Computer Aided Modelling of Rubber Pad Forming Process
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Abstract. Rubber pad forming (RPF) is a novel method for sheet metal forming that has been increasingly used for: automotive, energy, electronic and aeronautic applications [1]. Compared with the conventional forming processes, this method only requires one rigid die, according to the shape of the part, and the other tool is replaced by a rubber pad [1]. This method can greatly improve the formability of the blank because the contact surface between the rigid die and the rubber pad is flexible. By this way the rubber pad forming enables the production of sheet metal parts with complex contours and bends. Furthermore, the rubber pad forming process is characterized by a low cost of the die because only one rigid die is required [2].

The conventional way to develop rubber pad forming processes of metallic components requires a burdensome trial-and-error process for setting up the technology, whose success chiefly depends on operator’s skill and experience [4][5]. In the aeronautical field, where the parts are produced in small series, a too lengthy and costly development phase cannot be accepted. Moreover, the small number of components does not justify large investments in tooling. For these reasons, it is necessary that, during the conceptual design, possible technological troubles are preliminarily faced by means of numerical simulation [4],[6].

In this study, the rubber forming process of an aluminum alloy aeronautic component has been explored with numerical simulations and the significant parameters associated with this process have been investigated. Several effects, depending on: stamping strategy, component geometry and rubber pad characterization have been taken into account.

The process analysis has been carried out thanks to an extensive use of a commercially finite element (FE) package useful for an appropriate set-up of the process model [7],[8]. These investigations have shown the effectiveness of simulations in process design and highlighted the critical parameters which require necessary adjustments before physical tests.

Introduction

Minimization of response times and costs and maximization of the efficiency and quality in the industrial contest are imperative for survival in the competitive manufacturing industry [6]. Sheet metal forming is a widely used and costly manufacturing process, to which these considerations apply [6]. Many companies in aeronautical industry are recently required to manufacture curved products that are small in lot size, which means both a higher cost per detail and a need for multiple tools [6]. A possible alternative forming method, which can reduce production costs for such application contests, it is represented by flexible forming process [5][6]. This process, also known as Rubber Pad Forming (RPF) or Guerin process, is schematically represented in Fig. 1.

The RPF process requires: a rubber filled chamber, a blank and a form block, a punch (Fig. 1). This forming process finds useful applications as a sheet shaping method for metal as well as composite parts in the aerospace industry. The flexibility of operation, the capability for drawing, bending, and embossing of simple or moderately complex parts, the protection of sheet surface by rubber, and low tooling costs are the underlying advantages of the process [6].
A versatile way to investigate process parameters influence on product performance, which is supported by dramatic advances in computer processing power and software tools, is numerical analysis, however, few numerical investigations of RPF process could be found in literature [1][2][4].

This study aims at simulating RPF using commercial finite element software. Thanks to the application of the Finite Element Analysis (FEA) interesting considerations can be made on the influence of process variables on the product/process performance.

**Numerical Model**

The Finite Element (FE) model is composed by: a rubber pad, which is modelled with solid elements, a rigid tool (punch) and a blank; the punch and the blank are both modelled with shell elements, as reported in Fig. 2. As the test case is represented by a component made by aluminium alloy characterized by symmetry planes, appropriate symmetry constraints have been introduced to the rubber pad and to the blank. The rubber pad is rigidly attached to a metal box that contains it. In order to simulate this condition all the nodes on the external sides of the rubber pad are restrained in appropriate way.

**Table 1**

<table>
<thead>
<tr>
<th>Case</th>
<th>Fillet Radii</th>
<th>Overall Dimensions [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>R1, R2</td>
<td>237.5 x 246</td>
</tr>
<tr>
<td>Case B</td>
<td>R1, R2, R3</td>
<td>237.5 x 246</td>
</tr>
</tbody>
</table>

The reference model is characterized by three different fillet radii: R1, R2 and R3 as in Fig. 3, where the overall dimensions of the punch are also reported. In detail two cases, Case A and B, with two different combinations of fillet radii values have been investigated (Table 1).
Table 1. Fillet radii cases definition

<table>
<thead>
<tr>
<th>Case A</th>
<th>R1 = 5 mm</th>
<th>R2 = 7 mm</th>
<th>R3 = 5 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case B</td>
<td>R1 = 12 mm</td>
<td>R2 = 7 mm</td>
<td>R3 = 12 mm</td>
</tr>
</tbody>
</table>

In order to explore the design space, for each considered case, different combinations of initial blank thickness and hardness of rubber pad have been investigated, as reported in Table 2.

Table 2. The investigated hardness values and the blank thickness for Case A and Case B

<table>
<thead>
<tr>
<th>Case A/B</th>
<th>Rubber Pad Hardness [Shore A]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50</td>
</tr>
<tr>
<td>Blank Thickness [mm]</td>
<td>1.1</td>
</tr>
<tr>
<td>Shore 50</td>
<td>1.1</td>
</tr>
<tr>
<td>Shore 70</td>
<td>1.1</td>
</tr>
<tr>
<td>Shore 90</td>
<td>1.1</td>
</tr>
</tbody>
</table>

In total 18 combinations have been investigated with blank dimensions equal to 436 x 200 mm².

The blank material is an aluminum alloy Al2024, which has been modeled as anisotropic elasto-plastic material (*MAT_37 of Ls-Dyna), while the punch has been modeled like a rigid material. The mechanical properties of the blank material are reported in Table 3.

Table 3. Mechanical properties of the blank material

<table>
<thead>
<tr>
<th>Young Modulus (MPa)</th>
<th>Poisson Ratio</th>
<th>Density (kg/mm³)</th>
<th>σy (MPa)</th>
<th>σR (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>72394.5</td>
<td>0.3</td>
<td>2.7 E10⁻⁶</td>
<td>262</td>
<td>427.5</td>
</tr>
</tbody>
</table>

The rubber pad is a polyurethane pad with a hardness range varying from 50 to 90 Shore. Its analytical formulation is the result of several considerations on the elements size, contacts formulation between the rubber pad and the blank, and material formulation. As it is possible to observe in Fig. 2 (a), in fact, the finite elements size increases going from the inner side to the outer side of the pad. Adopting such a kind of discretization it is possible to reduce the total number of elements without affecting the deformation mode of the rubber pad.

The polyurethane behaves as a hyperelastic material, so the adopted material law is *MAT_27 of Ls-Dyna library, that is a Mooney-Rivlin material formulation [8] with A and B coefficients [9] reported in Table 4 for the three different investigated hardness values.

Table 4. Mechanical properties of Rubber Pad material formulation

<table>
<thead>
<tr>
<th>Shore</th>
<th>A</th>
<th>B</th>
<th>Poisson Ratio</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shore 50</td>
<td>0.302</td>
<td>0.076</td>
<td>0.499</td>
<td>2E10⁻⁶ kg/mm³</td>
</tr>
<tr>
<td>Shore 70</td>
<td>0.736</td>
<td>0.184</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shore 90</td>
<td>2.824</td>
<td>0.706</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The density and the Poisson ratio are constant for the three investigated levels of the rubber pad hardness.

**Numerical Results**

**Process Performance Evaluation.** In order to evaluate the process performance of each studied configuration, different performance indexes have been considered. The first one is the process capability to obtain the nominal concave (respect to the rubber pad) fillet radius, R2 (Fig. 3). In fact, while for R1 and R3 the deviation from nominal values is very small, in the case of R2 it assumes large values and it depends on the process variables and the geometry. This capability has been measured as reported in the analytical expression in the equation (1).

$$|R_{i_{\text{deviation}}} = R_{i_{\text{nominal}}} - R_{i_{\text{obtained}}}| \quad \text{with } i = 1, 2 \text{ and } 3. \quad (1)$$

The R2$\text{nominal}$ value is reported in Table 1, while R2$\text{obtained}$ is calculated on the formed component as shown in Fig. 4.

![Fig. 4. R2$\text{obtained}$ calculation on the formed component](image)

In detail in Fig. 5 and Fig. 6, respectively, the R3 and R2 deviations versus Shore A, for the three initial blank thickness and the two cases A and B, are reported.

![Fig. 5. R3 deviation vs rubber pad hardness for three different initial blank thicknesses and for the two cases as reported in Table 1](image)
Fig. 6. R2 deviation vs rubber pad hardness for three different initial blank thicknesses and for the two cases as reported in Table 1

Observing Fig. 5, it is possible to conclude that the R3 deviation is very small if compared to the one measured for the concave radius R2 in both cases A and B. Relative to R2 deviation (Fig. 6), the Case B has a better behaviour if compared to Case A. Moreover, a low value of initial blank thickness shows a minor R2 deviation, while the hardness of the rubber pad has a clear effect to reduce the deviation for higher values. Starting by these observations it is possible to conclude that the better solution is given by the Case B with initial blank thickness equal to 0.53 mm and Shore A equal to 90.

The second performance evaluation index is relative to the maximum reaction force, in order to calculate the minimum technological request of the needed equipment. The maximum reaction force is calculated at the end of the punch stroke, which is equal to 100 mm for all the studied configurations. The trend of the reaction force versus punch stroke is similar for all the investigated combinations; an example is reported in Fig. 7.

Fig. 7. Reaction force [kN] vs punch stroke [mm] evaluation for half model

In Fig. 8 the maximum reaction forces values versus initial blank thickness and rubber pad hardness for the Case A and the Case B are reported.

The maximum requested force is relative to the maximum rubber pad hardness value, Shore 90. Among the Cases A and B there is not a great difference in terms of maximum reaction force, while there is a great difference among different evaluated Shore values. Comparing the obtained results in the test cases where 90 Shore and 70 Shore have been adopted, it is possible to find a reduction of the mean maximum reaction force value higher than 70 %, while a reduction equal to 60 % has been detected going from Shore 70 to Shore 50.
In relation to the investigated process parameters it is possible to observe that a polyurethane pad with a hardness range varying from 70 to 90 Shore A can be considered appropriate for rubber forming of component with small concave fillet radius. Considering as predominant performance index the capability to obtain the minimum concave fillet radius, the better configuration is relative to Case B with an initial blank thickness equal to 0.53 mm and rubber pad hardness equal to 90 Shore. The results of this configuration are reported in Fig. 9 and Fig. 10.

At the end of the punch stroke (Fig. 9 (a)) it is possible to notice how the maximum stress for the rubber pad is concentrated in the area of the fillet radius R3 and it is equal to 24.75 MPa, as shown in Fig. 9 (b).

The effective plastic strain and thickness percentage reduction distributions are reported in Fig. 10 (A) and (b) for the formed part.
Fig. 10. (a) Effective plastic strain distribution and (b) percentage thickness reduction distribution for formed part (Case B, thickness equal to 0.53 mm, 90 Shore)

The simulation results show that a variation in pad hardness does not have a big influence on plastic strain distribution of the formed component, but it has a great importance in fillet radii forming capability. By this way, it can be said that the rubber pad hardness is very critical: the obtained results have shown how as soon as the hardness increases also the capability to form the concave fillet radius increases. At the same time the reaction force and, then, the technological request for the equipment increases, so the best solution has to be matched with the technological limits and the costs of the needed equipment.

Summary and Conclusion

The use of FE simulation in the better understanding of forming operations is becoming more important as it provides a cheap and efficient way to determine process parameters and moreover their influence on the process itself. This work describes a numerical simulation study concerning the RPF process.

The rubber pad forming process has been shown to be capable of producing, from thin aluminum alloy blank, shallow formed parts with a reduced metal thinning.

In this study, deformation characteristics in the rubber pad forming have been investigated with the developed of an appropriate FE model. Based on the FE analysis the minimum available fillet radii for aluminum sheet have been found in terms of the proposed measure.

From the obtained results it is possible to conclude:

- To decrease the minimum available concave fillet radius, that is R2, the R1 and R3 radii should be increased.
- Rubber hardness is a dominant process parameter that affected the cross-sectional deformation of the sheet. Its effect on blank deformation becomes prominent when the convex radii, R1 and R3, increase.
- The adoption of thinner blanks leads to have smaller concave fillet radii.

Tooling costs are reduced considerably as only one tool needs to be manufactured per component. The simplicity of the tooling will reduce lead times and it will enable the rapid production of prototype parts.

References


