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THE INFLUENCE OF DEFORMATION IN THE SHEET THICKNESS DIRECTION TO OBTAIN THE FORMING SPEED IN DP600 STEEL
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Márcio Madi
IFPR - Istituto Federal do Paraná – Campus Curitiba, Rua João Negrão, 1285. Rebouças, Curitiba, Pr, Brasil
marcio.madi@ifpr.edu.br

Luiz Mauricio V. Tigrinho
IFPR - Istituto Federal do Paraná – Campus Curitiba, Rua João Negrão, 1285. Rebouças, Curitiba, Pr, Brasil
luiz.tigrinho@ifpr.edu.br

Rogerio Gomes
IFPR - Istituto Federal do Paraná – Campus Curitiba, Rua João Negrão, 1285. Rebouças, Curitiba, Pr, Brasil
rogerio.gomes@ifpr.edu.br

Wagner Chiesorin Uhlmann
IFPR - Istituto Federal do Paraná – Campus Curitiba, Rua João Negrão, 1285. Rebouças, Curitiba, Pr, Brasil
wagner.uhlmann@ifpr.edu.br

Abstract. *The mechanical forming in sheet metals is a manufacturing process that produces parts for several industrial sectors. Among which can be mentioned the sectors of home appliances and automobiles. In these areas of the industry that are competitive, there is a concern with the reduction of times and costs. In some sectors of the industry, which require bigger resistance, special steels are currently used. The need to use steels with higher resistance limits and the need for lighter products, led to new steels being studied in recent decades. The result of research into new steels, starting in the 1960s, was the significant increase in the use of advanced high-strength steels, driven mainly by the automobile industry. The use of these steels allows working with thinner sheets; however the appearance of failure in this material can be frequent due the forming and to the decrease in thickness, compared to carbon steel sheets with a ferritic matrix. Numerical simulation, using computational codes, which describe failure control in ductile materials, is widely used to optimize mechanical forming processes in sheet metal. Therefore, the analysis of sheet thickness as a conformability characteristic in Advanced High Strength Steels and the study of the influence of forming speed on the appearance of failure is the purpose of this work. Thus, there is necessity to study the mechanism of formation and execution of ductile fracture in metallic materials, which is carried out in this study. The numerical simulation of the forming that describe the failure mechanisms in ductile materials is common practice to investigate which failure criteria, in the literature, best represents the results obtained in experimental practice. This study presents computational data collection through literature review, use of computational simulation results with an existing and tested model, obtaining simulation results for formulating conclusions based on the thickness of the forming sheets. The result of this study is a methodology that evaluates the most appropriate speed for forming in DP 600 steel by measuring the deformation in the direction of sheet thickness.*

Keywords*:* *Mechanical forming, Simulation of Speed, Evaluation of Thickness at Failure*

1. INTRODUCTION AND OBJECTIVES

The industry has promoted huge advances in the metallurgical evolution of steels over the years. Just remember that the first structural products had their compositions based on the formability of ferritic-pearlitic steel sheets. This happened as a result not only of the precariousness of metallurgical science at the time, as well as the limitations of industrial refining and forming processes. However, the need to reduce weight and improve the designs of these products forced the mills to evolve technologically to produce steel with high formability.

The main objective of this sector has been to offer increasingly innovative materials, as well as production methods and assembly techniques that are better adapted to its needs, with a focus on obtaining an increasingly higher level of safety and weight reduction of these industrial products, according to Andrade et al. (2002), De Cooman (2004) and Grajcar (2005).

At least three decades ago, new steels, which came to meet this need for better mechanical properties, were included in a single family, designated as Advanced High Strength Steels (AHSS). The increase in the level of mechanical strength achieved with these steels almost inevitably leads to a reduction in their total elongation, that is, their formability. However, the use of suitable microstructures allows minimizing the loss of ductility.

In the study of the fracture mechanism in metallic materials, a good tool that has been used to relate the forming limit of the material, determined on a laboratory scale, is the forming limit curve (FLC). This relationship allows concluding whether the material and process are suitable for manufacturing the part in question. The use of FLC is an important tool for determine the conditions under which a given product can be formed (Sampaio et al., 1998).

At the end of the 1970s, the first specific development on DP (Dual Phase) steels appeared, Rashid (1977) or ferritic-pearlitic normally present in common low carbon alloys.

In order to describe the mechanism of plastic deformation in steels and predict the appearance of failures in these materials, models have been studied since the 1960s. However, there is no single model that can consider all forming situations for any material. This causes existing models to be applied with restrictions according to an evaluated characteristic or property, such as: decrease in resistance, original porosity of the material, evolution of discontinuity, etc.

Nonconformity in a finished product means that the choice of forming parameters was not made properly. The depth, forming direction, forming speed, lubrication and other tooling and process parameters were not all evaluated correctly that the final product would conform.

Experimental methods for determining the behavior of a single type of material with respect to formability yield satisfactory results. However, the time spent is high. Numerical simulation can help to obtain faster results with the same reliability as experimental methods.

This study has as objective to contribute to the choice of preferred methods and directions in the mechanical forming of metallic materials, with the aim of improving these forming processes. The present work presents a proposal to obtain the best forming speed for sheets metals, in this case AHSS, through the evaluation of the damage and failure in sheet thickness. In this way, the use of a computational model for simulation in the forming processes, already existing in the study Madi et al. (2018) who evaluated a fracture criterion in AHSS steels, will be taken as a reference.

According to Moreira et al. (2003), the amount of plastic deformation that the sheet metal can withstand before the occurrence of localized necking is of great importance in sheet metal forming. The FLC is defined on the axes of the smallest and largest principal deformations obtained in the sheet metal. The curve established through linear deformation paths remains constant during the forming process. In the determination of the forming limit curve (FLC), the most common is to simulate the states from the biaxial deformation condition to the uniaxial tensile stress condition, through properly prepared specimens. On these specimens, networks of circles or squares are printed, touching each other or intertwining, with strictly determined dimensions. The Nakazima stamping assay, found in Nakazima et al. (1968), uses rectangular sheets that vary their widths. Meshes are drawn on these specimens and after conformation are measured to verify the formability of the material.

The methodology of the present work aims to computationally investigate the conformation of DP 600 steel as a function of sheet thickness. Therefore, a computational model will be used to simulate and evaluate the forming parameters of this material. This model is proposed in a decoupled way, obtained through the post-processing of the results and implemented through a computational code using the ABAQUS software, as presented by Madi et al. (2015).

2. METHODOLOGY

The experimental data obtained from Chemim Filho et al. (2013) and Tigrinho et al. (2013) were used to feed a computational model used in the simulation of sheet forming of DP 600 steel. The authors propose studies of the fracture of this steel through the variation of the load of the plate holder and different states of stress and deformation during the forming, respectively.

In the determination of the forming limit curve (FLC), the most common is to simulate the states from the biaxial deformation condition to the uniaxial tensile stress condition, through properly prepared specimens. On these specimens, networks of circles or squares are printed, touching each other or intertwining, with strictly determined dimensions. The Nakazima stamping test uses rectangular plates that vary their widths (Nakazima et al. (1968)). Figure 1 shows the FLC curve of the DP600 steel, determined through the Nakazima test.

The FLC is experimentally met and used to feed the simulation as a result of failure of the DP 600 steel, as well as the tooling settings that were fed in this simulation by Madi et al. (2015).

No numerical model of the sheet was used, the elasto-plastic formulation and mesh with 4 mm square elements. The contact between the matrix sheets without lubrication was used. The matrix was considered rigid in the simulation. The integration used was the standard of the ABAQUS program.

For the use of the damage and failure parameters, it is important to point out that the damage is the evolution of the element deformation to increase the simulation that may cause the failure. In this simulation of failure that is decoupled from damage, the Von Mises failure criterion was used.

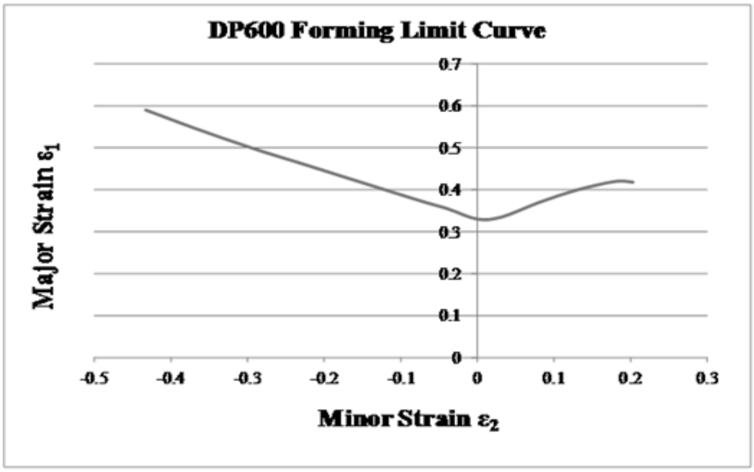

Figure 1: Forming limit curve of DP 600 steel, obtained through the Nakazima stamping test (Nakazima et al. (1968))

Using the optimization method described by Madi et al. (2015), after nine iterations, a value close to 1 mm/s for forming speed was obtained as an optimal simulation result. The study then suggests that with a few steps of iterations in a reduced time, compared to the experimental adjustments of the process, it is possible to determine the ideal forming speed for a given case. Therefore, it was necessary to feed a computational code with the parameters of the processed material, as well as to introduce the characteristics of the matrix, punch and sheet codes.

The simulation proposed in this study is able to save time with the preparation of the process and helps to achieve better levels of productivity, always meeting the quality requirements through the conformity of the final product.

3. SIMULATION

The deformations analyzed in the simulation of this study are those calculated through the difference in size, before and after forming, of the elements of the simulated mesh in the sheet thickness.

The analyzed deformation regions were parallel to the main crack (Figure 2) and in two forming lines perpendicular to the main crack (Figure 3). This first region, parallel to the main crack, was chosen because it follows the evolution of the crack in the direction of its propagation. The chosen elements are those closest to the main triplet, but without being part of it. That is, immediately next to the rupture. In the lines perpendicular to the main crack, the region of line 2 (Figure 3) is the one closest to the secondary crack formation. This crack was noticed in the simulation of higher simulation speeds. It was chosen again for analyzing points immediately close to the rupture formation. In line 1 (Figure 3) are the points farthest from the break in the secondary crack.

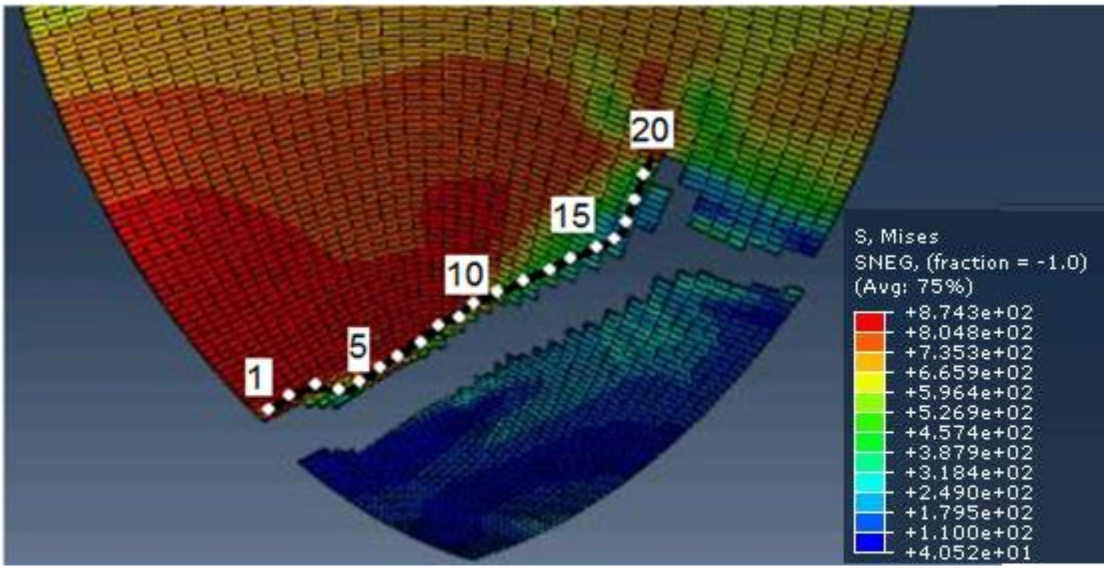

Figure 2: Deformation analysis region parallel to the main crack

The analyzed points are twenty elements of the simulated mesh and the deformation is logarithmic, LE deformation in absolute values, in the sheet thickness.

By analyzing the uniaxial strain and defining the logarithmic LE as the deformation measure, an additive decomposition of the deformations is reached, which allows a simpler analytical and numerical treatment to portray finite plastic deformations.

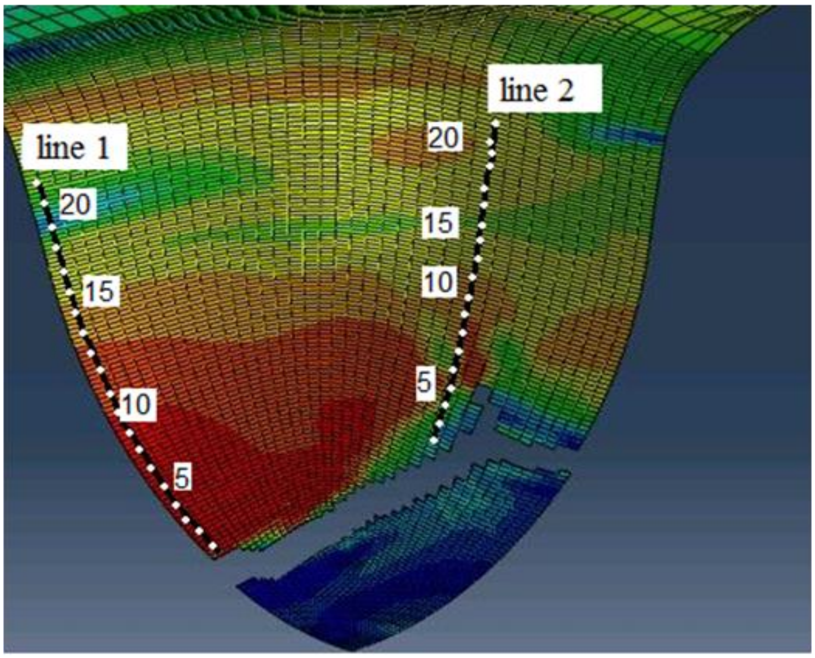

Figure 3: Deformation analysis region perpendicular to the main crack.

Table 1 shows the characteristics of the specimen simulated in the ABAQUS software, as presented by Madi et al. (2015) in this simulation.

Table 1: Simulation parameters.

Parameters of the experimental procedure	
Material	DP600 steel
Sample	200 x 200 mm
Thickness	1.5mm
Mesh	4 mm
Punch diameter	65mm
Sheet press diameter	165mm
Sheet press load	50 bar
Lubrication	No

In this study, some speeds of interest were simulated until reaching the optimal simulation speed for this case study. The simulated speeds varied between 1 and 4 mm/s because it is an interval applicable in the practice of industrial equipment, and the optimal speed, that is, the one optimized by the methodology, is a speed of 1.083 mm/s.

In this section, the evolution of the deformation at the points shown in Figures 2 and 3 is presented, in relation to the thickness of the sheet formed in the simulation.

In Figure 4 it is possible to observe that for the lower speeds (1 mm/s and 1.083 mm/s) the deformation is between 45% and 50% in the average of the analyzed points. As for the higher speeds (4 mm/s, 3 mm/s and 2 mm/s), in most of the points analyzed, the thickness reduction is greater than 60%.

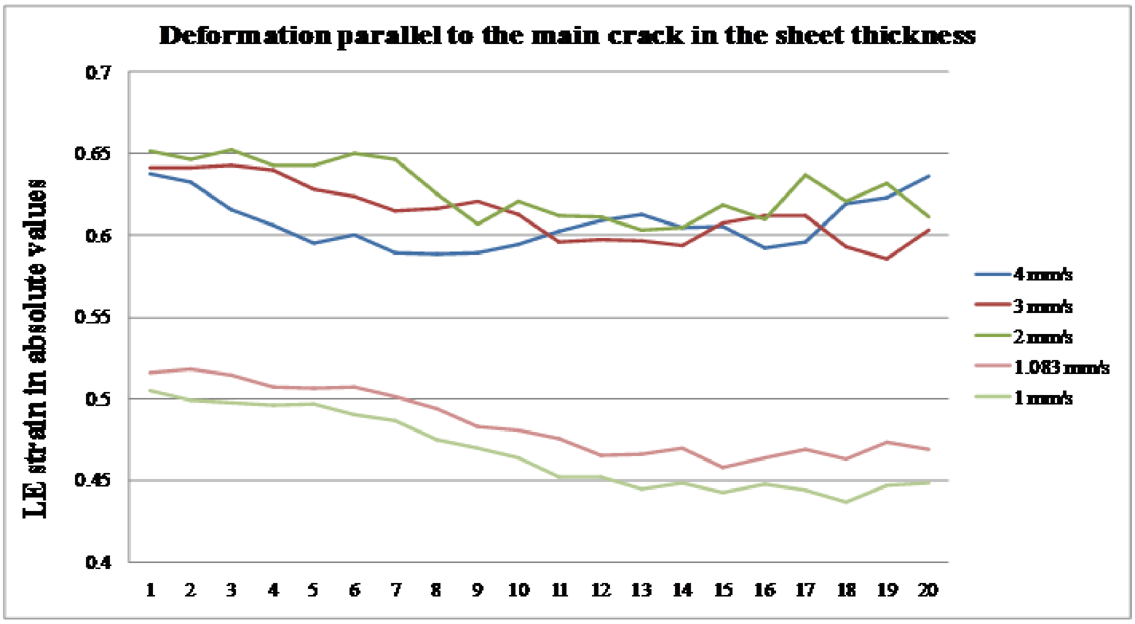

Figure 4: Deformation parallel to the main crack in the sheet thickness.

With the analysis of the deformation of the elements in the region parallel to the crack (Figure 3), the simulation result is shown in Figure 5 for the points of line 1 and in Figure 6 for line 2.

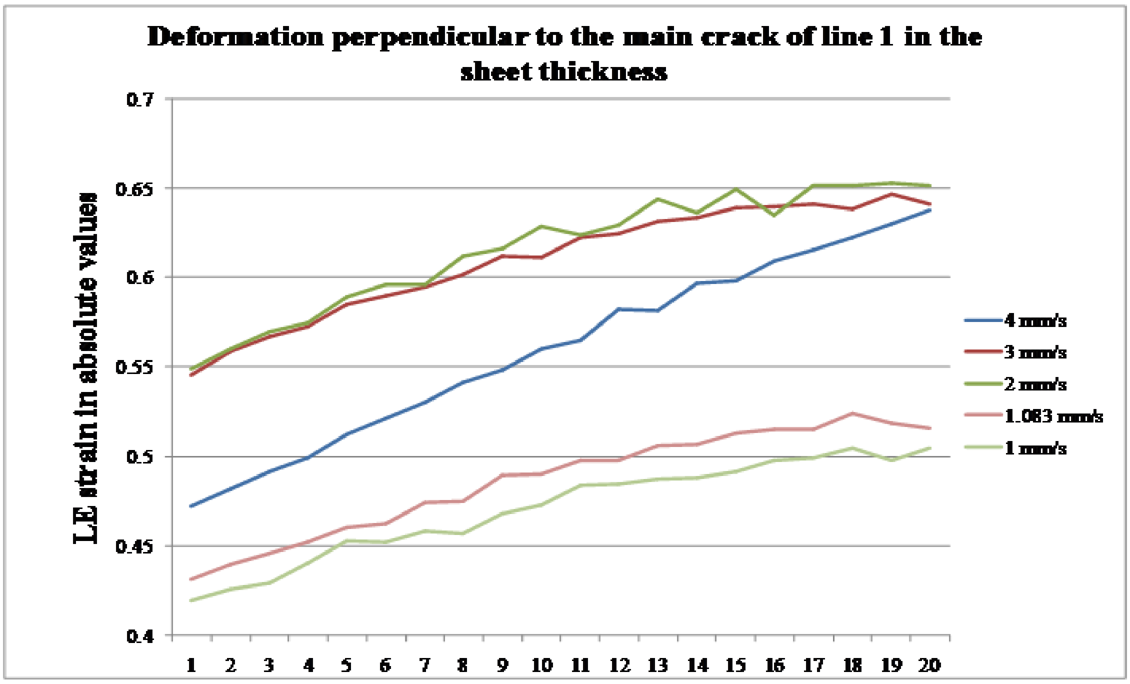

Figure 5: Deformation perpendicular to the main crack in line 1 in the sheet thickness.

In this analysis, it is possible to observe the same trend of evolution for all velocities and a great difference between the higher speeds (4 mm/s, 3 mm/s and 2 mm/s) and the lower speeds (1 mm/s and 1.083 mm/s), with regard to the simulation results for the absolute strain.

This evaluation suggests that in sheet thickness, deformations are less uniform at higher forming speeds, as shown in Figure 5 (speed of 4 mm/s). That is, the evaluation methodology shows that lower forming speeds present a forming process that obtains better results for the final product. This is justified by the fact that the specimens were formed with the same amplitude, depth of the punch in the sheet, with less deformed mesh elements.

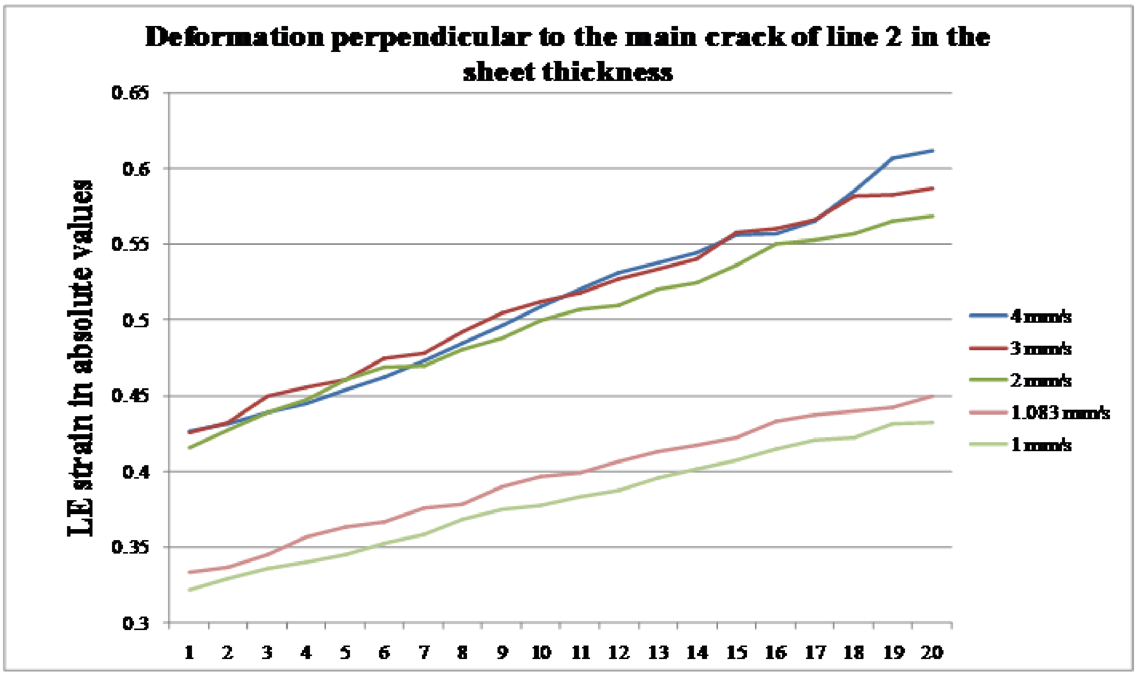

Figure 6: Deformation perpendicular to the main crack on line 2 in the sheet thickness.

4. CONCLUSION

The simulation study of the present work proves to be effective for presenting a faster and more reliable solution, compared to practical experiments, to improve the results of mechanical forming processes in sheet metal.

The evaluation of the simulation on the thickness of the sheet shows a safe result regarding the choice of forming speed that provides reduction in the frequency of defects appearing in the final product.

The reduction of forming time and determining the optimal forming speed through simulation and evaluation of this speed, for a given material, was presented in this methodology. Therefore, there is a need to feed the data of this material, as well as characteristics of the process and tooling.

This case study presents a gain in productivity and greater reliability in the final result of the shaped product, regardless of the data fed, for each specific case of forming. That is, the methodology is capable of saving time with the preparation of the process and helps achieve better productivity levels.

It is possible to verify through the analysis of the simulation that the suggested methodology presents a greater possibility of forming, in terms of depth, for lower forming speeds. This conclusion also shows that higher forming speeds present early rupture. Because during the simulation, the forming limit was established by fixing the depth. The lowest speeds, close to 1 mm/s, did not show rupture.

The simulation shows that the deformation is more uniform in all analyzed elements when they were formed with lower speeds. This conclusion proposes that strains are better and more uniformly distributed for forming with lower strain rates.

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