

PAPER • OPEN ACCESS

On the accurate characterization of the drawbead up-lift forces

To cite this article: I. Gil *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **418** 012092

View the [article online](#) for updates and enhancements.

On the accurate characterization of the drawbead up-lift forces

I. Gil, L. Galdos, N. Otegi, J. Mendiguren* and E. Saenz de Argandoña

Department of Mechanical and Industrial Production, Mondragon Unibertsitatea, Loramendi 4, Mondragon 20500, Gipuzkoa, Spain

*jmendiguren@mondragon.edu

Abstract. The competitiveness of the automotive sector has led to a high demand of accuracy and reduction in lead-time of the deep drawing tool making process. In that regard, the numerical simulation of the deep drawing process has become a key method for the correct die design. Even though the accuracy of these simulations reached some high quality levels in terms of formability and defects, the material holding force remains an open issue among the die maker companies. This inaccuracy is related with the inability of shell elements to correctly reproduce the behavior of the material around the drawbeads. In order to overcome this problem, commercial stamping software used an analytical model to predict the drawbead holding forces. Nevertheless, most of these models are based on an experimental methodology developed in the 70's that do not exactly represent the industrial drawbead configuration. In order to be able to experimentally analyze the necessary up-lift force of each drawbead, in this work a new experimental procedure is presented. A wide range of automotive sector materials, ranging from mild steels up to high strength steels, have been tested and new values, compared with previous experiments, have been found. In that regard, the force distribution on the drawbead is also studied stressing the importance of the flat surfaces around the drawbead more than the drawbead punch itself.

1. Introduction

Deep drawing is one of the key processes in the automotive industry. Its high cadency and the ability of complex shape forming has led to the extensive use of this technology [1]. The simple explanation of the process is that a flat metal sheet is drawn between a punch and a die with the desired final shape (it is well known that the springback effect modifies that final die shape [2] but is not of high relevance in the present work). In addition to the die and the punch, a blank holder is introduced on the system, where its main objective, as its name predicts, is to hold the sheet in order to: a) avoid wrinkles and b) control the flow/stretching of the material [3]. This blank holder has two main tools to control the material flow. On the one hand, the friction between the sheet and the blank holder-die produces a restraining force, opposite to the material flow. On the other hand, the drawbead punch and grooves forces the material to bend and unbend through the drawbead area restraining in this way its flow into the die cavity [4]. The geometrical properties of the drawbead allows the optimization of the material flow by defining the necessary drawbead geometry at each point of the blank holder.



In order to achieve that optimum drawbead configuration, it is necessary to use the finite element method (FEM). These numerical tools allow the process engineer to check the suitability of the punch-die and blank holder designs in order to achieve the objective stretching configuration [3]. However, the reduced relative size of the drawbeads (an average size of 10-30 mm in comparison with a full component up to 2 m) highly increases the needed computational time and the introduced errors due to singularities on the numerical method (e.g. big errors are introduced by using the shell hypothesis on those small areas) [5]. That is why, generally, analytical equivalent drawbead models are used in the industrial commercial codes. These models predict the equivalent restraining force of each drawbead geometry as well as the necessary force to achieve the closure of the drawbead, known as up-lift force. Numerous models have been formulated in the last years, that of Stoughton [6] being the principal one. Most of these models were formulated taking as a reference the early experimental results of Nine [7]. In 1978 developed an experimental set up (with the objective of analyzing the behavior of some lubricants) where the up-lift and restraining force could be measured. However, the proposed experimental set up was composed by a die, punch and a set of rollers to avoid the material to be lifted when the punch was penetrating. This configuration differs from the industrial drawbead geometry where a groove is performed on the die and a rounded high is maintained on the blank holder [8]. Larsson in 2009 raised the hand and implied that not using the flat surfaces (characteristic of the blank holder surfaces) could lead to major errors on the approach [9].

In view of all this, in the present work, a new drawbead test set up is presented in which the flat surfaces of blank holder are taken into account. Before presenting the new set up, a numerical evaluation of the influence of the flat surfaces is performed in which the original Nine's set up is compared to the schematics of the new set up proposed by Mondragon Unibertsitatea, in order to do so the original material of Nine's work is used. Then a high strength DP780 has been characterized and experimentally analyzed on the new drawbead test set up. The work is presented as follows. First, both materials are presented. Then, the numerical analysis of the impact of the flat surfaces on the up-lift force is shown. Next, the new drawbead experimental set up is presented and the characterized up-lift and restraining forces for the DP780 are presented. Finally the results are discussed and the conclusions are drawn.

2. Materials

Two different materials have been used in this study. On the one hand, a Rimmed steel material taken from Nine's work [7] has been used in order to numerically analyze the difference between Nine's test set up and MU's set up. As shown in Table 1, the analyzed material corresponds to a lower anisotropy deep drawing steel with a hardening exponent > 0.15 .

Table 1. Reference material taken from Nine's work for the analysis of the influence of the flat surfaces.

| Material | Thickness | K | Hardening exponent | Anisotropy |
|--------------|-----------|---------|--------------------|------------|
| Rimmed steel | 0.86 mm | 559 MPa | 0.23 | 1.05 |

On the other hand, a DP780 high strength steel has been used as a reference material for the drawbead up-lift and restraining force characterization. In that regard, conventional tensile tests following the ISO 6892-1:2009 standard have been conducted at RD (rolling direction), TD (transverse direction) and 45D (45 degrees to the RD). Table 2 shows the average values at the RD direction as well as the average anisotropy coefficient. The dispersion values were under 4% for each value.

Table 2. DP780 material characterized for the drawbead up-lift and restraining force experimental analysis.

| Material | Thickness | Elastic modulus E | Elastic limit Rp02 | Maximum stress Rm | Elongation at Rm | Anisotropy |
|----------|-----------|-------------------|--------------------|-------------------|------------------|------------|
| DP780 | 1.49 mm | 198 GPa | 540 MPa | 893 MPa | 10 % | 0.9 |

As previously explained, the Rimmed steel will be used for the numerical study while the DP780 is the material that has been characterized in the drawbead tester developed in MU.

3. New drawbead tester

Prior to the presentation of the new drawbead tester, it is shown the importance of including the flat surfaces on the experimental set up in order to achieve ‘real’ drawbead up-lift force results. In order to do so, two different configurations have been numerically analyzed (Figure 1). On the one hand, Figure 1a, there is the drawbead test set up proposed by Nine [7], where the sheet is on the die surface and the punch goes down while two static rollers restrict the up-lift of the sheet.

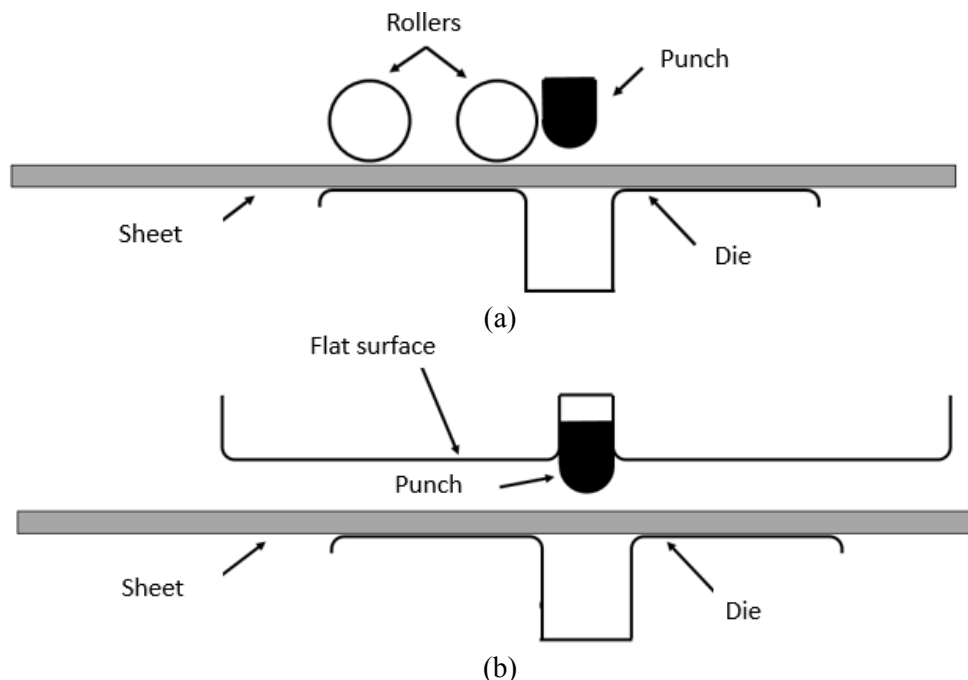


Figure 1. Drawbead simulations: a) Nine’s work configuration and b) MU’s test set-up configuration.

On the other hand, on the MU’s test set up (Figure 1b), the real flat surfaces, emulating the blank holder surfaces, are included.

A numerical analysis has been conducted to evaluate the up-lift force of both configuration. The tools have been idealized as rigid while the sheet is deformable where its properties are those of the rimmed steel previously presented. Abaqus/Explicit FEM code has been used where the thickness of the sheet has been discretized in 11 reduced integration plane strain elements CPE4R, achieving 11 IP though thickness. The longitudinal discretization has been performed following a 1 aspect ratio rule. In Nine’s simulation, the punch has been moved down up to the desired penetration while in MU’s work, both the punch and the flat surfaces have been moved down.

As a result, the up-lift force of the set up is obtained. Following Nine's work, in its configuration the up-lift force of the punch is taken into account while in MU's set up the addition of both punch and flat surfaces is taken into account. Figure 2 shows the resultant force values of the simulated tests.

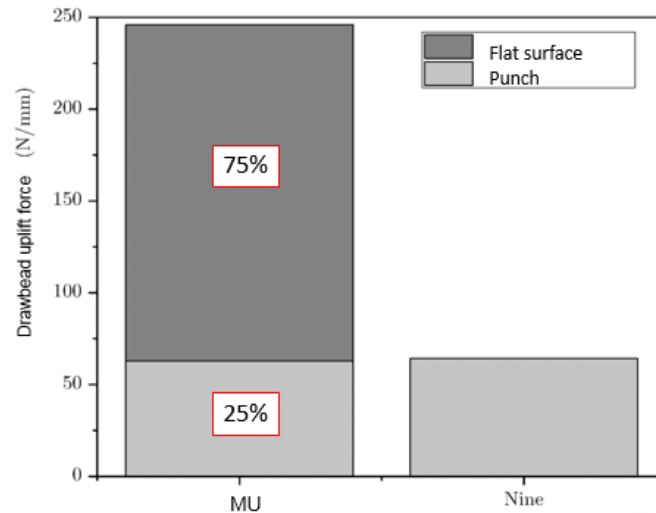


Figure 2. Overview of the up-lift forces for both configurations (Nine's and MU's).

From these results, it can be appreciated the big difference between both experimental whereas at qualitative level MU's set up predicts five times more up-lift force than Nine's set up. Analyzing the influence of the flat surfaces and punch respectively, it can be seen that both set up show similar punch force values but it is in the flat surface effect where the differences are found.

Taking into account this big impact of the flat surfaces, a new drawbead experimental set up has been developed, Figure 3.

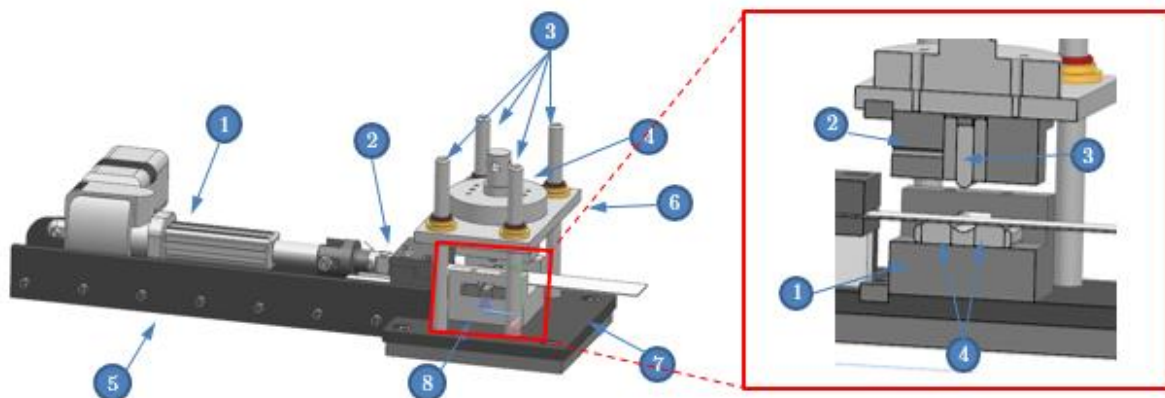


Figure 3. MU's test set-up configuration.

The new experimental set up consists of two differentiated blocks. On the one hand, the closing system. In this block (numbers 3, 4, 6, 7, 8, 9 on the left picture and 1-4 on the detail) a modular drawbead system is mounted in a four column driven die. This block is mounted in a precision compression Zwick test machine, in order to have an accurate measurement of the force vs. displacement. On the other hand, the pulling block (numbers 1-2, 5 on the left picture) is composed by a linear motor with a load cell with the objective of pulling the sheet once the drawbead is closed in order to obtain the restraining force of each drawbead configuration.

In this first work, a classical round drawbead with 5 mm radius on the punch area and 3 mm radius on the die area has been studied (Figure 4). The width of the groove is dependent on the sheet thickness (leading to 14.5 mm in this case), while the penetration depth (H) is a variable parameter that allows to increase or decrease the restraining force of the drawbead.

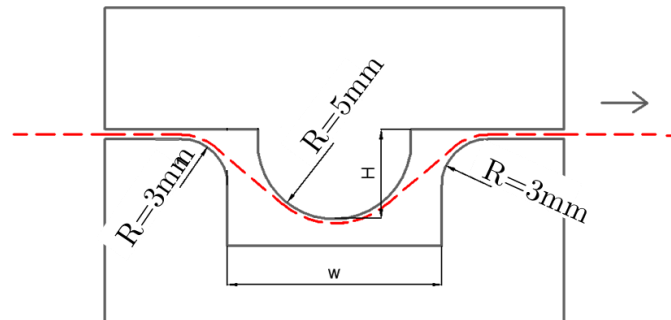


Figure 4. Used drawbead schematics.

In order to calculate both the up-lift and restraining forces, the following testing procedure has been followed: First, the upper part of the drawbead is moved down until the complete closure of the drawbead, the necessary force to achieve this closure is the up-lift force. Then, the upper part is moved up 0.05 mm and the sheet is pulled through the drawbead in order to calculate the restraining force. This movement up allows neglecting the friction forces between the sheet and the flat surfaces on the majority of the blank holding area (it will still remain the friction effect on the places where the sheet contacts the upper die near the drawbead). A schematic illustration of the test procedure is shown in Figure 5.

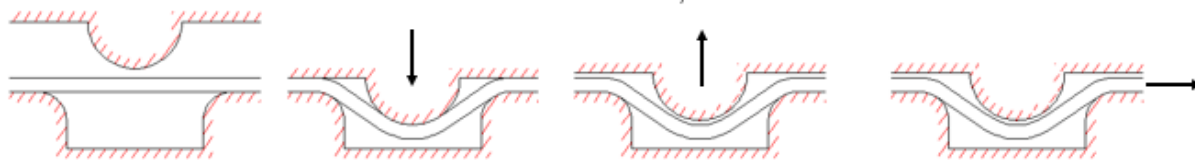


Figure 5. Drawbead tester movement protocol

4. Experimental results

In this preliminary work the DP780 material has been characterized with drawbead heights of 2 to 5 mm. For each height, 5 tests were conducted and the average values of up-lift and restraining force were calculated. Table 3 shows the averaged values where the deviations between tests are in every case less than 7%.

Table 3. Experimental drawbead up-lift and restraining forces for the studied DP780 material.

| Drawbead height (mm) | Up-lift force (N/mm) | Restraining force (N/mm) |
|----------------------|----------------------|--------------------------|
| 2 | 447.0 | 258.9 |
| 3 | 586.6 | 390.5 |
| 4 | 709.8 | - |
| 5 | 831.0 | - |

Only two restraining heights have been obtained (2 mm and 3 mm heights). This is due to the fact that micro cracks were induced on the sheet surface during the closing with 4 mm and 5 mm and that led to the split of the sheet during the pulling step. This is not a surprising phenomenon as low height drawbeads (or square drawbeads) are used in industry for these kind of high strength steels.

5. Discussion

From the values shown in Table 3 different analysis can be obtained. On the one hand, in terms of drawbead design and used, it can be seen how (with the followed technique) the restraining force has increase in a 50% from using a 2 mm high drawbead to a 3 mm high drawbead. However, this 50% increase on the restraining force lead only to a 31% increase of the up-lift force. On the other hand, focusing on the up-lift force, increasing from 2 mm to 4 mm the drawbead height an increase of 60% of the up-lift force is achieved while an 86% of increase is shown when increasing the height up to 5 mm. In order to emphasize the importance of these results, it has to be noted that, as previously presented on the introduction, most of the analytical drawbead models up to date are based on Nine's results where it has been shown that 75% of the force was neglected. Therefore, these new results, open a new work window in order to develop more accurate (closer to the industrial necessities) drawbead prediction models.

6. Conclusions

The main conclusions of the presented work can be summarized in the following key sentences:

- The new presented MU's drawbead test set up takes into account the effect of the flat surfaces, the effect of these being around 75% of the up-lift forces.
- The new set up allows the rapid characterization of up-lift and restraining forces for a variety of materials and drawbead geometrical configurations opening a new work window for model developers.
- An increase from 2 mm of drawbead height to 3 mm increases the restraining force by 50% while only increasing the up-lift force by 31%.

Acknowledgments

The authors would like to thank the Ministry of Economy and Competitiveness of the Spanish Government for funding the project HRD: High Reliability Dies under the program RETOS with reference number RTC-2015-3643-4. The collaboration and technical support in the study of the company MATRICI S. Coop. is also gratefully acknowledged.

References

- [1] Dwivedi R, Agnihotri G, Study of deep drawing process parameters 2017, Mater. Today-Proce, Vol 4. 820-6.
- [2] Wagoner RH, Lim H, Lee MG, Advanced issues in springback 2013, Int. J. Plasticity, Vol 45. 3-20.
- [3] Stoughton TB, Zhu X, Review of theoretical models of the strain-based FLD and their relevance of the stress-based FLD 2004, Int. J. Plasticity, Vol 20. 1463-86.
- [4] Wang Z, Zhang Q, Liu Y, Zhang Z, A robust and accurate gemoetric model for automated design of drawbeads in sheet metal forming 2017, Computer-Aided Design, Vol 92, 42-57.
- [5] Kpeky F, Abed-Meraim F, Daya EM, New linear and quadratic prismatic piezolectric solid-shell finite elements 2018, Appl. math. comp., Vol. 319, 355-368.
- [6] Stoughton TB, model of drawbead forces in sheet metal forming 1988, Proceedings of the 15th biennial IDDRG, 205-2015.
- [7] Nine HD, Drawbead forces in sheet metal forming 1978, Mech. Sheet Metal Form, 179-211.
- [8] Gil I, Mendiguren J, Galdos L, Mugarra E, Saenz de Argandoña E, Influence of the pressure dependent coefficient of friction on deep drawing springback predictions 2016, Tribology Inter., Vol 103 266-73.
- [9] Larsson M, Computational characterization of drawbeads 2009, JMPT technology, Vol. 209, 376-86.