

Brass 70/30 and Incremental Sheet Forming Process

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Abstract. This work addresses through bibliographies and experiments the behavior of sheet brass 70/30 for Incremental Sheet Forming process, based on the parameters: wall angle (Ψ), step vertical (Δz) and strategy tool path. Experiments are based on the method called Single Point Incremental Forming - SPIF. For execution of practical tests, resources were used: software CAD / CAM, CNC machining center with three axles, matrix incremental, incremental forming tool and a device press sheets. Furthermore, measurement was made of the true deformation (ϕ) and thickness (s_1). Practical tests have shown that the spiral machining strategy yielded a greater wall angle, compared to the conventional strategy outline.

Introduction

The incremental forming sheet (ISF) is a recent process in the field of sheet forming when compared to traditional processes, however, a technique is extremely flexible.

Given that this technology covers a wide and varied market, with singular characteristics, the incremental forming adapts very well to some of the new market demands, such as agility in manufacturing of prototypes and small series production of components and obtain parts that by having a high geometrical complexity would become unfeasible by conventional methods [1].

The disadvantages cited in this process is the time required to perform the task and its geometric and dimensional accuracy.

The main gains over a conventional process is the possibility to obtain greater deformation, eliminate the need for mold / die and expand portfolio product companies that already have CNC machine [2].

In this process, a small punch moves along a predefined path, locally deforming the sheet and thus modeling the desired shape [3]. Because the deformation is caused by movement of the punch, so only a small part of the sheet is actually formed at a given point in the process, since this punch follows a defined path across the sheet [4].

The model is conformed to be generated from CAD¹ files converted into three-dimensional CAM² files. The tool path is controlled by a program using CNC³ technology [5].

The incremental forming is currently a promising process with regard to plastic forming of sheet materials, and is not restricted solely to the shaping of sheet metal. More recent studies [6, 7, 8] show the operation of incremental sheet forming in polymers.

Over the past three years the incremental forming process, a lot of work has focussed on the understanding of deformation mechanisms, responses to the process of new materials, multi-stage configuration for obtaining geometries with larger wall angles and broadening of its range of applications [9].

¹ Computer Aided Design

² Computer Aided Manufacturing

³ Computer Numeric Control

Within this diversification of applications studied, Silva [10] has proposed the fairings of a wind turbine (Fig. 1 a) by means of ISF, while Jeswiet *et al.* [11] showed the manufacture of rapid prototypes for the automotive industry (Fig. 1 b) and other areas (Fig. 1 c), achieving varied geometric shapes by this process. In medical field, Castelan *et al.* [12] discuss the application of incremental forming in making cranial prosthesis (Fig. 1 d) with titanium sheets.

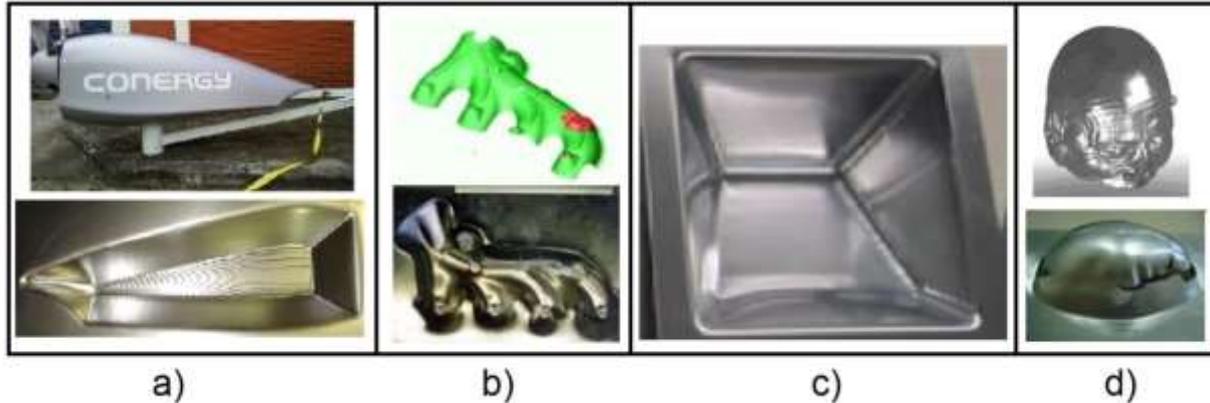


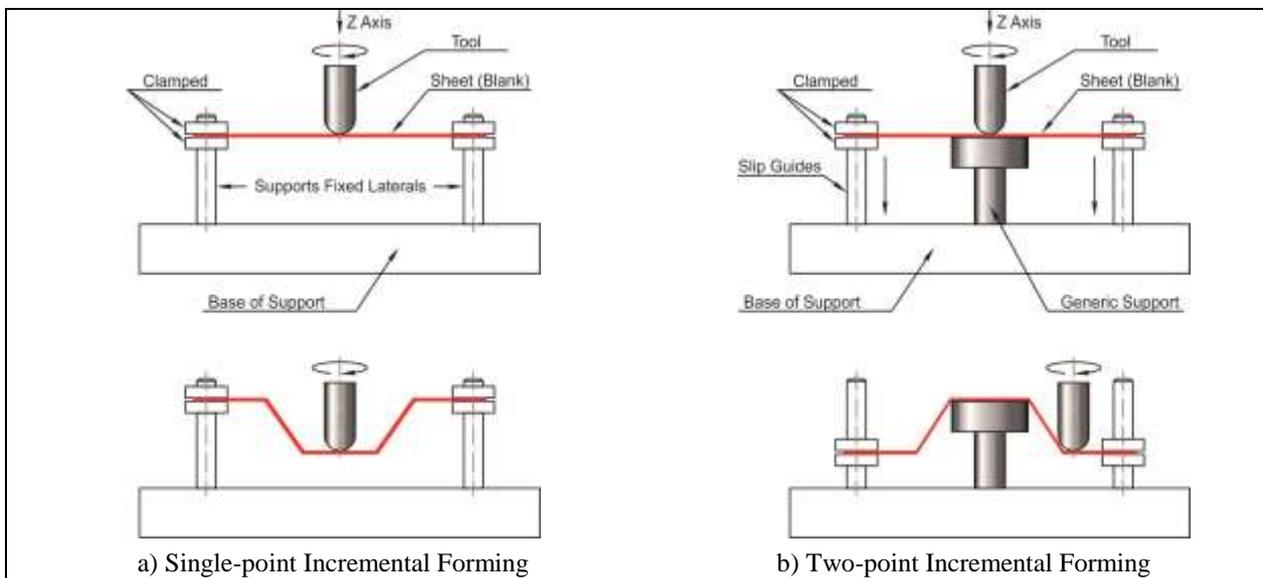
Fig. 1: a) Wind Turbine and one of the experiments carried out by Silva [10]; b) Protector automotive of heat / noise; c) Cavity solar oven; [11]; d) Results obtained in the manufacture of cranial implant [12].

Besides applications in the ISF using CNC machines, there are studies submitted with the use of industrial robots [13, 14, 15], plus some projects machines dedicated to this process [16, 17].

However, the use of robots and even dedicated machines does not compare to the number of CNC machine tool (3 axes) used in most studies, which showed great efficiency to perform the incrementally forming process [11, 18, 6, 19, 20], among others.

Incremental Sheet Forming Modalities

The incremental sheet forming process can be divided into Single Point Incremental Forming (SPIF) and Incremental Forming Two Points (TIPIF). Therefore, the number of points of contact between the punch, the sheet and the matrix (when present) determines its modality [21]. In this case, it is evident that to achieve a more precise forms this process uses lower support (die) specific to the desired shape, primarily for obtaining organic and complex surfaces. This support, in turn, can be positive (shoulder) or negative (cavity) [22, 18]. Fig. 2 below illustrates the modalities mentioned.



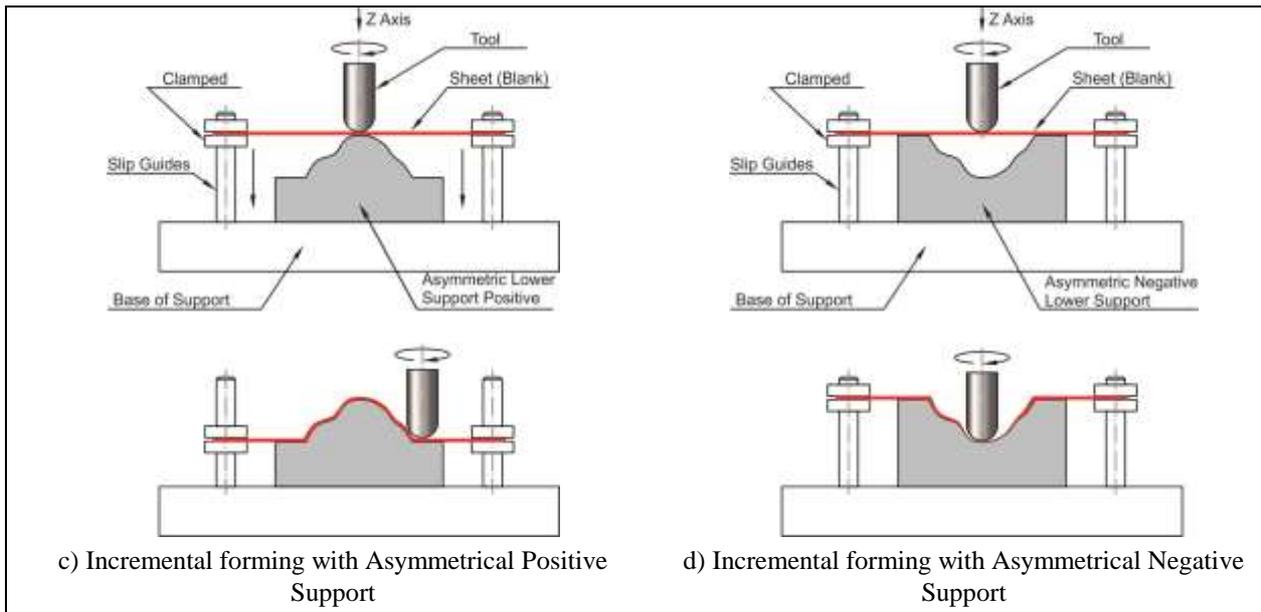


Fig. 2: Incremental forming modalities. Adapted [23].

Specifically on the SPIF modality, used in this study, [24, 25] define the process as a flat metal sheet, attached on a mobile device, which slides parallel to the axis Z. A ball nose tool controlled by CNC, slides over the sheet, and gradually through vertical increments (Δz) in negatives Z plastically deform the sheet, transforming it into a three-dimensional geometry, without the need for a support matrix.

Castelan [23] which adds no lower support point, the shape of the end piece is determined only by the displacement of the tool in three axes (X, Y, Z). The sheet is fixed to lateral a support which maintains constant height relative to the base. Hussain [26] cited in their studies, that these fasteners prevent the movement of the sheet during the process, culminating in its plastic deformation. Fig. 3 illustrates the process characteristics described by the authors.

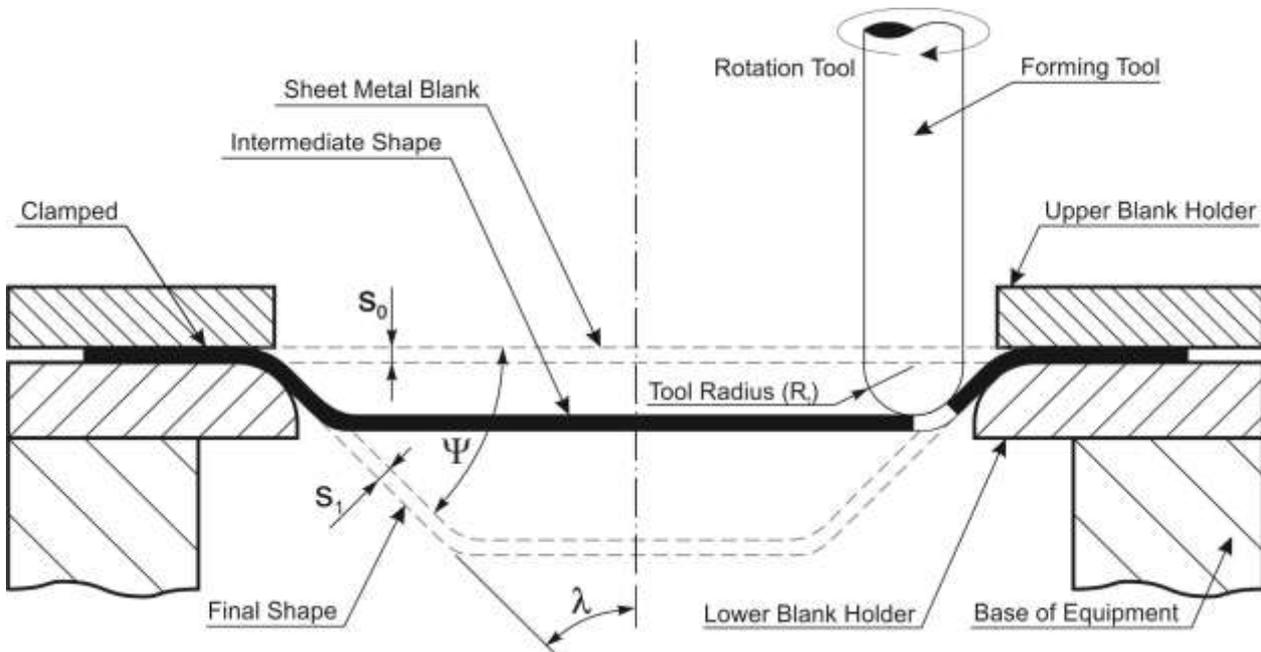


Fig. 3: Single-point Incremental Forming (SPIF). Adapted [27].

In incremental forming there are values maximum angles wall (Ψ) (65° on average) that allow the plastic forming the material without causing fractures or at least a drastic decrease the sheet thickness, causing a low mechanical resistance [28]. Be deemed to as wall angle (Ψ) the angle formed between the horizontal plane and the wall of the shaped part.

For calculating the final thickness (s_1) of the sheet after forming, is used to Sine Law, which is applied the values of the wall angle (Ψ) and the original thickness (s_0) of the sheet, expressed by equation 1.

$$s_1 = s_0 \cdot \sin \psi (90 - \Psi) \dots [\text{mm}] \quad (1)$$

Where s_0 is the original thickness of the sheet, s_1 is the sheet thickness measured in a given stage of the forming process and the wall angle (Ψ) of the sheet this same point.

Besides the original thickness (s_0) of the sheet and vertical step (Δz) used this to some extent, formation of the wall angle (Ψ) is also influenced by the tool tip radius (R_t). This beam influences the strength forming, where the larger the radius, the greater the strength [29].

Experimental Procedure

Based on the studies reported experiments in brass sheet 70/30 with 0.5 mm thickness were developed with the aim of provide relevant information for prototyping and customization of products made of this raw material, such as locks mirrors.

Eighteen (18) experiments were performed aiming at mainly set the wall angle (Ψ) to sheet brass 70/30 with 0.5 mm thickness, altering step vertical (Δz) and machining strategy. The seven (7) initial experiments were treated as preliminary and the other as final.

The model of study was based on a truncated pyramid with a square base of side 220 mm, depth 40 mm and radius of concordance 10 mm. For the project of this blank was used SolidWorks® software (Fig. 4a). For machining strategies EdgeCAM® software was used (Fig. 4b). Were used the conventional machining strategies and spiral.

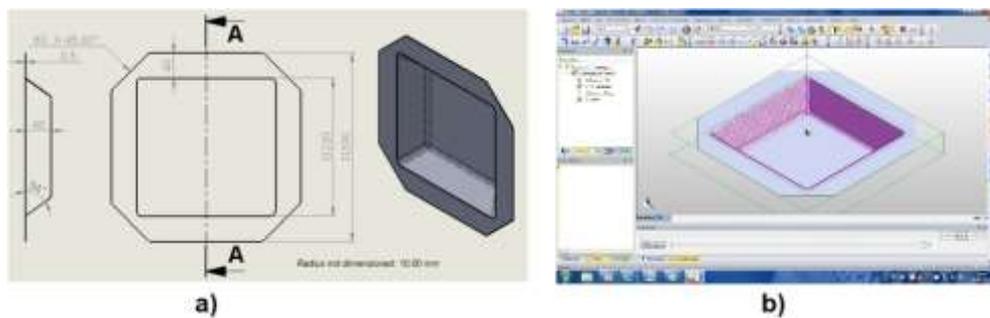


Fig.4: a) Drawing the projective blank, b) Simulation tool path forming.

Were also analyzed actual deformation (φ), suffered in the main experiments as well as the variation of thickness (s_1).

The experiments were performed at a machining center with a device designed to adequately press plates SPIF mode, and a tool for forming semi-spherical head with a radius R_t of 5 mm, made of 4340 steel without a coating, specific for practical tests (Fig.5).



Fig. 5: Machining Center, device and tool for incremental forming used in the experiments.

For measurements of the deformations φ_1 and φ_2 , all sheets were a recording of an electrochemical mesh circles with initial diameter (d_0) of 2.5 mm at the bottom surfaces of the sheets before they are formed. Was also measured distance (d') of the center of first ellipse measured (base of the experiment) (Fig. 6) at every center of ellipses other measures. For this, it was determined $d'=0$ as the first point measured.

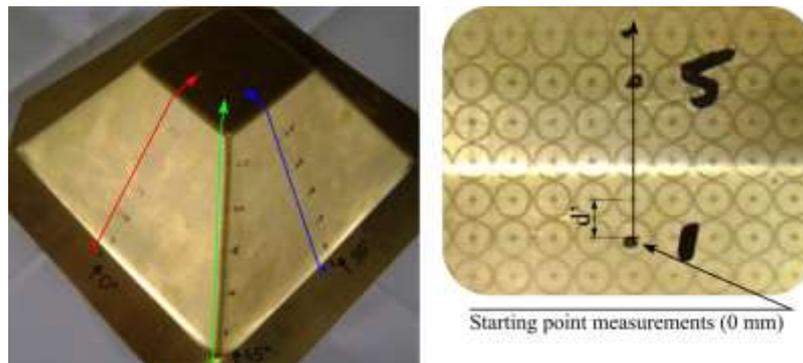


Fig. 6: Measurement region of deformations.

To perform the measurement of the final thickness (s_1), the center of every ellipse was measured, starting from the same initial ellipse in the analysis of deformations. In this way, after analyzing the deformations (φ), the experiments were cut at 0° , 90° and 45° in relation to the rolling direction.

RESULTS AND DISCUSSION

Table 1 presents the results obtained in the eighteen experiments in SPIF modality.

Table 1: Parameters analyzed in experiments.

Experiment	Depth [mm]	Vertical Step (Δz) [mm]	Wall Angle (Ψ) [°]	Strategy	Status	
Preliminary	1	40,00	1,00	60	Conventional	Fracture at 6 mm
	2	40,00	1,00	45	Conventional	No fracture
	3	40,00	1,00	52	Conventional	No fracture
	4	40,00	1,00	55	Conventional	Fracture at 13 mm
	5	40,00	1,00	53	Conventional	No fracture
	6	40,00	1,00	54	Conventional	Fracture at 15 mm
	7	40,00	1,00	54	Spiral	No fracture

<i>Final</i>	8	100,00	1,00	54	<i>Spiral</i>	<i>No fracture</i>
	9	100,00	1,00	55	<i>Spiral</i>	<i>No fracture</i>
	10	100,00	1,00	56	<i>Spiral</i>	<i>No fracture</i>
	11	100,00	1,00	60	<i>Spiral</i>	<i>Fracture at 14 mm</i>
	12	100,00	1,00	58	<i>Spiral</i>	<i>Fracture at 23 mm</i>
	13	100,00	1,00	59	<i>Spiral</i>	<i>Fracture at 12 mm</i>
	14	100,00	1,00	57	<i>Spiral</i>	<i>No fracture</i>
	15	100,00	0,50	57	<i>Spiral</i>	<i>No fracture</i>
	16	100,00	0,50	58	<i>Spiral</i>	<i>No fracture</i>
	17	100,00	0,50	56	<i>Spiral</i>	<i>No fracture</i>
	18	100,00	0,50	55	<i>Spiral</i>	<i>No fracture</i>

According to the data in Table 1, observes a fracture in the experiments (in the 1, 4 and 6), reaching a wall angle (Ψ) minimum of 54° before reaching the designed depth (40.00 mm) (Fig. 7). In this case, the fracture was due to the low thickness of the sheet in this region, causing a breakup by pressure, a fact that usually occurs after the tool formed this point.

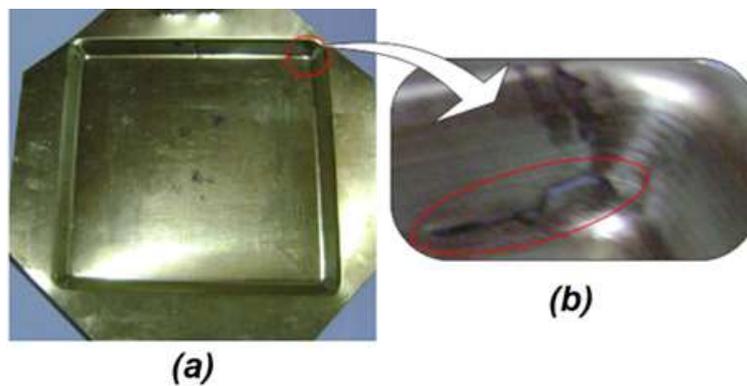


Fig. 7: Experiment 4; b) Enlarged detail of the fractured region. (Ψ : 55° | Δ_Z : 1,00 mm).

The experiments 2, 3 and 5, where maximum wall angle (Ψ) of achieved was 54° , reached the projected depth (40.00 mm). However, due to the strategy of conventional machining, the point where the tool always effected the increment vertical (Δ_Z) has generated a deformation not projected on the sheet (Fig. 8).

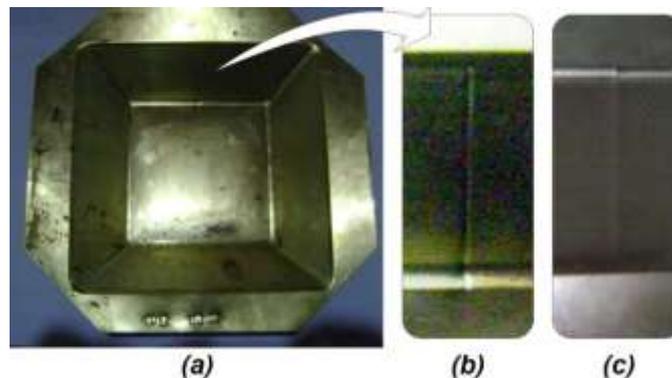


Fig. 8: a) Experiment 2, b) Entry point of the tool at Z; c) Mark the point of entry of the tool in Z on the outside. (Ψ : 45° | Δ_Z : 1,00 mm).

In the seventh experiment again was repeated wall angle (Ψ) of 54° and the vertical step (Δ_Z) of 1.00 mm. However, strategy has changed to spiral of conformation.

In this new situation, no breaking of the sheet (Fig. 9) unlike the experiment 6. Another detail to be emphasized is that on this new machining strategy, the sheet does not get branded input tool in Z.

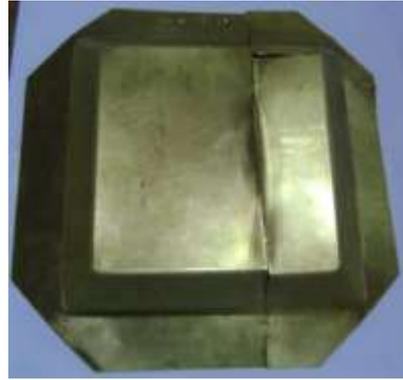


Fig. 9: Experiment 7 cut out for the measurements of thicknesses and true strains. (Ψ : 54° | Δ_z : 1,00mm).

Due to the success of the experiment at 7, the experiments of 8 to 18, Final experiments were considered, and executed with the strategy of forming spiral and 100 mm depth.

In experiments 8, 9, 10 (Fig. 10) and 14, where the vertical step (Δ_z) was 1.00 mm and in experiments 15 to 18, where the vertical step (Δ_z) was 0.50 mm, there was no rupture of the sheet.



Fig. 10: Experiment 10 without fractures during ISF (Ψ : 56° | Δ_z : 1,00 mm).

In experiments 12 to 14, of the sheet breakage occurred (Fig. 11).

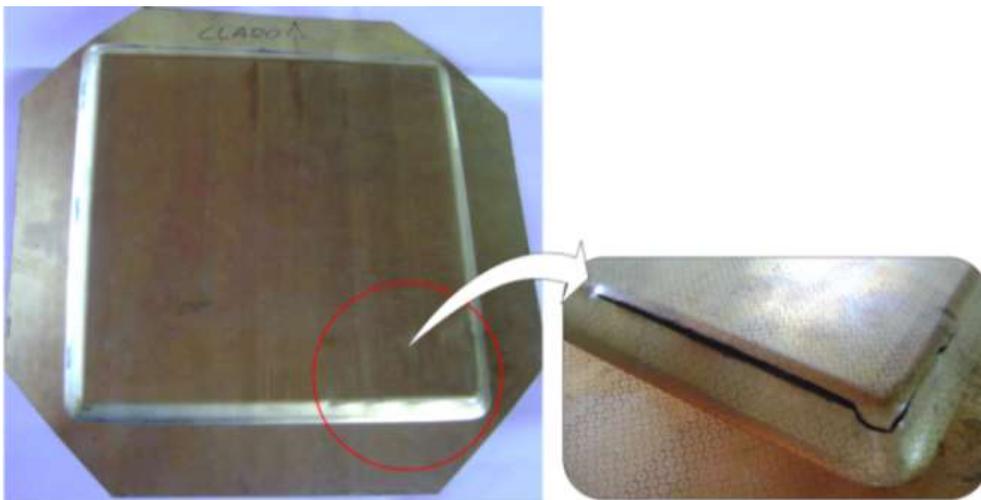


Fig. 11: Experiment 13. Fracture of the plate in enlarged detail (Ψ : 59° | Δ_z : 1,00 mm).

Measurements of True Strains

To analyze the true strains (ϕ_1 and ϕ_2) the experiments analyzed were 12 and 16 (Table 1), both with the wall angle (Ψ) reached a maximum of 58° .

The presented results (Fig. 12 and Fig. 15) refer to the longitudinal (0°) and oblique (45°) laminating the sheet. The results for the lamination transverse direction (90°) of the sheet, because they are similar to the longitudinal direction (0°), are not shown in order to minimize this work.

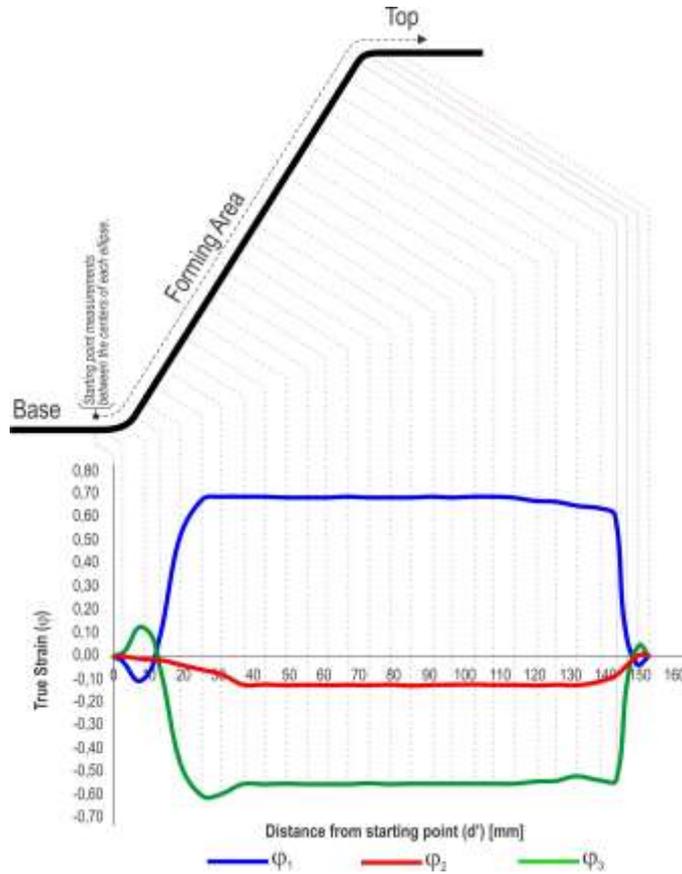


Fig. 12: True strain (ϕ) x Distance from the starting point d' at 0° in relation to direction of rolling in experiment 16. ($\Psi: 58^\circ \mid \Delta z: 0,50 \text{ mm}$).

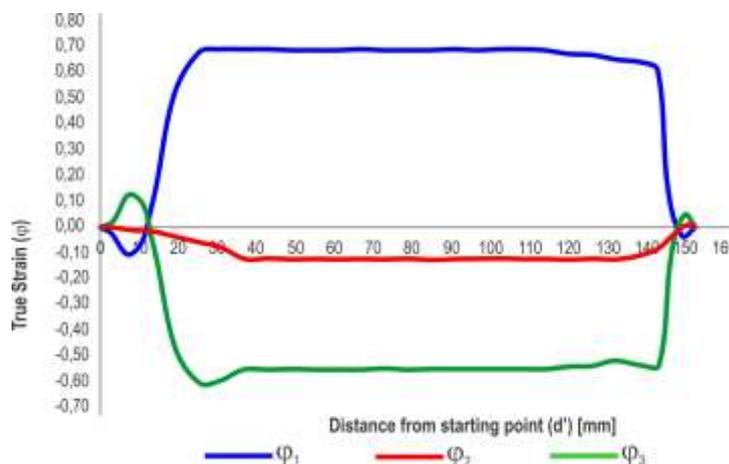


Fig. 13: True strain (ϕ) x Distance from the starting point d' at 45° in relation to direction of rolling in experiment 16. ($\Psi: 58^\circ \mid \Delta z: 0,50 \text{ mm}$).

The graphs show a trend, that the way to strain occur very close to the plane strain ($\phi_2 = 0$). However, while the values of strains measured in the direction of lamination 0° (Fig. 12) presented negative values, the values of strains steps towards lamination to 45° (Fig. 13) showed positive

values and more expressive than the previous ones. This difference can be attributed to the geometric form of the regions measures, regions where the rolling direction 0° are "flat" and the measurement region in the rolling direction 45° is exactly on the "curve" of agreement between the faces of the pyramid. Can still observe the maximum values strain of 0.68 towards 0° , and 0.48 towards 45° in relation to the rolling direction.

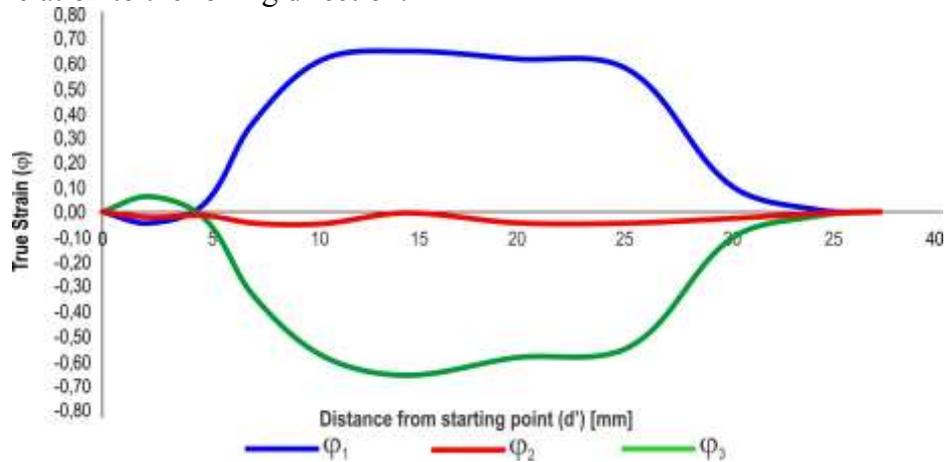


Fig. 14: True strain (φ) x Distance from the starting point d' at 0° in relation to direction of rolling in experiment 12. (Ψ : 58° | Δ_Z : 1,00 mm).

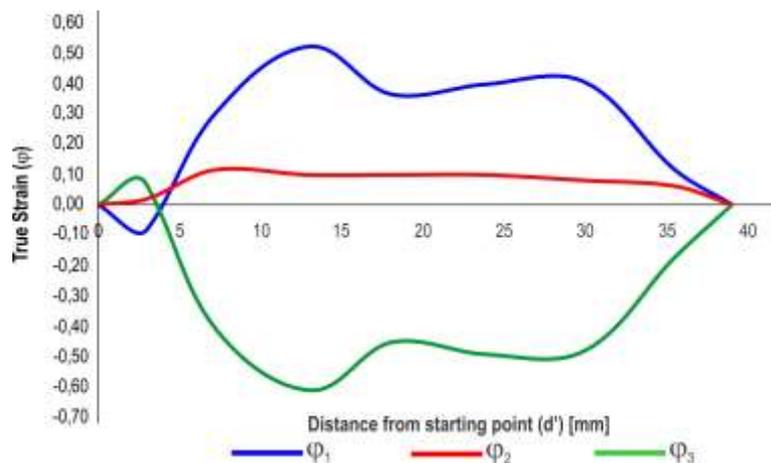


Fig. 15: True strain (φ) x Distance from the starting point d' at 45° in relation to direction of rolling in experiment 12. (Ψ : 58° | Δ_Z : 1,00 mm).

Similarly to the analysis of the of the experiment strains 16 are very close strain plane ($\varphi_2 = 0$), analysis of the deformations of the experiment 12 showed the same behavior. The maximum values for deformation of 0.65 towards 0° , and 0.42 towards 45° in relation to the rolling direction.

Thickness Measurements after ISF

After the measurements of the deformations (φ_1 and φ_2), the experiments 12 and 16 (Table 1), were cut in the three directions of lamination (0° , 45° and 90°) to measure the final thickness (s_1) of the sheet since measuring point d' . The Fig. 16 and Fig. 17 show the variation since thickness measuring point d' .

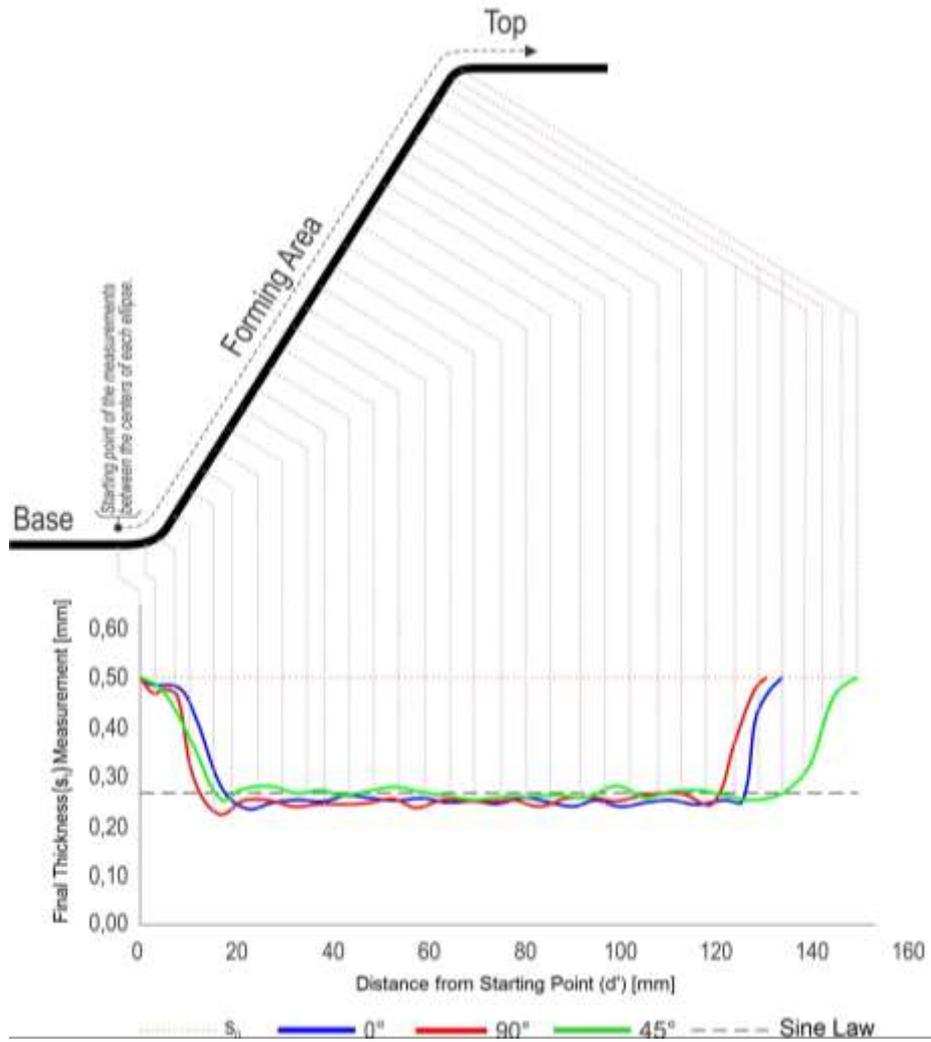


Fig. 16: Graphic of variation of thickness of the experiment 16 ($\psi: 58^\circ \mid \Delta_Z: 0,50 \text{ mm}$).

From the data presented in Figure 16, it is stressed that the value obtained by calculating the Sine Law (Equation 1) for the wall angle (Ψ) of 58° of the experiment it is $16 \approx 0.26 \text{ mm}$. However, in the longitudinal direction of lamination of the sheet (0°) and in the transverse direction of lamination of the sheet (90°) was reached a thickness of 0.23 mm , and 45° from of lamination direction of the sheet as the smaller thickness was 0.25 mm .

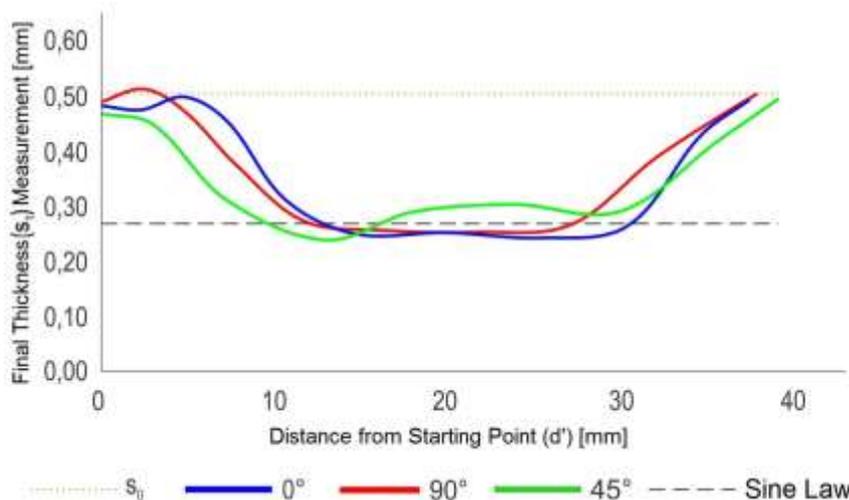


Fig. 1: Graphic of variation of thickness of the experiment n°12 ($\psi: 58^\circ \mid \Delta_Z: 1,00 \text{ mm}$).

Just as in Experiment 16, also it was observed thicknesses (s_1) below the limit established by Sine Law (Eq. 1) for the wall angle (Ψ) 58° (≈ 0.26 mm). For the of lamination longitudinal direction of the sheet (0°) and 45° to the of lamination direction of the sheet was reached a thickness of 0.24 mm and to the transverse direction of lamination of the sheet (90°) the smaller thickness was 0.25 mm.

Conclusion

By means of the realization of practical experiments, was evidenced the good applicability of software CAD/CAM and CNC machining center in prototyping parts as from brass sheet 70/30 with 0.5 mm thickness using the incremental sheet forming process, SPIF modality.

According to the parameters used (Table 01) showed that the maximum wall angle (Ψ) forming of the sheet of brass 70/30 with 0.50 mm thickness varies according to the strategy conformation and the vertical step (Δz).

It was found that by changing the conventional strategy for strategy spiral, a gain in the angle of the wall (Ψ) of 4° (Experiment 5 versus Experiment 14) without breaking the sheet.

Also it was proved that with decreasing vertical step (Δz) to 0.50 mm; there was a gain in the angle of the wall (Ψ) of 1° , concluding a product (Experimento16) of 100 mm depth without breaking.

Analysis of strains In experiments performed, indicate a planar deformation ($\phi_2 = 0$), especially in directions 0° and 90° in relation to of lamination direction of the sheet Toward the 45° of lamination direction of the sheet, strains occur in directions greater than 0° and 90° , given that this occurs exactly on the fillet radius of the conical faces of the piece.

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