Developing an experimental case in aluminium foils 1100 to determine the maximum angle of formability in a piece by Dieless-SPIF process.

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Abstract. Incremental sheet forming by the method of single point incremental forming Dieless-SPIF, is a widely studied process, experimented and developed in countries with high manufacturing technologies, with friendly costs when the productive configuration in a productivity system is based in small production batches. United states, United kingdom and France lead this type of studies and cases, developing various proof with experimental geometries, different from the national environment such as Colombia, Bolivia, Chile, Ecuador and Peru where this process where discretely studied. Previously mentioned, it pretends develop an experimental case of a particular geometry, identifying the maximum formability angle of material permissible for the forming of a piece in one pass, the analysis of forming limit curve (FLC), with the objective to emphasizes in this innovative method based in CAD-CAM technologies, compare with other analogous process of deformation sheet metal like embossing, take correct decisions about the viability and applicability of this process (Dieless) in a particular industrial piece, which responses to the necessities of productive configurations mentioned and be highly taken like a manufacturing alternative to the other conventional process of forming sheet metal like embossing, for systems with slow batches production.

1. Introduction

The incremental forming process by the method of supporting a single point Dieless (SPIF), involves the transformation of a metal sheet by a mechanical stress which produces a progressive deformation in the sheet. The process is done in several stages: it starts with a CAD (Computer aided design) modeling which represents the experimental geometry in three dimensions of the particular piece, the second stage is fed by the CAD file, assigning parameters such as the advance, RPM (Rev/Min),
diameter tool, step depth, to a CAM (Computer aided manufacturing) system, you get a programming tool path, expressed in machine code known as G code\(^3\). This code is entered into a machine with CNC technology which reproduces the toolpath on the surface and deforms the end of the geometry piece, which is the final stage. Figure 1, illustrates a representative form of this process.

The incremental deformation process without matrix (Dieless), is a recent process (its inception refer to 1994) [1] with respect to other techniques of conventional foil strain such as embossing, stamping, superforming and hydroforming, which are costly and involve working tooling and high volume production runs for its construction and operation.

The purpose of this paper is to study an experimental case associated with a particular one, which is due to a conical geometry, to analyze the deformation of the same building through the forming limit curve diagram (FLD), identify the maximum angle of formability obtained for this geometry, through the test assembly with various inclinations. The formability of a sheet or foil, such as its ability to be deformed by forming a specific process from its original form to the final piece flat, without the occurrence of failure in the material, either broken or necking, the ease of a material to plastic deformation without defects. [1]- [3].

The above is intended to orient the investigation to work with geometries that approximate and apply to a principle or Industrial application case, making decisions on the viability argued acceptable or not the process and have a specific comparison with the filling process. With the ultimate goal of making a functional prototype tested mechanical and dynamic evaluations of this process, to ensure the functionality and usability of a product manufactured under this innovative manufacturing process such as Dieless.

2. Procedure and method
For the experimental procedure followed the next methodology:

A. As a starting point, we determine the geometry of the part: settled for the experimental case geometry conical differential characteristic angle formability, as shown in Figure 2.

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\(^3\) G-Code
The G code is a language through which people can tell computer-controlled machine tools do and how. These “what” and “how” are defined mostly by instructions on where to move, how fast moving and toolpath or follow. Typical machines are controlled is code are milling machines, cutting machines, lathes and 3d printers.
The blank plates or training are square sheets of 100 mm 1100 aluminium side and 1 mm thick.

B. For construction of diagrams-forming limit curves, it was necessary to perform the marking of the pieces, which consists of a grid of continuous circles of 2.5 mm diameter. In Figure 3, this system can be observed on the piece of lined, which was made into a laser marking machine.

C. Once the marking of parts is carried generation strategy and toolpath: The helical toolpath responds to a helical scan is made along the inner surface of the sheet deformed, it was necessary to work with CAM software, which is mentioned below.

Was subsequently carried determining process parameters Dieless SPIF. Both for design (CAD) of the experimental geometry, generating cutting strategies CAM, and assigning values to parameters involved in the process, it has high engineering software.

D. Machine Preparation and installation: Dieless-SPIF device, Figure 4 shows the assembly of the part-SPIF Dieless device.
3. Results and discussion

The testing and subsequently different experimental cases with different angles of formability: were specified angles between 64 ° and 76 °, which are detailed below. The formation and fracture criterion answers the formability evaluation part as mechanical forming; Figure 5 shows the visual appearance of a formed part and a fractured part formation.

![Formed piece and Fractured piece](image)

Figure 5. Aspect for a formed and fractured piece

In Table 1 are recorded angles and training criteria, fracture, as the case:

| FORMABILITY ANGLE | Piece (Formed/Fractured) |
|-------------------|--------------------------|
| φ1 76              | Fractured                |
| φ2 74              | Fractured                |
| φ3 72              | Fractured                |
| φ4 68              | Formed                   |
| φ5 70              | Fractured                |
| φ6 69              | Fractured                |
| φ7 64              | Formed                   |
| φ8 66              | Formed                   |
| φ9 72              | Fractured                |

Looking closely at table 1, the largest angle of formability obtained without breaking the piece present, is 68 °, from this angle values above such as 69 °, 70 °, 72, 74 ° and 76 °. For angles less than this value, such as 66 ° and 64 °, the piece does not show break and trained properly, as modeled in CAD geometry. This is presented as the first fundamental result of this work, as it is known in principle the maximum angle of taper formability for experimental geometry, which will aim to make decisions about a close and future applicability to an industrial part obedient geometries angles such limits established in this work.

From a distance of 20 mm depth, measured from the surface of the workpiece, such crack had fracture in the same place. As a hypothesis sheet thinning located at this point, which together with the formability angles than 68 ° are two extreme conditions which result in the presentation physically cracks and long shapes as shown in Figure 6, which is then analyzed.
The cracks occur as a result of residual stresses produced in the work piece. These residual stresses are a major feature in the sheet forming operations and are commonly caused by non-uniform deformation during forming, causing a partial distortion when cut, and producing said cracking [4]-[9]. The piece, with maximum angle of formability determined not presented wrinkles across the study areas.

The parameters presented in Table 2, are best suited and recommended for this geometry work, several authors in their research and procedures used tool diameters between 8 and 12 mm, high RPM and feed rates relative to the depth of cut [9] - [12], has been shown that the lower step, the surface quality and formability of the material are much better, considering cutting times are greater.

| FORMING PARAMETERS PROCESS |
|-----------------------------|
| Tool diameter (mm)          | 8,7 |
| RPM                         | 3000 |
| Cutting feed (mm/min)       | 4000 |
| Step depth (mm)             | 0,7-1-1,2 |

Observing the process parameters shown in Table 2, it is important to note that the progress, which has a value of 4000 mm / min, corresponds to approximately 50% of the maximum speed of the CNC machining center used (maximum advance machining center used 7200 mm / min). The strategy or tool path tool path was helical steps and depths of 0.7-1 and 1.2 mm.

**FLD Curve construction**

The diagram limit shaped for a sheet, is a graphical representation of the boundaries of main strains, where it may arise failure in plastic deformation during the forming process. From the above definition, we can identify areas along the deformed surface of the test piece, and account for the formability of the material.

For construction of the limit curves forming or diagrams FLD is necessary to calculate the result of the conventional deformation suffered by the piece, which is the relationship between the change in length of a specimen in the direction that applies strength and the original length of the sample considered [5]. In Equation 1 shows how to calculate it:

\[
\text{\%Stretching} = \frac{L_f - L_o}{L_o} \times 100 \quad (1)
\]

From the equation above, it is important to take data in different areas of the deformed part, before and after the process in order to obtain readings of initial lengths \(L_o\), and final lengths of the same \(L_f\).
Data for construction of curves FLD

Table 3 shows the data measured once deformed the workpiece, with the aid of the grid circles, ellipses now to determine the major and minor deformities in different areas of the piece, to analyze the formability of it.

Table 3. Datum for FLD construction curve

| Datum | Major Length (mm) | Minor Length (mm) | % Major strain | % Minor strain |
|-------|------------------|------------------|----------------|---------------|
| 0     | 2.3              | 2.3              | 0%             | 0%            |
| 1     | 2.3              | 2.4              | 12%            | -2%           |
| 2     | 4.8              | 2.2              | 92%            | -12%          |
| 3     | 7.5              | 2.6              | 23%            | -4%           |
| 4     | 8.2              | 2.1              | 16%            | -16%          |
| 5     | 6.5              | 2.3              | 160%           | -8%           |
| 6     | 6.8              | 2.5              | 17%            | 0%            |
| 7     | 6.8              | 2.35             | 172%           | -6%           |
| 8     | 6.6              | 2.65             | 164%           | 0%            |
| 9     | 7                | 2.8              | 180%           | 12%           |
| 10    | 4.25             | 2                | 30%            | -20%          |

The above data obtained were plotted on the graph of FLD curve for the product obtained with maximum angle of formability.

As seen in figure 7, shown at the top right, a circular geometrical figure, shaded continuous contour which represents the circle inscribed in the aluminum foil before being deformed, and dashed ellipse in which due to the two-dimensional geometry of the elongated circle (ellipse) once the piece has been deformed. The dimensions of the coordinates shown with the letter b, the lengths are larger and smaller, respectively, which are the final readings (LF) to determine the percent elongation and major and minor strains required for the construction of the curve obtained FLC above.

Greater deformation has been shown in axis Y, always positive due to stretching occurs and less deformation can be negative or positive, as can occur when stretched narrowing (Poisson effect) the initial specimen. It can be stated that under bounded or curved line are safe values and above the fault. For the particular case, there is an extreme value for which the strain is 70% higher and lower distortion is -20%, suffered in aluminium alloy 1100, which represents a good plastic deformation of
the material obtained by through this process. The formability of a particular material will be better when the FLD curve is higher [4].

Comparing analogous to the process of drawing, on what is commonly used in the manufacture of hollow pieces such as this geometry experienced in this work and responds to the fundamental principle of sheet metal processing, are shown in Table 4, a general comparative Dieless process [12]-[16] and stamping-drawing, for performing the piece addressed in this paper.

**Table 4. Process comparative – stamping and dieless**

|                          | STAMPING-DEEP DRAWING | DIELESS               |
|--------------------------|-----------------------|-----------------------|
| **Principle**            | Deforming a metal sheet, which is pressed against a die by a punch which generates deformation and make a hollow. | Deformation a metal sheet with a round tool that presses the sheet, outlining its surface until the final geometry. |
| **Types**                | HOT STAMPING: The sheet is heated to a temperature of 800 ° to 850 °  | SPIF: (Single point incremental forming, Forming negative) fixed frame and draw the shape tool inward, increasing the Z axis is not required matrix  |
|                          | COLD DRAWING: Practice at room temperature. | DPIF: (double point incremental forming, forming positive) the frame moves up and down and draw the shape tool outward, increasing the Z axis, it is necessary to use a matrix |
| **Tools**                | Requires a large and expensive tooling with a die, a punch, a metal foil and a device for tightening the foil and avoid folds. | It takes a round ball mill, a matrix if necessary (DPIF), a metal foil and a support device to hold and tighten the foil. |
| **Production**           | There is no flexibility in the design, restricting the complex geometries, is used for high-volume production or for a unique product. | Flexibility to changes in design, allows for complex geometries, is used for low volume production scale prototypes and functional models |
| **Quality**              | Good | SPIF: moderate surface quality |

With the overview of processes of forming two sheet metal details the analogy to perform the experimental part, for which respective comparisons are described based on the observations in Table 5 which shows a comparison of the performance part case study worked through the two processes in question, according to the calculations made for the part geometry and particular design parameters for the filling process [4], and any of the parameter values specified for Dieless-SPIF.

**Table 5. Comparative to obtain geometric part by dieless and stamping- deep drawing process**

|                          | Dieless | Drawing-stamping |
|--------------------------|---------|-----------------|
| Die for forming part     | No      | Yes             |
| Blank holder for forming part | No  | Yes             |
| Speed (mm/min)           | 4000    | 30000           |
| Steps Number             | 1       | 3               |
| Process press (Kg/cm²)   | Low (Max. 4) | High (10) |
| Tooling Costs            | Low     | High            |

According to the above tables, IV and V, that for high-speed production cycles or production rate for the manufacture of the part studied in this work, the drawing process would be the most convenient alternative, but requires investment in tooling and tooling to ensure the formability of the sheet, such as matrix, blank holders to ensure the strength and pressure of the process described above. Dieless-SPIF process, contrary to what stated above, does not require blank holders, receivers and since the force and pressure in the process are relatively low [17]-[20], only one pass is required to obtain the shaping of the work piece but the speed is much lower compared to the stamping–drawing process.
4. Conclusions

As a conclusive principle and fundamental objective of this work was obtained aluminium sheets 1100, the value of 68 ° maximum angle of formability an obedient taper experimental geometry. With the above provides a starting point and also an important step in finding a near future implementation of the process and a piece of industrial applicability.

The results shown in this paper and demonstrate, FLC curves constructed for the product obtained with the maximum angle of formability argue the ability of the material, in this case aluminium that it deforms plastically without presenting any kind of defects for the critical angle obtained in this work, which is 68 °. This will make safe and acceptable of the application of Dieless-SPIF process to national and international manufacturing environment.

Dieless-Spif process is a relatively new process compared with the sausage pieces, allows greater flexibility in the design of various surfaces, even complex, requires high labor costs in tooling and dies. Parts formability is acceptable, as demonstrated in the results of this work.

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