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Review on Micro Incremental Sheet Forming

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ABSTRACT

Microforming becomes utmost important in the recent technology innovations to manufacture miniaturized products. Micro Incremental sheet forming (μISF) is an emerging metal forming technology in which numerically controlled tool motion locally deforms the metal and results higher formability than the conventional stamping process. Three dimensional miniature components can be economically made without using a specific dies, provides a competitive alternative in the potential application areas of aerospace, biomedical, automotive, home appliances, marine and prototyping industries. This article is aimed to discuss the present state-of-the-art technologies, potential applications, inadequacies and scope for valuable contributions in the field of μISF.

KEY WORDS: Forming, Micro incremental sheet forming, Sheet metal forming, Review.

1. INTRODUCTION

Micro forming is defined as the production of metallic parts by forming with at least two part dimensions in the sub millimetre range. Today's trend of product miniaturization, increased the importance of state-of-the-art micro part manufacturing. Research on this area over the recent decade has been moved from "process and technology focus" to "market/product"-driven activities.

In the Micro Incremental Sheet Forming (μISF), the miniature features on sheet metals can be fabricated using CNC controlled hammering, piezoelectric-actuated micro-probes for dimpling (high frequency vibration actuated). Only the CAD data is used to control the path of tool for making complex shapes. No dies are required, but a backing plate is needed to establish some clearance angle transition in the sheet surface. Since the deformation mechanism is incremental in nature, this process can stretch even low formable metals. It is much user friendly but possesses some longer forming time, multi-step approach, dimensional accuracy due to continuous spring back phenomenon. It is applicable only for small and medium batch size. Because of the size of the produced parts is comparable with the grains of material used, resulting in hard to control material behaviour. The very small volume of the parts changes the failure behavior due to different probability of happening of a defect in a particular workpiece, if homogeneous defects with low density exist in the raw material. As precise handling is necessary for joining operations, joining is less desirable. Therefore parts should integrate multiple functions to reduce the components in an assembly and reduce the number of handling as well as joining operations. In turn, it support in a more complex design of at least the intermediate phases of the product. As an example, interconnected multiple parts are manufactured as one workpiece, which are separated after assembly to achieve independent electrical functions. Instead, the small weight might need more expensive materials. This is also true for micro forming tools, which may be manufactured from a single crystalline diamond. Confirmation to the required feature is difficult task compared to macro parts, as many methods usually employed may not be possible in the measurement of micro part dimensions. Also the (scaled down) tolerances interfere greatly with the precision of the metrology, using the methods like statistical process control (SPC) impossible.

Size Effects: Since the reduced scale from the conventional to the submillimetre range, sheet's micro-structure and its surface topology, remain unchanged. So, the ratio between the part dimensions and micro-structure or surface parameters is changed, called size effects. It is generally difficult to predict and control deformation behaviour of the microscale material due to the small size of deformed parts. Moreover, more interactive factors are influencing the material deformation, namely tooling-workpiece interface condition, grain size, workpiece size and feature size. Also they affect the micro forming process in terms of deformation load, stability of the forming system, dimensional accuracy, mechanical properties and surface finish of the formed micro parts. In micro forming, the surface-to-volume ratio increases by reduction in workpiece size, which makes the ejection of workpiece from die difficult. Furthermore, the adhesive forces on part surface prone to stick with forming tools, leading to the difficulty in handling the micro-sized workpiece between operations. Material handling between forming operations is thus of particular concern as it affects the positioning of micro formed preforms prior to the next forming operation and the achievement necessary dimensional accuracy.

Though the many researches explored the material deformation behavior in micro forming processes, performance prediction optimizing the parameters related to part design, process determination, design of forming tool, and quality control are nontrivial since the interaction of different size effects is very complicated and there are still many unknown physics phenomena behind the size effects. The design and development of micro forming processes thus required to consider these factors. Next chapter explains the state-of-the-art micro forming processes recently developed.

Single Point Micro Incremental sheet forming: A new Single Point µISF machine (Figure 1) was developed in with seven main elements called, x-y table, z stage, θ_x and θ_y Gonio stages on the x-y table, motor spindle, blank holder and base. The conventional desktop CNC milling machine was used for their study. The work materials used were A8021 aluminium foils (AL-2, AL-3 and AL-4), a commercially pure aluminium foil AL-5 and a pure gold foil GL-1 with thickness of 12, 12, 6.5, 0.8 and 2.5 µm respectively. The tip radius of 10, 20 and 100 µm cemented carbide tool were used µISF in their study (Figure 2). Since the forming limit of a blank could decrease with increasing tension applied to the blank, Obikawa (2010), developed a special HT type blank holder without using backing plate. Pure water was used as lubricant for avoiding adhesion and abrasion. Due to low viscosity, deep penetration at the narrow gap of high hydrodynamic pressure becomes easier that high viscous lubricants. Obikawa (2010), formed pyramids as an example of micro shells with different base size (L = 50 to 100 µm), height (h), half apex angle (θ = 26 to 64°) on different blank thickness (t) and analysed the influence of tool rotational speed (ω+ clockwise and ω- counter clockwise rotation = -60,000 to 30,000 min^{-1}), table speed (v = 0 to 1 mm/s) and axis feed (dz = t) per planer tool path (dx and dy). The process of SPµISF and sample miniature pyramids developed by Obikawa (2010), is presented in Figure 3. Also the miniature number 3 and letters D, T, U were formed on aluminium blanks. Results show certain amount of fluctuation in forming limit with tool rotational speed. It would be due to low rigidity of forming tool because of a straight shank. The lower rotational speeds at 3000 min^{-1} proved maximum forming limit. It was concluded that SPµISF is applicable to the miniature products of 100 µm in size although the relative shape accuracy decrease with decreasing the size of a product. As the size the pyramid was decreased the roughness of its surface became noticeable. From the series of experiments, the optimum parameter values has been approximated as $dz \simeq t$ when $L \geq 100t$; $dz \simeq L/100$ when $L < 100t$; $\omega \simeq 20000$ when $L \geq 55t$; $\omega \simeq 30L$ when $L < 55t$; $v \simeq 0.000015\omega$ where dz, L and t are defined in µm. The severe shear deformation localized in the thin surface layer, involves the crystal grains and results the surface layer with finer crystal grains. It increases the flow stress and the strain hardening coefficient, leading to extremely high formability even if aluminium foil is very thin.

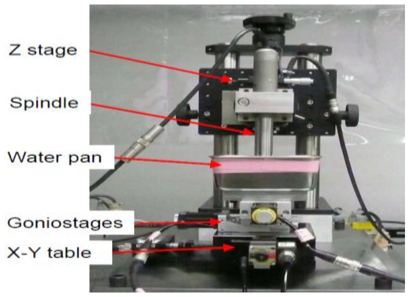
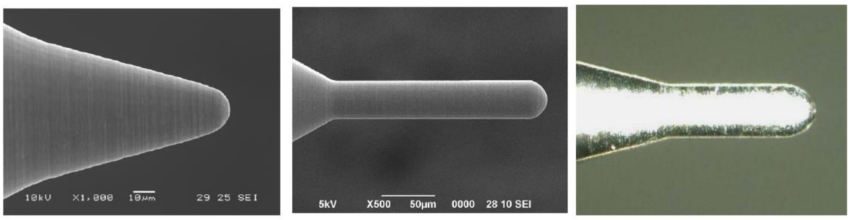


Figure.1. SPµISF machine developed



(a) R = 10 µm (b) R = 20 µm (c) R = 100 µm

Figure.2. SPµISF tool used

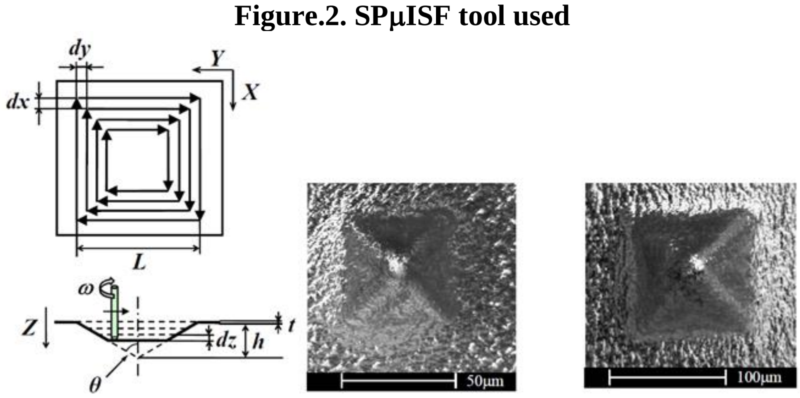


Figure.3. SPµISF process and sample pyramids

The formability evaluation was done through SPµISF of three polygonal pyramids: triangular, pentagonal and nanagonal complex shell structures. The manual rotary table placed on the z stage is controlled by tilt angle of the forming tool. The contact between the tool and blank was detected accurately by a simple electric circuit shown in figure 4. The tool path for a forming shape was clearly developed. The tool and foil contact and re-contact lengths are geometrically presented and concluded that a large area of re-contact area is responsible for pinholes or cracks nucleated on a foil. The difference in forming shape increases the damage effect as the processing area decreases to micro range. The conditional forming limit was attributed to the adverse interaction between two adjacent pyramids formed on a blank, thus the range should be taken into account in case of the forming of plural number of shell structures on a blank.

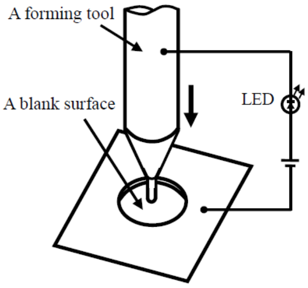


Figure.4. Tool Electric circuit

Otsu (2007), formed pure Ti foils (7mm x 1mm x 10μm) by means of a hemispherical diamond tool with a radius of 5μm, using the piezo actuator (Figure 4). Plural indentations were carried out linearly. Micro-incremental forming was performed by changing forming pitch, forming load, line pitch and line number. Effects of forming load, forming pitch, forming line pitch and forming line number on bending angle were investigated and the results shown that although bending angle was greater as forming load increased, increasing rate became small when the indentations overlapped each other. When forming pitch was larger, bending angle became smaller, however, the effect of forming pitch on bending angle was not large. Bending angle had a maximum peak when forming line pitch was changed in plural line forming.

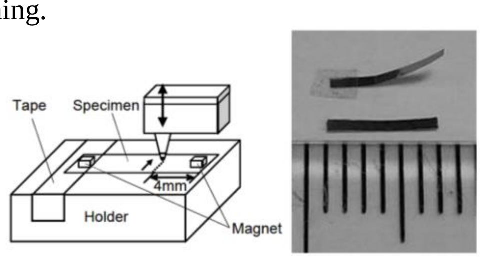


Figure.5. SPμISF and the formed specimen by Otsu (2007).

Saotome and Okamoto (2001), developed a SPμISF system for foil materials. Incremental bending and bulging deformation of sheet metal was generated by hammering (figure 6). Using this system, they formed a 600 fm long micro-car body shell without dies in a scanning electron microscopic field of view.

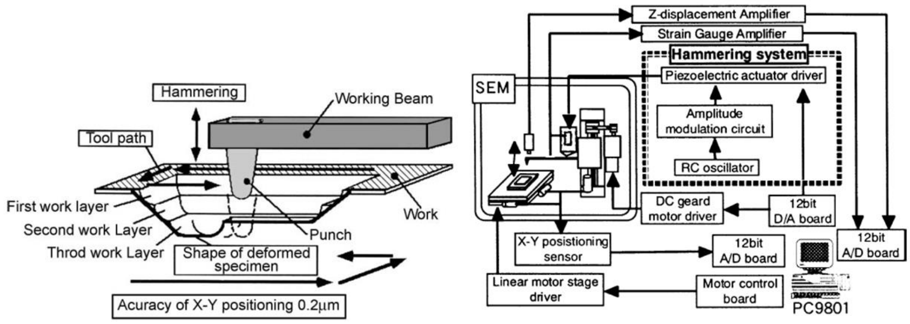


Figure.6. SPμISF hammering system by Saotome and Okamoto (2001)

Song (2012), utilized the incremental plastic forming technique to form herringbone type radial grooves on the shaft in high-precision micro-fluid dynamic bearings. The groove was uniformly shaped with depth of 3 μm considering the elastic recovery while excluding the tip area. In addition, the simulation results were validated by experimental results. Lee (2007), applied SPμISF to a substitute method of Micro Electro Mechanical Systems using a 5-axes CNC system that composed of precision AC servo motor stages (4-axes) and PZT actuator (1-axis). A PZT actuator was used in a precision actuating axis because it can be operated in the nano scale stroke resolution. This micro die less incremental forming system had the advantage of minimization in manipulating distance and working space. As equipment and tools become smaller in size, minute inertia force and high natural frequency can be obtained.

Based on the above discussion, some useful observations and guidelines for μISF can be summarized as follows.

- Only the SPμISF has been reported so far whereas μISF can also be attained by Two Point μISF, and Hybrid μISF.
- Only Aluminium, Titanium and Gold sheets are analysed in μISF. This analysis may be extended on all other types of materials like Magnesium, Polymer etc.
- The forming path and tool path strategy must be explained and optimized in possible applications like geometry accuracy.
- Only the rigid hemispherical end tool is practised in SPμISF. It can be extended with multi head, electric hot, laser spot and flat end tools.
- The mechanism of formability limits in terms of tool failure and failure must be evaluated in detail.
- Simulation of μISF in terms of numerical, parametric and optimization modes must be developed.
- Although spring back is hard to measure in micro level, it can be mentioned as a major subject.
- The size effect, feature effect and grain orientation will be highly important in terms of μISF. They need to be addressed in all types of methods.
- The effects of process parameters of μISF not yet been started.
- The control mechanism, measurement instruments, failure theories must be explained in detail.

CONCLUSION

Review of μISF process has been presented with only limited number of publications. By summarizing all the previous works, the characteristics of proposed new μISF machine have been highlighted. It was found that significant progress has not yet been achieved in understanding as well as modelling the μISF process itself. There are more number of areas that have to be resolved or investigated in the design and development associated with each factor. It is hoped that this proposed literature review will give a quick idea about the research areas in μISF and will provide the researchers with a clear vision and indications for the research area that they should focus on.

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