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Research article

Investigation of forming process of the floor of Volvo truck's body via FEM simulation

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Abstract

Since a large number of the parts of the body vehicle are made of sheet metals, they are produced through sheet metal forming processes including die press forming, hydroforming, cutting, and so forth. Die press forming is a method for producing sheet metal parts with high accuracy and production rate and also complex geometry. In the present study, a part related to the body of a Volvo truck is investigated for manufacturing via die press sheet metal forming. To analyze the behavior of materials during the die press forming process, the FEM simulation procedure is applied. The effective factors in the proper execution of the process help to achieve high-quality products and optimal geometry. It is worth mentioning that the initial design and scanning were accomplished using Catia software. The FEM simulation is performed via ABAQUS software. The material of the sheet metal is low carbon steel with 0.2mm thickness. The results of the simulation show that the forming process of the part was performed perfectly without any wrinkles and tears. The blank holder force and the pressing force required for this purpose were obtained at 10kN and 97.4kN respectively

Keywords: FEM simulation, Die press, Sheet metal forming, ABAQUS

1- Introduction

The increasing number of trucks and heavy vehicles on the roads and also the financial purposes, encourage manufacturers to produce automotive parts. Low-cost manufacturing in the automotive industry is one of the main targets due to the ever-increasing global competition among car manufacturers all over the World. Sheet metal forming is one of the most important key technologies in the automotive industry; therefore, the elaboration of new, innovative low-cost manufacturing processes is one of the main objectives in sheet metal forming as well [1]. During the forming process, the metal is plastically deformed by a force that exceeds the material yield strength where strain hardening occurs. To be able to successfully form, the material should have a low yield strength and high ductility, while strain rate and lubrication affect the performance too. Some methods of sheet metal process are: hydroforming, bending, deep drawing, creep forming, stamping, and so forth [2, 3]. Finishing processes can be applied to improve the surface quality of the products [4-9]. Sheet metal stamping is one of the most common methods of sheet metal forming processes. Like many other sheet metal forming processes, the sheet metal stamping method involves the machine (the press), the dies (including progressive dies and transfer dies), and the material (the sheet metal blank). The press is driven by an electrical motor through a crank mechanism or a hydraulic system. One of the most sensitive process parameters in sheet metal stamping is the Blank Holder Force (BHF), therefore, can be used to precisely control the deformation process. By controlling the blank holder force as a function of press stroke, one can improve strain distribution and stiffness, reduce spring-back and residual stresses, and increase product quality and process robustness [10]. In recent years, significant research activities have been carried out in order to simulate and optimize the sheet metal forming processes, to achieve a flawless part, and to predict the press force as well as BHF. In the following, some of which are reviewed: Bruschi et al. conducted a survey about testing and modeling of metal's response when subjected to sheet forming operations. They focused both on the modeling of hardening behavior and yield criteria and on the description of the sheet metal formability limits [11]. Yussof et al. recommended the use of alumina Nano-coolant Al_2O_3 in the cooling channel of hot-press forming dies [12]. Park et al., investigated the Extensive interface exfoliation (flaking) mechanism occurring in the bead-slide region using numerical and experimental methods [13]. Allen et al. outlined experimental work conducted to determine the influence of lubrication on the expansion of a die ring during the deep drawing of axisymmetrical steel cups [14]. Nick et al., investigated the damage after deep drawing of rotationally symmetric cups. [15]. Lua et al. investigated the size effects and the influence of the blank holder-die gap on Micro-deep drawing (MDD). They developed advanced FE models to simulate the MDD process taking into account material inhomogeneity and surface morphology of the foils at micro-scale [16]. Choudhari et al. used numerical and experimental approaches to analyze the effect of different drawing parameters such as blank shape, blank thickness, load, and dry/wet lubrication on the square cup drawing process using extra deep drawn steel sheet material [17]. Goud et al. experimentally determined the forming limit diagrams for extra deep drawing steel at room and elevated temperatures by conducting stretch forming operations using a designed and fabricated warm forming tooling setup [18]. Singh et al. investigated the warm deep drawing process of circular blanks using a 20-ton hydraulic press and a finite element model coupled with thermal analysis [19]. Firat presented a numerical technique in order to assess formability conditions for tearing-type sheet metal failures in automotive stamping applications [20]. Hardt et al. employed closed-loop control of sheet-forming operations to determine optimal blank-holder force trajectories [21]. Yossifon et al. performed further research in the area of variable blank-holder force. They implemented a control scheme that allowed the BHF path to be pre-set over the entire range of the punch stroke [22]. Majlessi and Lee also developed a diagram that shows the onset of wrinkling and fracture at various blank-holder force values as a function of punch travel [23]. In addition, there are many surveys that studied the machining processes such as conventional machining, powder metallurgy, and electrical discharge machining processes which are related to manufacturing dies and punches that are investigated here [24-31].

In this study, the feasibility of manufacturing a part related to the body of a F500 Volvo truck (Fig. 1) by die press metal forming process is investigated via FEM simulation. The mentioned part was imported before and in the present project, it is attempted to manufacture this part. By applying the simulation method, the production costs are reduced to prevent unpredicted events in the manufacturing process. To obtain the forming parameters including the press force, blank holder force, material thickness reduction, and maximum stress and strain, the process is simulated by ABAQUS software and the results are compared to the experimental test. It is worth mentioning that the initial design and scanning are accomplished using Catia software.

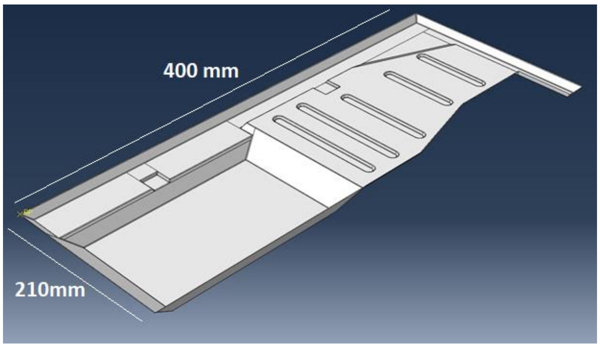

Fig. 1 Case study: body of F500 Volvo truck

2- Materials and methods

For 3D modeling of the die, the dimensions of the part are required. Therefore, the truck's part was digitized through a 3D scanner, and the cloud points were extracted. Afterward, the 3D model was prepared through the Shape Design module of Catia software. Then, the two halves of the stamping die were designed and modeled in Catia. Figure 2 shows the punch and Fig. 3 shows the blank-holder.

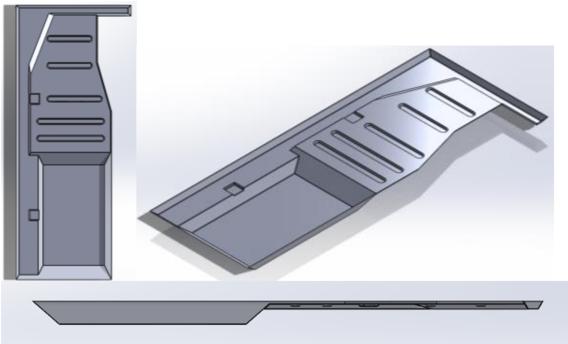

Fig. 2 Three dimensional model of punch

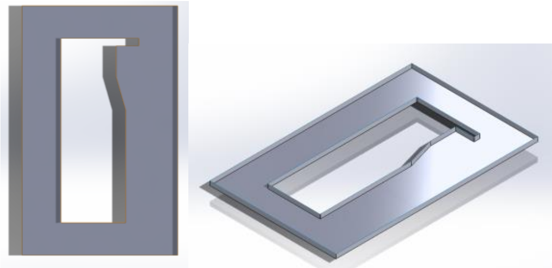

Fig. 3 Three dimensional model of blank holder

The blank holder is the significant part of a die and its application determines the total forming process. The blank holder holds the sheet metal on the matrix and prevents its slippage during the punching process. Thus, the accuracy and correctness of the final shape of the product depend on the blank holder's design and force. In this project, the blank holder's force is considered a concentrated force imposed on the main pivot of the blank holder, and the coefficient of friction between the sheet and the blank holder is defined as 0.25. Here, the blank holder force is determined through trial and error to obtain a complete final shape of the product without wrinkles.

Since the body of trucks have high strength and low weight, the St22 steel alloy is pinpointed for this purpose. St22 steel alloy is very common for the trucks' body due to its proper strength, high formability, and low cost. According to the abovementioned issues, the St22 steel alloy is applied in this project. The physical and mechanical properties of this steel used in the Property module of ABAQUS are introduced in Table 1 and Table 2 respectively (reference: ASTM standard, 1020 steel).

Table 1: Physical properties of the St22 steel

Modulus of elasticity (GPa)	Mean coefficient of thermal expansion	Thermal conductivity (W/m·°C)	Density (gr/cm^3)	Poisson's coefficient, ν
210	1.38E-5 1/K	28	7.8	0.33

Table 2: Mechanical properties of the St22 steel

Yield strength (MPa)	Ultimate strength (MPa)	Impact KV/Ku (J)	Elongation A (%)	Brinell hardness (HB)
325	535	33	35	150

In this study, the simulations are performed in ABAQUS software version 2019. The initial model is designed via Catia software. The initial part imported in the Part module is 3D and formable and on the other hand, the die is solid and non-formable. Figure 4 shows the assembly of the parts in the assembly modules of ABAQUS.

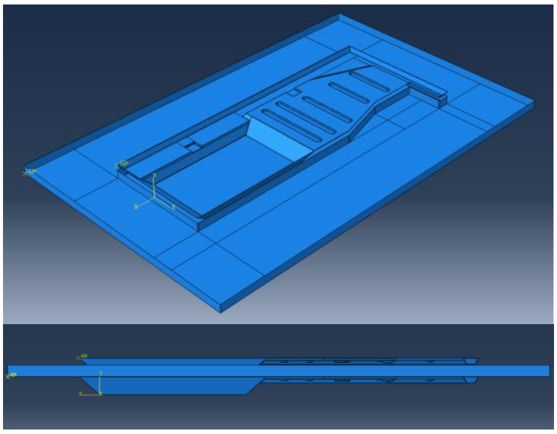

Fig. 4 Assembly of the parts in the assembly modules

In the Interaction module, the coefficient of friction between the sheet and dies is defined as 0.125 and the coefficient of friction between the sheet and blank holder is defined as 0.25. The general contact is defined to match the related points of the part and die. It is worth mentioning that an industrial oil is applied during the experimental test to reduce the friction. In the Mesh module, the 0.2mm mesh size is selected. The meshed part is shown in Fig. 5.

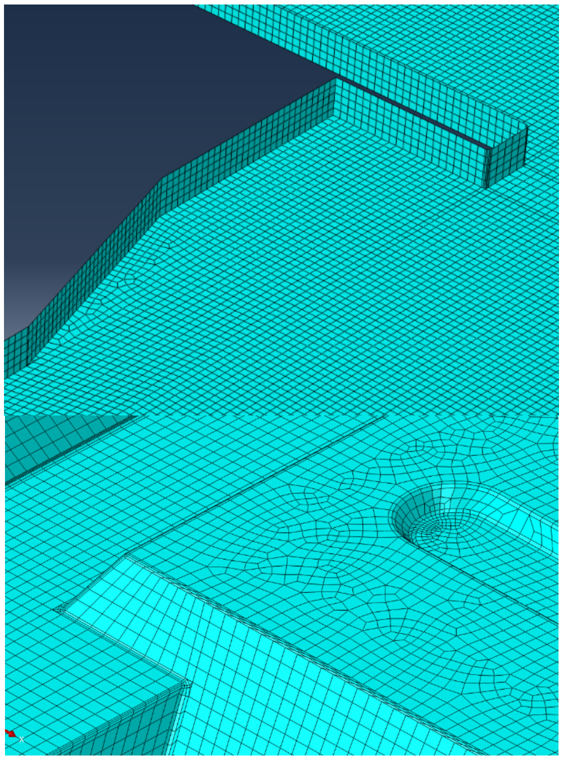

Fig. 5 Meshed part

The Dynamic Implicit solver is selected at the Step module to solve the problem and perform the simulation. In the Load module, the blank holder force which is determined by trial and error technique is imposed on the blank surface. The degree of freedom of the die is zero and it is completely constrained.

3- Results and discussion

In this study, the feasibility of manufacturing a part related to the body of an F500 Volvo truck by die press metal forming process is investigated via FEM simulation. In the following, the results of the simulations are investigated.

According to Fig. 6, the maximum stress obtained from FEM simulation is about 460MPa (tensile stress: 336MPa), and therefore, at many points, the sheet metal shows plastic behavior. The final shape of the sheet metal is in accordance with the main product. The internal edges of the part demonstrate the maximum stress in which the probability of tear and fracture is high. On the contrary, the points located at the flat sections of the part undergo minimum stresses. The blank holder plays an important role in this issue. High blank holder force results in the tearing of the sheet in the critical points, while the low one leads to incomplete forming of the product. Therefore, determining the right value of the BHF is very significant. In this project, the blank holder force has been obtained from several simulations, and among these runs the best value for the BHF was 9.85kN (approximately 1ton). In addition, the contributing pressing force was obtained at approximately 100kN (precisely 97.4kN) which means that at least a 10-ton press is required for this process. As it is obvious, by adjusting these parameters, the final shape of the sheet metal is completely in accordance with the geometry of the desired part (Floor of Volvo Truck's Body). Figure 7 shows the experimental sample which has been formed with a 50-ton hydraulic press. There is no sign of tearing or fracture (especially at the corners) observed in the formed part and the shape and size of the pressed part are completely in accordance with the CAD model.

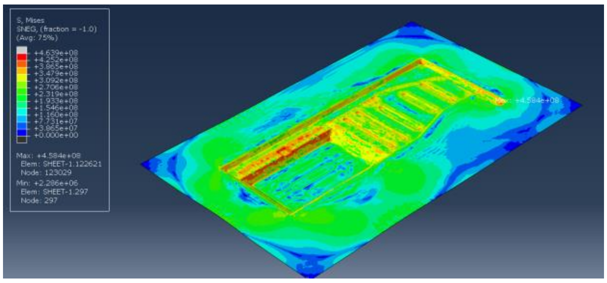

Fig. 6 Von Mises stress in sheet metal

Fig. 7 Experimental sample

Figure 8 shows the strain obtained from the FEM simulation. The maximum strain has occurred around the internal walls (in which the maximum stress was observed) and this means that the internal walls of the part are the critical sections and have high potential for forming defects.

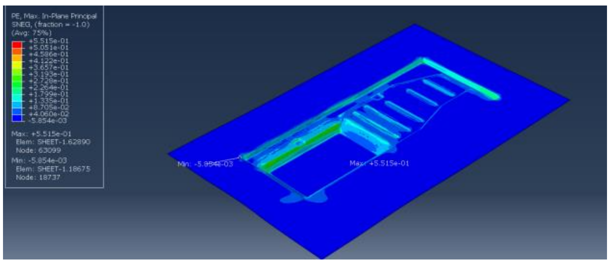

Fig. 8 Strain in sheet metal obtained from FEM simulation

Figure 9 demonstrates the thickness reduction in the sheet metal. As shown in Fig. 9, the maximum reduction is about 1mm and occurs at the internal walls of the part. It is worth mentioning that the initial thickness of the sheet metal was 2mm and this amount of reduction indicates an acceptable strength of the formed part. The thickness of the experimental sample at the critical points was about 1.12mm which indicates a proper match between simulation results and experimental ones (the obtained error is 12%).

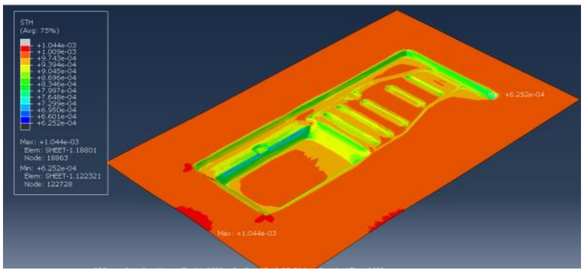

Fig. 9 Thickness reduction in sheet metal

The simulation presents that the forming process was performed perfectly the sheet metal fills the die and the edges perfectly are formed. In Fig. 10, the convergence of the result (stress) by increasing the number of mesh elements has been demonstrated. According to this figure in a point of the part, with the 1000 mesh elements (mesh size equals 0.6mm), the stress equals 326 MPa. And accordingly, by more increase in mesh elements to 3000 (mesh size equals 0.2mm), the result is converged to 370 MPa.

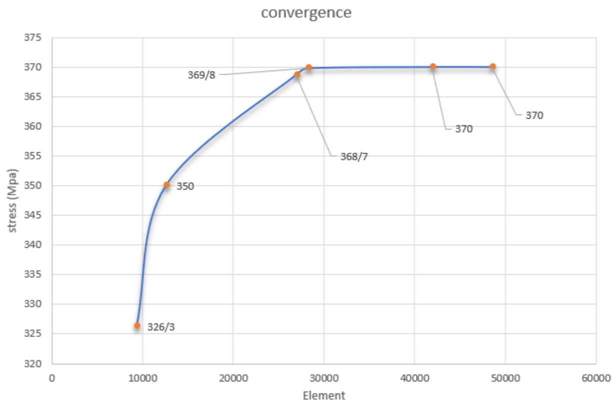

Fig. 10 Convergence of results (stress) by increasing the numbers of mesh

4- Conclusion

In this study, the feasibility of manufacturing a part related to the body of a F500 Volvo truck by die press metal forming process is investigated via FEM simulation. The maximum stress, the maximum strain, and the reduction in the thickness of sheet metal were obtained via simulation that are explained as follows:

- The maximum stress obtained from FEM simulation is about 460 MPa. The final shape of the sheet metal is completely in accordance with the geometry of the desired part (Floor of Volvo Truck's Body) and the experimental sample validates this issue.
- The blank holder force has been obtained from several simulations and equals 9.85kN. In addition, the contributing pressing force was obtained at approximately 100kN which means that at least a 10-ton press is required for this process.
- The maximum strain has occurred around the internal walls in which the maximum stress was observed.
- The maximum reduction is about 1mm and occurs at the internal walls of the part. The thickness of the experimental sample at the

critical points was about 1.12mm which indicates a proper match between simulation results and experimental ones (the error was 12%).

Acknowledgment

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