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Original Research Article

Performance evaluation of high-speed incremental sheet forming technology for AA5754 H22 aluminum and DC04 steel sheets

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ABSTRACT

Incremental sheet forming (ISF) has received tremendous attraction in industrial, academia and research segments due to its inherent advantages. To deploy ISF technology in the manufacturing sector, various aspects have to be addressed such as geometrical accuracy, non-homogenous thickness distribution, and process slowness. In this study, extensive experimental work was performed to satisfy the industrial requirements. The influence of forming parameters (step depth, forming wall angle and feed rate) was investigated to access the ISF feasibility at higher speeds when forming the AA5754-H22 aluminum alloy and DC04 steel. The surface roughness, thickness distribution, and microhardness tests were carried out for the samples, which were successfully formed at the higher levels of process parameters. These experimental results were obtained at different locations on the sheet after forming. The analysis has revealed that the possible reduction in the execution time is up to 84% faster for AA5754 H22 aluminum alloy and 74% in case of DC04 steel. In this way, the current study not only provides the necessary framework for the future development of ISF but also commercialization of this technology.

1. Introduction

Sheet metal forming is a demanding technology in aerospace, automotive, marine, and nuclear sectors. In the conventional forming technique, the dies and punches have been made based upon size, the shape of sheet metal product to be obtained and their suitability for mass production. The cost of dies and punches is a capital investment, and that can be shared with a number of formed products [1]. Nowadays, the single point incremental forming (SPIF) techniques (see

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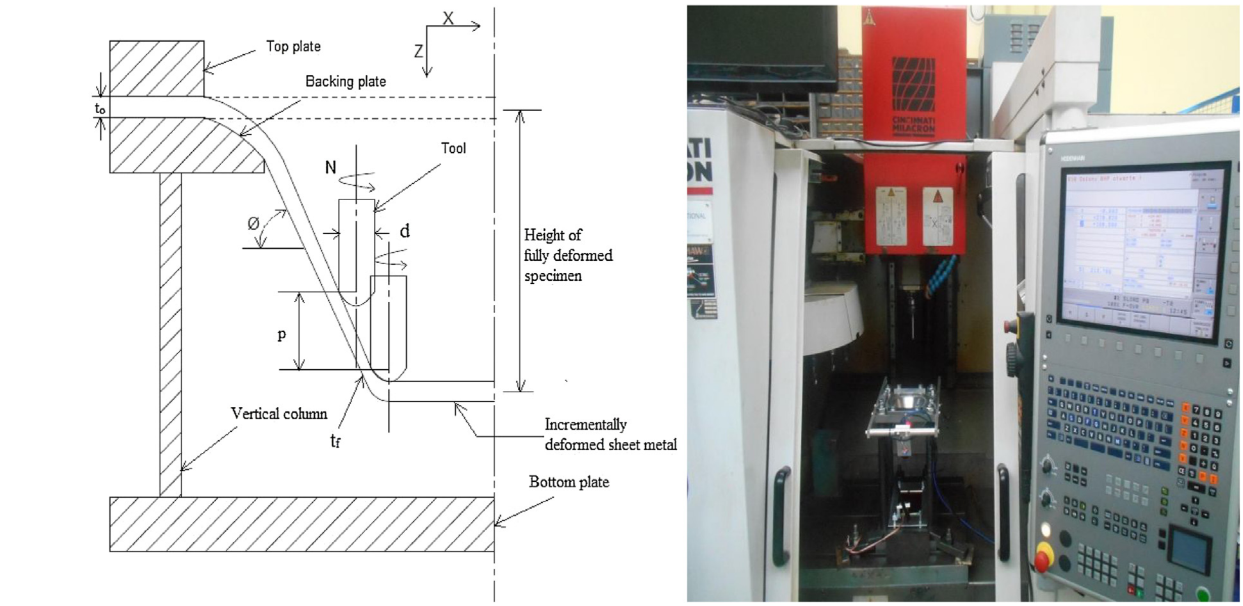

Fig. 1 – Schematic diagram of SPIF process [26] and utilized CNC equipment during forming. From Mulay et al. (2017); reprinted with permission from Springer.

example in Fig. 1) have received a great attention due to the advantages over the conventional processes such as higher formability, lower forces, production flexibility, rapid prototyping and cost reduction, etc. However, this technology has few limitations like process slowness, material thinning and dimensional accuracy [2–4]. SPIF is a very flexible sheet forming process, which economically forms the sheet metal into the desired shape for small batch production. SPIF performance is greatly affected by tool motion, process parameters, lubrication, and thermal effects, etc. It is important to know about fracture point in SPIF to take advantage of increasing formability by incorporating choice and values of process parameters during the actual production. Incremental sheet forming (ISF) has process parameters like tool rotational speed, sheet thickness, feed rate, step depth, and responses are like surface roughness, formability, forming forces, etc. SPIF is also called as a die-less process because all the information about geometry comes from a path of forming tool not by supporting die. The deformation in this process is equal to a summation of local plastic deformations created by the tool. This process uses the CAD data that represent the desired part. Spindle speed, table feed, and step depth can influence the magnitude of friction generated between tool and sheet interface. The large tool diameter requires higher force to deform sheet surface than the small tool diameter, which affects the process performance. In the case of sheet thickness, it can be obviously understood that larger sheet thickness will show higher formability because of more material available to flow under same forming load. According to material incompressibility and geometrical consideration in the forming process, sheet thinning may be modeled using sine law [5]. Due to repeated loads during the SPIF process, the shearing and stretching of the sheet cause thinning which leads to fracture and the former can be approximated by sine law:

$$t_f = t_o \sin(90 - \varnothing) \tag{1}$$

Eq. (1) considers only initial thickness (t_i) and instantaneous forming angle (Ø), neglecting all the other process parameters for the approximate estimation of final thickness (t_f). The parameters involved in Eq. (1) are presented in Fig. 1. To consider this technology in real-time applications, it is always necessary to manufacture a product with a higher formability and best surface quality.

From the available literature, it has been observed that a lot of work was performed on the fundamental mechanism of SPIF to know production, quality, and viability. The effect of lubricant on the surface quality of aluminum 1050 and steel DP780 sheets in ISF was studied by Azevedo et al. [6]. They performed experimental investigation by employing lubricants such as mineral oil, petroleum oil, paste lubricant and lithium based grease. They developed a relation between the material hardness and lubricant viscosity to get smooth surface roughness. An experimental study was carried out by Bhattacharya et al. [7] to investigate the effect of process variables on surface finish and formability obtained during ISF. Mirnia et al. [8] have shown that thickness distribution can be predicted by sequential limit analysis faster than any other FEM software. Experimental and simulation results were compared to check the reliability of the model for single stage and multi-stage SPIF. They concluded that the significant improvement in distribution of the cone thickness is possible by implementing a new multi-stage technique in comparison to single stage and conventional three-stage forming strategy. Gulati et al. [9] worked on optimization of process parameters to get the desired level of formability and surface roughness by using Taguchi's L_{18} array. They performed experimental work by incorporating maximum possible process parameters such