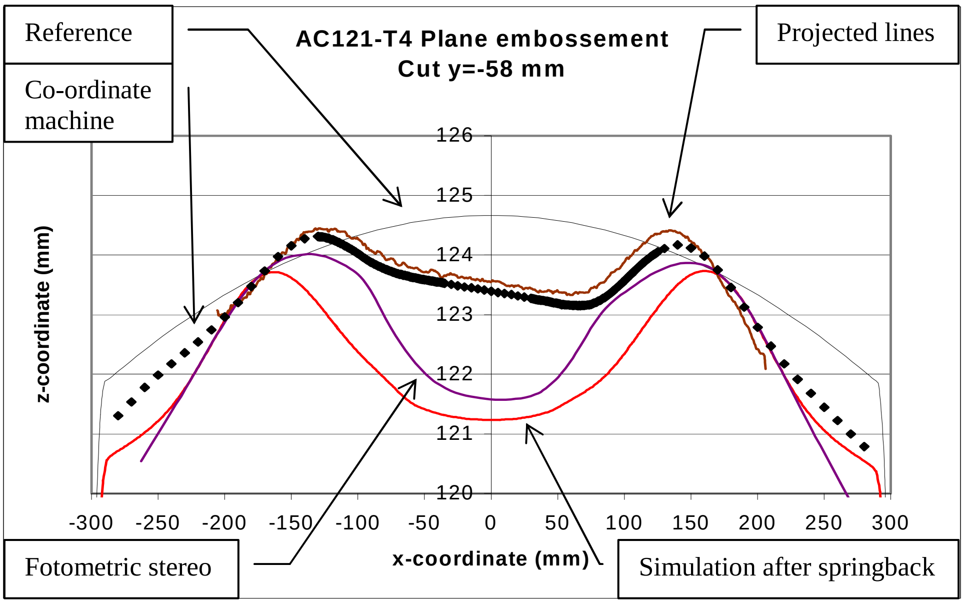

Figure 4. Results for plane embossement. Material AC121-T4.

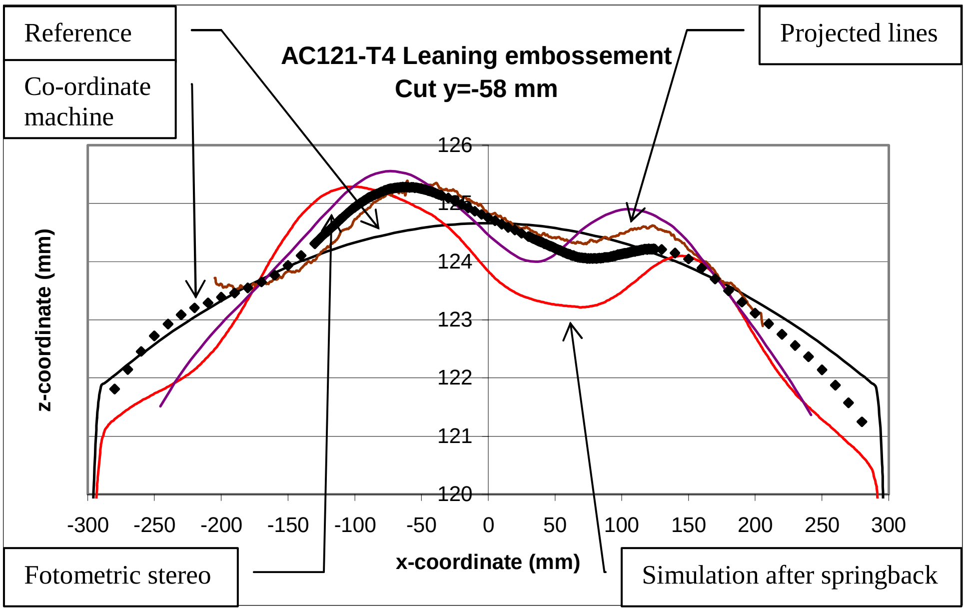

Figure 5. Results for leaning embossement. Material AC121-T4.

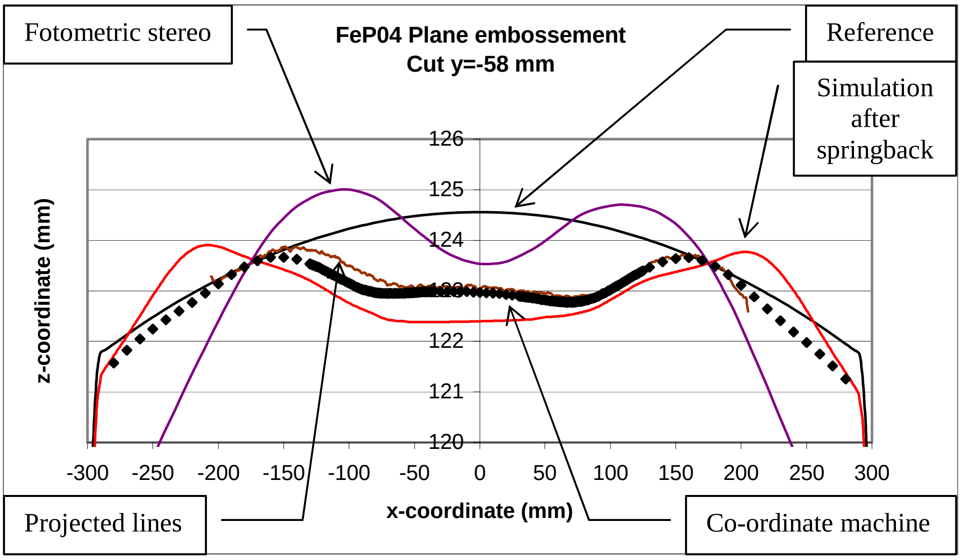

Figure 6. Results for plane embossement. Material FeP04.

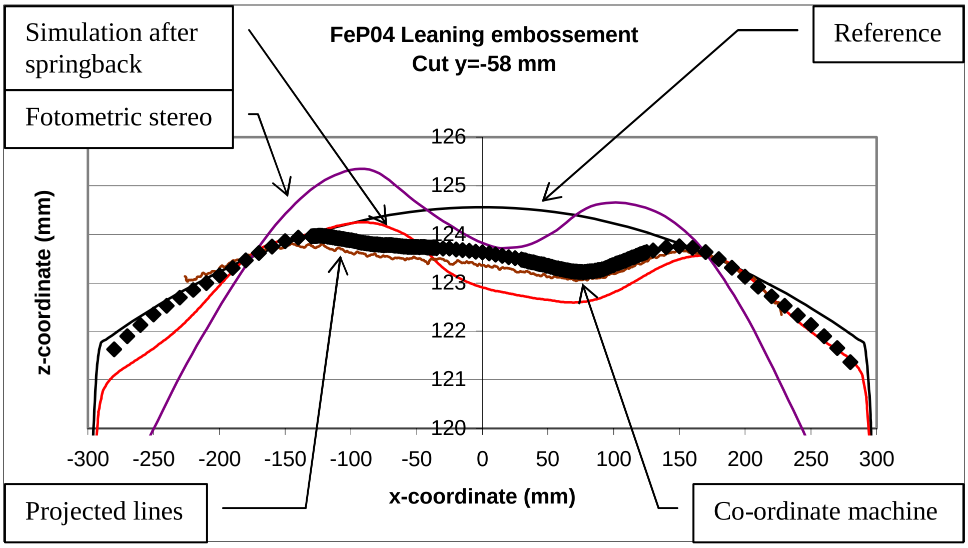

Figure 7. Results for leaning embossement. Material FeP04.

8 DISCUSSION AND CONCLUSIONS

Normally surface defects appear in areas with small strains. These areas are also more sensitive for springback. Therefore is it vital to take the springback into consideration when you are evaluating surface defects since these phenomena affects and appear in the same areas and are sensitive for the same conditions, small strains.

The results from experiments and simulations are difficult to compare. The experimental panels are difficult to measure since the defects are small. The results are therefore uncertain. Another problem is the choice of reference point. If the results from experiments and simulations are to be comparable, they must have the same orientation when the results are evaluated. Since the springback contributes to a change of the shape in the panel, it is very difficult to choose a comparable orientation for experimental and simulation evaluation.

The defects that were detected are more like waves than typical surface defects of the “teddy bear ears” type. One reason for this could be the big clearance in the tool. More experiments should be made where more focus is concentrated on achieving defects like “teddy bear ears”.

An experimental study of an similar panel, with the embossement in the corner, was performed by Hayashi (1996). In his experiments shape defects appeared around the corners of the embossment.

In order to achieve better simulation results the effect of the following could be investigated:

- Material law.
- Hardening rule.
- Element formulation.
- Visualisation methods.

Dutton & Pask (1998) showed a method for visualisation and comparison of experimental and simulated results which could be of interest for further studies. Another interesting visualisation method is described by Kase et al. (1999).

There are two different approaches of how to analyse surface defects based on sheet-metal-forming simulations. One is to analyse the geometry after springback. The other is to analyse stresses and strains after the forming operation. In this article the first approach is discussed. Further work will be done in order to compare the approach with analysing the geometry to analysis of stresses and strains.

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