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INCREMENTAL SHEET FORMING OF ALUMINUM ALLOY 1050 AND 6063 FOR COMPLEX PIECE

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Abstract. *The purpose of this article is to present a comparison of the SPIF conformation with heating between the aluminum alloy sheets 1050 and 6063, with 1.0 mm and 1.2 mm thickness respectively, in order to verify the processing parameters for alloys and thickness of different sheets thus validating the process of SPIF with heating. The hot forming is due to the type of geometry to be used, complex geometry, using a high combined rotation heating and halogen lamps, thus exceeding a temperature of 210 ° C. Also, tests with low rotation were carried out to verify the influence of rotation in the incremental forming process with heating. As a result, it was observed the possibility of conformation of complex pieces with rich detail in both materials. However, for aluminum sheets 6063 of 1.2 mm thickness due to its higher tensile strength, it was necessary to pay special attention to the lubrication of the process to avoid rupturing of the sheets due to lack or inadequate lubrication of the process. It was also verified that it is important to verify the relationship between the size of the tool and the details to be conformed in the part, as this directly influences the quality of lubrication necessary to conformation of these small details.*

Keywords: *Incremental sheet forming, heating, high rotation, complex geometry, aluminum alloy 1050 and 6063.*

1. INTRODUCTION

Globalization forces industrial markets to seek continuous improvement to become competitive and still requires the continuous creation of new processes and manufacturing techniques with a focus on reducing time, cost and increasing quality. The incremental forming is presented as a new trend for the production of small lots and prototypes, but the process presents some limitations that still prevent its active contribution in the industrial forming market.

The main advantage of incremental forming (IF) over conventional forming is the exchange of dedicated die systems for simple and low-cost systems. These forming tools are basically sticks with semi-spherical tip moved and controlled by a numerical control that for the purpose of forming the sheet, the tool performs successive and localized plastic deformations, Silva and Martins (2013).

The incremental sheet forming process can be performed in a variety of ways, for the manufacture of symmetrical parts such as cookware, the lathe can be used in a process called conventional Spinning and Shear Forming. For larger and asymmetric parts, a 3-axis machining center is used, which means the incremental forming process of single point, double point or with the aid of a dies, which can be positive or negative. The dies are made of materials such as wood, plastic and resin, Allwood *et al.* (2006).

The process of SPIF is relevant both industrially and scientifically because with it is possible to produce a piece of complex geometry in a short time, without the use of punches and dies of high complexity. The SPIF basically consists of a sheet forming, where the sheet is fixed in a device and with a hemispherical tool that follows a controlled path and carried out by a CNC machine for the realization of the part. A drawing of the process is shown in Fig. 1.

The Fig. 1 briefly shows the SPIF conformation process where, the angle α is the angle of the part, V is the speed of rotation the tool, Δ_z and Δ_x are the steps of advancement in x and y of the process.

One of the great challenges of incremental forming is the difficulty in obtaining complex pieces with high quality surface and dimensional, Lu *et al.* (2013). To make the sheet more malleable and increase its formability, heating was introduced into the forming process.

The hot forming allows the formation of thicker sheets and also of other materials that could not be formed at room temperature. In addition to better finishing of the final part, it reduces the required forming force in the process, without which it could still be higher than the limits of the machine, causing the rupture of the bearings of the spindle of the machine.

A good example of increasing the formability of the material using process heating is the case of titanium and its

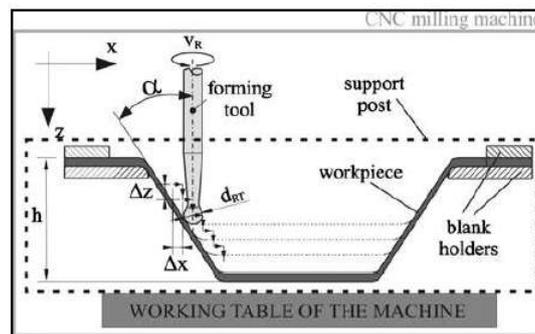


Figure 1: Basic principle of the SPIF, Bahloul *et al.* (2013)

alloys, which are difficult to form at room temperature. With the heat acting in the process, the necessary efforts for the conformation are reduced, being able also to realize the increase of the feed rate and with that to reduce the processing time. Titanium has difficult conformation at room temperature, as demonstrated in such works as Asghar and Reddy (2013) and Göttmann *et al.* (2011).

The rigid temperature control and the analysis of the shaped parts allows to get a structure with lower residual stresses, a more stable process and, therefore, achieving a more reliable and accurate SPIF conformation results, besides a shorter forming time thus reducing the costs of the process.

The incremental forming with warm requires special attention to the design of the equipment in order to ensure a homogeneous distribution of the temperature in the sheet. Ambrogio *et al.* (2009). The main methods of heating are by electric current, heating band, high friction and laser.

The Electrical Hot Incremental Forming (EHIF) is a good solution to reduce dimensional error, since electric current heating occurs at the point of contact of the tool with the sheet, which locally reduces the voltage of deformation. In other words, the high temperature and the respective thermal expansion do not occur in the whole plate, but only in the point being formed, which allows a better control of the dimensional error. Shi *et al.* (2013).

A comparison of dimensional error of incremental forming at room temperature and the addition of heat by EHIF to a DC04 steel plate showed that in the piece performed with the addition of heat there was a reduction of the dimensional error, within acceptable tolerances for shaped parts. The Fig. 2 shows a comparison analysis between the profile of a piece formed by hot process versus a room temperature process when compared with their original piece CAD model. This analysis shows that better results are obtained in the hot process, Shi *et al.* (2013).

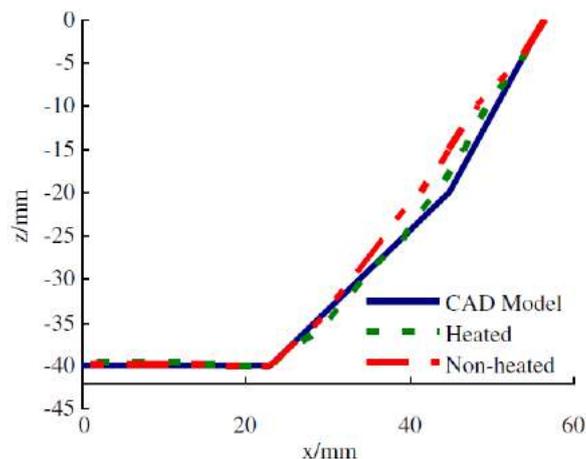


Figure 2: Final shape of parts with and without electric heating, Shi *et al.* (2013)

When comparing pieces formed with and without heating to the CAD model profile, there is a better approximation to the CAD model of the part conformed with warm. As can be observed in Fig. 3 below the part formed with the addition of heat showed a slight improvement in specific points and also a subtle improvement in the entire profile of the workpiece, Silva and Alvares (2015).

The Fig. 3 shows comparison of the profile obtained by scanning the workpiece with and without warm and the CAD model. In detail A, can be seen that the profile of the formed pieces are more than 2.6mm (the farthest point) from the desired beam profile.

A simple heating solution is shown at Fig. 4. In this case, it carries the total heating the part where we have to insert

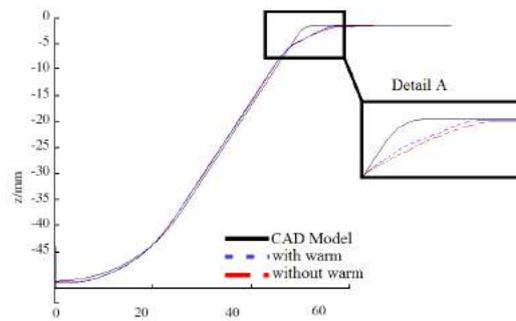


Figure 3: Pieces formed with AP of 0.4mm-Comparison between real formed piece and project CAD, Silva and Alvares (2015)

a new parameter to the process that is the expansion of the material to be formed. Getting consider the dilation necessary for the process to reach the required dimensional tolerances in the project.

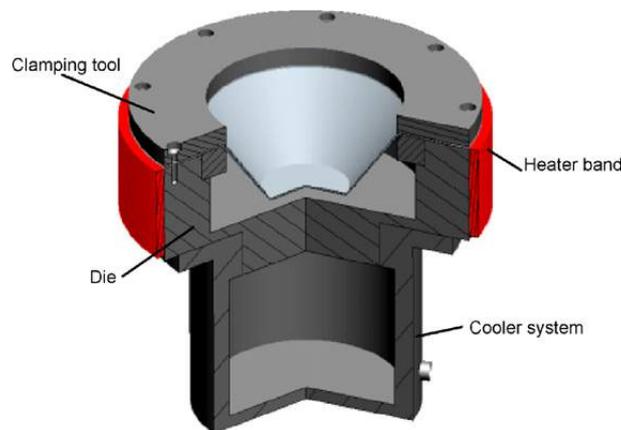


Figure 4: Heating device with heating band
Ambrogio *et al.* (2008)

Another way to carry out hot forming is to use electric current for heating pieces of complex geometry. When used in the magnesium alloy AZ 31, the results shows that the technique is simple to apply. Figure 5 demonstrates how the sheet processing devices were constructed, Fan *et al.* (2008).

The simplest way of inserting heat into the incremental forming process is the frictional heating of the tool in the sheet to be formed. This friction occurs with the high rotation of the tool in contact with the plate. This method of heating is the most economical and feasible, but friction can generate excessive wear of the tool and especially of the sheet to be formed. Putting at risk the quality of the desired end piece.

Otsu *et al.* (2014) performed several high rotation tests to verify the conformability of magnesium, aluminum and titanium and achieved to increase the conformation limits in relation to the wall angle.

The present study aims to develop a technique for using the incremental sheet forming with warm technology. The heat is provided by halogen lamps, and the technique is based on the Single Point Incremental Forming (SPIF) to form a complex geometry in two types of aluminum alloys 1050 and 6063, 1mm thick and 1.2mm respectively.

2. EXPERIMENTAL SETUP

The heating, during the SPIF, aims to increase the ductility of the material, and also makes the deformation process easier and even faster. At an elevated temperature, the materials strength is reduced by strain hardening. As the conformed plate is made from aluminum (Alloy 1050 and 6063), the experiments are scheduled to obtain the highest temperature possible during processing. Therefore, the heat also provides a reduction in strain hardening of the workpiece during the SPIF process.

The dimensions of the heating device were defined in accordance with the external dimensions of the piece to be conformed; i.e. width, length and depth of 150x150x80mm respectively. It has a square base, 11 halogen lamps of 100W and length of 117.6mm, which were installed by 2 on each side and 3 on the bottom, as shown in Fig. 6. The machine used is a CNC ROMI D600.

To start with the initial warming, the forming process was performed with a pre-heating of 50 minutes. During this

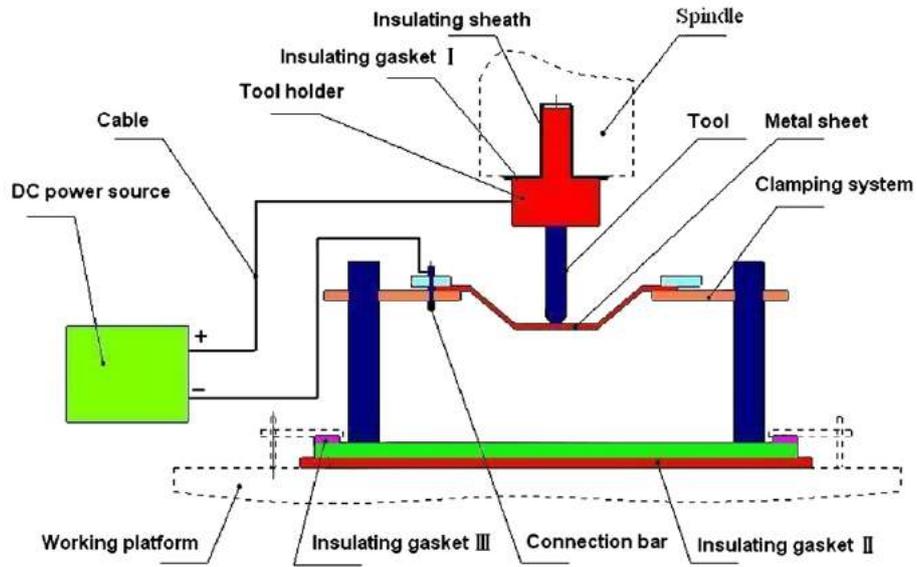


Figure 5: The principle of electric incremental forming
 Fan *et al.* (2008)

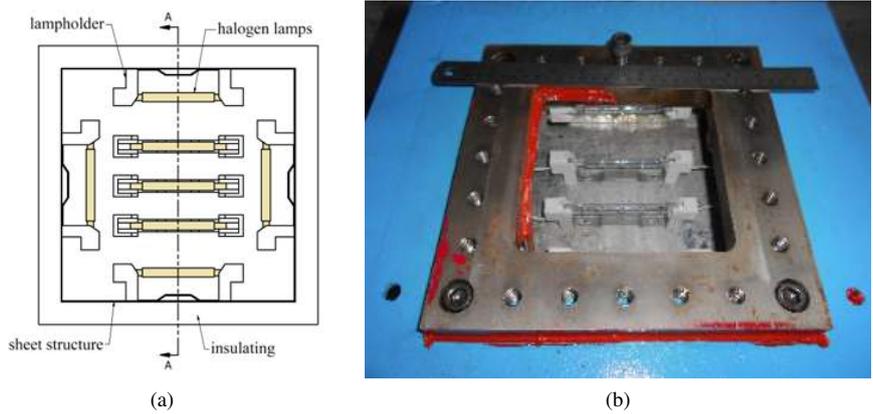


Figure 6: The figure (a) shows the device design; (b) shows the real device

preheating time, measurements were carried out by checking the temperature which was performed with two different equipments: a thermal FLIR camera brand I40 (0 to 350 ° C) with an accuracy of $\pm 2^\circ$ and an infrared thermometer brand model FU 900 EN 00 with a temperature range of -50 to 900 degrees Celsius, including an accuracy of ± 1.5 degrees, from which the acquired data is presented in the heating profile.

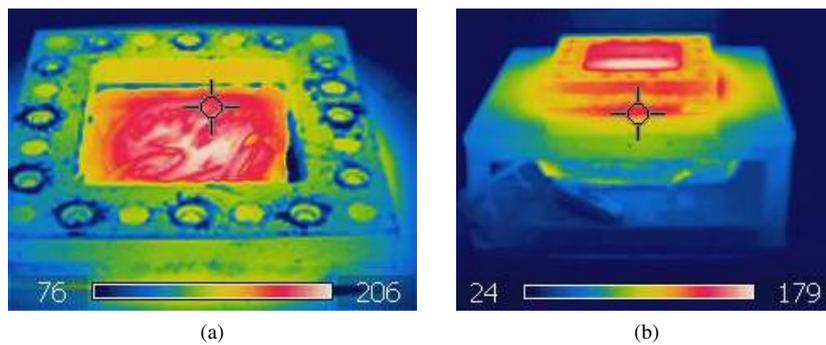


Figure 7: Heating profile

2.1 Experiment planning

The conformation strategy is to use the single point incremental forming method with heating. The heating will be given by means of a device with 11 halogen lamps. To verify the efficiency of the tests was used high rotations of 6000 RPM and low rotations of 600 RPM. As it treats of a conformation with heating the lubricant used was white grease of high temperature.

With the variation of the rotation is noted that the influence of the rotation in the process of SPIF with heating happens in two great strands, superficial finishing and improvement of the conformation.

The geometry to be shaped is an human face in scale. We have some critical points of conformation in this piece, the chin and the nose. The chin has a wall inclination close to 87° and the nose has a significant point depth, as shown in Fig. 8.

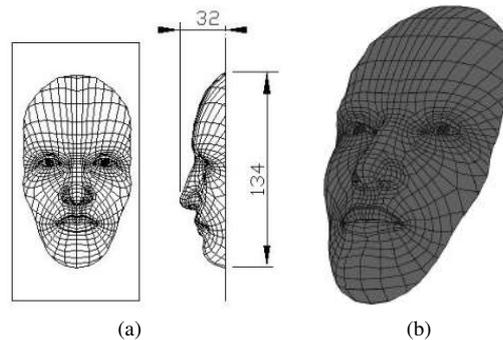


Figure 8: Face (a) technical drawing in 2D (b) 3d image

Four tests were planned with different processing parameters, presented in tab. 1. To perform a comparison between different materials where used 1050 aluminum, that has tensile strength of 55 MPa, and alloy 6063 that has tensile strength 130 MPa, conforming sheets whit different thicknesses 1.0 mm and 1.2 mm respectively.

Table 1: Parameter of process.

Test Number	Parameter of process				
	Ap(mm)	f(mm/min)	S(RPM)	Material	warm
01	0.2	1200	6000	Alloy 6063	Yes
02	0.2	1200	6000	Alloy1050	Yes
03	0.2	1200	600	Alloy 6063	Yes
04	0.2	1200	6000	Alloy 6063	No

All tests were performed with the same conformation strategy with helical tool path while moving the three axes, X, Y and Z, so that the forming speed is maintained constant. Since the piece has small details, the adaptive Z-step was used when the software verifies the need to reduce the Ap, to reduce conformation errors, a variation is made in the Ap automatically, without direct user interference.

2.2 Execution of the test

In the execution of Test 01 several problems with respect to the conformation occurred, which were corrected throughout the processing. The first and most serious was that during the conformation, after 4 mm depth, the tool began machining the sheet material, removing material from the sheet with significant release of the chip. To work around this problem, the rotation was reduced from 6000 to 3000 RPM, but the problem persisted. It was decided to reduce the feed from 1200 to 600mm / min, which also did not have an effect and the process continued with a lot of friction generating machining in the sheet.

For a new solution attempt we return with the original values of rotation and advance to 6000RPM and 1200mm / min and reanalyze all the processing.

In this new analysis the existence of 4 distinct regions in the part being conformed was observed. The first more in the periphery of the piece has the white grease intact, because the tool did not pass through this region. The second in the most central part of the sheet, where you can see that the grease becomes slightly dark, because the tool has already passed through this place. The third and most important region, shown in Fig.450 with red arrows, is the conformation region where the tool is in direct contact with the sheet to be formed and which does not have any type of lubrication. The fourth region is the area still to be shaped.

In this way, to continue the test 01, lubricant was added directly to the sheet during the entire processing. This grease has been inserted continuously throughout the entire process at a point in the tool path and near its tip, so that the tool is able to distribute this lubrication all the way through.



Figure 9: Test 1

As a result of test 01, it was possible to conform the whole piece with various defects and nonconformity. As shown in Fig. 10a, undesirable marks are observed on the part and small cracks in the sheet along the profile are observed. More specifically, there were 4 cracks, which, although very subtle cracks, may compromise the piece's applicability.

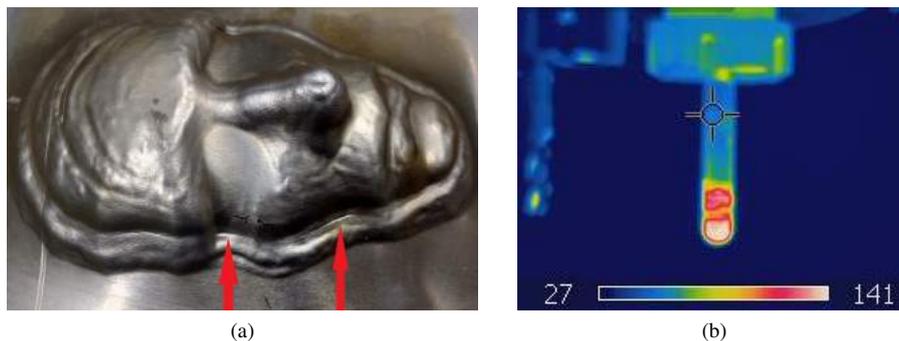


Figure 10: Test 1 (a) Shaped part (b) Tool after forming

The temperature profile after forming is shown in Fig. 10b, where the highest temperature is obviously at the tip of the tool. It is important to note that the temperature of the tool body does not exceed 50 degrees Celsius, which means that the integrity of the machine and the tool clamping system are not affected by the heating.

After processing the tool was checked and it was observed that there was no wear on the tool, however, it had a lot of material adhered to its tip. For the tool to return to its initial characteristics a polishing with 2000 grit sandpaper was carried out. Fig.11(a) shows the tool after forming and the figure Fig.11(b) the tool after polishing.



Figure 11: Tool (a) after forming 01 (b) after polishing

Test 02 using Alloy 1050 was then performed to analyze the differences between materials. The conformation occurred without any problem managing to conform the piece to its fullness without any mark or imperfection, Fig. 12.



Figure 12: Test 02 - aluminum alloy 1050

The test 03 with rotation at 600 RPM, ten times smaller than test 02, was performed to verify the influence of the high rotation in the process of incremental forming with heating and to verify if the high rotation is not expelling the lubrication during the processing. To achieve the total conformation a larger amount of lubricant was added, on average 12 grams, to avoid having to add more lubricant during the test as occurred at test 01.

Fig. 13 presents the piece conformed by test 03 which presents only a small fracture at the tip of the nose, where this fracture may have run due to lack of lubrication since the tool is large in relation to the detail of the piece to be shaped the tool drops down without a range of motion on the X and Y axes.

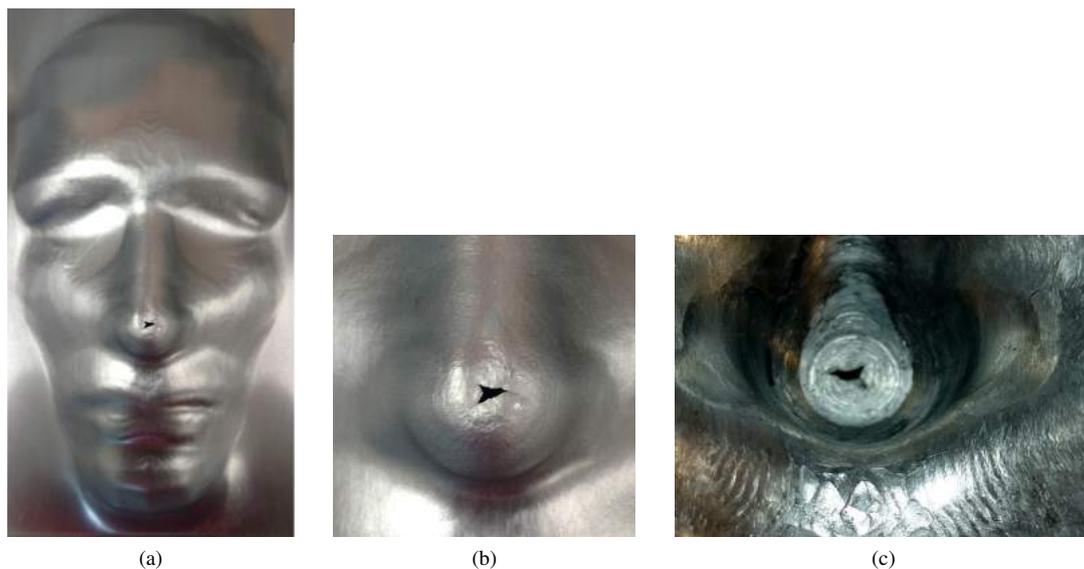


Figure 13: Test 03 (a) Final part (b) Detail of the external fracture (c) Internal detail of the fracture

Is shown at Fig. 13(a) the general characteristics of the final part where the fracture that occurred at the tip of the nose, the details of this fracture are shown in Fig. 13(b). The internal part of the piece, where the workpiece is formed, is shown in Fig. 13(c) which shows the detail of the internal part of the fracture.

Test 4 is performed without heating to verify that the forming process with heating brings advantages to the heating process. Fig. 14(b) presents the final part and Fig. 5 shows the detail of the region where the sheet rupture occurred. When we compare the rupture occurred in test 03 and in test 4 it can be observed that the rupture of test 4 is much larger in size and area of rupture.

The rupture of test 4 is due to the thinning of the plate, because in the region of rupture the sheet became extremely thin not supporting the conformation.

Test 01 was redone but now with plenty of grease, in average 16 grams, to reduce imperfections, this test was able to conform the piece in its fullness however with a fracture at the tip of the nose but this fracture is much smaller than the other tests and possibly this fracture can be avoided by reducing the size of the tool, with this the area gets more access to insert the lubrication.

Fig. 15 (a) shows the final shaped piece and the detail of the fracture of the part Fig 15(b) and the inner part of the sheet, the side coming into contact with the tool is shown in Fig 15(c).

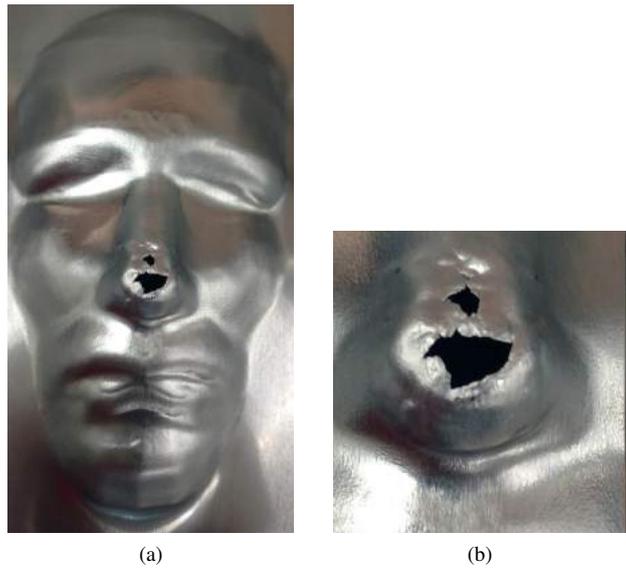


Figure 14: Test 04 (a) Final part (b) Detail of the fracture

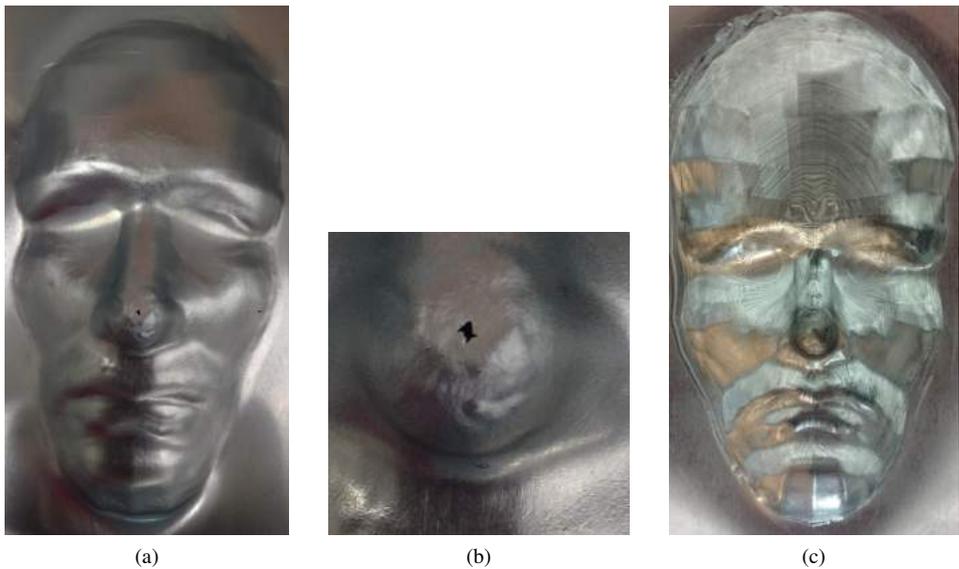


Figure 15: Test 01 second part (a) Final part (b) External fracture detail (c) Internal part detail

3. CONCLUSIONS

The single point incremental forming process can produce high quality parts. When the heating is inserted in the process, complex parts can be conformed easier. In SPIF with heating and high speed, special attention must be paid to the lubrication because high rotation can eject the lubrication that should have existed between the tool and the part. However the high rotation brings benefits to the conformation as an improvement of the conformation capacity of the process

The conformation with heating presents itself as an option for the conformation of complex pieces with steep angles. The high rotation assistance is relative as if the lubrication is not abundant enough for the process the parts may come to fracturing during processing. The present study makes an important contribution to the academy and industry showing the viability of the single point incremental forming process with heating. At industry is not sold CNC machine with heating system inside on in, and it could open doors for the industry produce new and complex pieces by SPIF.

To conclude, for conformation success it is necessary to choose an appropriate tool size that can perform the part conformation easily from start to finish, taking into account all the details of the desired end piece. As a practical criterion it can be assumed that all the cavities of the part must be greater than the tip of the tool by at least 50%.

4. REFERENCES

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