Enabling stamping processes through meticulous FE Modelling - segmented drawbeads and remesh criteria

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Abstract. Drawbeads are valuable tools to control the material flow in stamping processes. Its accurate design is necessary so that the part can be formed with a minimal, and well-distributed plastic strain, and so that defects such as fractures or wrinkling can be avoided. This paper analyzes the use of a segmented drawbead to improve the results of a stamping process. Simulations, based on the Finite Elements Method, were conducted for a dual-phase 500 steel, 1.2 mm thick blank, formed using no drawbead, uniform drawbeads, and a segmented drawbead. The influence in the results of using different remesh criteria was also evaluated, and the computational time of each approach compared, the use of different criteria on the region of the blank in contact with the drawbead and the region in contact with the die and punch achieved realistic results with relatively less computational time. By adopting a segmented drawbead, it was possible to improve the results of the simulation, reducing wrinkling and fracture, based on the Forming Limit Diagram.

Keywords: Segmented Drawbead, Stamping, Sheet Metal Forming, Finite Elements Method, Remesh Criteria.

1. State of the art

Stamping can be defined as a process in which the sheet is subjected to plastic deformation that can be categorized in three major types: bending, stretching and deep drawing [1-2]. In this process, tooling design is a complex and inaccurate procedure that requires adjustments by trial and error.

In single action stamping processes using blankholders, initially the peripherical region of the blank is pressed between the blankholder and the die. The punch then forces the sheet into the die cavity. For the straight-section regions, without drawbead, the restriction forces generated during the process are caused by friction. In those regions it is possible to vary the restriction forces by varying the blankholder force (BHF). By adding a drawbead, restraining forces that are caused by the bending deformation appear in the sheet [3].

In sheet metal forming it is important to control the rate of material flow into the die cavity [4]. This is usually achieved by adjusting the BHF or using a drawbead [5]. The drawbead is a geometry composed by a protrusion in the die or the blankholder, complementary to an indent on the other tool. Because of that, after the holding stage, in addition to the friction restraining forces, mechanical restraining forces appear, since the blank must deform plastically to go through the drawbead region [6].

High pressures would be required on the blankholder for cases requiring high restraining forces, and consequently, very robust presses and cushion systems would be necessary. High BHF can also cause tool wear or galling. To avoid these problems, a drawbead can be adopted [7]. Adopting drawbeads as substitute to high BHF can also be a good measure to reduce the cost of the process, but it might subject the sheet to excessive deformation. Other problems may also derive from relying on the drawbead to create most of the restraining forces, such as difficulties in adjusting drawbead geometries during die try-outs [5]. Since the blank goes through bending and unbending on the drawbead and the contact areas on that geometry are small, the contact forces generated on the surface can be very high. This may lead to early stage tool wear [8]. Therefore, it is important to define an optimal relation between BHF and drawbead restriction forces (DBRF).

Proper drawbead design is very important to obtain viable stamped parts, thus it is also important to define drawbead design rules for various components [9]. An advantage provided by the application of drawbeads is the possibility of applying work hardening to the part prior to the actual forming, because the hardness of the material increases after passing the drawbead. This is useful for reducing the weight of the parts, since work hardening grants the same resistance to the part with less weight [10]. If well optimized, the drawbead can better distribute thickness reduction on the formed part, this way reducing the occurrence of defects such as fracture and wrinkling [11]. Springback reduction is an important aspect of stamping processes, the use of a BHF that varies during the process achieves great results, but servo cushion is required, increasing the price of the process [12]. Therefore, the use of drawbeads can be advantageous, since they can be used to reduce springback, without the requirement of servo cushion, thereby improving part quality, at a lower cost. Also, if efficiently used, drawbeads can reduce press energy consumption [13].

Different methods can be used for drawbead geometry optimization, e.g., the inverse analysis (IA) approach, a method of optimization that bases itself on the final part shape, and then searches for nodal positions in the initial flat blank [14]. Combined with a mathematical programming algorithm the IA proves to be a great tool to optimize the drawbead design, achieving results similar to what has been observed experimentaly.

Models based on the Finite Elements Method divide the object of study in elements to calculate the results of a problem on each element separately. It was demonstrated, using an optimization method based on plastic flow, that it is possible to determine the magnitude of the influence of drawbead segments in the quality of the element's results using section lines correlated to drawbead segments at different distances. The proximity of a drawbead segment to an element increases its influence on the results of that element [15]. Therefore, this indicates that using segmented drawbeads can be useful to solve problems such as fracture and wrinkling in different regions of the part.

Drawbeads, especially its radii, are usually very small compared to the whole tool surface. Hence, small elements are required in that region to better represent the geometry and precisely simulate the deformation that the sheet goes through when modelling a problem using the Finite Elements Method. This increases the number of elements and requires a smaller time step. Therefore, using equivalent drawbeads can be more economical regarding computational time [16-18]. A model that incorporates the effects of sheet thinning and strain changes to achieve more accurate simulation results was created, but the drawbead forces and the strains must be obtained from experimental results or previous geometric drawbeads simulations [17-18].

The use of DBRF only, in computational simulation modelling of stamping processes, can be unsatisfactory in processes that demand accuracy. That is because by inputing only DBRFs, the previous deformation that the blank was subjected to is not considered. In the actual process, the blank is deformed while passing through the drawbead. Therefore, when being forced into the die cavity, those elements or regions have residual strains that must be considered in the simulation. Usually, after passing through the drawbead, the sheet has a different strain distribution and its thickness is reduced. It is also important to use a sufficient number of elements when simulating a stamping process with drawbead,

since the radii used are usually small, as previously affirmed. In that regard, it is important to use enough elements, at least in the regions affected by the drawbead, to avoid mesh problems in the simulation [19].

The equivalent drawbead has serious limitations, because it does not consider the bending and unbending that the blank suffers on the drawbead, causing deformation. When only entering restriction and opening forces into the software, the exit thickness of the blank and the change in yield stress, due to work hardening, are also neglected. A model that takes these two features into consideration was proposed [20]. It has been shown, through comparison, using experimental results and an iterative geometric optimization method for drawbeads, that the geometric model for drawbeads is much closer to the reality than the equivalent model [21]. Regarding drawbead shape, HAASE, et al. [22] conducted various simulations to evaluate the effects of the alteration of the geometric parameters of three different drawbeads. The study observed that square drawbead has higher restriction forces than the others in similar conditions, and the restriction increases when the radii decreases or the depth increases.

In view of all the advantages previously stated that can be obtained from the use of drawbeads, and the necessity of further study on that subject, the present paper first investigated on the use of drawbeads for enabling stamping processes. An evaluation of the use of segmented drawbeads as a viable tool to improve the results of a stamping process was be conducted and most importantly, the importance of using proper elements size and remesh criteria was also be evaluated.

2. Methodology

Different simulations were conducted considering a single action stamping process. Figure 1 shows a schematic of how this process was conducted. First, the outer part of the blank was pressed by the die against the blankholder, then these two tools move together, forcing the inner part of the blank against the punch, which ultimately draws the sheet into the die cavity.

The simulations conducted considered surface representations of the tools used in a stamping process, as represented in Figure 2. Tooling surfaces were set as rigid bodies granting a fairly accurate estimation of the reality, since the external surfaces are the only regions of the tools that exert contact with the blank, and the deformation on the tools during the process is minimal. In addition, it saves computational time, which is an important issue regarding computational simulation for industry. The software used to simulate was Pam-Stamp [23], that was validated as a viable modelling tool, using computational simulation of basic stamping operations [24].

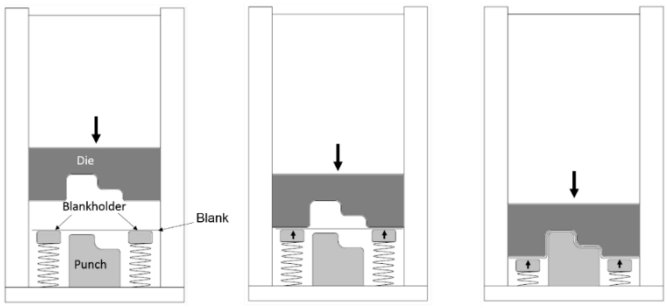


Figure 1. Schematic on single action stamping processes.

Simulations considered three stages of the stamping operation: gravity, holding and stamping. The first stage was calculated implicitly, and the following stages were calculated explicitly. The gravity stage evaluates the effect of gravity on the blank when positioning it on the blankholder. For large blanks, it can suffer considerable deformation on this stage, even reaching the plastic deformation range, but this was not the case. On the holding stage, the die presses the blank against the balnkholder, and

then, on the stamping stage, both die and blankholder move forcing the blank against the punch, as shown in Figure 3.

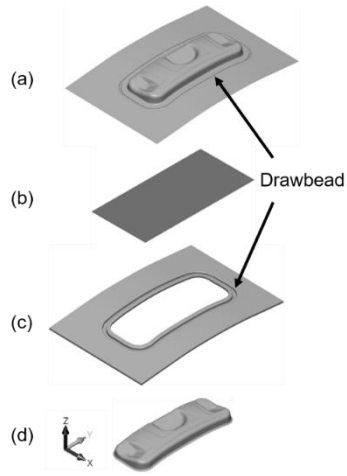


Figure 2. Objects representation for (a) die, (b) blank, (c) blankholder and (d) punch, with drawbead outline featured by black arrows.

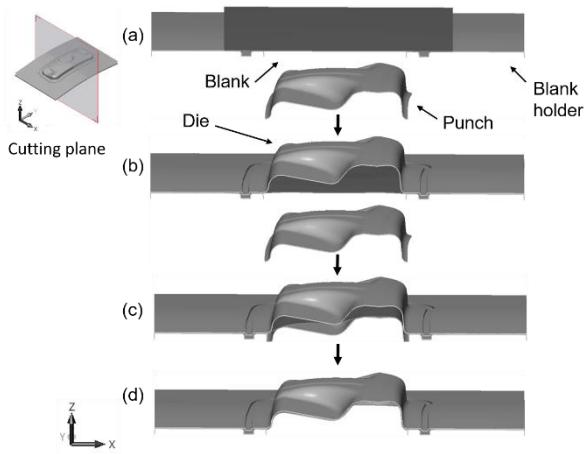


Figure 3. Cut view of the stages of the process, (a) gravity, (b) holding and (c;d) stamping.

The simulations were performed using mostly the same base parameters, but with differences in the drawbeads considered for each process replicated and on the remesh criteria adopted. Final part geometry (Figure 4) was maintained, as well as rolling direction, through Y, and initial blank size at 390 mm height, 790 mm length and 1.2 mm thickness. A friction coefficient of 0.12 (Coulomb) was used, which is the value suggested by the Pam-stamp library as the usual friction value for cold forming stamping operations [23]. The material used was the DP 500, and its Flow Curve and Forming Limit Diagram were also obtained from the software library (Figures 5 and 6, respectively). BHF used for all the simulations was 600 kN, to ensure that the blank would be in contact with the tools during the whole stamping stage.

The initial rectangular blank was discretized in 2964 square elements with 10.4 mm sides. An automatic remeshing criteria based on tools' smallest radii was adopted. That way, a dynamic remesh occurred, so that only problematic elements were divided into smaller ones. On that way, the problem was accurately represented, without mesh problems, and computational time was saved. The density of elements was adjusted based on the necessities of the distinct regions of the simulated process. Figure 4 presents the mesh wireframe before and after the process. The remesh criterion adopted on the simulations is based on the smallest radius to be considered, it was an adaptive remesh triggered by inhomogeneous deformation and aimed to ensure geometric description accuracy.

Since the smallest radius on the drawbead (2 mm) is smaller than the smallest on the die and punch (4 mm). The remeshing when considering the smallest radius on the die and punch used 4 refinement levels and reduced the initial element size to a minimal of 1.3 mm, while when considering the smallest radius on the drawbead 5 refinement levels were used and the elements were reduced to a minimal size of 0.65 mm, therefore the remesh criterion based on the radius of the drawbead is more refined. With that considered, the remesh criteria used was based on the smallest radius of the drawbead for all the simulations, except for simulations number three and five, which were conducted to evaluate the difference in computational time caused by adopting different remesh criteria. The final element sizes aimed on each remesh were calculated using equation (1), in which F_{es} stands for final element size, T for thickness and R_m for minimal radius.

$$F_{es} = \left(\frac{T}{2} + R_m\right)\frac{1}{4} \tag{1}$$

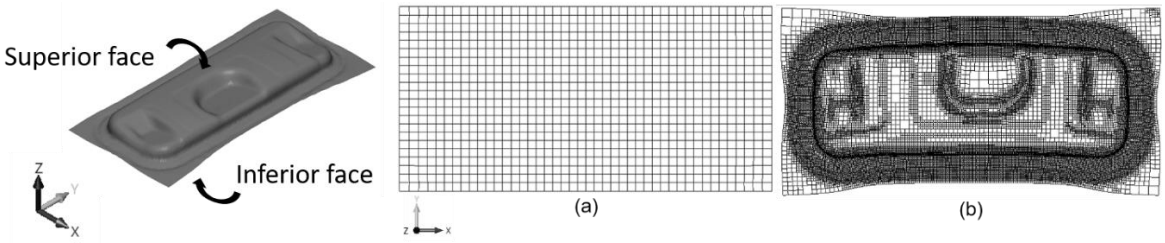


Figure 4. Isometric view of the final part geometry and Wireframe of the mesh (a) before and (b) after the process, showing the remesh result.

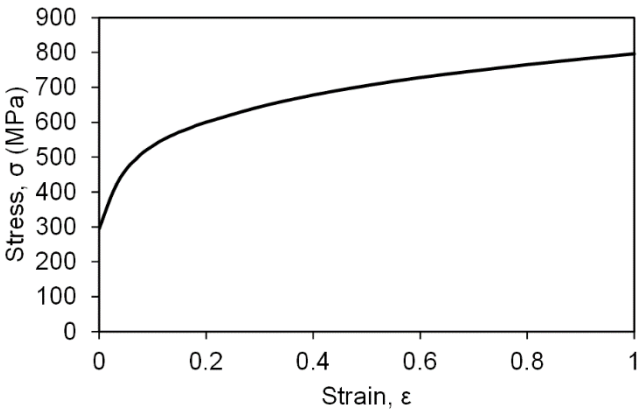


Figure 5. Flow Curve for DP500 steel,1.2 mm [23].

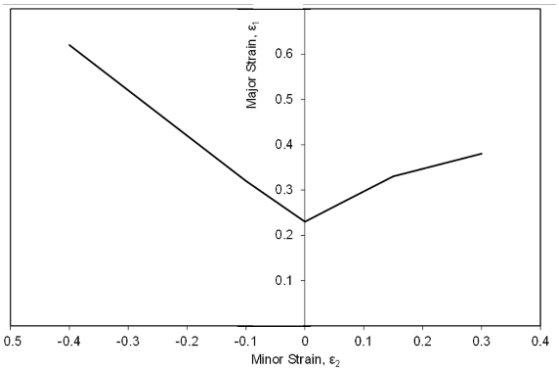


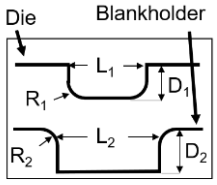
Figure 6. Forming Limit Diagram for DP500 steel, 1.2 mm [23].

Table 1 presents in detail the drawbeads, the geometrical parameters, and the remesh criterion adopted for each of the conducted simulations. It was used geometric drawbeads, and the type chosen was the square drawbead, as illustrated in Figure 1 (a).

The first simulation was conducted with no drawbead, and its results were used as a basis. The second simulation used a uniform drawbead, with high radii values, so that the restriction forces generated would be low. Simulations number three, four and five considered the same geometrical parameters for a uniform drawbead, the difference between them were the remesh criterion adopted. On the third one the remesh criteria was based on the smallest radius on the die and punch, and the fourth was based on the smallest radius of the drawbead adopted. The fifth simulation used a remesh criterion based on the smallest radius on the tool for the region of the blank deformed between the die and the punch, and also another criterion, based on the drawbead's smallest radius, for the region of the blank deformed by the drawbead. Figure 7 shows the different regions on the blank defined for the two different remesh criteria used. For simulation six, a segmented drawbead was considered, with geometrical parameters varying on each segment according to the segments in Figure 8.

Table 1. Drawbeads, geometrical parameters and remesh criteria used in the simulations.

Simulation	Drawbead	Segments	Remesh Reference	Dimensions (mm)						
				L_1	L_2	R_1	R_2	D_1	D_2	G
1	No drawbead	-	Drawbead	-	-	-	-	-	-	-
2	Uniform			12	16.8	6	6	4	6.4	2.4
3			Die and punch			2	4			
4			Drawbead							
5			By regions							
6	Segmented	I	Drawbead	-	-	-	-	-	-	-
		II		12	16.8	2	3	4	6.4	2.4
		III				2	2			
		IV				2	3			
		V								
		VI		-	-	-	-	-	-	-



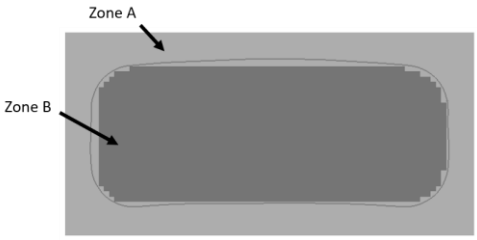


Figure 7. Different remesh regions used on Simulation 5: Zone A, based on the smallest radius on the drawbead; and Zone B, based on the smallest radius on the die and punch.

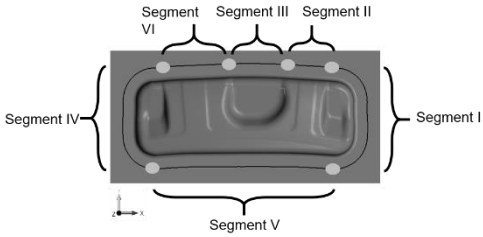


Figure 8. Drawbead segments definition for the fourth simulation.

3. Results and discussion

Forming Limit Diagram is a valuable tool to analyze and compare the results of stamping processes. Softwares based on the Finite Element Method can calculate the strains of each element, and then plot them on the FLD. This enables the observation of defects, such as fractures and wrinkles predicted on the part, and the visualization of which region they are more prone to occur.

The results simulated for each of the six simulations conducted were plotted on the FLD showing the results of each element on the final part. The regions corresponding to wrinkling trends or insufficient stretching were circled in black, and the fractures were pointed with white arrows.

The first simulation (Figure 9.1) considered no drawbead, in order to obtain a comparison base parameter, representing the behavior of the blank throughout the process in a condition of less restriction to its movement. This condition can be observed in the FLD results on the major regions of wrinkling trend and insufficient stretching, and no fractures.

In Simulation 2 (Figure 9.2) a uniform drawbead was added, resulting in a restriction force of 98 N/mm on the drawbead. The restriction to the movement of the blank increased in comparison to Simulation 1. That can be confirmed because the regions with wrinkling trends were reduced considerably, although there were still large regions with insufficient stretching.

The third simulation (Figure 9.3) also considered a uniform drawbead, but the radii were reduced in comparison to the second simulation, thus the restriction force increased to 326 N/mm. This phenomenon reflected on the results as the wrinkling and insufficient stretching regions were reduced and a fracture appeared. The remesh criterion used was based on the smallest radius of the die and the punch.

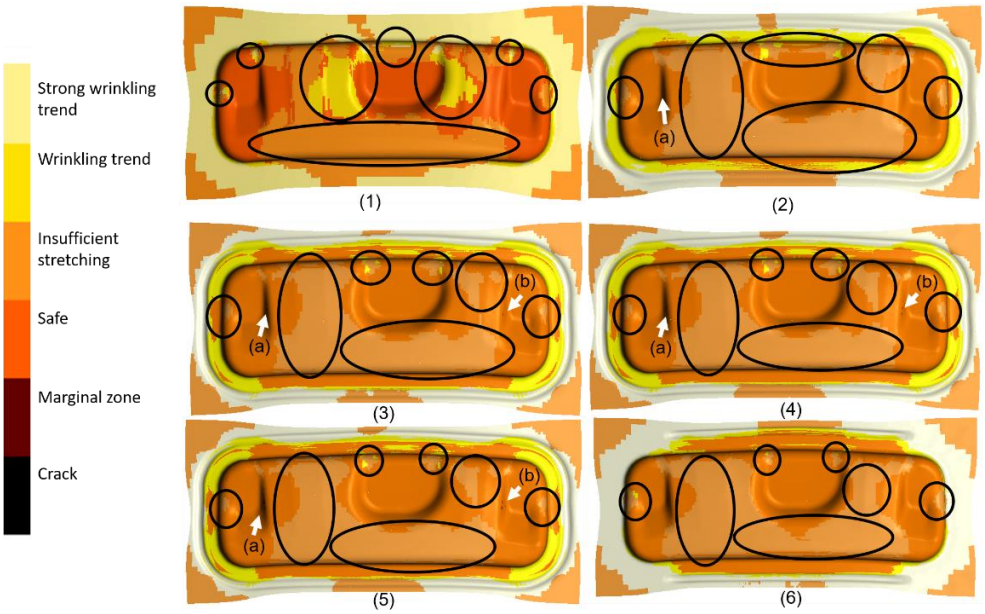


Figure 9. Results for each simulation (1; 2; 3; 4; 5; 6) with insufficient stretching and wrinkling regions circled in black and fracture points (a;b) indicated by white arrows.

Simulation 4 (Figure 9.4) used the same drawbead as Simulation 3, but the remesh criterion considered the smallest radius on the drawbead, instead of the smallest radius on the die and punch. The results obtained were similar, but the preexistent point of fracture was better represented and the point previously in the marginal zone is a fracture in this case.

Figure 9.5 shows the results for simulation 5, where remesh criteria with distinction for two different regions was adopted. Remeshing was based on the radius of the drawbead for the region of the blank in contact with the drawbead and based on the die and punch for the region in contact with those. The results obtained were very similar to the results observed on Simulation 3. There were slight differences in the fracture points and other regions.

Simulation 6 (Figure 9.6) considered a segmented drawbead. From the results of the previous simulations, the drawbead geometry on each segment was chosen, according to Table 1, trying to improve the results of the process, regarding wrinkling and fractures. The restriction force on segments II, III, VI, V were 395, 502, 395 and 395 N/mm respectively. Segments I and VI used no drawbead and therefore, no restriction force was imposed, except for the ones created by the contact of the blank with the tools. Using different restrictions on the segments chosen it was possible to better distribute the stretch on the blank. Evidence to that is the fact that the wrinkling trend regions were almost eliminated, and the fractures were eliminated. There were still regions with insufficient stretching, circled in black.

Throughout the study conducted in this paper, it was observed that the drawbead is a tool of great importance for the optimization of industrial stamping processes. This can be confirmed by alterations in the drawbead that presented direct influence on the results of the stamped part. Also, it could be observed that the adoption of different remesh criteria for different regions of the blank can be useful to achieve realistic results with less computational time that when adopting a more refined criterion on the whole blank. Figure 10 shows a segmented drawbead example.

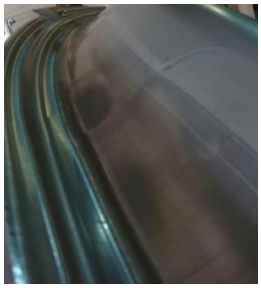


Figure 10. Double and segmented drawbead.

4. Conclusion

Using a drawbead was useful to increase the restriction forces to the movement of the blank, but uniform drawbeads are limited in the sense that they do not allow different restriction forces for different regions. Consequently, adopting uniform drawbeads might not be the best solution for parts with geometries that require contrasting restriction forces depending on the region to be properly formed. That is because using low DBRF would cause wrinkling on a certain region, but increasing the restriction to solve that would ultimately cause a fracture on another region. In that event, segmented drawbeads proved to be powerful tools, allowing to vary the constraints according to the needs of the formed zone. The choice of the remesh criteria to be used on stamping simulations proved to be an important factor also, since it affects both the quality of the results, regarding the proximity to reality, and the computational time of the simulation.

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