Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 47 (2020) 535–540

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

23rd International Conference on Material Forming (ESAFORM 2020)

# Temperature Dependent Friction Modelling: The Influence of Temperature on Product Quality

Daan Waanders[a,]*, Javad Hazrati Marangalou[b], Matthäus Kott[c], Sabrina Gastebois[d], Johan Hol[a]

[a]*TriboForm Engineering, Hengelosestraat 500, 7521 AN, Enschede, the Netherlands*
[b]*Nonlinear Solid Mechanics, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands*
[c]*Opel Automobile GmbH, Bahnhofsplatz, IPC42-12, D-65423 Rüsselsheim am Main*
[d]*ESI Group, EXCELCAR - La Janais, Route de Nantes, BP 57633, 35176, Chartres-de-Bretagne, France*

* Corresponding author. Tel: +31 88 0085500; *E-mail address:* d.waanders@triboform.com

## Abstract

In the stamping of industrial parts, friction and lubrication play a key role in achieving high quality products and reducing scrap. Especially in the start-up phase of new production runs, transient effects can have a significant impact on the product quality. Before a steady-state production run is established, heating up of tools influence tribological conditions. This influences the performance of the forming operation and, consequently, the quality of the formed product. In the development process of new industrial parts, it is therefore crucial to accurately account for these transient effects in sheet metal forming simulations. This paper presents the modeling of the frictional behavior of two tribological systems as developed within the ASPECT project. The first tribology systems consist of a stainless steel with corresponding drawing oil and tool material. The sheet material of the second tribology system is a hot dip galvanized bake hardened steel. Subsequently, it is shown how temperature affects the frictional behavior of these tribology systems. Finally, generated friction models have been applied to a spare wheel well of Opel. The spare wheel well is modelled using a generally applicable approach to account for transient effects under industrial sheet metal forming process conditions. For varying temperature and tribological conditions, the spare wheel well can show cracks and differences in thinning and draw-in. This emphasizes the strong influence of transient effects on both part quality and the overall production stability.

*Keywords:* Friction; Temperature; Deep Drawing; Transient effects

## 1. Introduction

During the stamping of industrial parts, tribology, friction and lubrication play a key role in achieving high quality products and reducing scrap. Especially in the starting-up phase of new production runs, transient effects can have a significant impact on the product quality. Before a steady-state production run is established, heating up of the tools influence both the material properties and tribological conditions. This influences the performance of the forming operation and, consequently, the quality of the formed product. In the development process of new industrial parts, it is therefore crucial to accurately account for these transient effects in sheet metal forming simulations.

The quality of sheet metal formed parts is strongly dependent on the tribology, friction and lubrication conditions that are acting in the actual production process. These friction conditions are dependent on the tribology system, i.e. the applied sheet material, coating, tooling material, lubrication- and process conditions. Although friction is of key importance, it is currently not considered in detail in stamping simulations. The current industrial standard is to use a constant coefficient of friction (Coulomb). However, this limits the overall simulation accuracy.

Within the ASPECT project, multiple tribology systems have been experimentally tested and numerically modelled. Subsequently, these friction models have been applied to FEM simulations. Within this paper, two tribology systems will be

10.1016/j.promfg.2020.04.159

evaluated. A friction model of the first tribology system has been generated for the consumer goods industry (Philips) and considers a stainless steel with a commercially available drawing oil and a tool steel material. This tribology system has subsequently been utilized in the study of Veldhuis et al. [1]. The second tribology system is related to the automotive industry (Opel Automobile GmbH) and considers a hot dipped galvanized bake hardened steel with a commercially available drawing oil and a cast iron tool material. Friction models of the latter tribology system have been generated and analyzed in this paper for four different combinations in terms of lubrication amount and tooling roughness. Finally, these combinations have been applied to the spare wheel well of the Opel Insignia B and a comparison is made with experimentally obtained draw-in results [2].

## 2. Approach

This section describes the modeling and simulation approach to obtain the tribological behavior of the two tribology systems as considered in this paper. The two tribology systems are related to ASPECT's consumer goods and automotive partners. Each tribology system contains a sheet material, a lubricant and a tooling material.

### *2.1. Simulation of friction and lubrication conditions*

In this paper, the tribological behavior is modelled by the TriboForm software (Fig. 1.). The TriboForm software allows for multi-scale modelling of a time and locally varying friction coefficient under a wide range of process conditions. The tribology system information, as will be described in the following subsection, combined with the temperature dependent viscosity data of the lubricant, enables the generation of a TriboForm Library. The TriboForm Library includes the friction conditions for the considered tribology system. The required input information of the tribology system and procedure to generate TriboForm Libraries are described in the studies of Hol et al. [3,4]. The resulting 4D friction models are dependent on the pressure, velocity, temperature and strain. These models can be imported in ESI PamStamp using the TriboForm FEM Plug-In, replacing the constant coefficient of friction (Fig. 1.). A more detailed description of the simulation approach can be found in [5]. In this paper, the experimental data to calibrate the friction models were acquired from the measurements of Filzek.

### *2.2. Tribology system 1*

The first tribology system, which is related to the consumer goods industry Philips and used in the study of Veldhuis et al. [1], considers an uncoated AISI4520 stainless steel in the annealed state with a thickness of 0.3mm. The surface roughness of the sheet was measured by 3D surface measurements at different locations and had an average $S_a$ roughness value of 0.35μm (Table 1). The sheet is lubricated with the drawing oil Castrol Iloform FST 16 with a lubrication amount of 6.0g/m$^2$. The tool considers a polished Ceratizid CF-S18Z material and had an average $S_a$ roughness value of 0.05μm (Fig. 2).

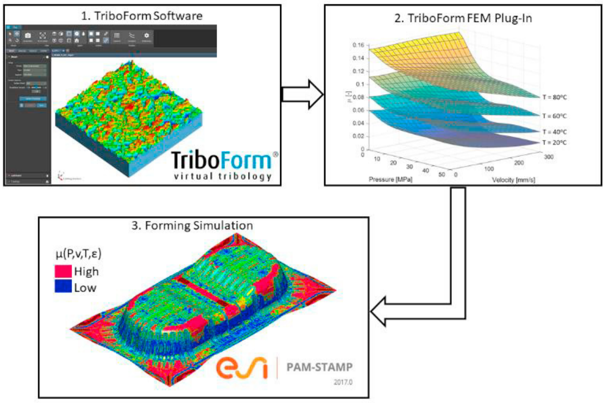

Fig. 1. Simulation approach for friction and lubrication modelling in sheet metal forming simulations.

Table 1. Settings tribology system 1.

| | Sheet | Lubricant | Tool |
|---|---|---|---|
| | **AISI420** | **Castrol Iloform FST 16** | **Ceratizid CF-S18Z** |
| Combination 1 | $S_a$=0.35μm | Lub.Am.=6.0g/m$^2$ | $S_a$=0.05μm |

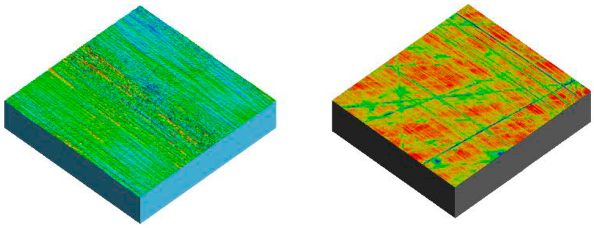
AISI420 CF-S18Z

Fig. 2. Representation of the AISI420 and CF-S18Z sheet and tool material, respectively.

### *2.3. Tribology system 2*

The second tribology system, related to the automotive industry, is a hot dipped galvanized bake hardened steel (HX180Z) with a thickness of 0.65mm. Again, the surface roughness was measured at different locations and an average $S_a$ roughness value of 1.29μm was measured (Table 2). The applied drawing oil was the PL61 of Zeller&Gmelin. The tool material was a GGG70 cast iron tool material. The tool topography and corresponding roughness have been acquired from the actual stamping tools of the Opel Insignia B spare wheel well. Measurements showed that the $S_a$ roughness of the die, blankholder and punch ranged from 0.65 to 2.32μm, with an average $S_a$ roughness of 1.12μm.

Four different combinations with distinct settings in terms of lubrication amount and tool roughness were considered (Table 2; Fig. 3). The lubrication amount and tool roughness of the first three combinations correspond to a low, medium and severe amount of friction. Combination 1 had a rather high lubrication amount and a low tool roughness, whereas combination 3 had a rather low lubrication amount and a high tool roughness. Combination 3 corresponds most to the actual tribological conditions of the forming process of the spare wheel well. The aim of these combinations was to assess the sensitivity of the spare wheel well to friction.

Combination 4 (Table 2) was directly based on experimental friction data measured by Filzek. For this purpose, the TriboForm Library Creator was utilized to generate a friction model representing the same tribological conditions as measured by Filzek. As the experimental dataset was only pressure and temperature dependent, the velocity and strain dependencies were acquired from a reference friction model yielding the same tribological characteristics, resulting in a 4D-friction model.

Table 2. Considered combinations of the second tribology system.

| | **Sheet** | **Lubricant** | **Tool** |
|---|---|---|---|
| | **HX180Z** | **PL61** | **GGG70** |
| Combination 1 | $S_a$=1.29μm | Lub.Am.=3.0g/m$^2$ | $S_a$=0.40μm |
| Combination 2 | $S_a$=1.29μm | Lub.Am.=2.0g/m$^2$ | $S_a$=0.80μm |
| Combination 3 | $S_a$=1.29μm | Lub.Am.=1.0g/m$^2$ | $S_a$=1.20μm |
| Combination 4 | $S_a$=1.29μm | Lub.Am.=1.5g/m$^2$ | $S_a$=0.90μm |

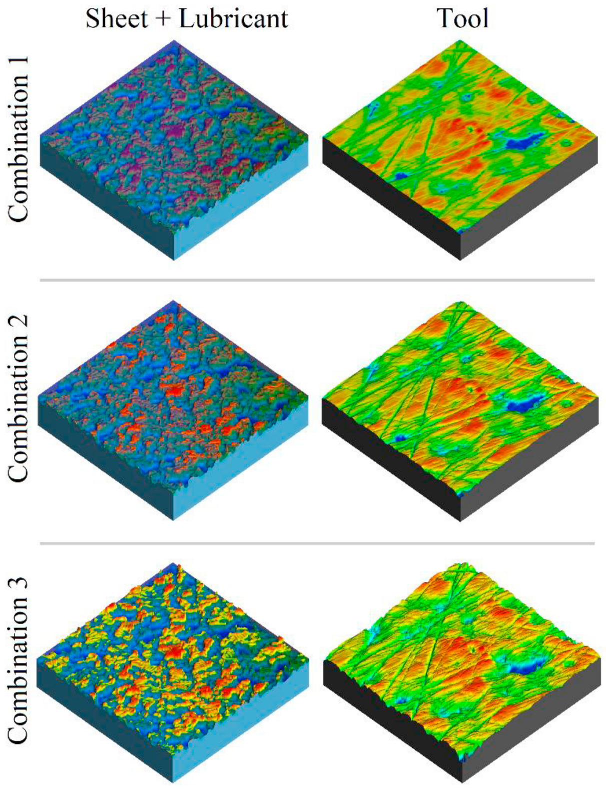

Fig 3. Representation of the first three combinations modelled. Note that combination 1 has the highest lubrication amount and lowest tool roughness. Combination 3 has the lowest lubrication amount and highest tool roughness.

## 3. Results

The following two subsections present the two generated friction models.

### 3.1. Tribology system 1

The frictional behavior of the tribology system generated for Philips is presented in Fig. 4. The four planes represent the distinct frictional behavior at the four different temperatures of the tribology system: 20, 40, 60 and 80˚C. An increased temperature results in increased friction. Moreover, there is a significant pressure dependency of the friction coefficient; increasing pressure results in a decreasing friction coefficient. Due to the lubrication type and the applied amount of lubricant, there is also a considerable velocity dependency. The friction model and application has been further discussed in the study of Veldhuis et al. [1].

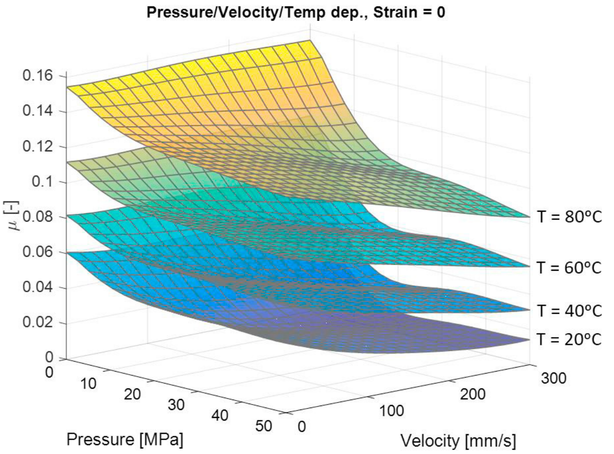

Fig. 4. Friction model of Tribology system 1.

### 3.2. Tribology system 2

The friction models of the four combinations of Tribology system 2 are presented in Fig. 5. Two temperatures are presented, 20 and 45˚C, which are based on the temperatures measured during production of the spare wheel well [2]. Considering combination 1, 2 and 3 and pressures below 20MPa, it is shown that combination 3 results in the highest amount of friction and combination 1 in the lowest amount of friction. For pressures beyond 20MPa, however, the friction of combination 3 is less than combination 1. This can be explained by the flattening of the sheet, which is enhanced by an increased tool roughness. This also explains why, despite the lower lubrication amount, combination 3 shows more velocity dependency than combination 1. When the temperature is increased from 20 up to 45˚C, the friction increases, especially at higher velocities.

Considering all four combinations, the 4th combination (based on experimental input data), results in the lowest amount of friction. The frictional behavior of combination 4 tends to be the same as combination 1. However, relative to combination 1, the lubrication amount and tool roughness of combination 4 were lower and higher, respectively, from which a higher amount of friction would be expected. The lower frictional behavior of combination 4 can be explained by the laboratory prepared tool topography, which is different from the topography of the combinations 1-3 which was based on actual surface measurements on the spare wheel well tools.

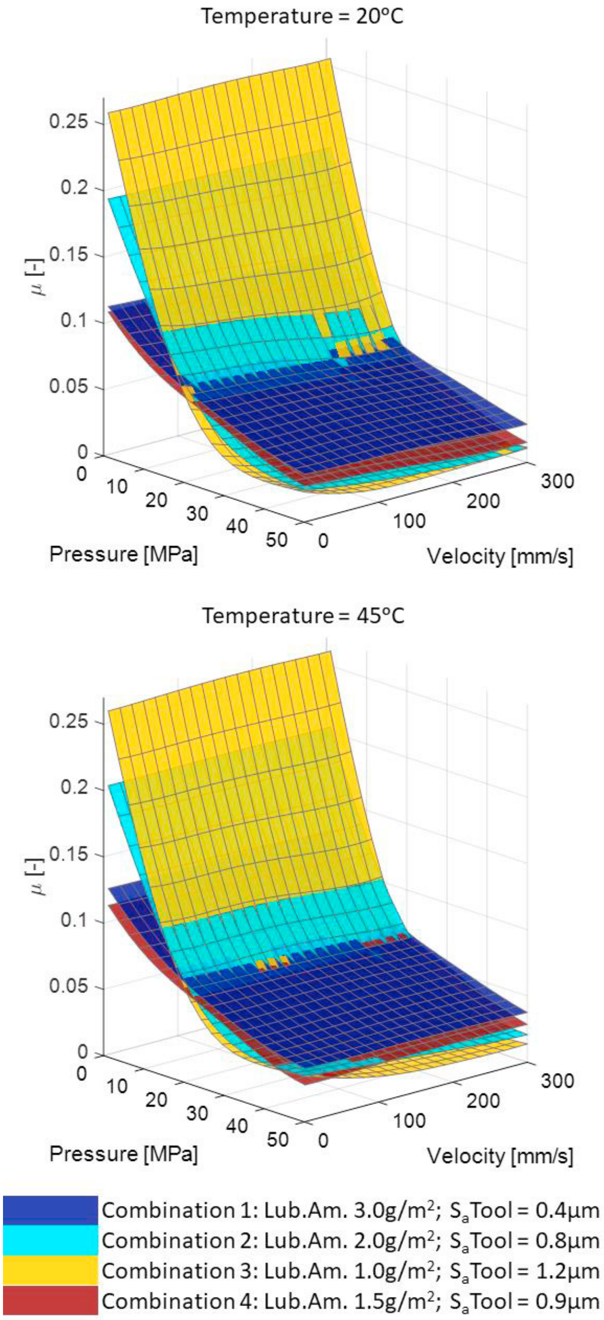

Fig. 5. The four friction models of Tribology system 2 at 20 and 45˚C.

## 4. Application

### 4.1. Introduction

As a demonstration case, the spare wheel well of the Opel Insignia B is considered. The spare wheel well is produced as a double part and has a relatively high drawing depth of 225mm (Fig. 6). Quality issues and failures are necking and tearing in the rib of the part [2]. These issues do not occur in the first drawn parts, but after approximately 500 drawn parts. It is assumed this is because of increased friction due to heating up of the tools; this leads to higher restraining forces and thereby failure of the part. Kott et al. [2] have shown that the temperature increase in the tools is about 25˚C: Initially, the temperature in the tools is around 20˚C, whereas the temperature rises up in time to a maximum of 45˚C.

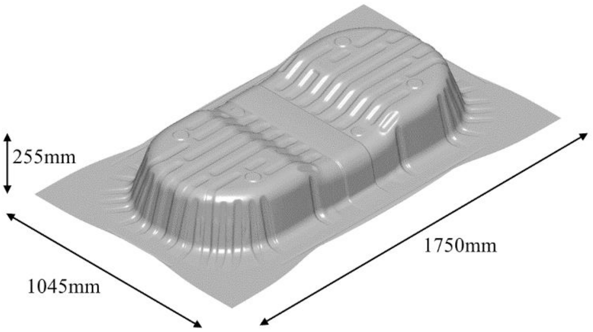

Fig. 6. Impression of the Opel Insignia B's spare wheel well; a double part with a relatively high drawing depth.

### 4.2. Simulation properties

The sheet metal forming simulations are performed using ESI Pam-Stamp v2017.0 in conjunction with the TriboForm FEM Plug-In for Pam-Stamp.

The material model contains a strain-rate dependent hardening curve with a Veger Standard yield locus as well as a forming limit curve (FLC) as determined by Nakazima tests [6]. The temperature dependency of the material behavior is neglected as the effect of the formability of the deep drawn part appears to be negligible for temperatures up to 100˚C [7]. It is, therefore, assumed that the frictional behavior is the only temperature dependent effect which occurs. As a result, isothermal simulations have been carried out at temperatures of 20 and 45˚C. Within these simulations, the friction models of the four combinations, as presented in Fig. 5, have been used. Additionally, the findings of the four combinations were compared to the findings obtained by a Coulomb friction in which a nominal constant friction coefficient of 0.08 has been used [2].

As post-variables, the draw-in, thinning and corresponding FLD have been considered. The draw-in is measured by eight sensors positioned at different locations around the circumference of the part (Fig. 7). The reference amount of draw-in for each sensor after 1 and 500 drawn parts equals the zero line in Fig. 7 for 20 and 45˚C, respectively. Draw-in results are further described by Kott et al. [2].

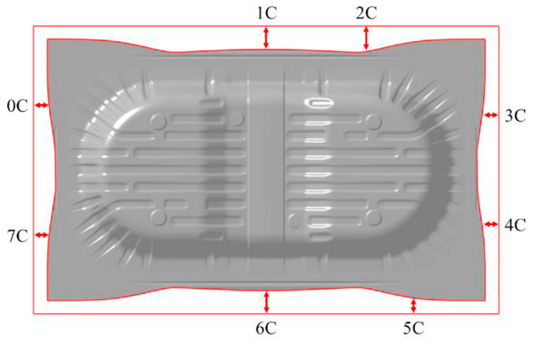

Fig. 7. Draw-in measurement locations.

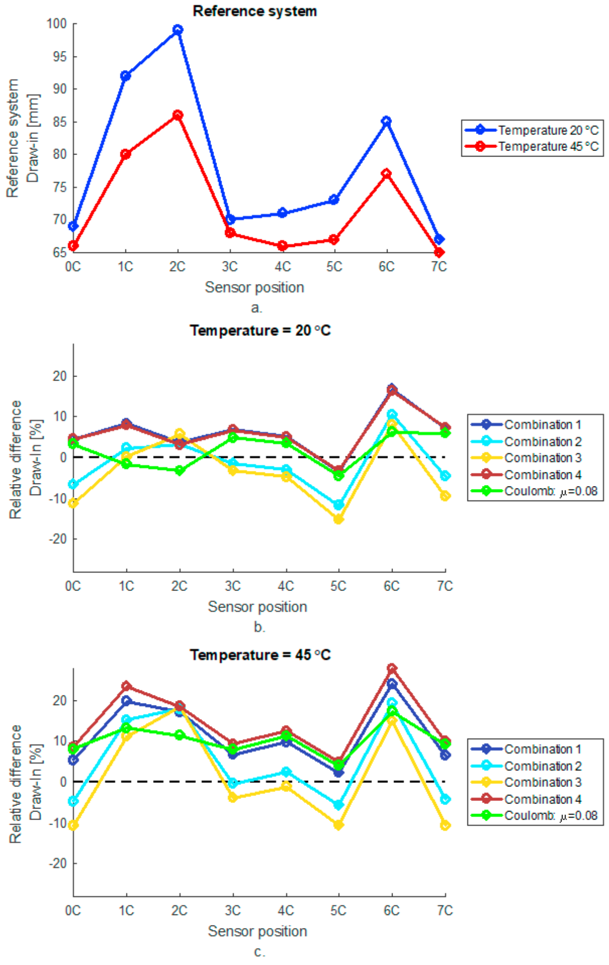

Fig. 8. Measured draw-in of the reference system at 20 and 45˚C (a.). Relative draw-in at 20 (b.) and 45˚C (c.).

### 4.3. Simulation results

When the temperature rises from 20 to 45˚C, the draw-in of the experimental reference system decreases (Fig. 8a.). Note that even though the part is symmetric and that locations 1C and 6C are positioned opposite to each other, there is a considerable difference in draw-in. Such differences are much less pronounced for sensors 0C and 7C or 3C and 4C.

At 20˚C, the relative difference of the draw-in with respect to the reference at 20˚C has been shown in Fig. 8b. At this temperature, the combinations 1 and 4 show almost the same amount of draw-in. With the exception of location 5C, the amount of draw-in is an overestimation relative to the reference system. The amount of draw-in determined by the combinations 2 and 3 are considerably less than combinations 1 and 4. Especially at the locations 1C, 3C and 4C there is a positive match relative to the reference system. Remarkably, all combinations show an underestimation of draw-in at location 5C.

At 45˚C combinations 1 and 4 are overestimating the amount of draw-in, indicating a too low amount of friction (Fig 8c.). Though the difference between combination 1 and 4 was negligible at 20˚C, combination 4 shows more draw-in than combination 1. Combinations 2 and 3 show an underestimation at locations 0C, 5C and 7C indicating too much restraining. Remarkably, for all combinations, the amount of draw-in at 1C and 6C were overestimated. Note that the amount of draw-in for the Coulomb simulations is the same for 20 and 45˚C. This explains the overestimation of draw-in at 45˚C considering Coulomb friction.

Regarding the formability, it was found that the combinations 1, 2 and 4 and Coulomb do not become critical at 20 or 45˚C. For combination 3 significant cracks were found at 45˚C (Fig. 9). Cracks occur in the longitudinal direction in the rib of the part, which corresponds to the cracks observed in the real part [2]. At 20˚C some critical areas were found, though very less pronounced than at 45˚C.

## 5. Conclusions and future work

In the current paper, 4D friction models of two tribology systems were generated. The tribological settings of the first tribology system were set according to reality. The settings of the second tribological system were set in such a way it showed a broad friction range suitable for a sensitivity study. Moreover, the fourth combination was based directly on experimental data. All four combinations were implemented in a practical case: Opel's spare wheel well. Subsequently, all four combinations were compared with experimentally obtained data of this part in order to get insight in its frictional dependency.

It can be concluded that transient effects during production can be accurately predicted with advanced friction modelling. Transient affects, such as temperature increase of the tools, will affect the amount of friction and can have, subsequently, an effect on the product quality. Based on the findings obtained by the application case of the spare wheel well it can be observed that the combination of tool roughness and lubrication amount has a significant effect on the draw-in and the formation of cracks in the drawn part. For a low tool roughness and high lubrication amount, the draw-in is likely to be overpredicted. Additionally, there is an absence of cracks. When the tool roughness is increased and the lubrication amount decreased, the draw-in gets closer to reality, though the amount of draw-in is underpredicted in some areas. Moreover, cracks were predicted, which had the same orientation and location as in reality. Direct implementation of experimental data resulted in an overprediction of the amount of draw-in.

Future work should focus on the implementation of (tribological) settings according to reality. Still discrepancies were observed in draw-in behavior, which might be attributed to the different tool topographies and corresponding roughness's observed for the different tools.

Besides the tribological settings, future work should focus on thermal FEA simulations instead of the isothermal simulations presented in the current paper. Initially, the tools will have a uniform homogenous temperature at ~20˚C. Kott et al. [2] have shown that a variation in the tool temperatures arises during production; while the temperature in the blankholder rises up to ~45˚C, the punch temperature stabilizes at ~33˚C. Krairi et al. [7] have developed the "jump of strokes method" in which the heating up of the tools during production can be reproduced.

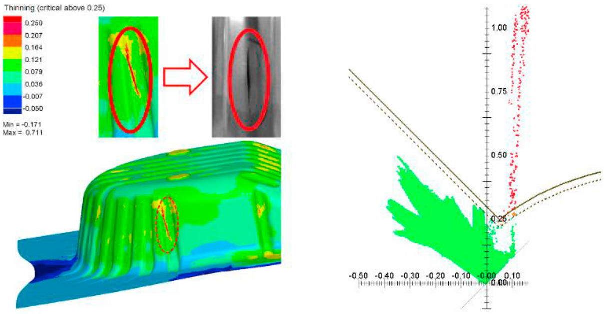

Fig. 9. Crack formation for combination 3 at a temperature of 45˚C. The cracks were found in the longitudinal direction in the rib.

## Acknowledgements

This research was carried out within the project "ASPECT – Advanced Simulation and control of tribology in metal forming Processes for the North-West European Consumer goods and Transport sectors" (project number NEW 220), cofounded by the INTERREG North West Europe program www.nweurope.eu/aspect.

## References

[1] Veldhuis M, Heingärtner J, Krairi A, Waanders D and Hazrati J. An Industrial-Scale Cold Forming Process Highly Sensitive To Temperature Induced Frictional Start-up Effects To Validate A Physical Based Friction Model. Procedia Manufacturing (in press). 23rd International Conference on Material Forming (ESAFORM 2020) Cottbus 2020

[2] Kott M, ErzC , Heingärtner J and Groche P. Controllability of temperature induced friction effects during deep drawing of car body parts with high drawing depths in series production. Procedia Manufacturing (in press). 23rd International Conference on Material Forming (ESAFORM 2020) Cottbus 2020

[3] Hol J, Meinders VT, de Rooij MB and van den Boogaard AH. Multi-scale friction modeling for sheet metal forming: The boundary lubrication regime. Tribology Int., 2014; 81: 112–128.

[4] Hol J, Meinders VT, Geijselaers HJM. and vd Boogaard AH. Multi-scale friction modeling for sheet metal forming: the mixed lubrication regime. Tribology Int., 2015; 85: 10–25.

[5] Hol J, Wiebenga JH, Carleer B. Friction and lubrication modelling in sheet metal forming: Influence of lubrication amount, tool roughness and sheet coating on product quality, IOP Conf. Series: Journal of Physics: 2017; Conf. Series 896, 2017

[6] Atzema E, Mulder H. Temperature Dependence of Steel Constitutive Behavior: A Simplified Model. Procedia Manufacturing (in press). 23rd International Conference on Material Forming (ESAFORM 2020) Cottbus 2020.

[7] Krairi A, Marmi J, Gastebois S, Veldhuis M, Kott M. A speed-up method for numerical simulations of multi-strokes cold metallic sheet forming processes. Procedia Manufacturing (in press). 23rd International Conference on Material Forming (ESAFORM 2020) Cottbus 2020.