Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 29 (2019) 232–239

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

18th International Conference on Sheet Metal, SHEMET 2019

Sheet metal bending with flexible tools

Veronica Geraldine Zaragoza[a]*, Matteo Strano[b], Lorenzo Iorio[c], Michele Monno[b]

[a]*MUSP, Str. della Torre della Razza, Piacenza, 29122, Italy*
[b]*Politecnico di Milano, Dipartimento di Meccanica, Via GiuseppeLa Masa, 1, 20156,Milan, Italy*
[c]*ESI Italia, Viale Angelo Masini n.36, 40126, Bologna, Italy*

Abstract

New technological opportunities and the recent needs of the market, which evolves towards mass customization, create a growing interest on the use of additive technologies (3D printing) to add flexibility on the production geometries and reduce tooling costs. In the sheet-metal bending manufacturing sector, rigid metallic tools are the most commonly used. This article presents recent findings in the field of no spring ban-metal tools for bending. This type of tool ensures long term performance but has limitations on adaptability to specific geometries and implies high production costs. Over the years, unfilled or reinforced plastic materials have often been considered a lightweight and cost-efficient alternative for replacement of metal mechanical parts. The use of polymeric materials can offer cost and time reduction by including new architectures to allow the integration of additive and subtractive production technologies. Furthermore, unfilled thermoplastics can be recycled at the end of the process. The introduction of equipment combining a metallic support base and a polymeric die insert with sufficient strength is proposed as a solution to reach high performances using non-conventional materials. The polymeric die insert may be produced by 3D printing or other rapid manufacturing technologies and it is rapidly changeable. The modular base allows heavy mechanical loads, while the polymeric die reduces the aesthetical defects of the bent sheets. The study shows that, in air bending, polymeric die inserts allow a process capability which is comparable to the capability reached with metal dies.

Keywords: Sheet metal bending; Flexible tools; Additive manufacturing; 3d printing; Polymeric materials

* Corresponding author. Tel.: +39-348 0358968.
E-mail address: veronica.zaragoza@musp.it

10.1016/j.promfg.2019.02.131

1. Introduction

The current evolution towards the digital fabrication, made possible by new manufacturing technologies, is required by a market which is more and more asking for more personalized productions. To this aim, there has been a growing interest in the use of additive technologies (as the 3D printing), that are considered more flexible and have the advantage of not requiring the use of dies for the production process. However, the business of the sheet metal forming industry is centered on the use of rigid, costly metal dies. This market is at risk of entering a crisis in the coming years, due to the high costs of the production of metal tooling that are only sustainable for medium/high volume productions.

The area of sheet metal forming is characterized by the use of equipment (dies, punches, blank-holder) manufactured with metallic materials and produced through long and expensive machining processes (like milling). The structure made entirely of metal, however life lasting and mechanically resistant, has a rigid nature that it is not easily modifiable to be adapted to different geometries. This disadvantage comes in addition to the high costs linked to both the material itself and the processing of it, due to the need of performing thermal and surface treatments to improve the quality of the finish. This scenario makes it necessary to develop alternative tooling design methods that include materials and criteria to produce molds that can allow a drastic reduction of their costs and production times. Clearly, the mechanical performance, the endurance of the tools and the forming process capability obtained with non-metal tools could deteriorate, and this risk must be assessed and evaluated.

Air bending (figure 1a) is the most diffused V-die sheet metal bending operation, because of its simplicity and the possibility of rapidly changing the obtained bend angle. The tooling only touches the material at three locations: the punch tip and the die shoulders. Bottoming (figure 1b) is more repeatable but less frequently used because of the larger force requirement. In bottoming, the punch and die are brought together so that the material makes contact with the punch tip and the sidewalls of the V-opening.

Over the years, many different types of flexible sheet metal forming methods have been implemented in the industry with the purpose of improving the performance of the bending process while trying to reduce the tooling production times and costs. Among the possible solutions, methods such as the development of single point and double point incremental forming processes have been studied [1], as well as the replacement of one or more of the metal tools with a rubber membrane (Guerin process) [2]-[3]. However, in the last few years, the tremendous growth of additive manufacturing technologies is changing completely the way of designing functional parts. Areborn attention is being given to Rapid Tooling technologies [4] that can be reached using hybrid systems, while De Souza studied the use of polymeric materials for sheet metal forming purposes [5]. Nakamura at al. [6] recently manufactured plastic punches and dies using fused deposition modeling process. Different combinations (plastic-plastic, plastic-steel and steel-steel) for the V-bending process were tested with the aim of analyzing the possible variations on the bend angle and the die angle, due to the elastic deformation of the plastic tools. The authors demonstrated that the springback angles for the three tool combinations were similar.

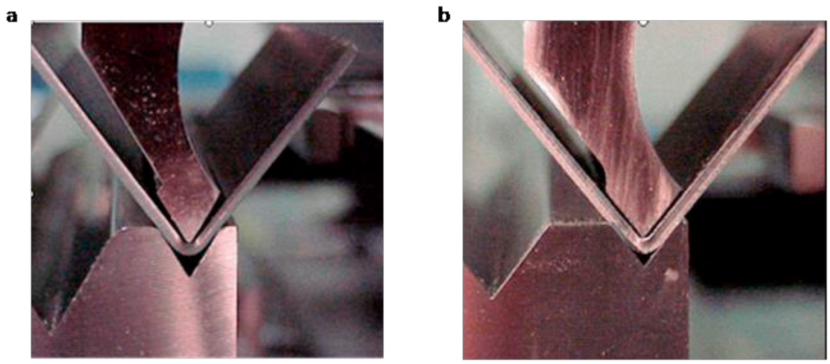

Fig. 1. (a) Air bending process; (b) bottoming process.

The approach presented in this article involves the design and production of hybrid systems, composed of a metallic part and a polymer part, as an alternative to the fully metallic systems currently used. The use of polymeric materials has the purpose of opening possibilities in the employ of other technologies (additive manufacturing technologies) that do not require the use of molds, and that are more flexible in terms of the geometry that can be manufactured. Compared with the current manufacturing methods, this technique could allow the formation of modular structures in a shorter time and with lower costs. Furthermore, it would allow the design of systems which can be recycled or reused over time, which would open the field for production of sheet metal parts with small batches. The principal focus of this article will be the study of hybrid systems for the air bending process.

2. Experimental setup

The idea of using hybrid systems as bending tool solutions consists in the design of a rapid tool composed of a rigid metallic framework where interchangeable polymeric inserts can be placed depending on the manufacturing needs (figure 2a and figure 2b). The polymeric die inserts have been produced with different technologies, depending on the polymeric material: 3D printing by Fused Deposition Modeling, machining or injection molding. The die insert constitutes the core of the tool where the bending operations will take place.

Experimental bending tests comparing a low cost commercial metal solution (C40 steel) and 6 different polymeric materials are conducted for the die inserts. The main tensile mechanical characteristics for each tested material are reported in Table 1. The polymeric tested materials with V-shape opening are (figure 2c, figure 2d and figure 2e):

- injection molded nylon (PA6),
- machined thermoset polyurethane (commercial name Necuron 1050),
- machined thermoset polyurethane reinforced with short glass fibers (Necuron 1150 and 1300),
- 3d printed polycarbonate.

Additionally, two types of rubber inserts have also been evaluated: a solid bock with square cross section, i.e. with no v-shaped opening, and another solid block with square cross section with the addition of a hole in the middle of it, in order to reduce the stiffness of the insert (figure 2f and figure 2g).

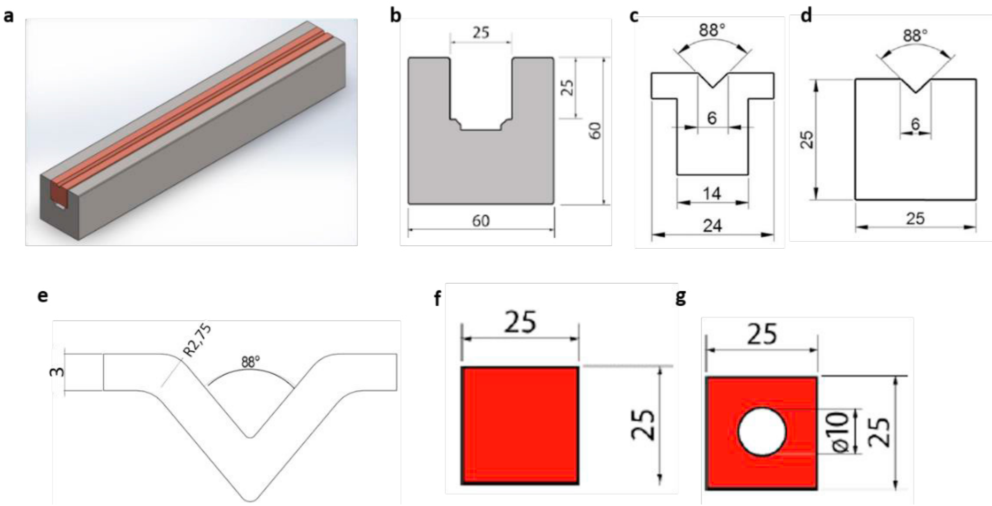

Fig. 2. (a) Air bending rapid die concept made of a standard metal casing and a rapidly interchangeable polymeric v-shaped insert; (b) cross-sectional drawing of the metal frame; (c) nylon insert dimensions; (d) polyurethane inserts dimensions; (e) polycarbonate inserts dimensions; (f) and (g) rubber inserts dimensions.

Table 1. Tensile material properties of the bending dies used in the experimental activities.

Material	Density (Kg/mm^3)	Poisson's coefficient	Young's Modulus (MPa)	Yield Stress (MPa)	Ultimate Stress (MPa)	Elongation (%)
Steel C40	$7.8*10^{-6}$	0.28	$208*10^3$	335	530	22
Nylon	$1.15*10^{-6}$	0.4	$2.50*10^3$	55	67.8	60
Necuron 1050	$1.2*10^{-6}$	0.34	$3.24*10^3$	30	38	3
Necuron 1150	$1.2*10^{-6}$	0.34	$2.91*10^3$	42.67	62.67	14.8
Necuron 1300	$1.15*10^{-6}$	0.34	$2.76*10^3$	37.33	49.33	12.07
Rubber shore 90A	$1.26*10^{-6}$	0.499	8.3	-	51.7	525
Polycarbonate	$1.2*10^{-6}$	0.37	$2.025*10^3$	43.45	70	100

The idea is to compare the results between the polymeric tools and standard metal tools. All experiments are carried out using a single V-metal punch with an opening angle of 88˚. In preliminary tests, for each type of die insert, the punch stroke has been adjusted by trial-and-error until obtaining the targeted bending angle after springback (120°, 130° and 180°) with a tolerance of ±0.5°.The commercial metal die consists also in a V-shaped cavity with an angle of 88°. A bending die width of 6 mm has been used. For the bending analysis different sheet materials (Al1050, Fe37 and A1008 CR) and thicknesses (0.7, 0.8, 1, 1.5 and 2 mm) have been considered. Since the sheet samples are shorter than the die inserts, they have always been positioned at the center of the die.

3. Experimental results

Different tests have been performed in order to achieve the targeted angles after springback, and several values of punch stroke have been used. To provide a synthetic representation of the results, these have been compared in terms of relative error of the obtained bending angle; the calculation is show in the equation 1:

$$Relative\ Error = \frac{\theta_{bending} - \theta_{target}}{\theta_{target}} \quad (1)$$

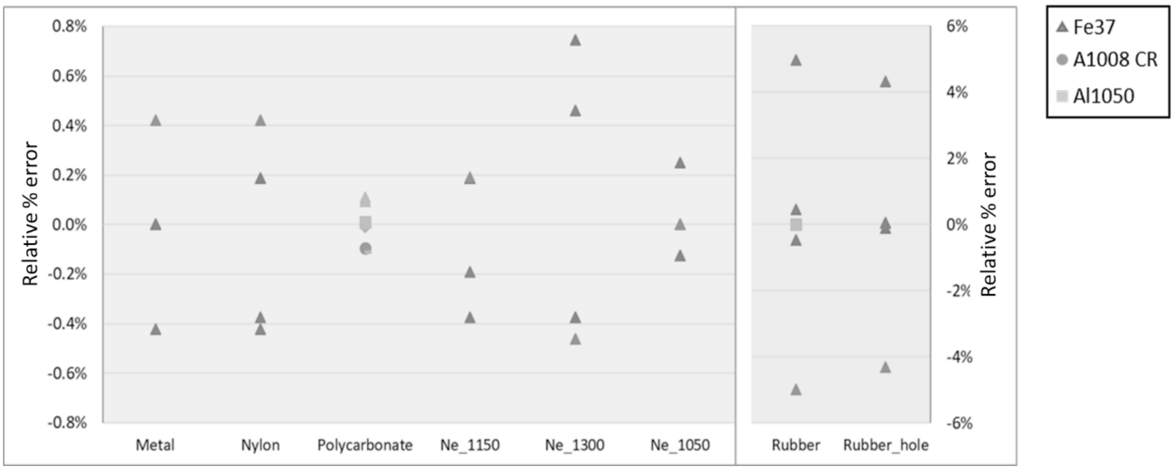

Fig. 3. Relative error on the bending angle after springback grouped by tool material (in descending order of yield strength).

The results are shown in Figure 3. As the legend shows, most tests were performed with the Fe37 steel (triangular dot). For each type of die insert, at least two repeated tests with the same sheet material have been performed. The ranges for each case show a good repeatability on the measurements, making it clear that the plastic die inserts can give the same magnitude of variability with respect to the rigid metal solutions. Within the polymeric inserts the polycarbonate shows the lowest variability. Instead, the tests demonstrate that the rubber tools behavior is different due to their hyper-elasticity that must also be considered to adjust the punch stroke during the bending process. Indeed, the mechanics of the sheet bending with the rubber die inserts cannot properly be defined as a pure air bending operation. In fact, the large contact surface between the sheet and the deformed die makes the process more similar to bottoming. Bottoming is when the bending tools reach the closure at the end of the process and the blank is in complete contact with them along its entire surface.

In general, for industrial applications of the bending process, there is not only a requirement of a specific bend angle. In some applications the aesthetical results are also important, because of the possible presence of scratches and marks on the blank surface. It must be noticed that specimens bent with metal tools show scratches near the bending zone, due to the contact between the blank surface and the rigid metal die. The use of polymeric dies can reduce or eliminate the presence of aesthetical defects. Specimens bent with polyurethane and rubber dies can guarantee the absence of scratches or other aesthetic defects on the external surface (figure 4b and figure 4c); However, with the use of metal (figure 4a) and nylon (figure 4d) dies, soft scratches can be observed in the surface area in contact with the tool surface. This implies the risk of rapid wearing when nylon dies are used.

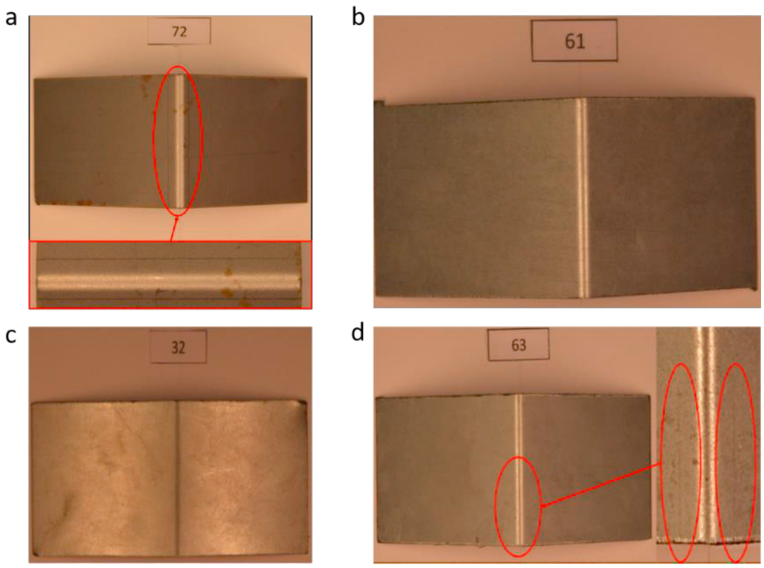

Fig. 4. Example of aesthetical defects on a specimen bent with (a) metal tools; (b) polyurethane insert tools; (c) rubber insert tools; (d) nylon insert tools.

4. Economic comparison

One of the main advantages of the design of hybrid systems (composed of a polymeric matrix and a metallic framework, as seen in the previous part) corresponds to the economic savings that can be obtained in large-scale production. In general, the cost of a single metal die is lower respect to the rapid die solutions due to the metal framework required in this second case. However, a single company often has to produce several (small) batches of sheet metal parts with different thicknesses and target angles. Therefore, with a conventional all-metal tooling solution, several tool setups are required for a diverse range of applications. By contrast, a modular design made of a standard outer case and a replaceable polymeric part offers an economic advantage. If the manufacturing cost of a single metal air bending die (less than 50 €) is compared to the manufacturing cost of a hybrid die (about 50 €), the traditional all-metal solution is to be preferred (see the left part of figure 5). However, if the cost of the hybrid solution, where only the insert is replaced, is compared to the manufacturing of several metal dies, the economic advantage of rapid tools becomes evident (see the right portion of figure 5).

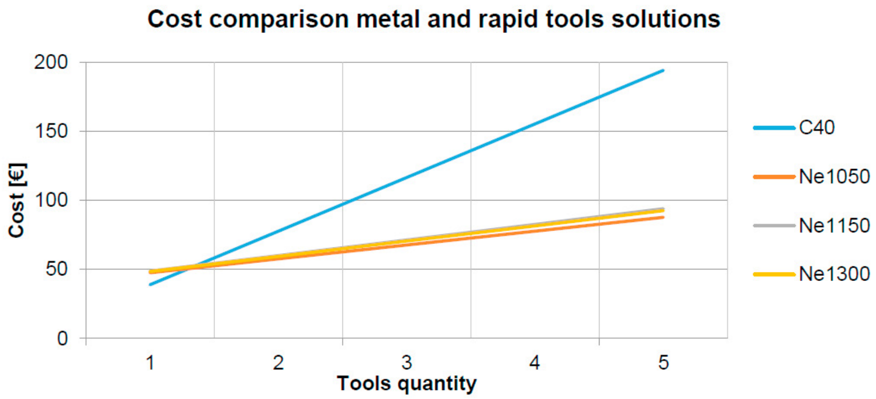

Fig. 5. Comparison of the trend of the tools cost respect to the purchase quantities.

The estimation on the cost of rigid v-bending die tools was done taking the information obtained from a bending tool manufacturing company, data reported in table 2. This data was compared with the production cost of a single rough polyurethane insert and the manufacturing cycle to produce inserts with dimensions 25x25x415 mm with a V-shaped cavity of 88° opening angle and 6 mm width, values reported in table 3. To calculate the total cost of the rapid die, the cost of the inserts should be added to the cost of the metal framework (considering a commercial profit margin at 37.42 €), obtaining a maximum cost of 48.69 € for the solution (metallic framework + Necuron 1150).

Table 2. Manufacturing costs of a commercial rigid die used as a reference product.

Rough dimensions		Cost data	
Width	65mm	Material cost unit	0.857 €/kg
Height	85 mm	Material cost	15.524 €
Length	420 mm	Machining cost	19.405 €
Volume	$2.320*10^3$ mm^3	Thermal treatment	3.881 €
Density	$7.870*10^{-6}$ Kg/mm^3	Total cost	38.81 €
Weight	18.099 Kg		

Table 3. Manufacturing operations data and total costs of the Necuron inserts.

Machining operations and times				
Flattening path	860 mm			
Facing path	57 mm			
Feed	2.83 mm/s			
Cutting speed	0.83 mm/s			
Facing time	20.15 s		**Total cost**	
Flattening time	303.95 s		**Machining cost**	**Material cost**
Cutting path	46.88 mm	Necuron 1050	10.04 €	2.68 €
Cutting time for V-shape cavity	293.35 s	Necuron 1150	11.27 €	3.92 €
Total time	661.98 s	Necuron 1300	11 €	3.65 €

5. Estimated tool life

Regarding the life of the rapid tool, the estimation is made considering a series of 50 experimental bending tests and measurements on one single type of die. It is therefore possible to determine the repeatability limit in which results can be obtained with the same bend angle. This limit allows performing an approximate calculation of the number of bends that can be applied before reaching a plastic deformation of the insert which requires printing a new insert. As an example, in figure 6 the bending angle variation is plotted along with a trendline, when bending aluminum blanks with 1.5 mm thickness for a 3d printed polycarbonate die. The chart shows a large variability of the results (tolerance 90°±1°), with a slow increasing trend of the bend angle, which increases on average by 0.004° per bent sheet.

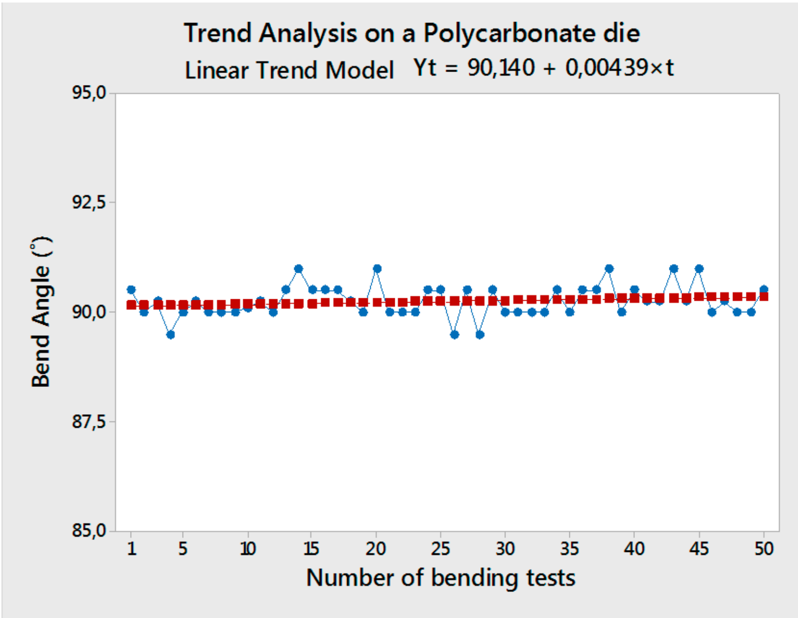

Fig. 6. Trend of the measured bend angle after springback in the repeatability test performed with the polycarbonate die on a 1.5 mm Al sheet. The blue dots represent the angle measurements. The red line is the trend.

The thermoset polyurethane inserts have shown a better repeatability over time, i.e. dimensional stability, with respect to the other die materials. For this reason, the material has been characterized not only with bending tests, but also with cyclic compression tests run on cylindrical samples. One of the obtained results is shown in figure 7. It is evident that the mechanical performance is stable for low values of deformation (below 0.02 strain), whereas the variability increases in compression, after the yield point is reached. This confirms the possibility of using these tools in areas of low stress where the material behavior is linear elastic and the expected tool life can reach the typical size of small batch productions (from a few hundreds to a few thousands of parts).

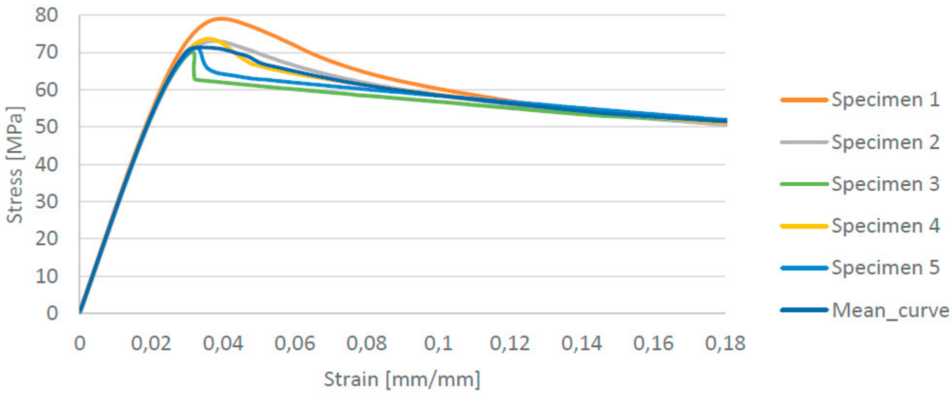

Fig. 7. Necuron 1300 stress-strain curves resultant from the compression tests.

6. Conclusions

The design of hybrid systems as rapid tools consisting of a polymeric part and a metallic framework has been introduced in the sheet metal bending process as a new solution. The rapid tool setup has been compared with commercial metal tools alternatives, typically used in the sheet metal bending industry. The experimental results demonstrate that the performance of the rapid tools is similar to that of metallic tools solution, once the punch stroke is adjusted. Using the same process parameters, the rapid tools show similar values of bend angles without any aesthetical defects (like scratches) on the product surface, contrary to the defects observed for the specimens bent with the metal solution. The results obtained show that the V-shaped cavities made of polymeric materials are stable and, if loaded at low stress, the tool life is sufficient to promote the use of these cost efficient tools for small batch industrial productions.

References

[1] R. Malhotra, J. Cao, F. Ren, V. Kiridena, Z.C. Xia, N.V. Reddy, Improvement of Geometric Accuracy in Incremental Forming by Using a Squeezing Toolpath Strategy with Two Forming Tools, ASME. J. Manuf. Sci. Eng., 133 (6) (2011) 061019.

[2] A. Del Prete, G. Papadia, B. Manisi, Computer Aided Modeling of Rubber Pad Forming Process, Key Engineering Materials, 473 (2011) 637–644

[3] M. Ramezani, Z.M. Ripin, R. Ahmad, Sheet metal forming with the aid of flexible punch, numerical approach and experimental validation; CIRP Journal of Manufacturing Science and Technology, 3 (3) (2010) 196–203.

[4] Chua CheeKai, Leong KahFai, Liu Zhong Hong. Rapid Tooling Manufacturing, Handbook of Manufacturing Engineering and Technology, Spinger, (2014), 1-22.

[5] J.H.C. De Souza, M. Liewald. Analysis of.the tribological behavior of polymer composite tool materials for sheet metal forming, International journal on the science and technology of friction, lubrication and wear, 268 (1-2) (2010) 241-248.

[6] N. Nakamura, K.I. Mori, F. Abe, Y. Abe, Bending of sheet metals using plastic tools made with 3D printer, Procedia Manufacturing, 15 (2018) 737-742.