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Investigations on structural thinning and compensation stratagem in deformation machining stretching mode

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Abstract

Deformation machining (DM) is a combination of thin structure machining and single point incremental forming/bending. This process enables creation of monolithic structures with complex geometries employing conventional tooling. Structural thickness influences the strength and stiffness of the formed component. In this study, experimental and numerical (finite element) investigations on structural thinning in DM stretching mode have been performed. Structural thinning was found to be highly non uniform along the forming depth at varying forming angles. A compensation strategy in thin structure machining has been proposed to obtain uniform structural thickness in incremental forming.

Keywords: Thin section machining; Incremental forming; Thinning

1. Introduction

Thin monolithic structures are widely used in aviation, marine and automotive industries, fast replacing assembled sheet metal components owing to their increased strength, safety and light weight. Quality and inexpensive fabrication of monolithic structures with complex thin features is a challenge. This requires complex and intricate dies and tooling, making the process expensive and inflexible. Smith et al. proposed deformation machining (DM) as a solution, a combination of two processes – thin structure machining and single point incremental bending and forming [1]. In this process firstly, thin structures are machined in the desired orientation and size from the bulk and then incrementally bent or formed into the desired shape depending upon the application. This process can create light weight monolithic components with novel and complex geometries employing simple tooling and equipment. Therefore, enabling cost reduction in equipment, fabrication, assembly and weight of the components. The potential applications of deformation machining and thin monolithic parts with complex geometries are: monolithic mold lines in aviation and automobile sectors, impellers, pressurized bulk heads, biomedical engineering (cranial plate, bone and joint supports, prosthetics, etc.) [2], heat transfer and dissipation (irregular, curved fins).

First aspect of DM is the creation of thin structures from bulk raw material employing thin structure machining. Thin structure machining requires different machining strategies and techniques owing to lack of stiffness in the machined structure resulting in chatter and poor surface finish. Tool contact with vibrating machined thin structure results in re-cutting, influencing dimensional accuracy [3,4]. Use of long slender end mills, relieved shank tooling, sacrificial structural preforms, backing plates along with high speed machining have been employed to address these issues [5,6].

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Second aspect of DM is bending or forming the machined thin structure into the desired shape depending upon the orientation and application of the component. To achieve this single point incremental bending (SPIB) and forming (SPIF) technique is used. SPIB/SPIF is a die less forming process where a hemispherical shaped single point solid tool is used to deform the thin structure to a desired shape incrementally using computer numeric control [7,8]. SPIF has enabled flexibility in creation of symmetric, asymmetric and random shapes.

Deformation machining is classified into two modes: (i) bending and (ii) stretching, based upon the orientation of the deforming tool and the component [1,9,10].

1.1. Deformation machining bending mode

In deformation machining bending mode the deformation is perpendicular to the axis of tool resulting in bending of thin vertical structure. Firstly, thin vertical sections are machined from the bulk material and then bent incrementally using a single point tool to the desired shapes (Fig. 1a).

1.2. Deformation machining stretching mode

In deformation machining stretching mode the deformation is along the axis of tool resulting in stretching of thin horizontal structure. Firstly, thin horizontal sections are machined from the bulk material and then stretch formed using a single point tool to the desired shapes (Fig. 1b).

Moreover, it is well established that incremental forming process results in higher formability compared to conventional forming processes like stamping, stretch forming etc, due to highly localized deforming action [11]. Sheet or structural thinning is one of the indicator of process formability and onset of fracture [12]. Present study is an attempt to map thickness profiles in formed structure at varied forming angles for DM stretching mode components along the forming depth both experimentally and through finite element simulations. Based on the results from experiments and simulations, a compensation strategy has been proposed and realized towards achieving uniform thickness distribution.

2. Methodology

Methodology includes experimental plan and process modeling using finite element approach.

2.1. Experimental plan

The material used in the present study is AA 6063-T6, a commonly used aerospace and aviation alloy. A 12×100 mm aluminium flat was used as a raw material. Samples were firstly machined using a tungsten carbide end mill tool with a tolerance of ± 5 μm and then formed incrementally using a single point hemispherical tool. A fixture was designed and fabricated, for mounting and clamping the samples. Thereafter, the samples were inspected for the section thinning on coordinate measuring machine (CMM) (Make: Accurate with Renishaw probes). The samples were radially measured at 20 locations across the depth. The thickness profile was evaluated by subtracting outer and inner measured radii along the depth. Fig. 2 (a) and (b) shows the fabrication, inspection respectively. Fig. 2(c) is the schematic depicting thickness measurement. Fig. 2(d) shows the actual component formed at 45°. Table 1 depicts the fixed level of incremental forming parameters. Thickness of the formed structure in incremental stretch forming is primarily a function of forming angle 'ϕ' and is given by cosine law (Eq. (1)).

$$t_f = t_i \cos \phi \tag{1}$$

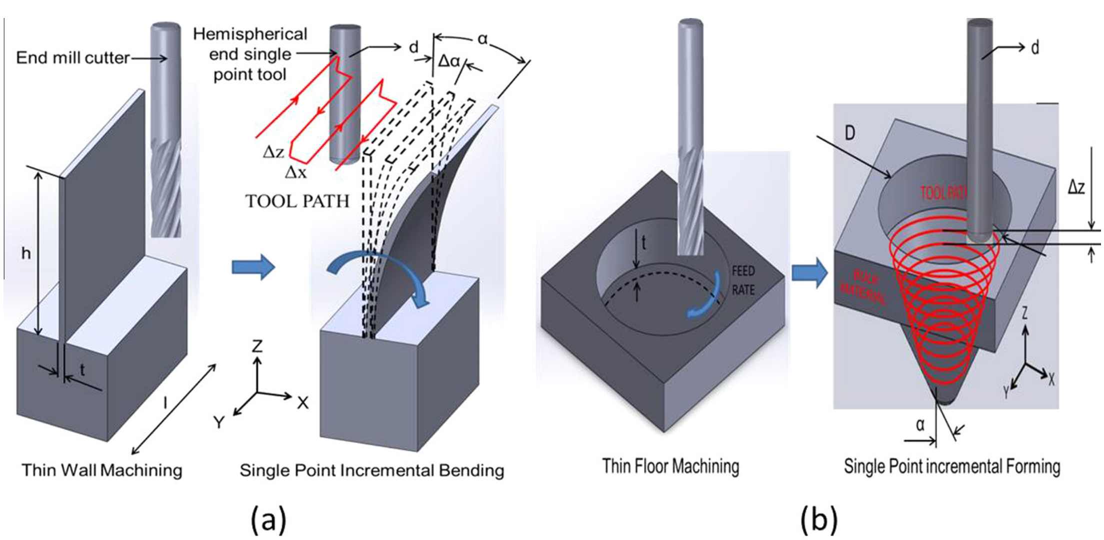

Fig. 1. (a) Schematic of DM bending mode; (b) schematic of DM stretching mode.