15th IMEKO TC10 Workshop on Technical Diagnostics
Technical Diagnostics in Cyber-Physical Era
Budapest, Hungary, June 6-7, 2017

Fracture diagnostics for Single Point Incremental Forming of thin Aluminum alloy foils

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***Abstract* – Nowadays many industrial sectors, as automotive or aeronautic industry, use forming processes in order to produce sheet metal components. The most widely used are the stamping process and deep drawing, based on big and costly dies and presses.**
A specific application, the Single Point Incremental Forming (SPIF), for sheet metal forming will be discussed in this paper.
Force estimation on AlMn1Mg1 sheets with 0.22 mm initial thickness is performed by continuous monitoring of servo motor currents.
The aim of this research work is to apply a non-traditional force monitoring on Aluminum alloy foils and detect fracture.

I. INTRODUCTION

Incremental Sheet Forming (ISF) is similar to metal spinning which dates back to a patent [1] granted in 1967. However, unlike metal spinning, where the sheet is formed on a lathe to an axial symmetric object by rotating and incrementally formed with a tool, in ISF the sheet is pressed down with a clamping frame and formed with a tool ending in spherical or flat head. In this process the final shape of the workpiece is not determined by a specific die, rather by the three-dimensional movement of the forming tool, for which an appropriate tool path has to be calculated, based on the workpiece geometry.
ISF aims at an innovative concept of sheet metal forming in short and medium volume of production, not for long series, where stamping or deep drawing are well established. ISF has two main groups (Single Point Incremental Forming – SPIF, illustrated in Fig. 1a – and Two Point Incremental Forming – TPIF, illustrated in Fig. 1b) and it is still an interesting research topic because of its extreme and complex mode for deformation, the flexibility of the process and the high forming limits compared to traditional forming processes.

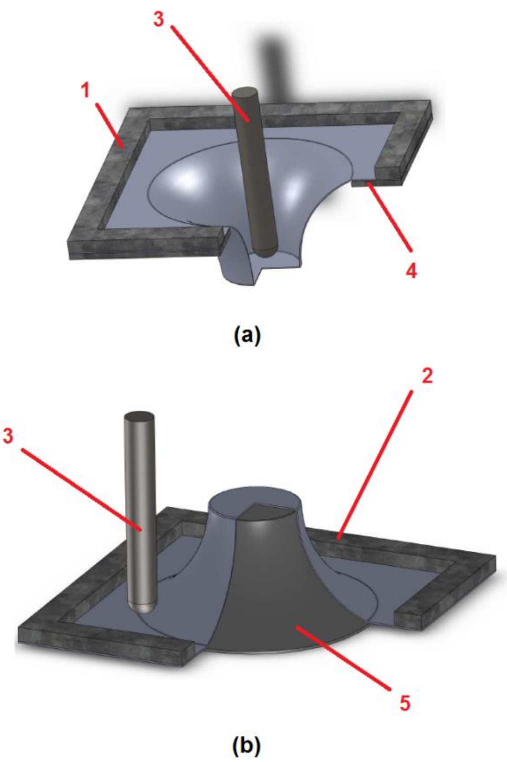

Fig. 1. Illustration of (a) SPIF, (b) TPIF with 1: stationary blank holder,2: moving blank holder, 3: forming tool, 4: backing- or faceplate, 5: stationary or moving, full or partial die

Excessive thinning of the material during forming processes could lead to cracks. To overcome fracture by necking, excessive thinning should be detected in real-time. Some research works are dealing with experimental study on force measurements for SPIF like [2] or [3], but only a couple of them are focusing on sheets with initial thickness less than 0.5mm [4-7]. The goal of this study is to apply a non-traditional force monitoring on AlMn1Mg1 foils to detect necking and cracks.

II. EXPERIMENTS

A set of experiments were carried out on a Rieckhoff CNC milling machine, the forming tool and a fast-clamping system is shown in Fig. 2.

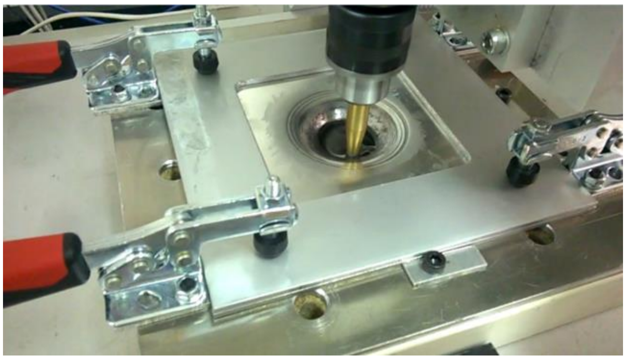

Fig. 2. Set-up of SPIF experiments.

The number of experiments required to determine the forming limit of a sheet can be reduced by using a part geometry with variable wall angle as claimed in [8].
For this reason, a conical frustum with circular generatrix was design as shown in Fig. 3.

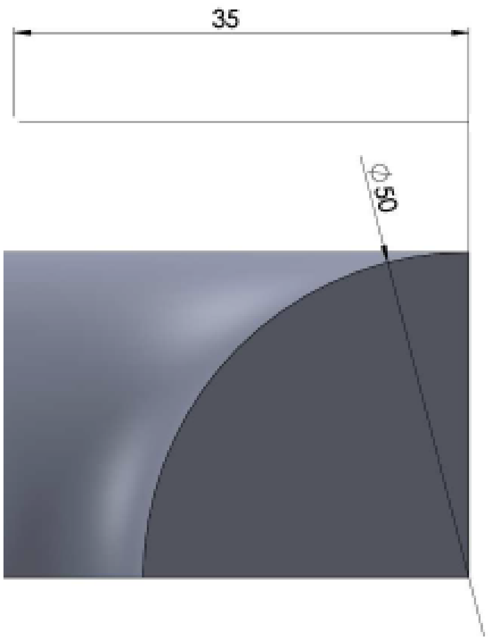

Fig. 3. Half of the conical frustum.

A. Control and data acquisition

The CNC Machine control was realised with an open-source Real-Time Control Software called LinuxCNC.
LinuxCNC uses a Real-Time Application Interface (RTAI) with several Modules and a Graphical User Interface (GUI) – see Fig. 4 – for motion commands interpretation.

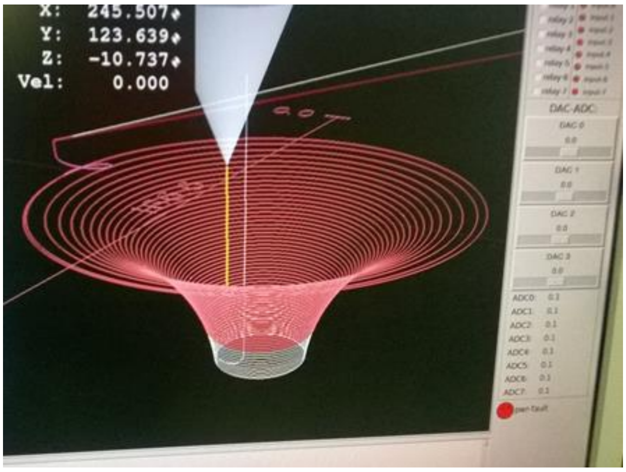

Fig. 4. Photo of the LinuxCNC GUI showing a helical SPIF toolpath.

Communication is solved through Neutral Messaging Language (NML) channels, except for the Hardware Abstraction Layer (HAL) which allows a number of "building blocks" to be loaded and interconnected to assemble a complicated system.
Fig. 5 shows a simplified System Architecture Diagram of LinuxCNC by Kent A. Reed [9].

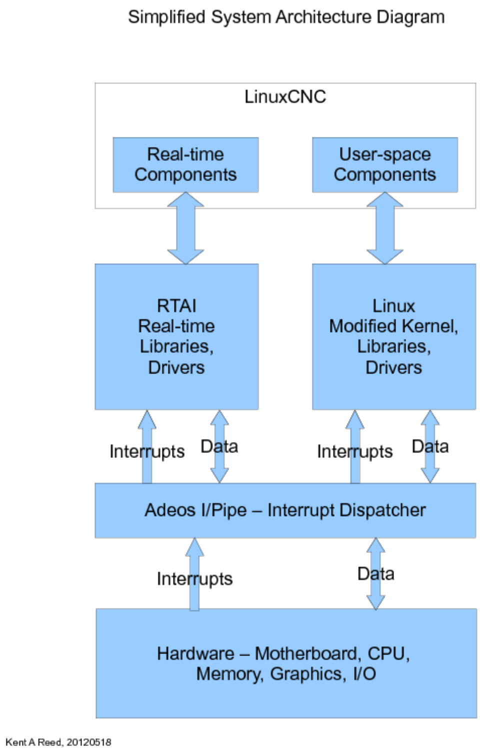

Fig. 5. Simplified System Architecture Diagram of LinuxCNC [9].

This control allowed to send the tool coordinates to a data acquisition program which collected also the Servomotor data of the Z-axis.

Previous experiments using direct force measurements on a 0.5mm thick Aluminum (Al1050) sheet with SPIF, applying a Z-level toolpath (see Fig. 6), showed that there is a significant change in the reaction force at the end of the forming.

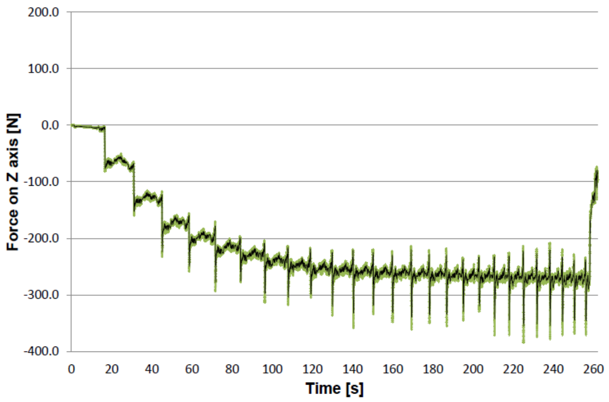

Fig. 6. Direct force measurement results (using a JR3 force cell) on the Z axis, SPIF of 0,5mm thick Al1050 sheet.

Current measurements were realised with a 0.33 Ohm electrical measurement resistance. From Ohms law the voltages on the Z axis can be obtained.
By using the data of the motor and the drive train, the force applied by the axle as a function of the motor current can be calculated. Z axis loads were obtained to monitor the necking and fracture as in [10]. Similar methodology was used by Rauch et al. [11] to evaluate tool loads in a parallel kinematic machine.

Fig. 7 shows a dataset with at least 30 measurement points per second (blue points) and a moving average with 16 periods (black curve). The first values of the measurement (before the forming started) were around 82 mV. Necking occurred at several points during the forming (values between 50 mV and 75 mV) but without fracture. An arrow is indicating the values of the fracture.
Experiments were carried out applying a hemispherical tool of 2.381mm in diameter, 500 mm/min forming speed and helical toolpath with 0.1mm incremental pitch. Fortilmo ADD 20 was applied as Lubricant.

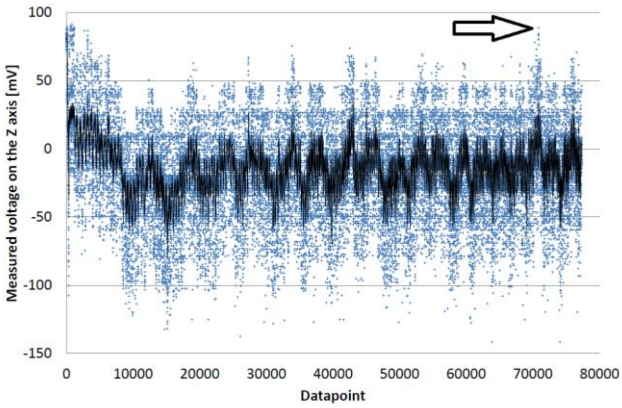

Fig. 7. Measured voltage on the Z axis indicating the values of the fracture.

In some cases, the part can be formed further without removing the end of the geometry. Fig. 8 shows the result of such a forming. An arrow pointing at the fracture.

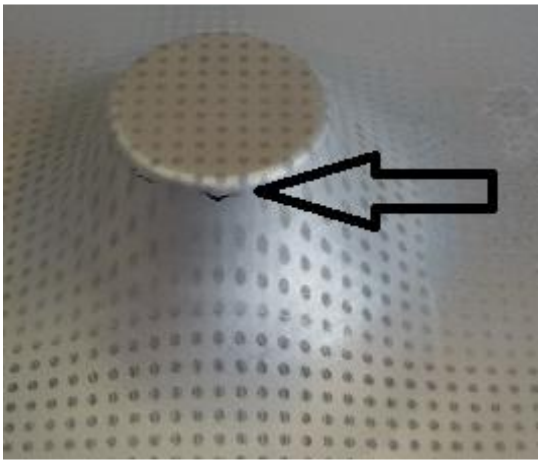

Fig. 8. Result of the forming with fracture.

In this case the forming tool moved further along the programmed tool path and the measured voltage showed no sign of a fracture (see Fig. 9).

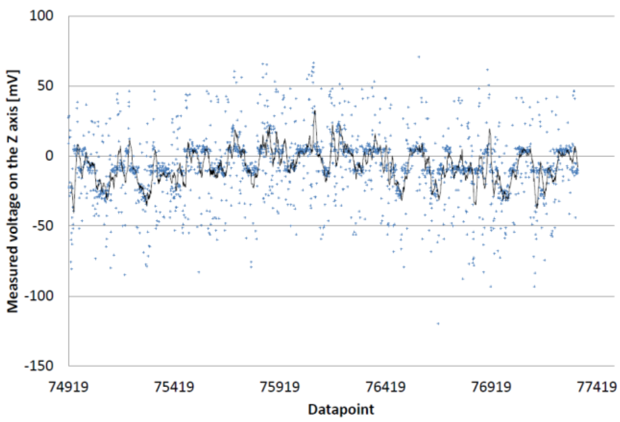

Fig. 9. Signals at the end of the forming, after fracture.

In case the forming tool continues to open the crack, a circumferential straight propagation path appears (Fig. 10) similar to that usually found in conventional stamping or deep drawing operations (and it is a clear evidence that crack opening is triggered by stretching mechanisms due to meridional tensile stresses) [12].

Fig. 10. Crack with circumferential straight propagation path.

A proper lubrication is indispensable, otherwise continuous presence of metal swarf can occur, surface roughness gets too high and forming depth drops down. Fig. 11 shows the result of a typical dry forming.

Fig. 11. SPIF result without lubrication.

The obtained results are similar to Incremental Forming outputs with thicker sheets.

CONCLUSIONS

In this paper, a non-conventional sheet forming application with the name Single Point Incremental Forming (SPIF) has been conducted.

The monitoring of servo motor currents during the forming of AlMn1Mg1 foils with 0.22 mm initial thickness allowed the estimation of the forming forces on the Z axis.

Results regarding the estimation of fracture caused by necking are consonant with the results obtained in SPIF of sheets equal or thicker than 0.5 mm.

Further investigations could be conducted to study the influence of other materials and geometries.

ACKNOWLEDGMENT

The work presented here has been supported by grants of the Highly Industrialised Region in Western Hungary with limited R&D capacity: "Strengthening of the regional research competencies related to future-oriented manufacturing technologies and products of strategic industries by a research and development program carried out in comprehensive collaboration", under grant No. VKSZ_12-1-2013-0038.

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