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Marko Delić¹

Vesna Mandić²

Nada Ratković³

Nikola Komatina⁴

Dušan Arsić⁵

Nikola Kastratović⁶

ANALYSIS OF THE INFLUENCE OF IMPORTANT FORMING PARAMETERS IN SHEET METAL STAMPING IN AUTOMOTIVE INDUSTRY USING FEA

ABSTRACT: Manufacturing of parts using stamping technology is very common in the auto industry. In this paper, for a hood inner panel, the effects of manufacturing parameters were analysed using the finite element method. The influence of blank holding force, holding surface and tribological conditions is considered. The success of the process was analysed using the forming limit diagram, which in combination with FEA provides significant opportunities for process improvement. Results shows that friction have great impact on fracture occurring and quality of parts.

KEYWORDS: stamping, FEA, FLD

¹ Marko Delić, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, marko.delic@kg.ac.rs,
 <https://orcid.org/0000-0001-5493-7569>

² Vesna Mandić, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, mandic@kg.ac.rs,
 <https://orcid.org/0000-0003-1624-3536>

³ Nada Ratković, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, nratkovic@kg.ac.rs,
 <https://orcid.org/0000-0003-1446-8678>

⁴ Nikola Komatina, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, nkomatina@kg.ac.rs,
 <https://orcid.org/0000-0001-6964-5673>

⁵ Dušan Arsić, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6, dusan.arsic@kg.ac.rs,
 <https://orcid.org/0000-0003-0326-0898>

⁶ Nikola Kastratović, Faculty of Engineering, University of Kragujevac, Sestre Janjić 6,
nikolakastratovic@gmail.com

ANALIZA UTICAJA BITNIH PARAMETARA PRI DUBOKOM IZVLAČENJU DELOVA U AUTO INDUSTRIJI KORIŠĆENJEM MKE

REZIME: Izrada delova tehnologijom dubokog izvlačenja je veoma zastupljena u auto industriji. U ovom radu su za unutrašnji panel poklopca motora korišćenjem metode konačnih elemenata analizirani uticaji proizvodnih parametara. Razmatran je uticaj sile držanja, površine držanja i triboloških uslova. Uspešnost procesa je analizirana korišćenjem dijagrama granične deformabilnosti (DGD) koji u kombinaciji sa MKE pruža značajne mogućnosti unapređenja procesa. Rezultati pokazuju da trenje ima veliki uticaj na pojavu loma i kvalitet delova.

KLJUČNE REČI: duboko izvlačenje, MKE, DGD

INTRODUCTION

Stamping technology produces very important parts in the automotive industry that have complex geometry. Numerous parameters affect the success of the process. For faster tool development, software that uses the finite element method is often used. The result of numerical simulation is the stress and strain state, and recently, the forming limit diagram, which is integrated into numerical simulation software, has been used significantly for process analysis.

In the numerical experiment, the influence of lubrication and surface condition was considered using different values of the friction coefficient. Coulomb friction was used and the values of the friction coefficient were 0.05, 0.1 and 0.15. The case where the friction coefficient has a value of 0.05 represents an example of excellent lubrication when using special oils. The coefficient of 0.1 represents an average value with some deep drawing oils and finally the coefficient of 0.15 represents an unfavourable case.

According to Stefanović et al. (1997), lubricants have the role of minimizing friction losses, reducing tool wear, improving surface quality, and enabling control of metal flow.

It is a well-known fact that proper blank holding has a significant influence on the accuracy of the forming operation. Radonjić et al. (2015) experimentally and numerically demonstrated that, by optimizing the stiffness of the blank holder, it is possible to prevent fracture occurrence in the stamping process of an automotive fender.

The stamping process is influenced by numerous parameters; therefore, Liu et al. (2024) applied artificial neural networks to determine the optimal parameter values for the stamping of battery covers used in electric vehicles.

A similar study was conducted by Jia-Yin et al. (2025), who optimized the manufacturing parameters for stamping a highly complex cover geometry by combining the finite element method with a Genetic Algorithm–Optimized Back Propagation Neural Network.

Khatir et al. (2017) demonstrated that lubrication, i.e., friction conditions, plays a significant role in the manufacturing process of bipolar plates made of SS316L stainless steel with a thickness of 0.1 mm. The use of lubricants helped maintain a more uniform sheet thickness distribution and deformation throughout the forming process.

In this study, the influence of friction conditions will be numerically investigated using three different coefficients of friction, while three different blank holder pressure levels will also be applied. The first part of the study, aimed at evaluating the influence of tribological conditions alone, was carried out without an active blank holder. In this case, the blank holder was fixed in position and served solely as a calibration element. The combined effect of friction and blank holding force was evaluated in the second part of the study.

NUMERICAL EXPERIMENT

The component considered in this study is a hood inner panel with a complex geometry. The component is intended to be manufactured from sheet metal cut from a coil strip. The manufacturing process is planned to consist of three operations: stamping, hole piercing, and trimming. Although it would probably be more favourable

to cut the sheet with radius at the ends, this would require an additional operation, which would further increase the production cost.

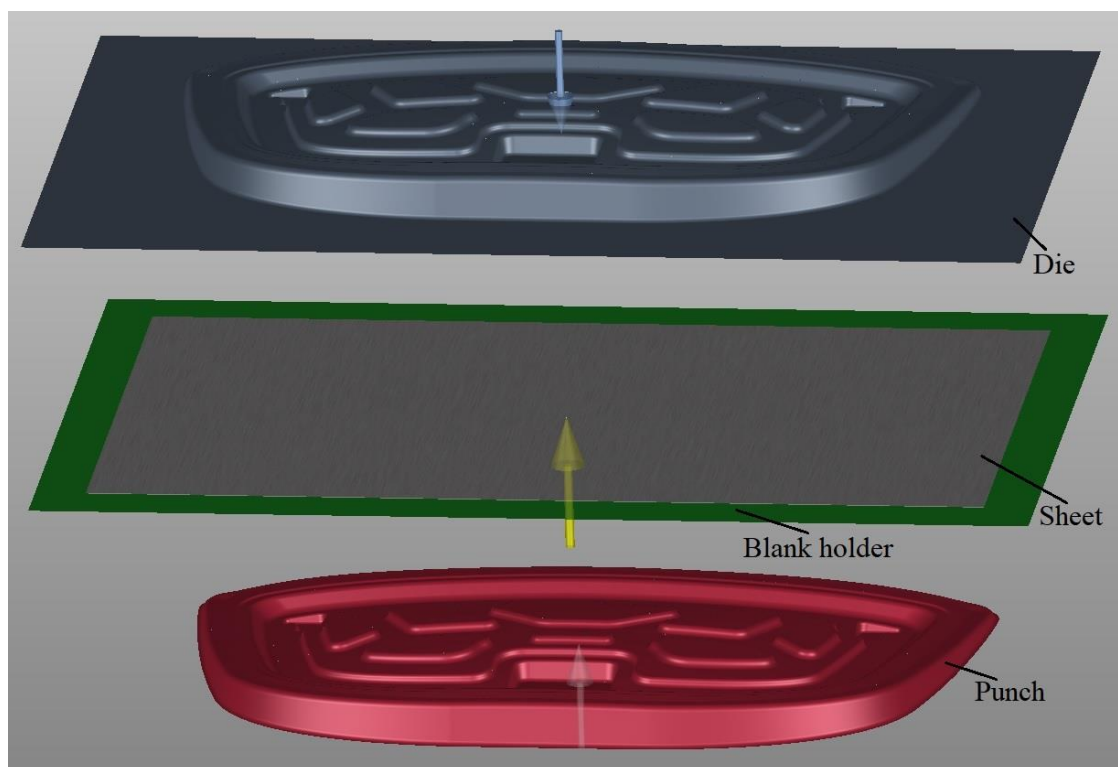


Figure 1 Tools for first operation

In this numerical study, the case of forming from a flat sheet blank will be analysed. The most important aspect is the design of all stamping tool components, particularly the blank holder, which plays a crucial role in preventing wrinkling. The prepared tools are shown in Figure 1. The punch is stationary and is positioned on the machine table. The sheet is clamped between the die and the blank holder. Low-carbon steels, high-strength steels, and aluminium alloys are commonly used for manufacturing such components in the modern automotive industry. In this study, DC04 carbon steel with a thickness of 0.8 mm was used.

The manufacturing process of the component is shown in Figure 2. Figure 2 presents the following stages:

- a) the initial sheet blank,
- b) the component after the stamping operation,
- c) the component after the punching operation, and
- d) the final hood inner panel.

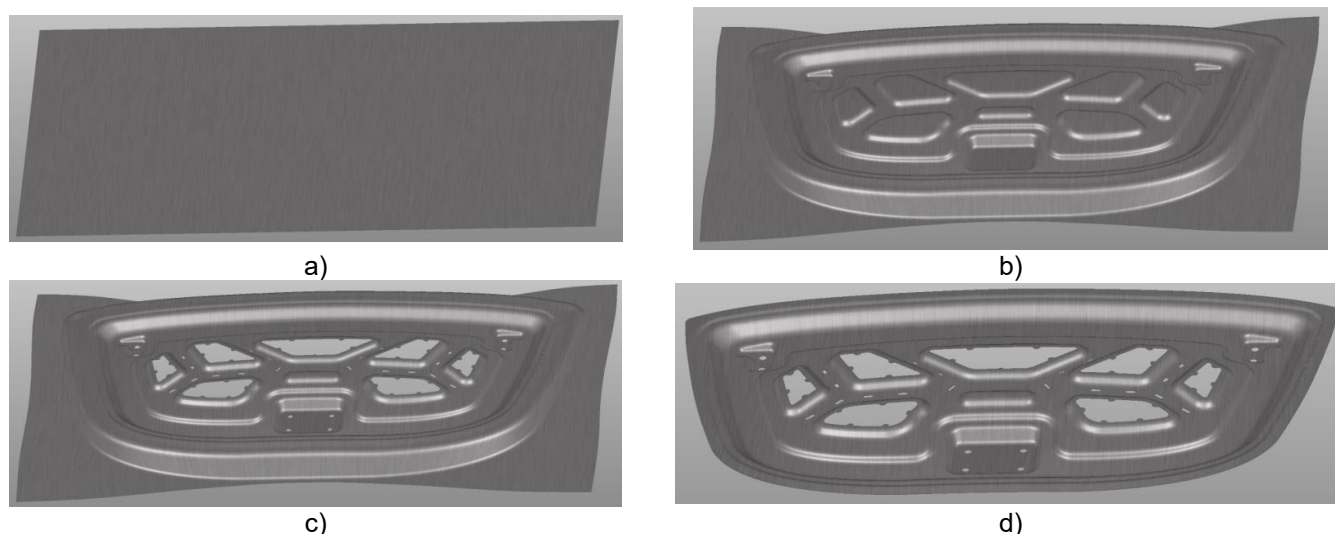


Figure 2 a) Blank b) stamping operation c) punching operation d) trimming operation

In this case, the simulation was performed using the Coulomb friction model, with identical tribological conditions defined for all tool surfaces. The following material properties were defined: a yield strength of 165.4 MPa, an ultimate tensile strength of 309.5 MPa, and a strain-hardening exponent of $n = 0.219$.

An important advantage of this steel is its good formability combined with a relatively low cost, which makes it suitable for the production of components with complex geometries.

Results of the first part of the experiment

The results of the first part of the experiment are presented in Figures 3, 4, and 5. Figure 3 shows the results obtained for a coefficient of friction of 0.15. An initial analysis of the geometry clearly indicates that the most critical region is the depression in the front section of the component. In this case, fracture occurred precisely in this region. The FLD diagram for this case is shown in Figure 3b, clearly demonstrating that, at a high coefficient of friction, the forming operation cannot be successfully completed and fracture will occur.

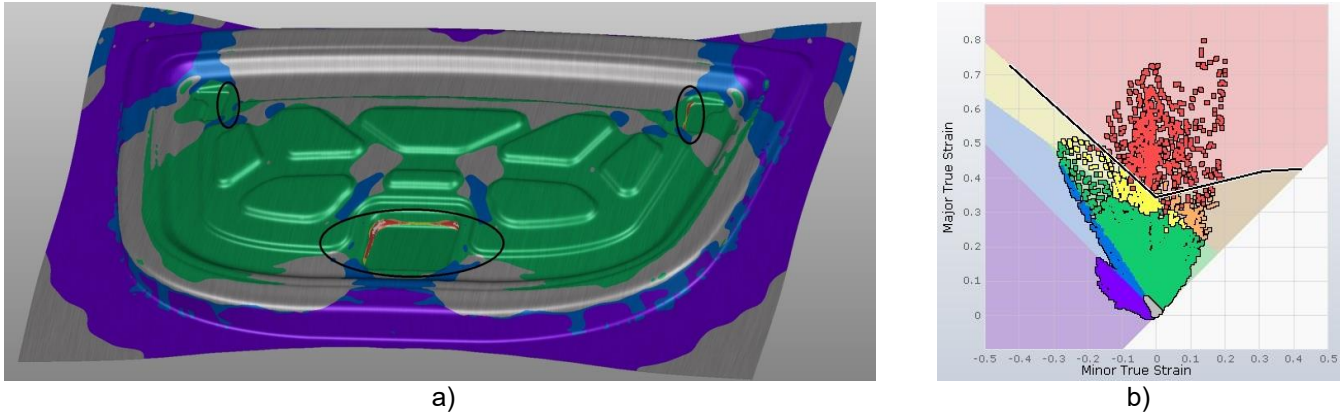


Figure 3 Results for friction coefficient 0.15: a) sheet after first operation b) FLD diagram

Figure 4 presents the results obtained for a coefficient of friction of 0.1. As in the previous case, fracture occurs in the same region. Analysis of the FLD diagram shows that the forming operation is close to being successfully completed, with only a small portion of the strain state extending beyond the forming limit curve.

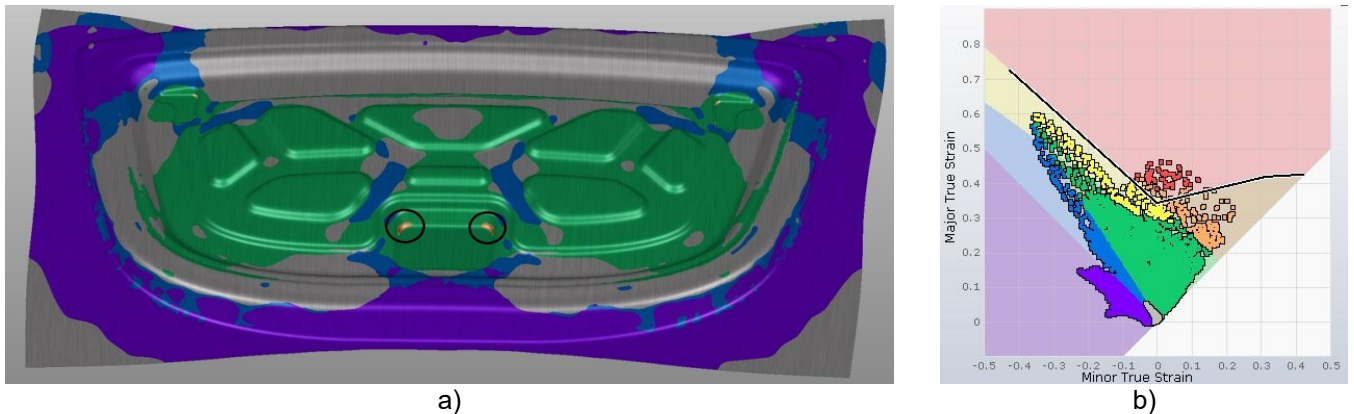


Figure 4 Results for friction coefficient 0.1: a) sheet after first operation b) FLD diagram

In the final case considered, the forming operation was successfully completed without fracture. The results are presented in Figure 5. It can be clearly seen from the figure that the process was successful and that reducing the influence of friction conditions achieved the desired outcome.

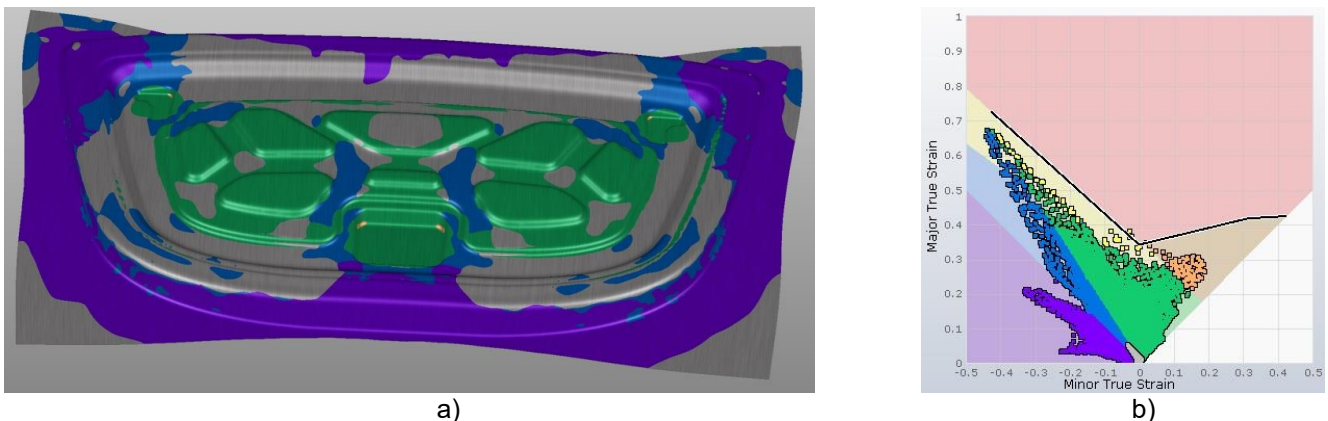


Figure 5 Results for friction coefficient 0.05: a) sheet after first operation b) FLD diagram

The three cases considered clearly demonstrate the importance of achieving appropriate tool surface conditions and lubrication conditions when stamping complex components. In addition to evaluating the success of the forming operation, the forming forces can also be analysed. The force values are presented in Table 1. Based on the results presented in Table 1, it can be observed that friction has a significant influence on the forming force. The forming force decreases as the coefficient of friction decreases.

Table 1 Forces obtained by numerical simulation

	0.15	0.1	0.05
Die	2698.6 kN	2688.8 kN	2565.4 kN
Punch	2468.4 kN	2353 kN	2242.8 kN
Binder (blank holder)	367 kN	399.9 kN	475.1 kN

Results of the Second Part of the Experiment

In the second part of the experiment, the influence of the blank holding force was analysed. Theoretically, the blank holding force is calculated based on the blank holder area and the specific blank holder pressure. According to the domestic literature, the recommended blank holder pressure is between 2 and 3 MPa. Therefore, three cases were considered in the second part of the experiment: 1.5 MPa in the first case, 2.5 MPa in the second case, and 3.5 MPa in the third case. The experiment was performed for all three values of the coefficient of friction.

The results of the second part of the experiment were as expected. The use of a blank holder produced significantly better results. The results of the numerical experiment are presented in Table 2. For a coefficient of friction of 0.05, the forming operation was successfully completed for all three blank holder pressure values. When the coefficient of friction was 0.1, the results were identical, with no fracture occurring in any of the three cases. This result demonstrates the importance of using a blank holder for the successful execution of the forming operation, since the operation was not successfully completed when forming was performed without a blank holder. When the coefficient of friction was 0.15, the forming operation was unsuccessful for all three blank holder pressure values.

Analysis of the FLD shows that, in the first case ($\mu = 0.05$), the forming process is completely safe and no fracture is expected to occur. Increasing the blank holder pressure reduces the possibility of wrinkling. In the second case ($\mu = 0.1$), the tendency for wrinkling increases compared with the previous case. At a blank holder pressure of 3.5 MPa, which is slightly higher than the recommended value, the sheet is very close to fracture. The case with a coefficient of friction of 0.1 is the most realistic scenario. Therefore, this example demonstrates that the influence of blank holder pressure should be carefully considered. In the case of the highest coefficient of friction ($\mu = 0.15$), it can be seen that successful forming is not possible.

Table 2 FLD diagrams for all cases

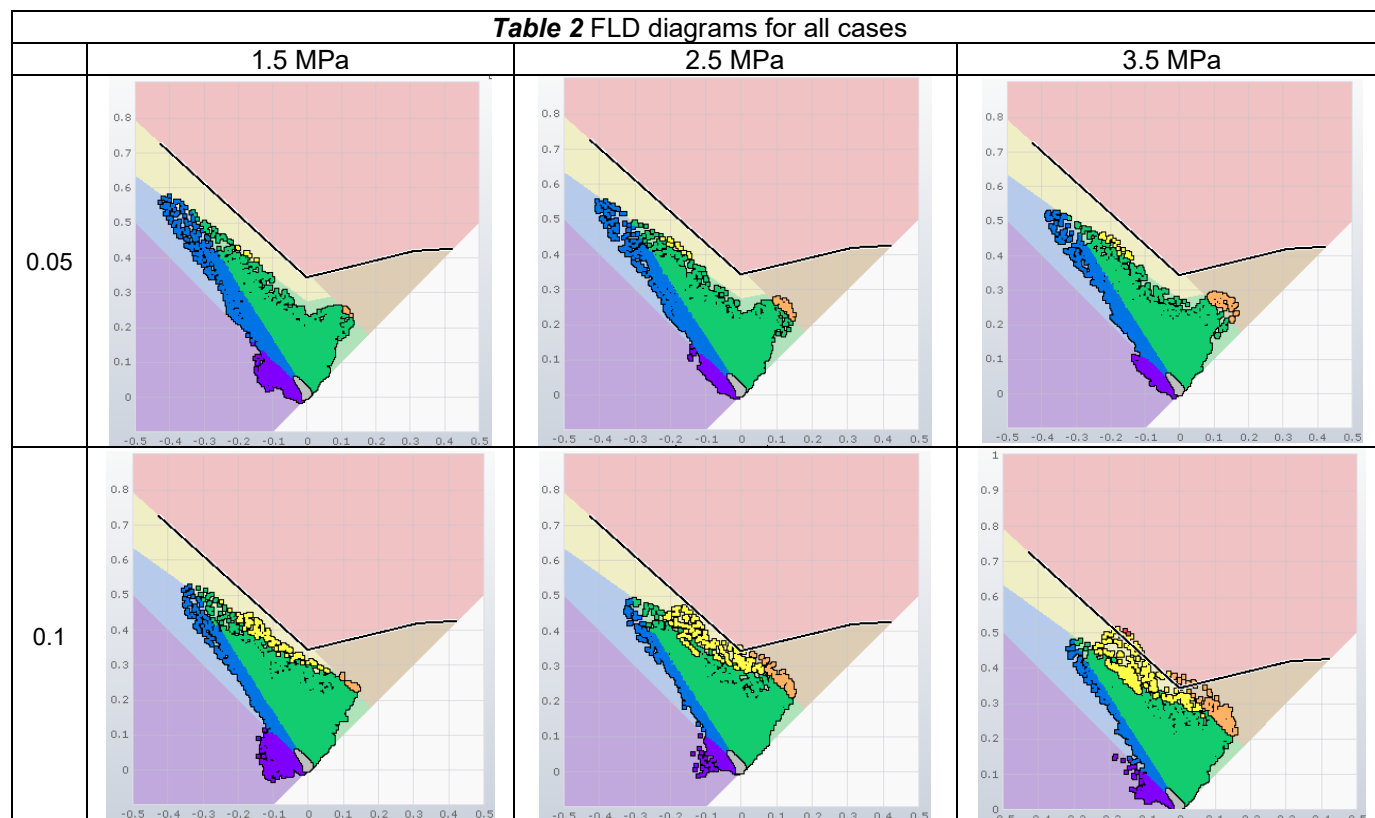
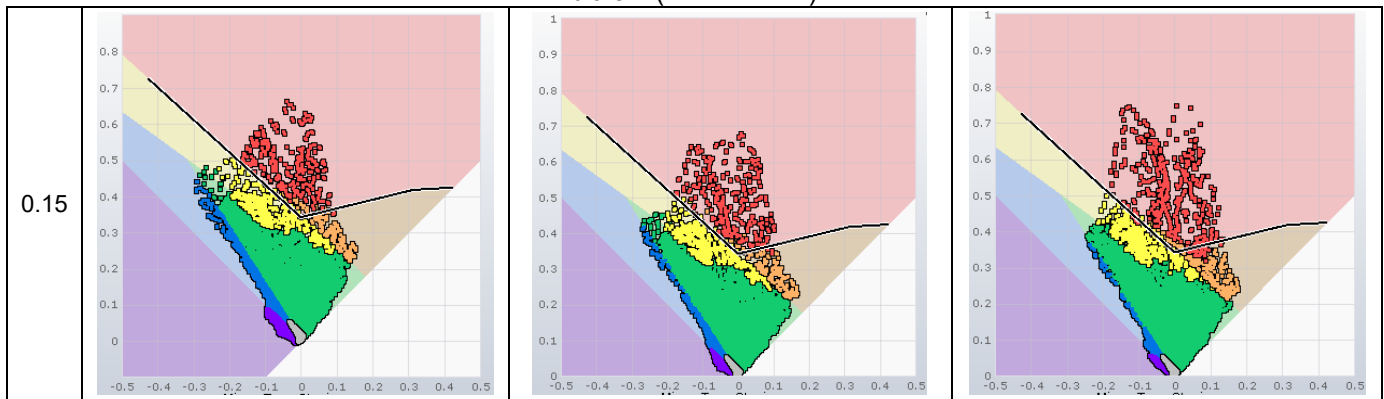


Table 2 (continuation)



Different tribological conditions during the forming process result in different levels of sheet thinning, eventually leading to fracture. The sheet thickness distributions for two cases, with coefficients of friction of 0.1 and 0.15 and the same blank holder pressure of 2.5 MPa, are presented in Figure 6. In the less favourable case, the sheet thinning is approximately 30–40% greater than in the case with a coefficient of friction of 0.1.

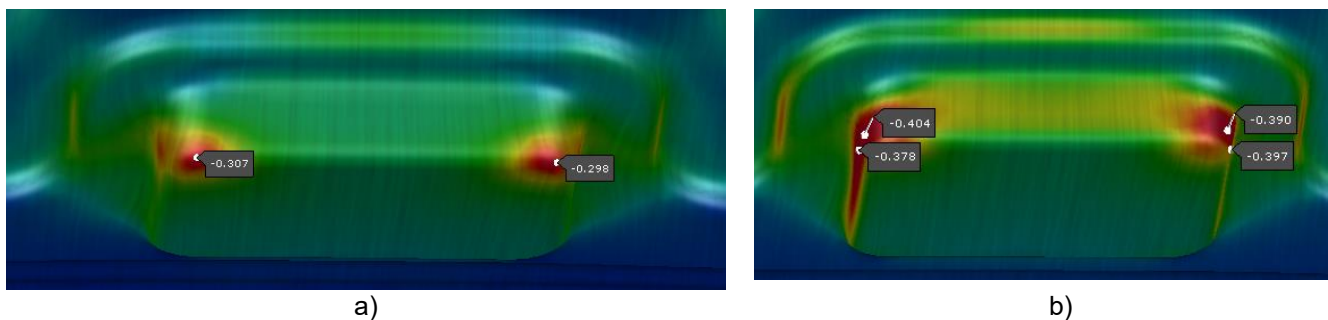


Figure 6 Sheet thickness for two cases a) 0.1 and b) 0.15

CONCLUSIONS

Based on the results of the numerical simulations for the manufacturing of the selected automotive component, conclusions were drawn regarding the influence of the main process parameters on the success of the forming operation. It was concluded that the use of a blank holder is necessary. In the case of stamping without a blank holder, the operation was successfully completed only when the coefficient of friction was 0.05, which represents an almost ideal situation. In the absence of a blank holder, the tendency for wrinkling increases significantly.

In the second part of the experiment, in which the influence of friction and blank holder pressure was investigated, the significant effect of friction was confirmed once again. When the friction conditions were ideal ($\mu = 0.05$) and realistic ($\mu = 0.1$), the forming operation was successfully completed for all three blank holder pressure values (1.5 MPa, 2.5 MPa, and 3.5 MPa). However, at a blank holder pressure of 3.5 MPa, the component was close to fracture.

A reduction in the blank holder pressure increases the risk of wrinkling, therefore, it was concluded that particular attention should be paid to the blank holder pressure and that it should be maintained within the recommended range. Excessive blank holder pressure results in excessive sheet thinning and increases the risk of fracture. The results showed that the best overall results were achieved at the recommended blank holder pressure of 2.5 MPa. Future research will focus on investigating the control of the stamping process under friction conditions that vary across different tool surfaces, as well as on the influence of variable blank holder pressure.

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