Formability evaluation of a pure titanium sheet in the cold incremental forming process

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Abstract Owing to its ability to deform a sheet metal locally, the single point incremental forming (SPIF) process produces larger deformations as compared to the conventional forming processes. In the present study, we investigated the effect of some process parameters – pitch, tool diameter, feed rate and friction at the interface between the tool and blank – on the formability of a commercially-pure titanium sheet. Trends between the process parameters and formability are presented in this paper.

Keywords Incremental forming · Formability · Process parameters

1 Introduction

Along with the conventional stamping processes, which are now-a-days still used in the mass production of various products, several dramatic changes in the last few decades have occurred in order to satisfy many new relevant and prevalent market demands. The production of customized products, the increasing demand of process flexibility and the necessity to reduce the time to market the products are probably the most significant requirements of the present era. On the other hand, metal stamping processes have traditionally been characterized by the relevant equipment capital and the tooling cost. For these reasons, the industrial applications have to be economically justified with a large-scale production. Furthermore, stamping cannot fully satisfy the demand of flexibility.

The aforementioned considerations clearly show that the current metal stamping processes may maintain a relevant role in the modern production routings only if cheaper and more flexible technologies are developed. A great deal of research is being carried out in order to achieve such objectives. In the last few years, many sheet metal forming techniques have been under study so as to develop the novel forming processes characterized by high flexibility such as laser forming, water-assisted forming and single point incremental forming (SPIF) [1–6]. Among these innovative processes, SPIF has been studied intensively.

In the simplest form of the SPIF process, the final component shape is determined by the relative movement of a small punch with respect to the blank rather than the die shape. This process is usually carried out on CNC machines where it is possible to assign and control the punch movement according to the fixed paths [4–7]. The process has two variants: (1) Single point negative incremental forming (SP-NIF), and (2) single point positive incremental forming (SP-PIF). In the latter, the blank is supported with a die that increases the probability to produce parts with sharp corners [8].

Its flexibility and low-cost tooling renders SPIF more economical than spinning, which had been considered as an economical process to produce axisymmetric components in small batches [9–10]. In addition to this, the SPIF process can be employed for a variety of applications as found in the literature [11–14]:

- It is a very economical process for rapid prototyping.
- The process is capable to manufacture a variety of irregular-shaped components and highly customized medical products.
The method creates large regions of homogenous deformation and avoids the large stress and strain gradients. Due to this fact, a specimen formed by the process is considered to be more reliable to calibrate a void nucleation model than the tensile specimens.

Several studies have been carried out on the formability in SPIF [15–22]. Shim and Park [17] performed finite element and experimental analyses and concluded that the deformation imposed by the forming tool is confined to the vicinity of the contact area with the sheet. This shows that the formability in SPIF is not affected by varying the blank size. This was also verified by Strano et al. [18], who formed a series of cones by varying the base curvature and found that the formability remains unaffected. Kim and Park [19] investigated the effect of some process parameters on the formability of an aluminum sheet. However, they did not study the effect of horizontal feed rate. Both Strano et al. and Kim et al. drew forming limit curve (FLC) to represent the formability in SPIF. In the present study, however, the formability was defined as the maximum wall angle ($\theta_{\text{max}}$, which is a practical forming parameter) that a sheet would endure without fracturing. The effect of most of the process variables on the cold formability of commercially-pure titanium (CP Ti) sheet has been addressed adequately. However, the effect of sheet thickness could not be investigated due to un-availability of sheets of different thicknesses. The varying wall angle conical frustum (VWACF) test, as reported in Hussain et al. [20–22], was employed in order to evaluate the formability ($\theta_{\text{max}}$).

2 A brief introduction of the formability test [20]

As mentioned earlier, the varying wall angle conical frustum (VWACF) test was employed to determine the SPIF formability of CP Ti. This innovative method makes use of a curved-line-generatrix to generate a revolved surface whose wall angle varies continuously (see Fig. 1). The surface is expected to fracture on a point $D(x_d, y_d)$ before reaching the designed depth. According to [20], $C(x_c, y_c)$ is a transition point after which the actual thickness of the part begins to disobey the sine law. Hence, the wall angle on this point is regarded as $\theta_{\text{max}}$.

![Fig. 1 Illustration of the formability test: (a) 2D view of the ruled surface, and (b) A section view of the fractured specimen formed to test the formability of an aluminum sheet [20]](image1)

![Fig. 2 The experimental set-up](image2)