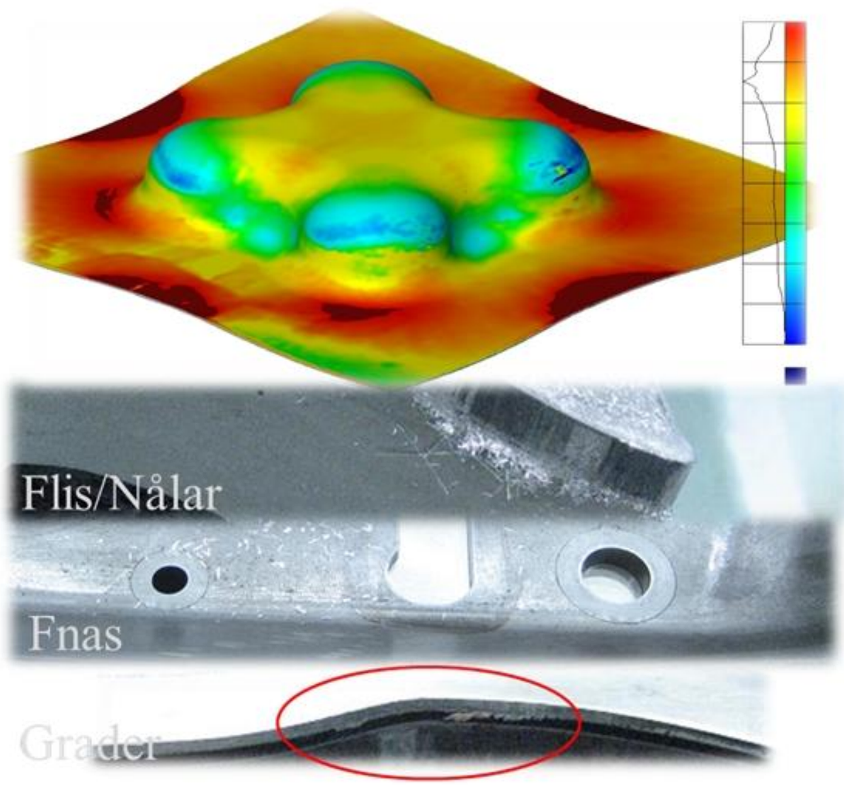
High-volume production of aluminum components, ALKOMP



Sustainable Production Technology

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FFI in short

FFI is a partnership between the Swedish government and automotive industry for joint funding of research, innovation and development concentrating on Climate & Environment and Safety. FFI has R&D activities worth approx. €100 million per year, of which half is governmental funding. The background to the investment is that development within road transportation and Swedish automotive industry has big impact for growth. FFI will contribute to the following main goals: Reducing the environmental impact of transport, reducing the number killed and injured in traffic and Strengthening international competitiveness. Currently there are five collaboration programs: **Vehicle Development, Transport Efficiency, Vehicle and Traffic Safety, Energy & Environment and Sustainable Production Technology.**

For more information: www.vinnova.se/ffi

1. Executive summary

The project ALKOMP have addressed challenges with aluminum in sheet forming. The challenges have been divided into two separate areas, methodology to manage material variants in early stages by the Finite Element (FE) simulation and methodology to analyze and counteract formation of burrs and slivers when trimming and punching.

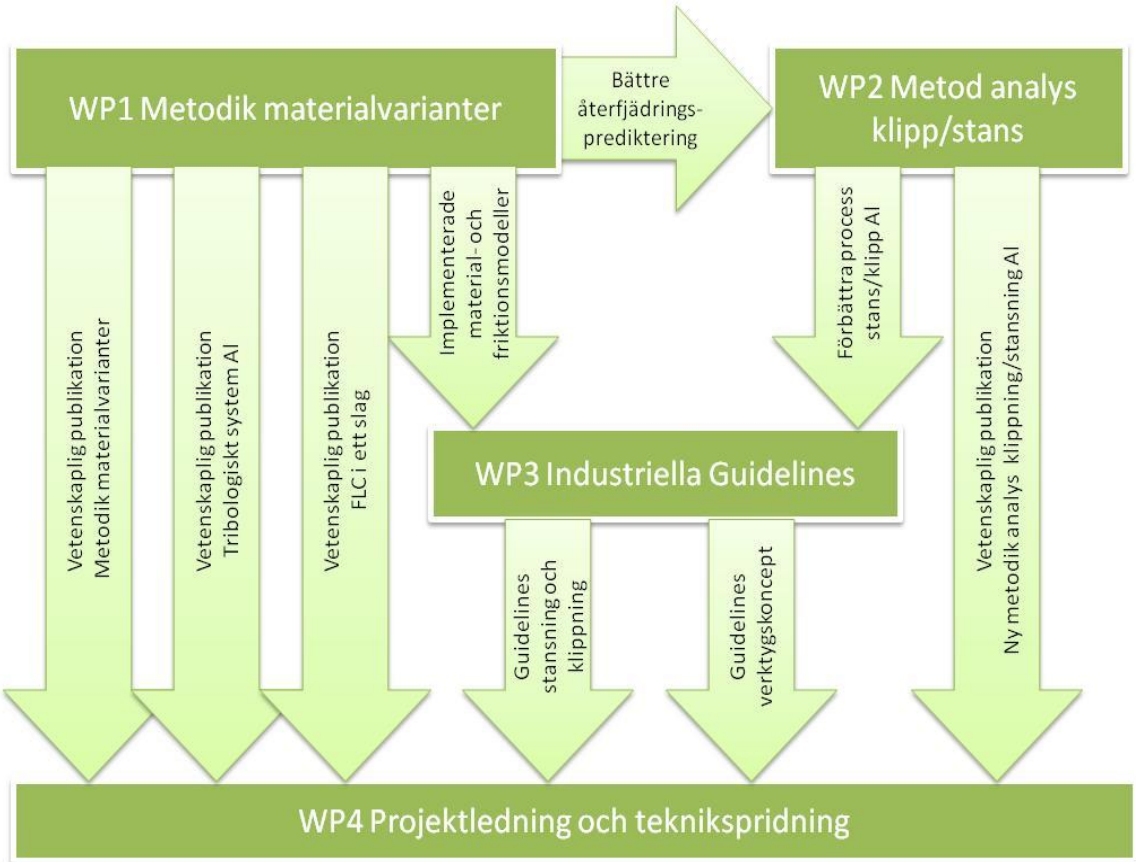

Figure 1 Project description, connection between the project's four subtasks.

The project's main objective has been to develop new methodologies and new knowledge in order to shorten lead time and cost required to develop new sheet metal components made of aluminum alloys and to ensure robust manufacturing of these.

Intermediate goals to achieve this were:

1. New methodology to obtain data for the simulation of varieties of material
2. New methodology for evaluation of formation of burrs and slivers when trimming/punching aluminum
3. Industrial guidelines

The project has delivered generic knowledge in terms of:

• Methodology for the development of material data to the selected material models through experiments and inverse modelling

• Unified methodology for evaluation of the forming behaviour of new material varieties

• Analysis of how spring back prediction can be improved through new material- and new friction model

• Analysis of tribological systems related to aluminium sheet metal forming

• New methods for the detection and analysis of burrs and slivers when trimming and punching aluminium sheet metal

2. Background

Currently lightweight construction is at focus in the automotive industry. Increased product requirements such as lower emissions, along with improved security and performance demands means that more components must be manufactured from lightweight materials such as high-strength steel or aluminum alloys. In a future scenario, 20% of the body-in-white consist of aluminum, a significant increase as compared to current solutions.

A study from 2012 [2] shows that there is already an average of 160 kg of aluminum in a car. Models from Land Rover, Audi and Jaguar stand out as most aluminum-intensive with bodywork and suspension entirely in aluminum. Volvo Cars is located just above the middle, with around 180 kg of aluminum, which represents less than 10% of the total weight of the models examined.

However, the aluminum sheet metal components, yet only a small proportion of aluminum used in a car, just over 20 kg per vehicle on average. Cast aluminum is the major share with over 110 kg of aluminum on average per car.

3. Objective

The project has aimed to meet two main challenges that has been identified for the successful introduction of new workable aluminum alloys in the Swedish automotive industry:

1) Robust production of various aluminum alloys through increased accuracy in the FE analysis of forming processes by use of more advanced material models combined with new methods for material evaluation.

2) Robust shearing processes for aluminum by production of new understanding of the mechanisms effecting formation of burrs and slivers during trimming / punching aluminum.

The project provides a strengthened position for the Swedish automotive industry in the production of lightweight solutions for body parts. The generic results of the project reinforces and builds knowledge base concerning the forming of aluminum sheet with emphasis on the influence of material variations.

4. Project realization

4.1 Material data and material modeling

The material model used in forming simulation has a large impact on the accuracy of a forming simulation. At the same time, it is often costly to obtain data for a complex material model and the computation time increases as well with the use of advanced material models compared to those used today in the automotive industry.

In this project, two new material models, BBC 2005 in the software AutoForm and Yld2000 in the software LS-DYNA was used. They are formulated in different ways, but if all parameters of each model are used, the resultant flow surfaces become identical. To prepare input data for them, the methodology presented in Banabic et.al.[1] have been used. The method involves combining data from several different material tests to derive as many input parameters as possible. In order to obtain high accuracy optical measurement methods are used during the experiments. The remaining parameters that the selected material model requires are obtained by inverse modeling, i.e. the results of an experiment are compared with simulation results for the same experiment. If there are differences in the results, the simulation model is modified until an acceptable accuracy is achieved. A further advantage of this method is that the correctness of other parameters can be evaluated.

Both models require nine different input parameters:
• Four yield limits, σ_y, in different directions.
• Four R values in different directions
• One exponent, M, which determines the shape of the flow surface.

Tensile tests in the rolling direction, diagonally to the rolling direction and across the rolling direction provides three σ_y and three R values. The equi-biaxial σ_y and the equi-biaxial R-value is received from a Viscous Pressure Bulge test. Finally, the exponent M is derived by inverse modeling of a stretch forming experiment using a spherical stamp with friction between the blank and the stamp.

The hardening curve, i.e. the ratio of plastic strain and tension, is obtained by combining results from tensile tests in the rolling direction and the Viscous Pressure Bulge test.

In order to determine whether there is a risk of cracks a Forming Limit Curve, FLC is required. In this project the FLC has been produced by forming plates with different widths. Each such tests have been filmed with an optical measurement system, ARAMIS. Analysis of results files from forming of the samples then gives the FLC used in forming simulations.

[1] Banabic D et. al., Sheet Metal Forming Processes. Constitutive Modelling and Numerical Simulation, Springer, 2010.

4.2 Tribological system, friction modeling and one-step tool

4.2.1 Friction modeling

The friction conditions between the plate and tools is vital to control how the sheet material flows into the tool. The Finite Element simulation (FE) of the forming operations today usually uses a classic Coulomb friction model to describe the conditions between the sheet and tool. In ALKOMP tribological studies have been carried out and a new friction model has been evaluated.

This model was chosen because it is based on an analytical solution that makes it easy to understand as well as computationally efficient. By means of its first-order physics it is also suitable for further development. The model can be considered as a generalization of the so-called Shear-cap and Emmen's models and its response surface is depicted in Figure 2.

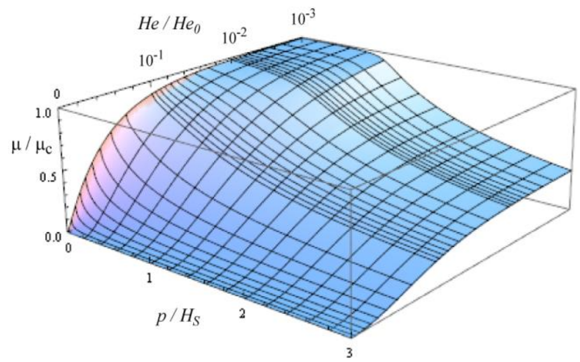

Figure 2 Response surface for the friction model.

4.2.2 Tribological experiments

The tribological system was evaluated by the BUT-tests (Bending-In-Tension), confer Figure 3. The experiment simulates tensile loading of a sheet metal over a tool radius in a forming operation with lubricant and the actual tooling material, a hard chrome plated ductile iron.

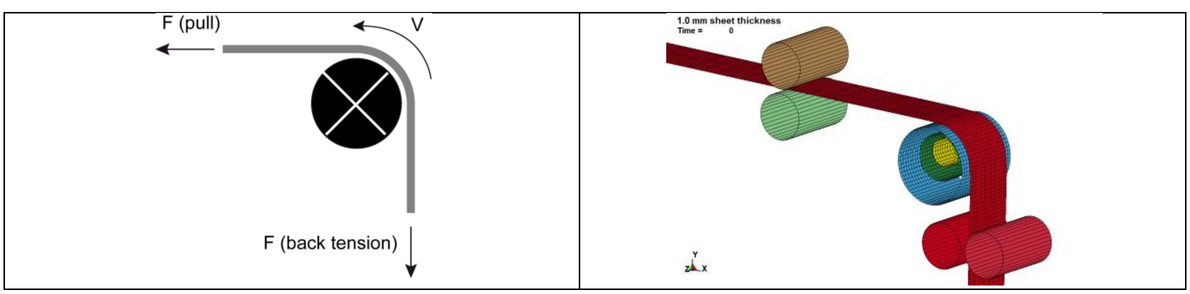

Figure 3 The picture to the left shows schematically the BUT experiment. The picture to the right shows the FE model that was used for calibration. It shows four freely rotating tools that reduces oscillation under tensile and three different radii that can gradually be exchanged for the calibration of the friction model.

4.2.3 One-step tool

A paper by Oh et al[2] describes a method for obtaining a forming limit curve in a single stroke. This is made possible by a tool that has been designed so that several distinct strain paths are obtained in different parts of the tool. The thesis is that it is possible to obtaining a sufficiently good approximation of the forming limit curve of a material without having to use significantly more time-consuming methods that are required for the traditional approach to experimentally obtain a forming limit curves. Furthermore, the tool provides a method to rank the formability of apparently similar materials, i.e. materials with the same brand names manufactured by different vendors or even with the same material designation from the same supplier but in different varieties. To verify the tool's functionality a CAD model was created and a finite element model was generated from this. The essay does not give a completely unambiguous description of the geometry, so the best possible assessment of what was left out has been made. Four different steel grades are reported and to verify the model, these materials have been used in this project to validate the model. Figure 4 shows the geometry of the tool and the results where only the blank shape is displayed.

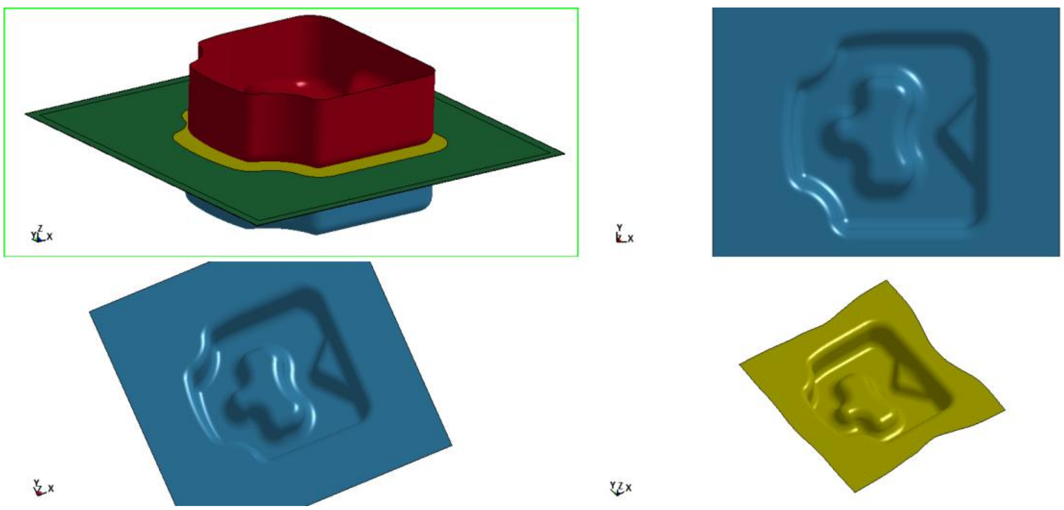

Figure 4 Geometry of the one-step tool

The three different aluminium alloys used in the project have also been simulated in the tool. A plurality of combinations of friction coefficients and blank holder forces have been used to evaluate the properties of the aluminium alloys. Figure 5 shows the thickness distribution of the different materials under otherwise identical conditions. Figure 6 shows the corresponding forming limit diagrams.

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[2] K.S. Oh, K.S., Oh, K.W., Jang, J. H., Kim, D.J., Han, K.S., Design and analysis of new test method for evaluation of sheet metal formability, International Journal of Plasticity, Vol. 211, pp. 695-707 (2011)

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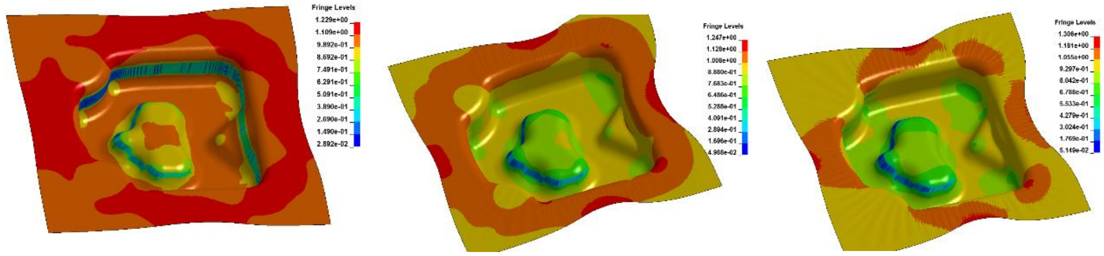

Figure 5 Thickness distribution in parts of the three evaluated aluminium alloys

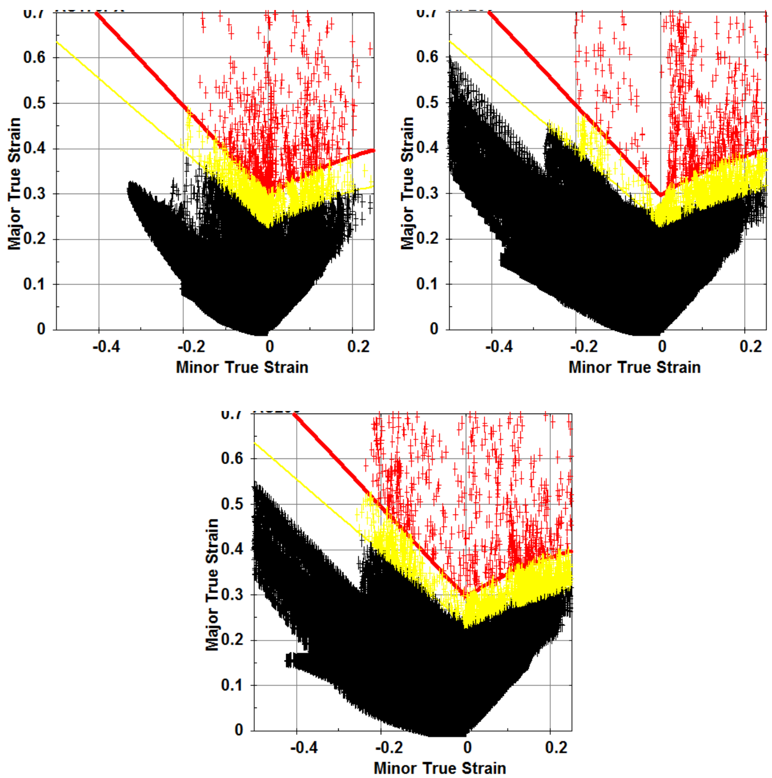

Figure 6 Forming limit diagrams for the three different aluminium alloys

The different aluminum alloys exhibit significant differences, in particular for one of them the strains in the part wall soon becomes so large that the "cup" splits into two parts, in addition, the strain distribution is more concentrated for that material. The forming limit diagrams shows a strain signature indicating that the risk of "failure" is wider for one of the alloys. This is taken as a pretext for that the tool geometry is sensitive to small differences in material properties. An adaptation of the tool geometry for aluminium is necessary so that full part depth can be obtained without completely separating the materials as indicated for one of the alloys.

4.3 Robust trimming- and punching processes for sheet metal aluminum

Better understanding of the mechanisms causing formation of burrs and slivers during trimming and punching of aluminum was needed to create robust trimming- and punching processes in a predictable way. In order to be able to work experimentally with these issues an existing evaluation methodology was modified to include more process parameters and thus better mimic the real production conditions. The previous methodology was shown not to provide results regarding the formation of burrs, slivers and galling in a way that reflected the actual production conditions in a sufficiently good way.

The biggest change was that the stresses and strains was introduced into the detail that would be trimmed or punched. A strain level of 7-9 % was targeted in the areas of the sheet that were to be trimmed or punched. Simulations were used to achieve a correct strain level. See Figure 7 and Figure 8 below.

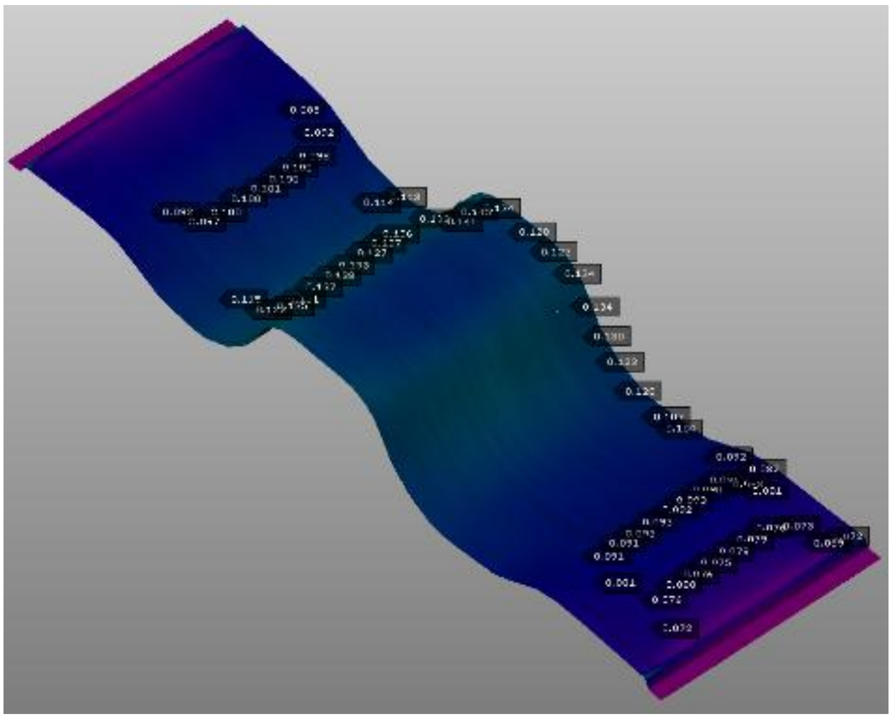

Figure 7 Simulated strains for the formed sheet metal component after one of the forming stations before trimming

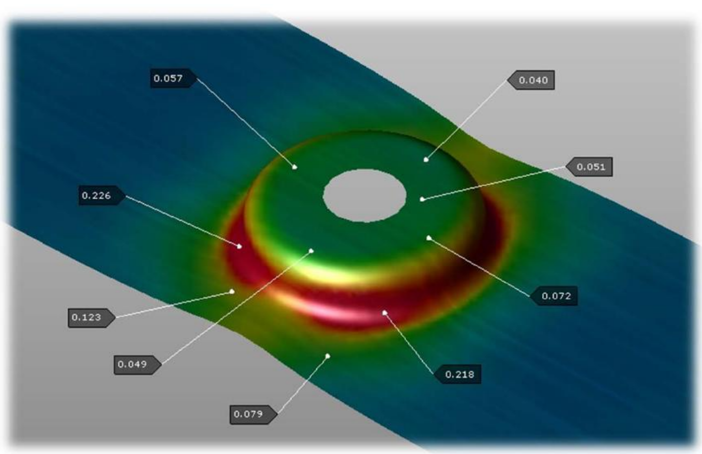

Figure 8 Simulated strains for the formed sheet metal component after the forming stations before punching

Experience and results from previous industrial tests were used as a base for the test matrix that was developed. Both trimming at different angles and punching were tested. Parameters that were varied were e.g. two different types of lubricants, two different edge radii, three levels of trimming clearance and three types of coatings as well as no coating. See Figure 9 and Figure 10 for schematic illustrations of the tools used in the testing.

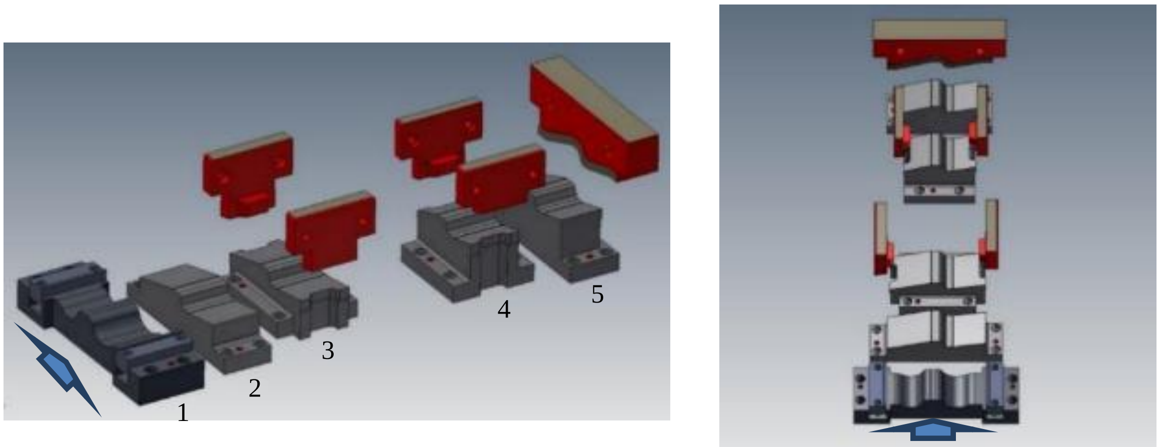

Figure 9 Layout of the semi industrial trimming tool that was used in the project

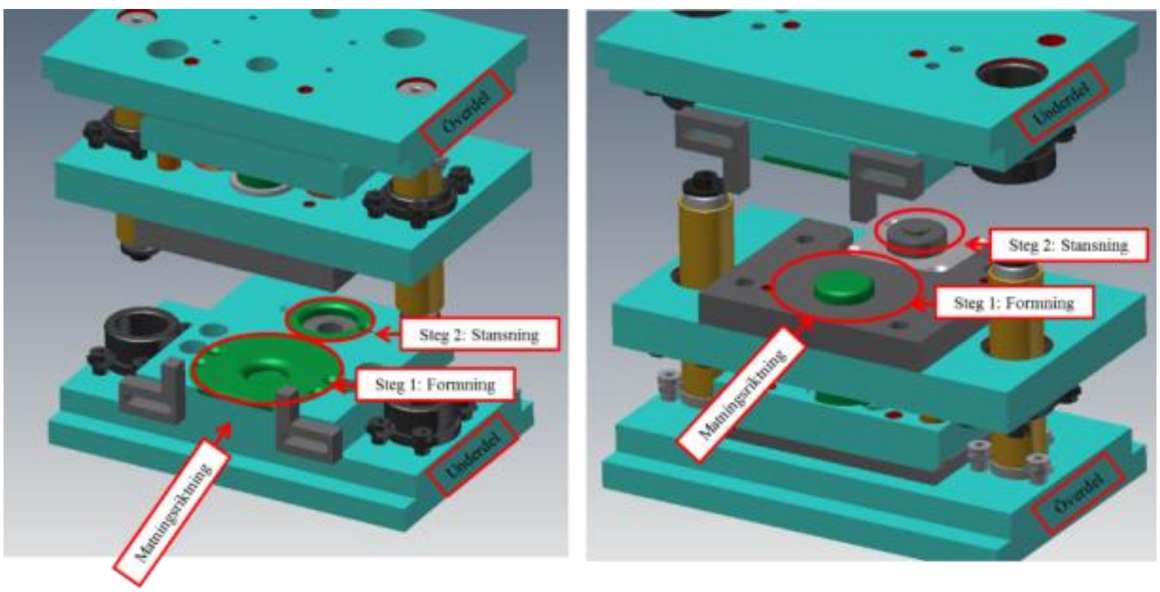

Figure 10 Layout of the semi industrial punching tool that was used in the project

5. Results and deliverables

5.1 Delivery to FFI-goals

The project has had relevance to the program by aiming to increase the competitiveness of the Swedish automotive suppliers and OEMs through increased efficiency in high-volume production of lightweight components. ALKOMP has endeavored to contribute to the 2015 target within the FFI collaboration program Sustainable Production Technology through the following project:

- **• Reduce emissions of fossil CO_2 and other emissions**
  • 40% higher productivity in the manufacturing preparation
  • 30% lower environmental impact from manufacturing processes
  • 30% higher productivity in production processes

Increased aluminum use in vehicles reduces fuel consumption by weight reduction in passenger cars and trucks. Introduction of aluminum in terms of sheet metal in a wider perspective requires improved accuracy in the FE analysis to which the project contributes by improving the material and friction modeling. Improved product quality with reduced waste and fewer rejections can be achieved with improvements in process- and product preparation as well as in the trimming and punching area which the project addresses. Reducing waste and scrap increases resource utilization, resulting in lower environmental impact. Reduced consumption of lubricating oils in forming and trimming requires knowledge of tribology and processes that are developed in the project.

The goal to eliminate at least one try out iteration provides reduced setup cost and reduced lead time for forming and trimming tools. Productivity is improved by reducing the need for tool maintenance due to less of chipping.

The project results in terms of guidelines may directly or indirectly be useful for manufacturing companies outside the project team. Swedish industry can benefit from the experience and practice concerning material characterization, material modeling and the use of more advanced friction models along with how they should be calibrated in the future when they are faced with the need to simulate the forming behavior due to the introduction of new materials. Furthermore, the results obtained and identified development opportunities can in the long run lead to research further advancing the frontiers of knowledge.

5.2 Material data and material modelling

5.2.1 Prediction of spring back

Spring back is a major problem in the pressing of aluminum alloys. Although the material is quite soft the spring back will be significant. This is due to the low Young's modulus, about 65-70 GPa. To accurately predict spring back using forming simulations is therefore very important. In WP1 testing of two different aluminum alloys have been conducted in a U-bend tool available at the IUC in Olofström. In Figure 11 the deviation between the scanned geometry after forming and the results of simulation for a sample is shown. In large areas of the detail there is good agreement. The large deviation on the part edges depends on a small deviation at the draw radius and this gives a large deviation out at the edge.

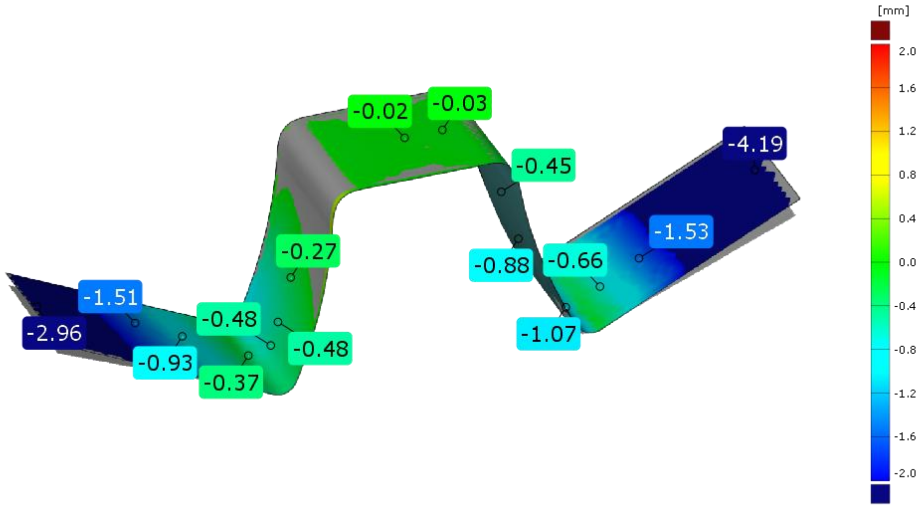

Figure 11 Deviation between the scanned geometry and results from simulation after spring back.

5.2.2 Simulation of Inner Hood, Volvo XC60

For final verification of the results a Inner Hood for the first version of the Volvo XC60 have been simulated with both Barlat 89 'and BBC2005. An analysis of the strains after forming showed small differences. But when it comes spring back the differences were significant in some areas, see Figure 12.

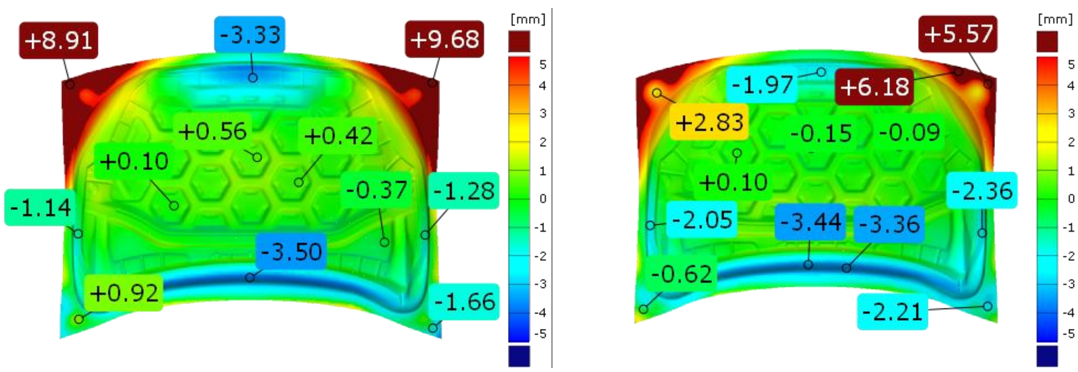

Figure 12 Spring back with Barlat `89 (left) and BBC2005 (right).

5.3 Calibration of the friction model

Figure 13 shows the different outcomes of the force response in the calibration of Shear-cap and the optimized solution. The result clearly shows that the friction model can be adapted to the tribological system with desirable accuracy.

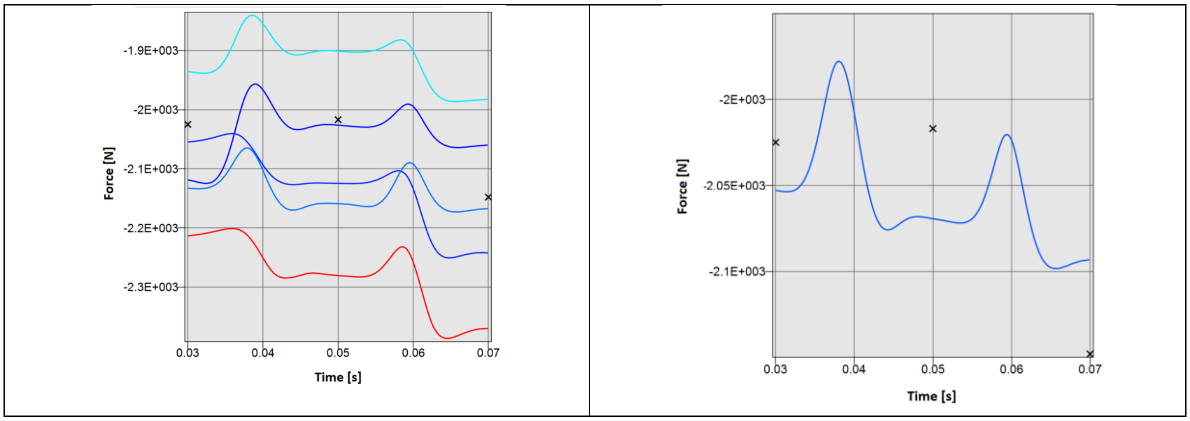

Figure 13 The picture on the left shows the different outcomes of the FE simulations with variable friction (iteration 1). The crosses represent the experimental values. The picture to the right shows the optimized solution of Shear-cap model.

Figure 14 shows the different outcomes of the force response in the calibration of Emmen's model and the optimized solution. The result shows that the model can be adjusted with acceptable accuracy to the tribological system at low speeds.

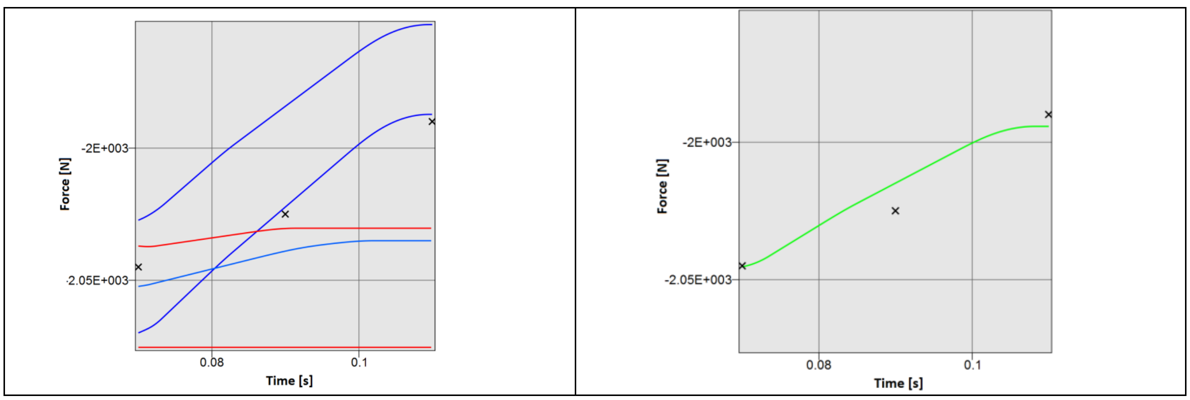

Figure 14 The picture on the left shows the different outcomes of the FE simulations with variable friction (iteration 1). The crosses represent the experimental values. The picture to the right shows the optimized solution of Emmen's model.

5.4 Robust trimming- and punching processes for sheet metal aluminum

The conducted tests gave results regarding the quality of the trimmed and punched edges, formation of burrs and slivers and galling onto trimming and punching tools. Several of the process parameters that were varied had impact on the outcomes. Parameters and factors that had a major impact was for instance type of coating, clearance and how well supported the part that was cut away was.

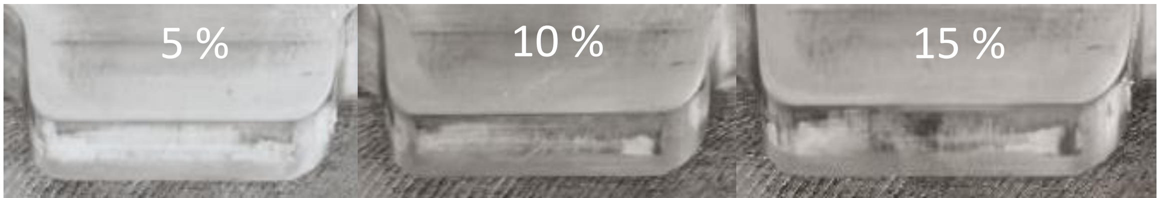

Figure 15 Example results regarding galling on trimming edges on trimming tool with different clearance (5, 10 or 15% of sheet thickness)

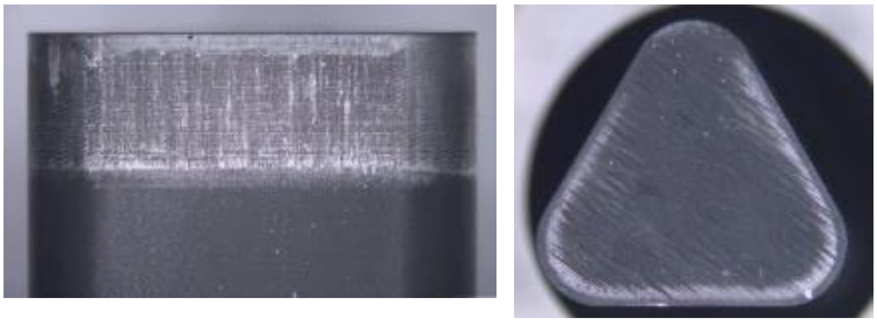

Figure 16 Example results regarding galling on trimming edges on punching tool

Figure 17 Example results regarding formation of burrs and slivers in trimming with different clearance (5, 10 or 15% of sheet thickness)

Figure 18 Example reuslts regarding quality of punched part. Burrs that have been formed and still are attached to the part are also visible

6. Dissemination and publications

6.1 Knowledge and results dissemination

Developed knowledge and documentation will be used internally at the participating companies. Parts of the project and will be presented at the annual FFI Conference. The compilation of work package 3, Industrial Guidelines will be published within the network Metal Forum by the network's newsletter.

6.2 Publications

Berglund, Johan; Kjellberg, Mikael; Liljengren, Magnus; Kjellsson, Kenneth; ,New Test Method for Detection and Analysis of Burrs and Slivers in Trimming and Punching Aluminium Sheet Metal, Proceedings of the 6th International Swedish Production Symposium, Gothenburg 16-18 September, 2014.

Efforts to evaluate and develop friction models has resulted in an article, "Evaluation of a First Order friction model into the deep drawing of aluminum sheet metals". This article will be sent to the "7th International Conference on Tribology in Manufacturing Processes".

7. Conclusions and future research

7.1 Conclusions and future work about friction modeling

The following conclusions have been drawn about the modeling of friction:

- Evaluated friction model is implemented correctly, has full functionality and is computationally efficient.
- A method for calibrating the first-order physics has been developed and the methodology works well.
- The evaluated friction model cannot describe the present tribological system.

The following changes in the friction model is proposed:

- The contact definition should be based on Pullen & Williamson[3] i) which assumes that the volume of deformed peaks results in the same volume as the ascending valleys and ii) the proportion of real contact area increases less than proportionally with the nominal pressure, ie Pnom / H = α / (1-α) where Pnom is the nominal pressure, H is the hardness and α is real contact area. This would create a much better description of the pressure dependence.

[3] Pullen, J. & Williamson, J.P.B. (1972). *On the plastic contact of rough surfaces*, Proc. R. Soc. London, Series A **327**: 159-173.

- Influence of shear stresses in the lubricant should be included. This will create a better description of the velocity dependence at high speeds.
- Include a strain dependant hardness because the influence of elongation is significant.

7.2 Conclusions and future work with the one-step tool

- The tool shows great potential for determining forming limits in one stroke.
- The tool shows great potential for the ranking of different materials with respect to the formability
- Obtaining different strain paths in one tool enables studies of friction models with variable friction and are expected to provide much valuable knowledge. The calibration made for X-die and U-Bend with one of the aluminum alloys will be implemented after the project's completion
- To enable balance between deep drawing and stretch forming in a better way than what is possible with the current geometry it is proposed that the tool is supplemented with devices to control the draw-in of the blank along the periphery
- Physical experiments with the tool in future projects is desired

7.3 Conclusions and future work for robust trimming- and punching processes for sheet metal aluminum

The following conclusions have been drawn regarding robust trimming- and punching processes for sheet metal aluminum:

- How well the sheet is controlled by the sheet holder influence the formation of burrs and slivers when trimming of aluminum sheet.
- Coating and surface roughness of the tools have a significant influence on the amount of galling on the trimming and punching tools.
- Trimming angle also has an influence on galling. A larger negative angle creates more galling that is more difficult to remove by polishing.
- Clearance influenced galling in some cases and also burr height in punching.
- The type of lubrication used did not influence the results.

The following topics could not be fully explored within this project and can be seen as suggestions for future research:

- The influence of surface roughness. It could be seen that roughness had an influence on the outcome, especially in combination with coatings.
- A limitation in the experimental setup for trimming was that only stresses and strains in one direction could be included in the test. To include stresses and strains in more directions could improve the outcome of the tests so that it better represents the outcomes in real production.

8. Participating parties and contact person

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