NEW CONFIGURATIONS OF THE SPIF PROCESS - A REVIEW

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Abstract: In the first part of the paper, some new configurations of the single point incremental forming process (SPIF) used to form lightweight materials are reviewed. In was found a significant lack of knowledge concerning the forming limits, the mechanism of deformation, the stress-strain state and microstructure, the influence of different process parameters on formability and parts accuracy. In the second part of the paper, the ability of a Zn alloy sheet to be processed by SPIF was investigated. A conical frustum was successfully formed but a significant springback affected the geometric accuracy of part.

Keywords: SPIF, lightweight materials

1. INTRODUCTION

One of the stringent problems facing our society is environmental degradation. The automotive industry has been played an important role to this, on the one hand by fuel consumption, a non-renewable resource, and on the other hand by the greenhouse gases, especially carbon dioxide, resulted from the fuels combustion that contributes to the greenhouse effect, the main cause of global worming. According to [1], transportation fuels account for up to one third of total anthropogenic CO2 emissions (Figure 1). Effective mitigation of global climate change requires action in this sector for which technology change options exist or are being developed.

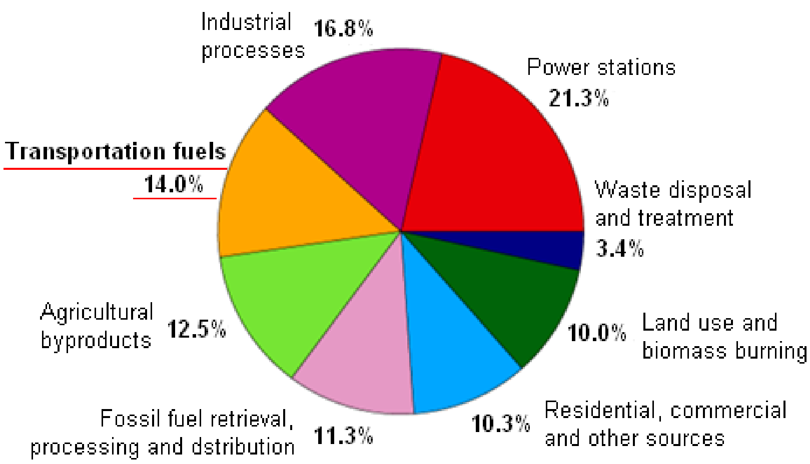

Fig. 1. Global anthropogenic greenhouse gas emissions broken down into 8 different sectors for the year 2000 [1].

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It is well known that fuel consumption is directly related to vehicle weight. Thus, reducing the weight of automobiles is one of the primary means by which their fuel consumption can be lowered. To address this problem, two basic approaches have been proposed by automotive industry and these are in automotive design and in materials selection. Regarding materials, there has been a trend toward the use of light metals and their alloys in automotive components, particularly automotive bodies, as a substitute for conventional steel and cast irons. Due to a high performance/weigh ratio, the light materials help to reduce the weigh of components. The most commonly used materials are aluminium, magnesium and their alloys, though some research has also been done on the use of titanium, zinc, metal-matrix composite castings and non-metallic materials.

The reverse of using light materials like magnesium or titanium, is that they introduce some criticisms, mainly related to the higher costs and to the lower workability at room temperature, especially for forming applications. But in the last few years a new trend is clearly emphasized in the metal forming industries, namely the development of flexible forming processes that allow processing even challenging materials like those mentioned above. One of the most recent and interesting processes is the single point incremental forming (SPIF), which assures an enhanced material formability due to the peculiar process mechanics [2].

2. SPIF OF HIGH STRENGTH MATERIALS

2.1. Process description

Single point incremental forming (SPIF) of metal sheets is a new cheap, flexible process that allows manufacturing sheet metal components without the need for expensive, dedicated tools. SPIF needs only a simple rig, positioned on the worktable of a CNC machine, to clamp the metal sheet, and a small tool with hemi(spherical) head whose movement is controlled according to fixed paths (Figure 2). Sometimes, a backing plate which has the circumferential shape of the part to be formed is used to increase the part accuracy.

The SPIF process is very suitable for rapid prototypes and small series production. Due to its characteristic of point-to-point forming it is quite slow and it cannot be used for the moment for mass production. Another draw back of the process is the lack of accuracy; since the largest aria of the material is unconstrained during forming, the part geometry may be very different from the desired one, especially when high strength materials are formed.

The main process parameters that influence the accuracy and the surface quality of formed part are: tool diameter (D_p), spindle speed (ω), feed rate (v) and tool vertical step down (Δz). By a proper choose of these parameters and by optimizing the tool path trajectory, a good quality of SPIFed parts can be achieved [3- 6].

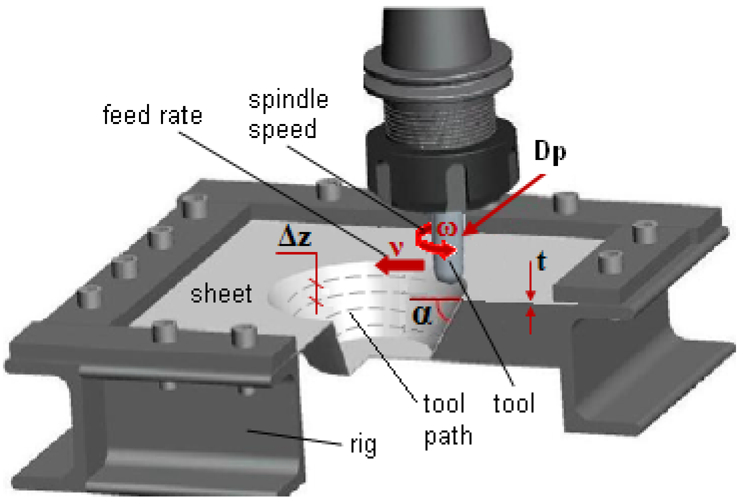

Fig. 2. The SPIF equipment and process parameters [adapted from 7].

2.2. Configurations of SPIF for processing high strength materials

2.2.1. Warm SPIF of magnesium alloys

It is well known that magnesium is the lightest structural metal, with a good to excellent corrosion resistance but with a lower formability at room temperature. That's why it is usually worked in "warm conditions", namely at a temperature ranging between 200 and 300^{o}C [8, 9, 10].

SPIF of magnesium alloys has been investigated by some researchers in order to test the process suitability and to fully utilize the formability of material. For instance, Ambrogio et al. [2] investigated the SPIF of AZ31-O sheet by carrying out experiments with a truncated cone with a major diameter of 100 mm, a depth of 40 mm and a minor diameter as a function of the wall inclination angle. The influence of three process parameters was analyzed: the punch diameter, the tool vertical step and the sheet temperature. The used equipment is presented in Figure 3. They found that a dramatic formability enhancement is possible forming magnesium in warm conditions: from a truncated cone of just 3 mm depth and 30^{o} wall angle obtained at room temperature to a fully depth of 40 mm and 60^{o} wall angle truncated cone formed at 250^{o}C. The main influence on formability was manifested by temperature and tool vertical step while the influence of tool diameter was found negligible in the investigated range (12- 18 mm).

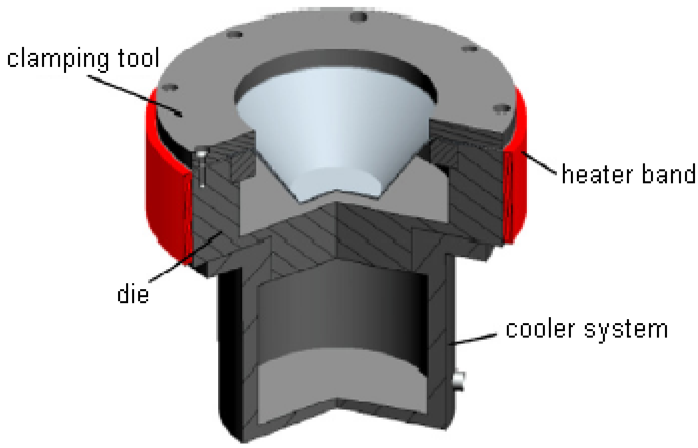

Fig. 3. The experimental equipment for warm SPIF of AZ31 sheet [2].

Ji and Park [11] also investigated the warm SPIF of magnesium AZ31 sheet by forming cones with various wall angles at a wide range of temperature, from 20 to 250^{o}C. They found that the formability increases as the temperature increases and introduced the concept of progressive forming to form by SPIF a circular cup.

Zhang et al. [12] investigated the influence of anisotropy of the magnesium alloy AZ31 sheets in SPIF. Four types of sheets fabricated by hot extrusion, slab + hot/cold rolling, strip-casting rolling and cross-rolling, respectively, were tested at elevated temperatures (150, 200, 250 and 300^{o}C). The authors found that the anisotropy of the sheets has remarkable effects on the formability and the surface quality of the formed parts, and that the effect becomes weakened with increasing temperature. They stated that the cross-rolling sheets are much more suitable for warm SPIF process. In a recent paper Zhang et al. [13] carried out a research in order to identify the most suitable lubricants and lubricating methods which can be employed to form a magnesium alloy AZ31 sheet by warm SPIF. They proposed two novel lubrication methods: application of the Nano-$K_2Ti_4O_9$ whisker and application of porous ceramic coating by pulsed anodic oxidation to the sheet surface. These suggested lubricating methods gave an excellent solid lubrication performance and good surface quality of the formed parts in warm SPIF process of the metal sheet.

2.2.2. Laser assisted SPIF

Duflou et al. [14] have been tested the effectiveness of a local, dynamic heating system with active cooling to improve the formability of high strength materials processed by SPIF. The key idea is to create a heated spot in the dynamic contact zone between tool and sheet, while keeping the rest of sheet at near the ambient temperature.

The used experimental setup is presented in Figure 4. The obtained results demonstrated that this variant of SPIF leads to reduced process forces, improved dimensional accuracy of parts and increased formability for a range of materials. The authors also concluded that appropriate settings of the local heating and cooling parameters leads to reduce residual stresses level.

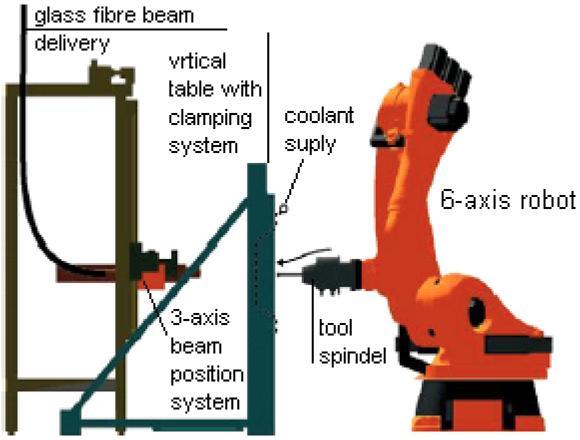

Fig. 4. SPIF with dynamic laser supporting heating [14].

2.2.3. Electric SPIF

To counter the costly laser set-up proposed by Dufou and his team, Fan et al. [15] proposed a cheaper alternative consisting in an electric heating system used for local heating of sheet at the tool-sheet interface (Figure 5). The authors tested the device suitability by forming a conical frustum with varying wall angle ranging from 30^o to 90^o, made by two high strength materials – AZ31 magnesium and $TiA_2Mn_{1.5}$ titanium alloy, respectively. They found that the electric SPIF is feasible and easy to control and that the process parameters (electric current, feed rate, tool diameter, tool vertical step size and resistivity) influence differently the formability: an increase in electric current increases formability while an increase in feed rate, tool diameter and tool vertical step can decrease the formability.

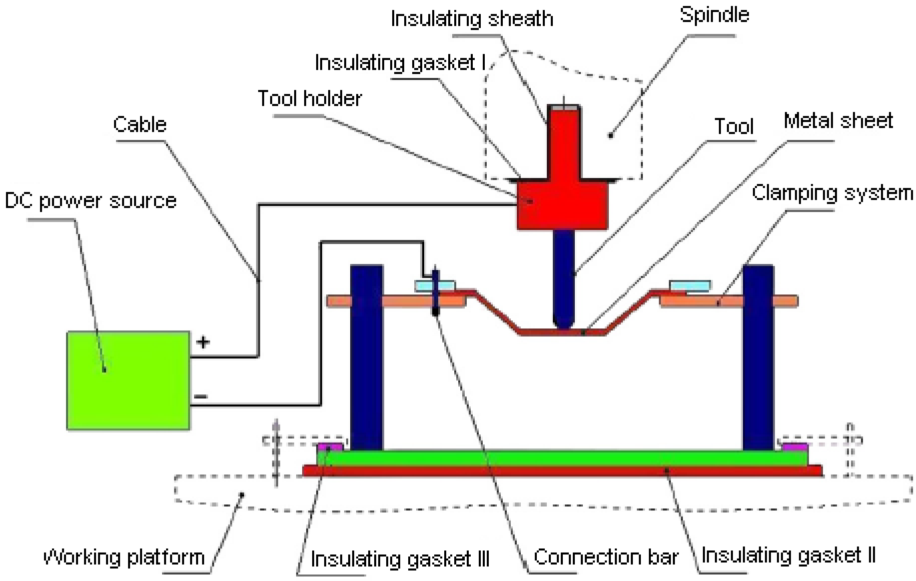

Fig. 5. The principle of electric SPIF [15].

2.2.4. Conclusions

Although the new configurations of SPIF are suitable to form high strength metals, one of the major drawbacks is losing of tooling simplicity and implicitly increasing of production costs.

The researches were mainly concentrated on the feasibility of these new configurations of SPIF and few or no studies concerning the forming limits, the mechanism of deformation, the quality of formed parts in terms of geometric accuracy and surface quality, have been performed.

3. TESTING THE FEASIBILITY OF SPIF OF A Zn ALLOY SHEET

3.1. The used equipment and the working parameters

The test was performed on a CNC milling machine RAPIMILL 700 (Figure 6). The rig used to clamp the sheet and the forming tool are presented in Figure 7. The tool has a hemispherical head in order to assure a punctiform contact with the sheet and was made on C120 steel.

Fig. 6. CNC milling machine.

Fig. 7. The rig and the forming tool.

The working parameters were the following ones: the spindle speed – 1800 rpm, the feed rate – 30 mm/min, the tool vertical step - Δz = 0.5 mm, the tool diameter – 10 mm, lubricant – organic grease. The tool movement has been done according to a contour tool path in the clockwise direction (Figure 8).

3.2. The part geometry

The part chosen to perform the experimental test is a pyramidal frustum whose geometry is presented in fig. 8. The used sheet specimen had the following dimensions: 150x150x0.4mm.

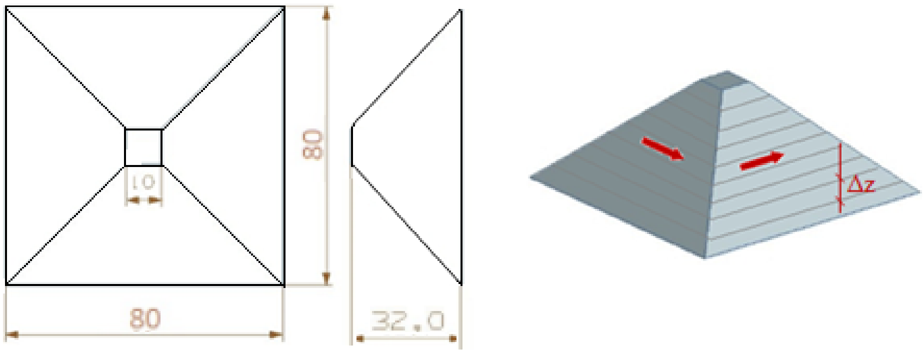

Fig. 8. Geometry of part.

3.3. The obtained results

By using the working parameters mentioned above it was possible to obtain the conical frustum without the failure occurrence (Figure 9). But due to the relative small dimensions of part compared to the sheet sample and because no backing plate was used to support the working aria, a significant springback resulted at the end of forming (Figure 10).

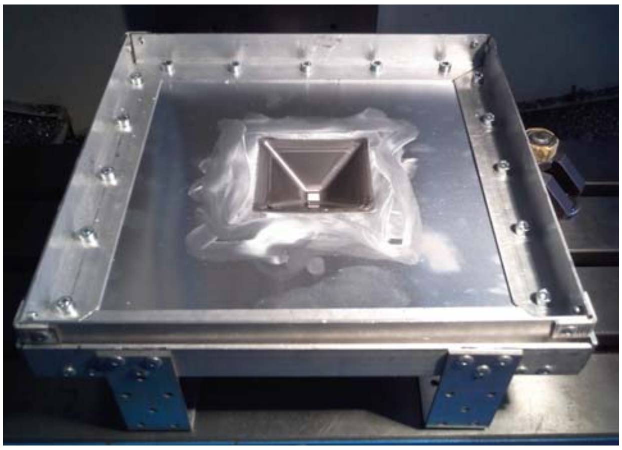

Fig. 9. Obtained part.

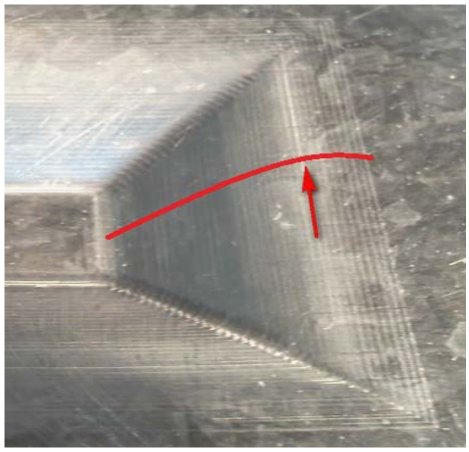

Fig. 10. Significant springback.

4. CONCLUSIONS

In the present paper different configurations of the SPIF process used to form lightweight materials were reviewed. The main advantage of these innovative configurations is that they allow manufacturing complex parts in short series production more economically than conventional forming processes. But, compared to the "classical" SPIF, they are more expensive.

Until now, the researches have been limited only to test the suitability and the feasibility of these innovative configurations so that many open questions remain concerning the mechanism of deformation, the forming limits, the influence of process parameters on the quality of parts, the residual stresses distribution since they are the main cause of springback.

In the last part of the paper the ability of a Zn alloy sheet, ticker of 0.4 mm, to be processed by SPIF was investigated. The part could be successfully formed but its geometry was significantly affected by the spingback phenomenon. Thus future experimental research will be performed in order to investigate the influence of process parameters on the part accuracy and to find the proper optimization method which leads to desired results.

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