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REVIEW OF RECENT STRETCH FORMING DEVELOPMENT

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Abstract: *The forming process, reviewed in the present paper, is a conventional method used in deforming metal sheet, using a clamping method and a die. Through the paper numerous types of processes were shown. The main consideration was the mechanists behind each process and how it improves key factor like producibility, repeatability, sustainability and conformability. Described in the introduction is the different type of sheet metal forming processes, the deformation mechanism, deform materials, industries where it is successfully implemented. The main types of processes described are classic die stretch forming, multi-point die stretch forming (MPSF), single point incremental forming (SPIF) combined with stretch forming and numerical simulation of the stretch forming process, with respect to classic die, multi-point die and flexible multi-grippers. More or less the aerospace industry has a high use of stretch forming parts. Nevertheless, industries like architectural constructions, automotive and naval benefit from the major developments of this process. MPSF and the hybrid SPFI and stretch forming processes solved the problem of multiple curvature sheet deforming, grooves and pockets. As a conclusion, to this review, it can be stated that conventional stretch forming has undergone a remarkable evolution in term of process adaptability and flexibility, being able to perform operations of high complexity.*

Key words: *stretch forming, flexible gripper, multi-point die, spring-back, SPIF.*

1. INTRODUCTION

Recent development in various sectors of industry require machining even more complex surfaces. A branch of this processes is sheet metal forming.

This forming process requires deforming using mechanical force, either at room temperature or by heating the die and/or part. Processes that enroll in their characteristics are: bending, coining, decambering, deep drawing, flow forming, hydroforming, hot metal gas forming, hot press hardening, incremental forming, spinning, shear forming, raising, roll forming, roll bending, rubber pad forming, shearing, stamping, super-elastic forming, wheeling, stretch forming.

Given the nature of continues advancement in any industry is a normal request for superior products. In our days the shift from fissile fuels based carburant motors to electric ones is present mostly in the automotive industry. Less weight uses less power to drive a system. This logic is implemented in industries like aerospace and automotive with the precise request of lightweight design [1]. Exterior and interior panels used in both industries must align to criteria's like: functional, durable and aesthetic. Materials like aluminum alloy, magnesium alloy and titanium alloy are being widely used in this industry, as they are lightweight, have a high strength-to-weight ratio and good formability [1]. The stages such as preforming, stretch-forming and technical drawing are very important in all types of stretch-forming. Even they are often considered complementary, one should complete with the importance of the stretch-forming process in the success or the failure of the deep-drawing. Both of them should be taken in consideration separately [2].

Stretch-forming it is used for large parts, relatively flat, in the productivity of unique products, small series, prototypes like bodywork parts, parts of the coating-leading edge of a wing, truck superstructure. A common metal used in the aerospace industry is Aluminum 2024 but, also refractory metals like titanium, nickel, steel [2].

The mechanism behind stretch forming involves both bending and stretching to achieve the desired shape in term of curvature and strain-hardening the material [3]. The flow resistance of the sheet metal induce plastic deformation and the blank can be bent and stretched in the same time into different shapes [4]. Stretch forming, is a metal bending technique that eliminates most of the spring back in a bend. Subjecting the work to tensile stress while bending will force the elastic region to be plastically deformed [5]. Aerospace exterior panels with simple shaped small curvature large dimensions cannot be procced through bend forming or stamping as it is not effective or convenient. To produce these panels, stretch forming process is extensively adopted: besides neces-

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sary bend loads, stretch loads are also applied in the sheet plane [6]. Stretch forming research does not consider as much the importance of plastic anisotropy and shift their attention to the effects of hardening and strain rate hardening [7].

Stretch-forming is defined as the deepening of an intact blank sheet with a rigid punch, clamped at both sides. The sheet metal is clamped at both opposite sides into a fix device, after that it is draped around a die without a contact with it by moving the grippers towards each other. The sheet metal is stretched and bend over the die at the same time [8].

Besides of the forming process, research in this field analyses the following phenomena: tensile instability, defect analysis, yield criteria, strain hardening, the nature of the defects, strain-rate sensitivity, fracture limit, strain paths, material thickness and wrinkling effect [9].

As demand is getting bigger, new method of efficiently conducting the stretch forming process had to be developed. Such improvements can be seen in both transversal or longitudinal stretch forming processes. To improve repeatability, and thus the sustainability, of the process tweaks like the use of a rotating table, movable gripping jaws, multi-point stretching die and single point incremental forming (SPIF) adjacent to stretch forming had to be implemented. Nevertheless, the use of numeric control systems and finite element analysis represents a major breakthrough in this field.

The specification needed for a part to become a finite product have to be precisely fulfilled. This has to consider the capability of a process to be able to respect these technical specifications. As one system cannot be defined by only one specification the process capabilities is thus limited to a multitude of factors. As noise variable represent of important factor in the review of a manufacturing system the process capability matrix and bias vector will represent it [10].

2. TYPES OF STRETCH FORMING PROCESSES

Undergoing the variety and variety of difficult to obtained surfaces that are currently being used in industry as a result of permanent optimization of different processes, it can be stated that it is not sufficient for stretch forming processes to be kept as simple as they were. Although the implementation of new technology is difficult to be made, in industries like aerospace and automotive it has to take into consideration crucial factors like very high long-term safety in exploitation as human lives are in stake. From simple automobile shapes to aerodynamical state of the art car body this technological advanced imposes the use of continuous surfaces. This trend is more and more seen in the design of new commercial or luxury/private airplanes. Nevertheless, the processing of complex, large shaped surfaces is a stretch-forming must. Airplane exterior panels, or the plane's fuselage are being manufactured in this way. The type of panels produces using stretch-forming can be concave or convex shaped.

2.1. Simple die stretch-forming

A simple representation of the stretch forming process is highlighted in Fig. 1 [3]. The sheet is clamped in

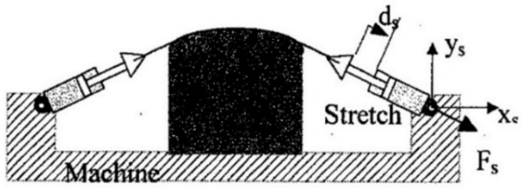


Fig. 1. Stretch forming principle [3].

gripping jaws, that in this representation are hydraulic. The jaws stretch the metal sheet across a die that usually has a cylindrical shape with a fixed radius. A force is applied both in the die (in some cases) and to the grippers. This strain can be applied before the bending (stretch-warp forming), after the bending (drape forming), or in combination [3].

During the process the sheet is clamped. It is pulled down, stretched and wrapped up around the die. Therefore, every gripper it is moving all along a horizontal and vertical path, process named motion interpolar, and also rotates around a single angle for obtain and remain the same relation between the sheet metal and the die: tangential relationship [12].

The process of stretch forming with distributed displacement loading is derived from the idea of simple stretch forming and the multi-point forming. Figure 2 shows the structure diagrams of two different stretch forming apparatuses. The simple way to charge the grippers it is replaced by distributed displacement load mode. Thus, the stretching is applied in a single point at the ends of the sheet metal so, we can control the loading trajectory. One of the advantages of this control of loading trajectory is that we can obtain good results in the process of stretch-forming [11].

2.2. Multi-point die stretch-forming

Stretch forming raises difficulties regarding to the ability of rapid machining and cheap to produce a new die. From this point of view the process is not sustainable. Therefore, it is needed a new way to adapt the die to different complex surfaces that need to be obtained. This improvement refers to a multi-point die stretch forming system MPSF (Fig. 3). The modification of the die consists in breaking it intro numerous pins that have a hemispherical tip. By making each pin move individually one

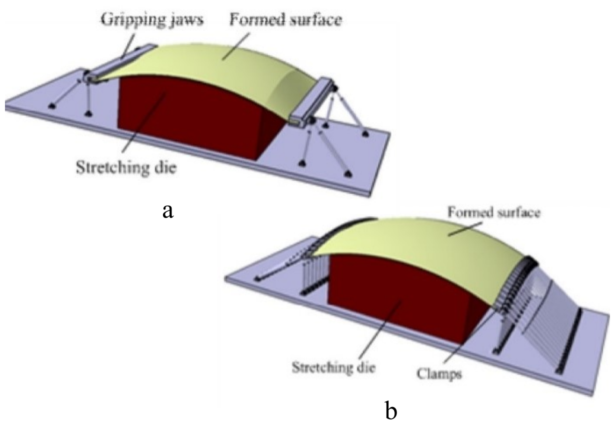


Fig. 2. Stretch forming: *a* – simple stretch forming; *b* – stretch forming based on distributed displacement loading [11].

each to another the surface of the die/tool can be modified. Such a system has the flexibility to adapt its shape to different 3D surfaces. Manufacturing time and costs are drastically reduced. Between the sheet metal and die and polymer pad is places as it dimples the workpiece. Several workpieces were fabricated in experiments, whose surface quality and final shape were perfect [12]. Nowadays, the 3D forms are easily to achieve because we have access to a variety of software applications. In the field of contemporary architecture, the free-form constructions conquer a new position on his development.

The new undulated skins are a very important item in the construction of the free-form buildings. The new instruments allow them to improve the production of double curved panels [13].

One major impediment in using stretch forming is that, by the nature of the finite product (ex. leading edge, cabin section), the number of parts needed is relatively low. In order to effect produce these 3D sheet metal parts the MPSF process can be used. One approach to this solution is using flexible rollers or dies. In order for the surface to be generated two dies need to work as positive (down) and negative (upper) shape. As concave and saddle-type surfaces (Fig. 4) are common airplane skin shapes most research in this field analyses this type of parts. A stereo vision measuring device was used to determine the quality of the formed parts. This measurements concluded that the parts have the specified shape and that the equations used are describing precise the process [14].

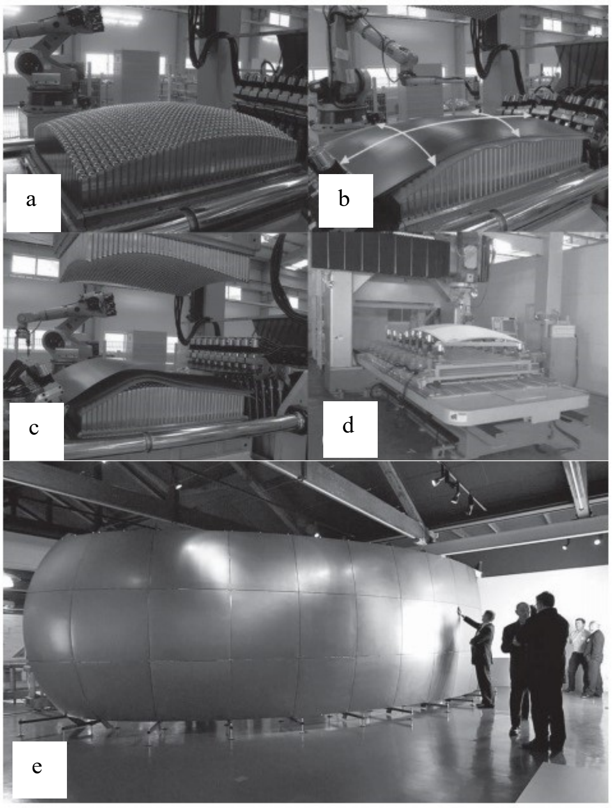


Fig. 3. Multipoint stretch forming machine (a–d). Free-form display 10 ×3 m at the Building Centre, London. Formtexx [13].

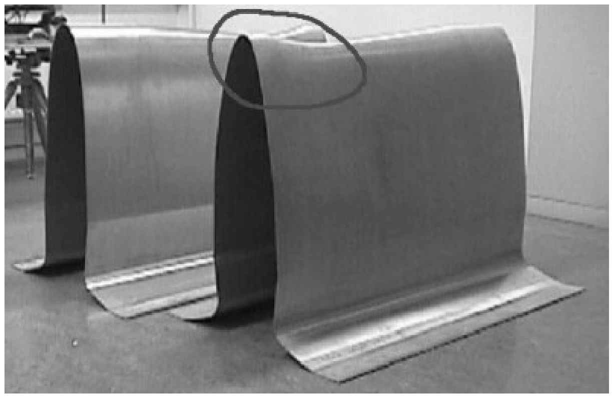


Fig. 4. Skin parts after stretch forming, saddle type surface [15].

The results of the MPSF aircraft skin panel should be studied in depth because the multi-point die is composed by a lot of punches. Factors like the thickness of the rubber pad cushion and free length have been analyzed on how they affect accuracy. A direct link was found between the rubber pad thickness and the dimple. As the thickness grows the dimples are suppressed. A longer free length leads to a smaller equivalent strain therefore a higher uniform distribution of thickness along the stretched part [16].

Another industry that can advantage of these flexible technologies is the naval sector. The main and strongest argument is that the usually used FRP (Fiber Reinforced Plastic) is environmental pollutant. As a solution this FRP was replaced by aluminum alloys. Despite the fact that a solution was presented another one toke its place. The forming process was made by manual labor. Without a systematic technique to curve the aluminum plates is was very difficult to obtain an end product that respect requirements in propulsion performance and hull design. The implementation of MPSF was a must do as it offers flexibility and the ability to deform large sheet panels of doubly curvature [17].

2.3. SPIF + stretch forming

The MPSF sistem can be substituted by a hibrid process witch involves the combined processing of a metal sheet by using stretch formin and single-point incremental forming. This process offers better results when double or various curved panels have to be deformed. Although the single-point incremental forming (SPIF) is a novel technique in sheet-forming, it offers solutions to deform complex parts without using a dedicated die. As the name describes the process it uses a single-point tool and a standard three-axis CNC machine.

A very important aspect is the formability of the metal and to the new formability curves because these new mechanics process allows higher strains [20].

This technique is commnly used in deforming sheet metal and polymers, as shown in Fig. 5 [18]. It is also used when complex high depth parts need to be obtained. SPIF machining makes it possible to obtain parts with the slope of the wall up to 80° and depths up to 70 mm from sheet metal blanks no thicker than 1.2 mm, by using just a very simple tool [19].

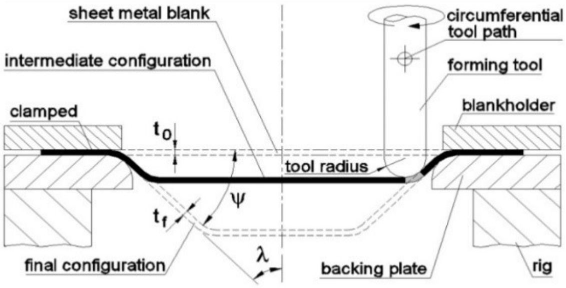


Fig. 5. Representation of the SPIF process [18].

As combined hybrid processes have to work simultaneous the interaction between the effects produced by each other has to be easily controlled, in order for the process to be performant. The main goal of a hybrid process is a lower processing time, also resulting in higher machinability, reductions of process forces and tool wear. One such process usually offers a very good surface integrity and great productivity [20]. The principle of a SPIF and stretch forming process is exemplified in Fig. 6. We can notice that the process of deforming is made in steps.

The stretch forming process is used to create a preformed surface. After the stretch forming reaches maximum pull the SPIF process will make the others features, like pockets or grooves [21].

The flexibility of the SPIF process leads to a variety of different branches that can be adapted with the stretch forming process (Fig. 7): two-point incremental forming (TPIF), single point incremental hydro-forming (SPIHF), two-point incremental forming with partial die, two-point incremental forming with full die [22].

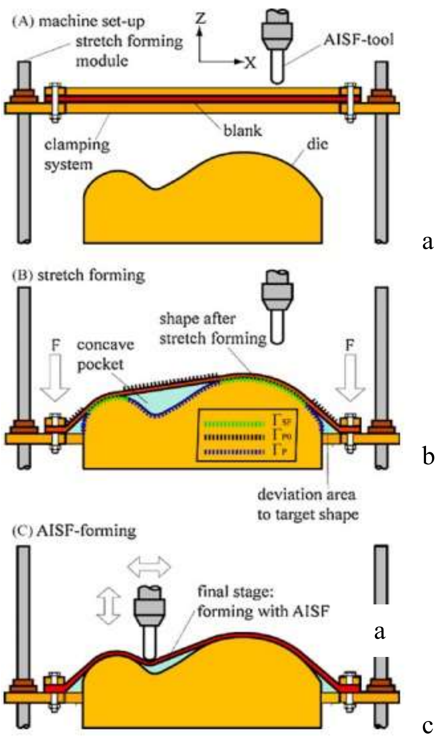


Fig. 6. Principle of combined SPIF and stretch forming [21].

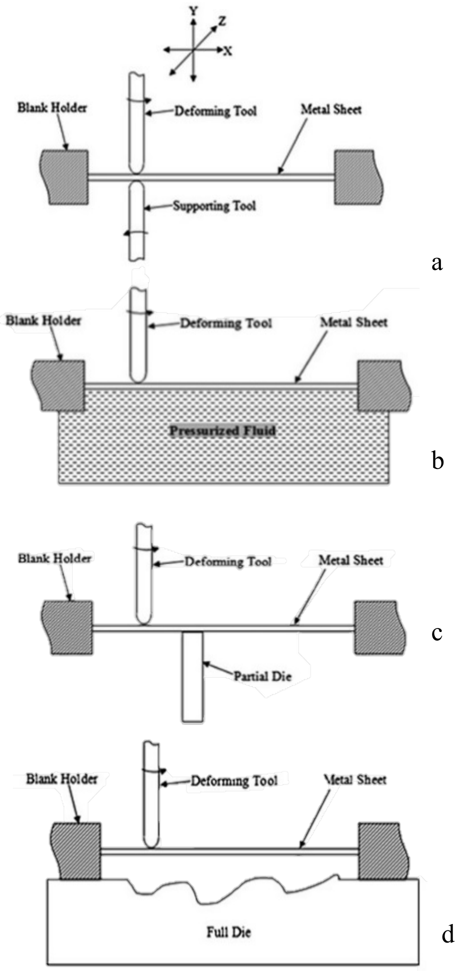


Fig. 7. Different SPIF hybrid processes [22].

2.4. Numerical simulation of stretch forming

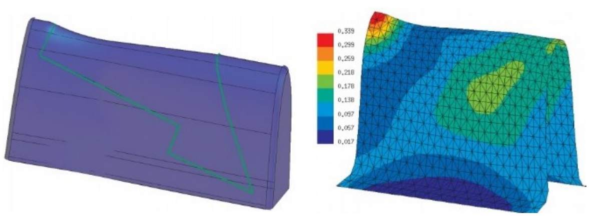
Numerical simulation using the finite element method is a technique to solve complex engineering and mathematical physics problems. In order for the software to generate a result is subdivides the large problem into more smaller ones, simple part which are called finite elements. Contacts, loads and constrains have to be define in order to fully describe the analyzed system. Research in the field of finite element simulation of stretch forming process is characterized by the type of model chosen for the sheet of die (usually is linear shell, reactively rigid body), material definition, type of contact between merging elements, the way loads act upon the system, and how everything is constrained.

The sheet, clamped with two gripper jaws, is formed around the stretch-block (Fig. 8,*a*), when the grippers move along the given trajectories. Accurately shaped products can be obtained with minimal spring-back, when stretch deformation is added to the bending deformation of the sheet (Fig. 8.*b*) [23].

Research in this field also study the simulation of the MPSF method. The modeling of the system is based on a matrix type die, with punch elements. In the paper "Numerical simulation for the multi-point stretch forming process of sheet metal" the results are high lither by comparison between traditional die and multi point die stretch forming. In both cases an elastic cushion, which usually is a rubber pad, is used to reduce the dimpling effect. The results are mainly based on the precision of the process by means of part shape accuracy. Also, the size of the elements and shape were varied and results were taking into consideration. The results may provide useful guidance on determining MPSF parameters and optimizing MPSF manufacture processes [24].

Highlighted in the study "Finite element simulation of multi-gripper flexible stretch forming" is a more complex system of fixing the metal sheet (Fig. 9,*a* and *b*). In this paper the author approaches the interaction between the grippers, sheet and die as a general contact algorithm, with the friction at the interfaces follows the Coulomb's law. This friction coefficient was considered 0.1. In order to relief the computation time it was take into consideration the symmetry of the model. Taking into consideration that is has two axes of symmetry, only one quarter of the model was used in the finite element analysis [25].

Research in this field analyses the dynamic behavior of the stretch forming process. A variety of type of processes derived from stretch forming were studied through the finite element method. From the traditional stretch forming to multi point die and flexible grippers, the numeric results mainly show the influence of transition length on forming force and strain distribution. Flexible multi-gripper and multi point die systems have the advantage of great conformability [25].



a b

Fig. 8. a. Geometry of the stretch block and the skin part, b. Major strain in the sheet at end of the trajectory [23].

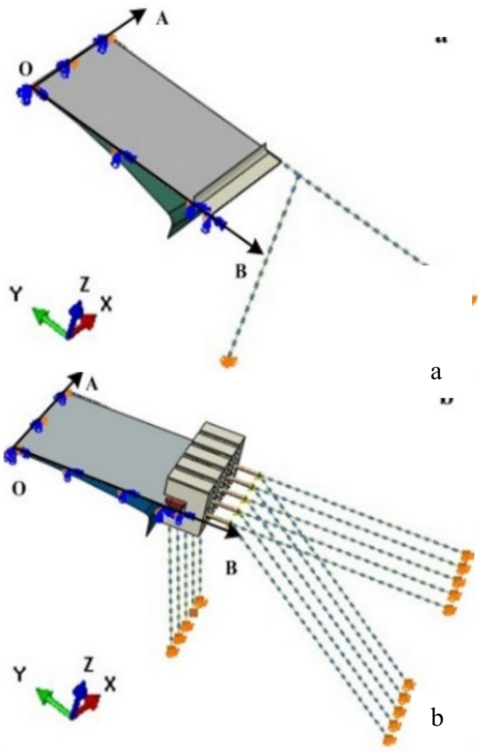


Fig. 9. Multi-gripper flexible stretch forming:
a – traditional stretch forming;
b – multi-gripper flexible stretch forming [25].

3. CONCLUSIONS

In the present paper the importance of stretch forming was discussed with regard its development, flexibility and various domains where it can be implemented. It was shown that the aviation sector has a great demand for stretch formed parts. The fact that this process allows the forming of large size parts taking into consideration that the accuracy of the design product can be achieved.

Other sectors that benefit from the stretch forming technology are architectural construction, automotive and naval. In constructions the technology is used when exterior of interior panels has to be made mainly just once. The fact that no building looks like other the manufacturing of a multiple number of dies is not economical viable, as they are very expensive to produce. In this case multi point stretch forming offers a viable solution with the possibility of adapting the shape of the die to the shape of every individual panel. In the case of naval construction large stretch formed panels toke the place of fiber reinforced plastics, as the toxicity of the process was a major setback for operators. The automotive industry uses stretch forming in small amount, as more of the exterior metal sheet body is manufactures on large stamps.

Multi point dies represent a normal development in this field. The results have shown significant improvement in the way sheet metal forming by stretch forming is conduction. Along with multi flexible gripping jaws the conformability of metal sheets has been highly improved. Another novel technique is a hybrid process that uses the benefits of single point incremental deformation along with stretch forming. It can be successfully used in part where grove and pocket have to be made, operation that are difficult to make using even multi point dies.

One major difficulty in deforming sheet metal is the spring-back that causes shape error in final product. This effect can be reduces if the material thickness is increased, while modifying the bending radius, reducing the punch travel distance, reducing the friction between blank surfaces and die surfaces by lubricant, etc. [26].

In the field of stretch forming the numerous researches conducted suggest that warm forming could cause the degradation of the process. It is necessary to take into consideration both factors (material strength and high coefficient of friction) have to be taken into account during warm forming [27].

For improving the formability of Mg alloys, the results prove that the multidirectional tensile twins induced by multi-steps compression has more yield compared with finite element simulations and it was concluded that these multidirectional tensile twins are induces by step by step compression. This improves formability of the magnesium alloy sheets [28]. This improvement is appointed to the tensile twinning that takes place at a specific grain size. When grain size is getting coarser it leads to impairment in matrix grains [29].

Regarding all that was analyzed in this review it can be concluded that stretch forming is a highly used process.

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