Evaluation of the supporting plate edge radius and position effects on springback in incremental forming, part A

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Abstract: Incremental Forming IF is a suitable technique for producing complex forms. The geometry of product is quite free; on the other hand, there are limitations regarding the sheet thickness and the tools used. The material formability is affected by the product profile requirements, and the straightening of product wall is affected by the tool path. Also, the wall angle is one of most important characteristics that are limited by the sheet profile thickness. The geometry of the product determines the type of supporting tool and its complexity. The horizontal surface can be produced without supporting tool, but will result inclined. Without supporting tool, the sheet tends to bend as an alternative of stretching and the surface becomes wavy. For the present study, Aluminum (A1025) alloy sheets are used to deform a product using a supporting plate (with radius). The supporting plate is used to analyze the effect of springback during the process and for better control over the material flow. The study aims to understand the distribution of strain at the deformed part section for each step size. Also, the primary reasons for the product failure by springback and the final products have been evaluated and analyzed in details.

1 Introduction

Incremental Forming (IF) is a process that uses the principles of the layered manufacturing. The geometry of the part is converted into multi layers and a 2D-dimensional contour of each layer is designed. The product is obtained by repeating the layers forming. A simple forming tool is used in this process to produces plastic deformation in a local position on the blank [1]. This process is numerically controlled by a CNC machine (Figure 1 [2]).
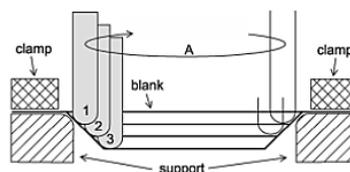
Fig. 1. SPIF process principle [2].

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IF has greater process flexibility and enhanced blank formability [3, 4]. It satisfies the demands of decreasing lead time and costs in manufacturing process while reducing energy consumption and environmental pollution [5, 6]. However, it has to be pointed out that the forming times in IF is much longer than those in conventional forming processes. According to the advantages and limits of IF, this technique is particularly suitable to small batch production and prototypes in automotive, aerospace and biomedical sectors [7, 8].

Advantages: A low cost method, producing rapid prototypes and small volume, giving a high flexibility, and the process does not require either positive or negative dies;

Disadvantages: The forming time is much longer than in conventional processes (deep drawing), the process is limited to small size batch production, and the forming of right angles cannot be done in one step (springback occurs) [9, 10, 11].

IF has some serious drawbacks. The main drawbacks are problems with producing steep walls, and low accuracy induced by the elastic springback.

Steep walls issues; the wall thickness depends on the part wall angle, (α). When α approaches equal 0°, the strain values are above the limit of forming curve and the part will tear. Some of investigators have described achieving α equal 0° [10, 12].

Elastic materials issues; Elastic springback effect plays an important part, mainly when the support space between the support edge and the tool is large or the deforming is performed without support. Therefore, the deviations of the large areas of the part will cause geometrical inaccuracies because of cumulating a number of millimeters.

Surfaces of large radius of curvature issues; the elastic springback causes this problem. Also, a smaller vertical steps size of the tool needs to be used to avoid visible deforming lines on the surface of the product.

The gap between the tool and the support issues; the deviation of the deformed part profile will be moreover large when the gap is too large. The sheet is constrained between the support edge and the tool until pressed when the gap is too small, producing ironing. As the un-deformed material is relatively stiff, the material constrained out from the support-tool contact area transfers up and lifts the deformed surfaces of the part off the edge of the support. This causes deviations in the range of several millimeters [10-13].

One of the disadvantages in the SPIF, Single Point Incremental process is springback, which can be divided into two types. Local springback: as the forming tool passes over the sheet material, following the contours of the desired geometry, the material located behind the advancing tool slightly deforms back to its original position. Global springback: results from the residual stresses worked into the material during forming. This form of springback is more pronounced after the part is released from the forming fixture. These residual stresses depend on material thickness, formed profile and tool path [14, 15].

Many advances in the reduction of springback in metals have been made. The use of direct electric current, both during and after SPIF on a variety of metals, has been shown to reduce springback [16, 17]. Other methods include laser-assisted incremental forming [18], and utilization of a backing die [19].

In this study, Aluminum (A1025) (thickness, t=0.9 mm) alloy sheets are used to deform a product with a frustum cone geometry using a supporting plate (with radius). The reason for using the supporting plate is to establish the effect of springback during the SPIF, Single Point Incremental Forming process and for better control over the material flow. The study also aims to determine the strain distribution for the deformed part section at each step size. Additionally, factors leading to fracture of the finished parts have been analyzed and discussed.

2 FE model of IF process simulation

The model takes into account the interface contact effect (forming tool, fixture and work piece) and the elastic plastic material property of the workpiece behavior. In the FE model

development, the effect of supporting plate profile is studied at constant boundary conditions of the workpiece, forming tool and fixture. The simulation mode is x-symmetric elements (2D dimensional), as demonstrated in the Figure 2. The pair Point-to-Surface contact elements CONTAC169 and CONTAC171-2D were used to represent the contact conditions.

For each contact surface a real constant set is used. The PLANE42-2D element to represent the rigid set and the V15C0106-2D element to represent the flexible set are used.

• Rigid-to-Flexible contact is represented by the forming tool\workpiece.

• Rigid-to-Rigid contact is represented by the blank holder\supporting plate.

• Flexible-to-Rigid contact is represented by the workpiece\supporting plate.

A convergence criterion, non-linear analysis, and specified incremental boundary conditions are applied. The tolerance of convergence was created depending on the force residual minimization. An Aluminum alloy (1050) with the mechanical properties resulted from load-extension curve of the tensile test has been used (Table 1).
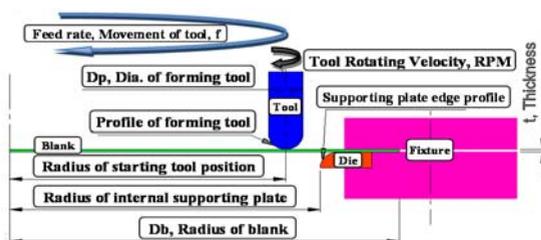
Fig. 2. Boundary conditions in the SPIF process.

Table 1. Material data for Al 1050 H14.

Property	Value	
Density, ρ	2.71	kg/m3
Proof Stress, σy	85 Min	MPa
Tensile Strength	105 - 145	MPa
Young's modulus, E	71	GPa
Elongation A	12	Min %
Poisson's Ratio, ν	0.3	
Tangent modules, Eτ	0.5	GPa

3 Results and discussion

A primary analysis of the predicted deformed product by AutoCAD is conducted, including the fixture mode, the design of the supporting plate (figure and position), and the values of the edge radius. This examination creates the framework for the analysis of the optimization conditions of the process (dimensions and contact boundaries).

The AutoCAD analysis offers a reliable level design prediction of the forming tool profile, the tool path and the values for analysis, for the generation of the tool path and modifications related to the supporting spaces for better analysis results.

The methodology is depended on two series (Figure 3-(1)), and both are depended on the same tool path and the tool position is started at distance 80 mm from the product center:

a. constant internal diameter value of the supported plate, 90 mm and changing the edge radius values, R = 2.5-10 mm, adding, and for sense the fracture statues (edge radius,1 mm);

b. constant edge radius, R = 5 mm and five values of the supported plate internal diameter (with changing 2.5 mm for each test) (distances, D = 2.5, 5, 7.5, 10, 12.5 and 15 mm).

Successive stages using small supporting plate edge radius (R = 2.5 mm) to produce the SPIF part profile are illustrated in Figure 3-(2). It is clear that the forming tool stroke influences greatly the stress values, as these values increase with stroke. The peak height appears to be a good indicator to assess whether a forming operation will be successful or not. The most severe stress distribution is located at the end of stroke and the occurrence of a localized neck is obvious. Fracture was observed along the sharp corner. This was predicted by a high stress value.

The incremental deformation simulation model of the frustum cone profile with 47 mm depth is shown in the Figure 3-(2). The springback is increasing with depth; the stress distributions along the deformed blank section are increasing as well. The blank material tends to wrap around the tool profile which is leading to increasing the friction region that causes fracture. The space region does not suffer high plastic stress during deformation steps, thus the thickness is near of the original thickness (small supporting space-less plasticity-less springback).
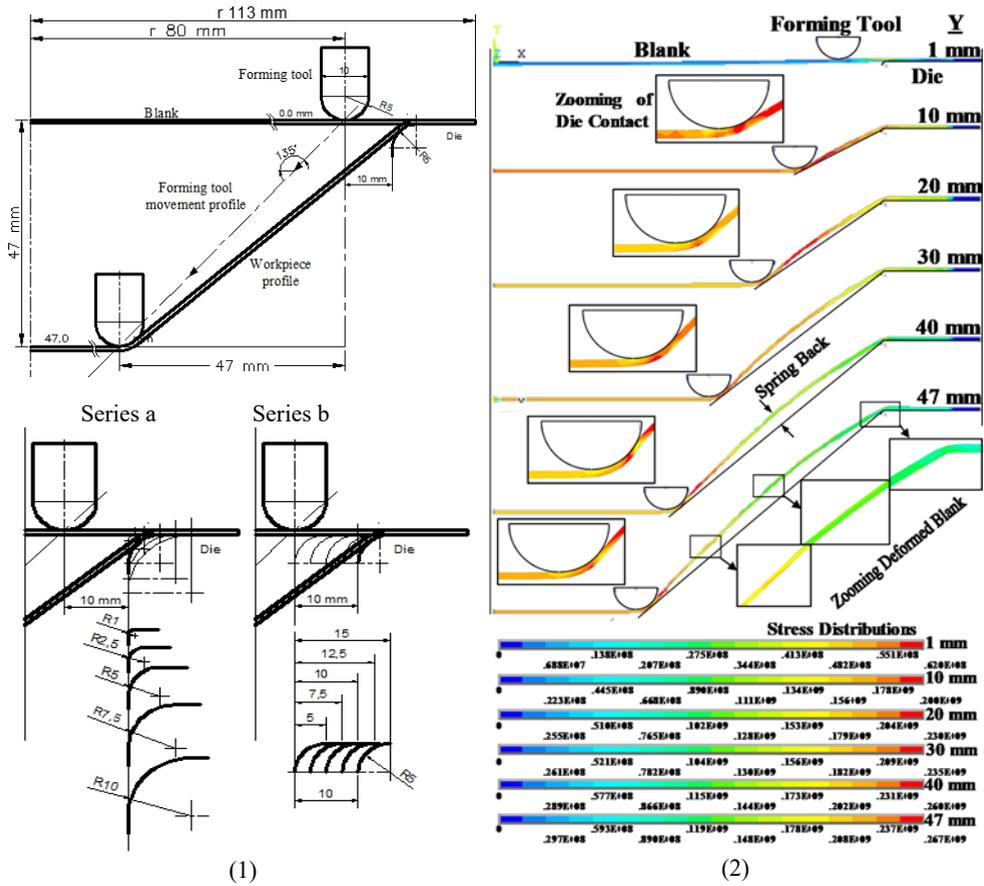
Fig. 3. Methodology details of supporting plate edge radius and internal radius effect.

The springback value is evaluated by the highest value of the wall deviation obtained in the deformed blank with the straight value of the wall predicted by CAD.

Prediction simulation models illustrate high values for springback in all the models of the deformed blank where the effect of the support plate radius is studied (series a), (Table 2 and Figure 4). Also, the springback value increases from 3.09 to 4.1 mm with R = 1 to 10 mm support plate radius, as represented in the Figure 4 and 6 (series a). Springback appears to be directly proportional with increasing of the internal support plate radius at constant edge radius, 5 mm (0.58 to 3.57 mm with distances, D = 2.5 to 15 mm), (series b) (Table 3 and Figure 5 and 6).

The results are demonstrated: increasing supporting plate edge radius, R from 1 to 10 mm, and with a constant value condition of internal supporting plate radius, R_i = 90.0 mm caused higher springback as shown clearly in series a, 25% (Table 2); increasing supporting plate space, S_s from 2.5 to 10 mm with a constant value condition of supporting plate edge radius, R = 5 mm, and considering the gap (tool profile-supporting plate edge profile) at least equal to the blank thickness, t_o, a clear deterioration is observed by raising the springback, from 0.58 to 3.57 mm, as demonstrated in the series b (Table 3).

Increasing the spacing ratio S_s/S_T, (where: S_T, Total Space), for both series a and b, results in higher springback, even with the different supporting edge radius and position. The same happens to the ratio S_s/R_i, while of the ratio S_s/R is inversely proportional.

Convolution of the deformed blank around the tool appears when increasing the internal support plate radius and increasing the deforming depth. As a result, fracture is predicted.

Table 2. Series a, effect of edge radius.

| Ss, mm	ST, mm	R, mm	Ri, mm	Ss/ST %	Ss/R	Ss/Ri	SB, mm
11.0	91.0	1.00	90.0	12.09	11.0	0.122	3.09
12.5	92.5	2.50	90.0	13.51	5.00	0.139	3.36
15.0	95.0	5.00	90.0	15.79	3.00	0.167	3.57
17.5	97.5	7.50	90.0	17.95	2.33	0.194	3.99
20.0	100	10.0	90.0	20.00	2.00	0.222	4.10
							1.01
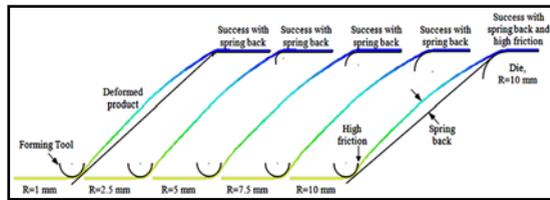
Fig. 4. The products of SPIF process, series a.

Table 3. Series b, effect of supporting distance.

| Ss, mm	ST, mm	R, mm	Ri, mm	Ss/ST %	Ss/R	Ss/Ri	SB, mm
2.50	82.5	5.0	77.5	3.030	0.50	0.032	Failed
5.00	85.0	5.0	80.0	5.882	1.00	0.063	0.58
7.50	87.5	5.0	82.5	8.571	1.50	0.091	1.65
10.0	90.0	5.0	85.0	11.11	2.00	0.118	2.33
12.5	92.5	5.0	87.5	13.51	2.50	0.143	3.11
15.0	95.0	5.0	90.0	15.79	3.00	0.167	3.57
							2.99
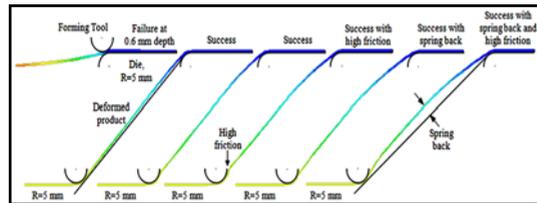

Fig. 5. The products of SPIF process, series b.
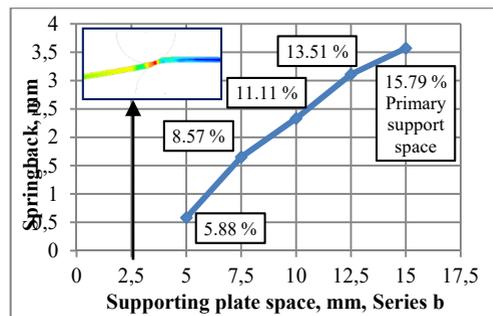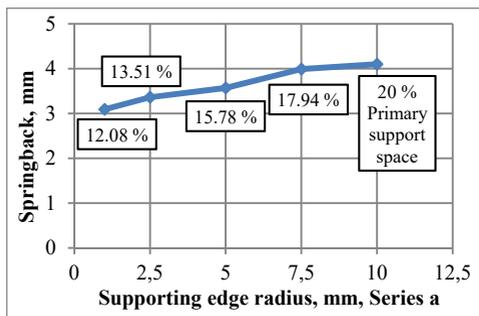
Fig. 6. Springback effect, Series a and Series b.

The general behavior of strain distributions for all models (Figure 7. series a) are the same and especially at the regions of the tool-blank contact (45-90 mm) from the blank center. The next region (0-45 mm), with increased supported plate edge radius showed decreasing of the strains. The increased radius caused raising of the values of the strains in the region between 90-105 mm, as the region affected by the radius of the supporting plate edge was wider. This region also became larger than the region obtained when using small radius. In other words, small radius results in narrow region which translates to high value at the tool profile, and large radius results in wide region and the strain translates at the space between the forming tool and the supporting plate edge (springback).

In the regions that are in direct contact with the forming tool movement the effect is more intense than in other regions (higher strain values), as illustrated in Figure 8 series b. Increasing of the internal supporting plate radius caused decreasing of the strains in the region between 0-35 mm from the blank center (inversely proportional). The supporting plate space suffered higher strains with larger space (a gradual bending), while, inversely, the strains decreased (a steep bending) due to reduced springback.
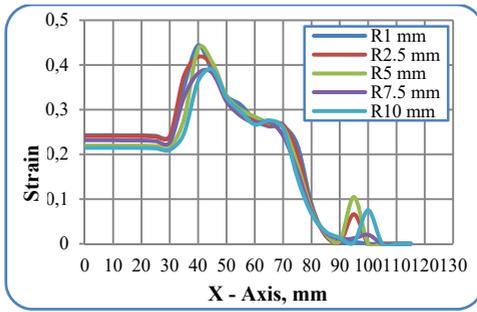
Fig. 7. Strain distributions, Series a.
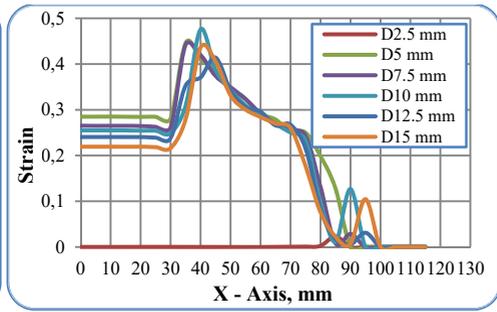
Fig. 8. Strain distributions, Series b.

4 Conclusions

The present work establishes the fact that any adjustment of the supporting edge radius and its position influences the IF formability based on profile shape of the edge. Product accuracy is not necessarily improved if the contact area is increased.

The supporting plate radius is applied as a controller of the material deformation movement for better results during the IF process.

The springback defects appear as an importance of the relations between supporting space to the total free blank profile. As a result, the supporting space has influence on the strain distributions, which if increased causes higher springback.

Simulation model with high quality 2D and number of settings is faster, and the evaluation of the status is quite quickly indicated.

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