THE LAW OF SIMILARITY AND ITS APPLICATION FOR NUMERICAL SIMULATION OF SHARP GEOMETRIES STAMPING

Lukáš CHRÁŠŤANSKÝ [1,2,3], Jan ŠANOVEC [1], Yatna Yuwana MARTAWIRYA [2], Michal VALEŠ [1,3]

[1]CTU - Czech Technical University in Prague, Prague, Czech Republic, EU, lukas.chrastansky@fs.cvut.cz

[2]ITB - Bandung Institute of Technology, Bandung, Indonesia, yatna@ftmd.itb.ac.id

[3]Škoda Auto a.s., Mladá Boleslav, Czech Republic, EU

Abstract

Numerical simulations are used for process planning of various manufacturing technologies and methods. These simulations are also used in the automotive industry, where currently sharp edges and geometries of small dimensions are used on various car-body parts to fulfil a design function or a function of a specific character. This article deals with the problematics and evaluation of simulations of forming small, sharp geometries and the application and verification of one of the basic laws of plastic deformation - the law of similarity in AutoForm software, which is often used for the planning of car-body parts manufacturing.

Keywords: Numerical simulation, stamping, law of similarity, AutoForm

1. INTRODUCTION

During processing of sheet metal in mass production which is typical for car-body parts manufacturing, simulation softwares are increasingly used. Using of softwares causes that the times required for the construction of complex tools are considerably shortened, and based on individual simulation results, the production process can be easily evaluated and optimized during production preparation. In practice, however, various local problems are located and it requires the tuning of existing simulation softwares. This article deals with simulation of special grooving forming in AutoForm simulation software. This grooving geometry and its dimensions represent a group of geometries in which it is difficult to determine if whether the forming process is done correctly without the risk of any defect in terms of material properties. AutoForm software is mainly used for numerical simulations of car-body parts that are characterized by their larger dimensions and specific surface geometry. However, the trend of recent times shows that the car-body design is more popular with use of sharp edges and design edges that are difficult to produce with regard to the material which is used, while retaining the desired properties of car-body part [1-3]. The task of this article is an evaluation how AutoForm software is able to evaluate the process of forming of a grooving profile which can be considered as a representative for such a group of geometries which are difficult to produce.

2. EXPERIMENTAL SIMULATION OF GROOVING PROFILE STAMPING

To verify the simulation of AutoForm software, a special grooving profile is selected, which is formed on a metal sheet. In real conditions the grooving profile (**Figure 1**) is used as one of the fixation elements for hemmed joints of car-body panel parts. The methods of fixation of the hemmed joints are used primarily during car-body production to ensure the dimensional stability of the joining parts so that the individual parts which form the hemmed joint do not move relatively to each other (**Figure 2**).

Various methods are used for fixation of hemmed joints of sheet metal car body parts, such as side doors, front bonnet, and trunk lid car. Each of the different method has its specific advantages and disadvantages, there are also differences in the applicability of the various methods, depending on the size, complexity and quality of the particular component[1,4-7].

One of possible solution to prevent movement of the inner metal sheet against the outer metal sheet in both directions can be created on the basis of a mechanical lock (**Figure 2**). By using a special tools, there are formed special elements around the whole circumference of the component on the inner and outer metal plate which after hemming stage create the mechanical lock. Experiment deals with stamping simulation of one of those fixation elements [1].

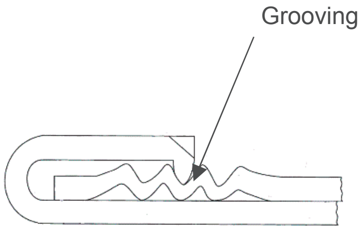

Figure 1 Grooving profile inside of hemmed joint [4]

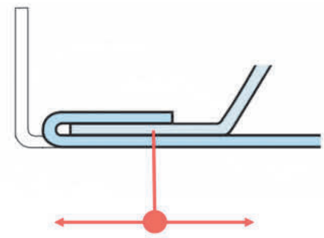

Figure 2 Possible movement of the inner sheet [1]

In the **Figure 3** is shown a cross-sectional view with such grooving profile, along with the geometry of the tooling [1,4].

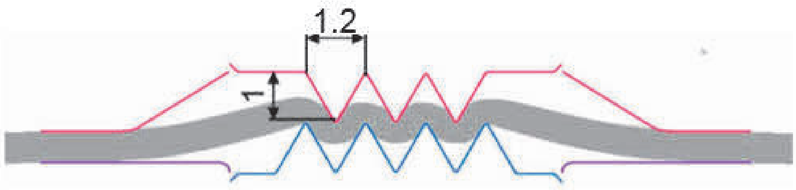

Figure 3 Grooving profile with tools in cross-sectional view

Based on the proposed design of grooving profile, it is necessary to verify the manufacturability and feasibility of grooving using numerical simulation, thus specifying the applicability of the current simulation software. For this experiment the basic conditions for simulation such as material, simulation system and scaling of CAD input are chosen:

Material - DX54D + Z, t = 0.65 mm

FE system AutoForm R6

Scaling of used CAD data: 1:1

The following results of numerical simulations were obtained using the simulation software AutoForm R6.

2.1. Output of numerical simulation of forming grooves

On the basis of the first simulation, where tools with original dimensions have been used, it is clear that the software Autoform R6 has difficulties in accurate calculation of numerical simulation. According to the **Figure 4a)** and **Figure 4b)**, it is clear that quality of output is not optimal and therefore in this case can be concluded that the continuation of the simulations with the original dimensions will not reveal required results. If the current simulation result would be considered as final result it would lead to conclusion that it is not possible to produce this grooving profile by stamping process due to defects which are detected in Forming Limit Diagram (FLD) - see **Figure 4c)**. In case that the results would be relevant, it would lead to use this solution in practice.

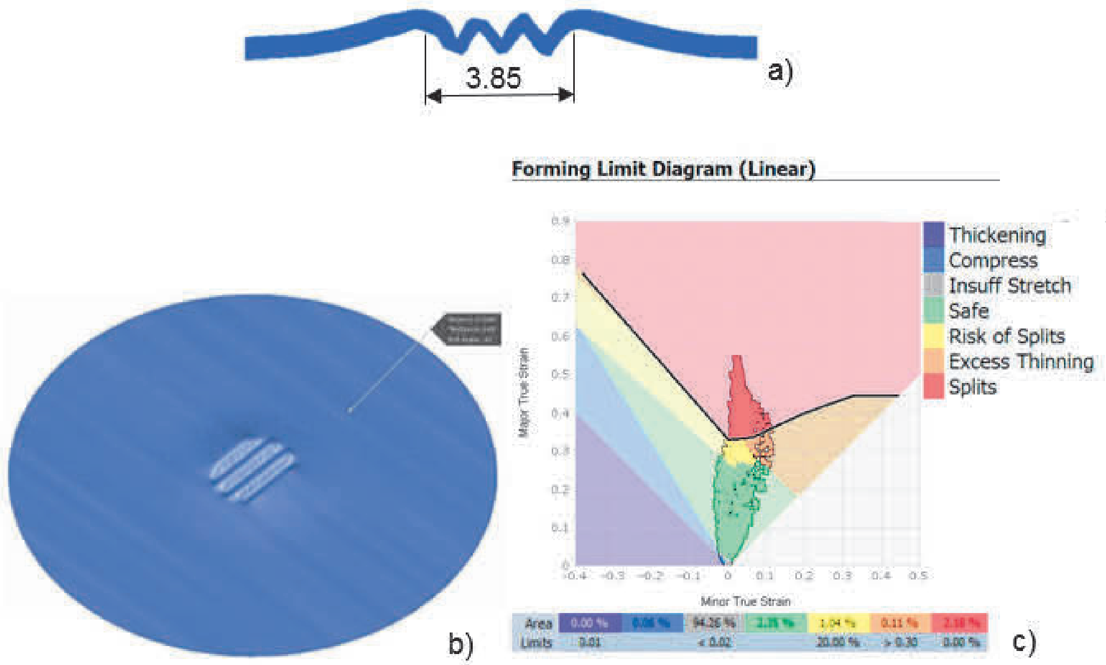

Figure 4 Output from numerical simulation of grooves with original dimensions

How it was mentioned in the Introduction, AutoForm software is mainly used for simulation in the automotive industry, for the production of car-body parts. The sharp geometry and small size of tool for groove stamping are too demanding for the software. Therefore, it must be chosen another method for designing the methodology for numerical simulation of grooving stamping to get relevant results. Possible solution for the trouble mentioned above can be applying one of the fundamental laws of plastic deformation, namely "Law Of Similarity".

3. LAW OF SIMILARITY AND ITS APPLICATION FOR SIMULATION

During plastic deformation of two parts, which comply with the geometric, mechanical and physical similarity, the following applies: ratio of deformation work is equal to the cube of the ratio of the linear dimensions, ratio of deformation forces is equal to the square of the ratio of the linear dimensions, deformation resistance is the same [5].

3.1. Mathematical expression of law

$$\frac{A_1}{A_2} = \frac{V_1}{V_2} = a^3 \tag{1}$$

where:

A_i - deformation work for first/second part (J)

V_i - volume of first/second part (mm^3)

a - linear dimensions of part [5]

$$\frac{F_1}{F_2} = \frac{S_1}{S_2} = a^2 \tag{2}$$

where:

F_i - deformation force for first/second part (N)

S_i - surface area of first/second part (mm^2) [5]

3.2. Geometric similarity

Volume ratio is equal to the cube of linear dimensions ratios:

$$\frac{V_1}{V_2} = \frac{h_1}{h_2} \cdot \frac{b_1}{b_2} \cdot \frac{l_1}{l_2} = a \cdot a \cdot a = a^3 \quad (3)$$

where:

V_i - volume of first/second part (mm^3)

h_i - height of first/second part (mm)

b_i - width of first/second part (mm)

l_i - length of first/second part (mm) [5]

Surface areas ratio is equal to the square of linear dimensions ratio:

$$\frac{S_1}{S_2} = \frac{h_1}{h_2} \cdot \frac{b_1}{b_2} = a \cdot a = a^2 \quad (4)$$

3.3. Mechanical similarity

Stability of ratio of adequate forces to the square dimensions and equality of deformation resistance.

The same size of the coefficient of friction on the contact surfaces.

Same size and directions of main axes of stress in the specific points of compared solids [5].

3.4. Physical similarity

Same chemical composition, structure and phase condition of compared bodies.

Same strain rate.

Same temperature during deformation.

Similarly distribution of stress in comparison parts [5].

3.5. Law of similarity application

For the application of the Law of similarity, it is necessary to follow all requirements mentioned in definition of the law. In this case of grooving profile stamping same conditions are used to keep the Mechanical and Physical similarity. For Geometrical similarity it is necessary to modify the input parameters of the numerical simulation, in this case, the tool dimensions are increased in compare to the original dimensions in ratio of 10:1. For this experiment the basic conditions for simulation such as material, simulation system and scaling of CAD input are chosen:

Material - DX54D + Z, t = 6.5 mm

FE System AutoForm R6

Scaling of used CAD data: 10:1

The conditions for simulation which are used for application of the Law of similarity are the same except for scaling of CAD input. Used CAD data and its dimensions are 10 times bigger than original data.

The results from FEM simulation show that it is possible to use definiton of the law in experimental practise. After comparing the result of simulation (see **Figure 5a)** and **Figure 5b)**), where was used the ratio of dimensions 10:1 to original dimensions, with the real experimental sample (see **Figure 6**) is obvious that the results from FEM simulation are correct. The correct results mean unbroken output from simulation with smooth shape of grooving without material failure. In the FLD diagram (**Figure 5c)**) the excess thinning is located, however on the real experimental sample the excess thinning is not located and the result is acceptable.

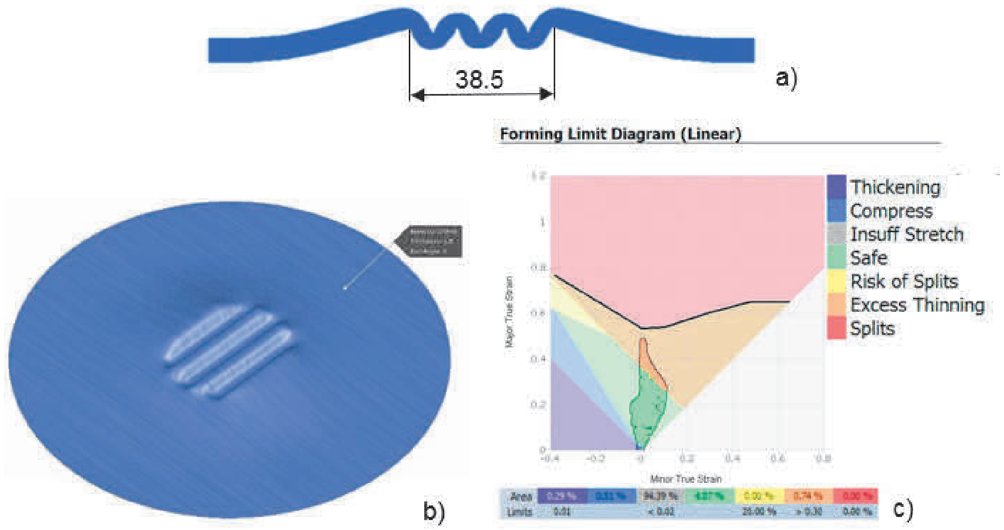

Figure 5 Simulation output after application the Law of similarity

Figure 6 Experimental sample of grooving

4. CONCLUSION

From the obtained results it follows that for a complete simulation of hemming with mechanical fixation, can be applied the Law of Similarity. Figures below show comparison of FLD diagrams. The FLD diagram on the in **Figure 4c)** represents the course of the stamping of the grooving profile of the original dimensions, while the diagram in **Figure 5c)** shows the course of grooving profile stamping after application of the law of similarity, where the original tool and blank dimensions are increased by a ratio of 10:1. On the first examination, it is clear that, according to the first diagram, the stamping can not be made without defects of material, while the second diagram shows the smooth process of stamping these grooving profile. On closer examination, it is obvious that the trends of both diagrams are the same. This fact is based on the confirmation of the theory of application of the law of similarity, in which the simulation software, despite the precise setting, can not give the results for the first simulation, i.e. before applying the law of similarity. The simulation of the original size of grooves had been calculated without any problems, however, in practice, this solution is unacceptable due to material failure. The simulation software used is primarily designed for large parts, and this experiment had been found to be unable to characterize the material behavior in detail during the stamping process of small and sharp dimensions.

It follows from the above conclusions that when solving the problems of stamping and drawing of sharp and small geometries, it is always appropriate to perform a simulation of the corresponding process not only for a designed process that only calculates the original dimensions but it is advisable to check the process by simulation just after application of the law of similarity and then compare both results. If both the FLD diagram trends match and at least one of the simulations finish with acceptable results, that is, without failure of the material, it can be said that the geometry is manufacturable.

REFERENCES

[1] CHRASTANSKY, L., HALEK, J., PACAK, T. and TATICEK, F. Methodology for mechanical joining of sheets for designing the hemmed joints. In *Metal 2016: 25th Anniversary International Conference on Metallurgy and Materials*. Ostrava,TANGER, 2016, pp. 345-349.

[2] ABLAT, MA. and QATTAWI, A. Numerical simulation of sheet metal forming: a review. *International Journal of advanced manufacturing technology*. 2017, vol. 89, no. 1-4, pp. 1235-1250.

[3] MAKINOUCHI, A., TEODOSIU, C. and NAKAGAWA, T. Advance in FEM simulation and its related technologies in sheet metal forming. *CIRP Annals*. 1998. vol. 47, no. 2, pp. 641-649.

[4] GOWLING, P., KORDA, R., HRADEC, M. and HALEK, J., AUDI AG and SKODA AUTO, *Sheet metal part assembly*. [Patent application] WO/2017/140332, Published: 24-08-17.

[5] HASEGAWA, E., TAKEISHI a NAKAMURA. HONDA MOTOR CO., Ltd., Tokyo. *Hemming working method and panel assembly manufacturing method* [patent]. US 2008/0230588 A1. Registrated 10. 8. 2010.

[6] RINTELMANN, J., and HANS, B. AUDI AG, A method of manufacturing a folding and gluing connection between sheet metal components and component assembly [Patent]. DE102013013001 B3. Registrated: 2.8. 2013

[7] POLON, M., SHELBY a MICH. GENERAL MOTORS CORPORATION, Detroit, Mich. *Method of interlocking hemmed together panels* [Patent]. USA. 5237734. Registrated: 24. 8. 1993.

[8] ČADA, R. *Technologie I: studijní opora,* VŠB - Technická univerzita Ostrava, 2007, p. 360.