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Investigating the Impact of Tool Velocity on the Process Conditions in Incremental Forming of Titanium Sheets

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Abstract

This paper deals with a study focused on the single point incremental forming (SPIF) of titanium Grade 2 sheets. The direct impact of the sliding velocity of the forming tool on mechanical and thermal process loads was experimentally investigated. A wide range of spindle speeds and feed rates were examined at different forming conditions. The developed profiles of the mechanical and thermal demands during the SPIF of titanium sheets are presented and discussed. Forming temperature and force were directly related to the tool rotation speed, higher temperatures and lower reactional forces correspond to higher speeds. At very high rotation, failure conditions occurred and the ability to shape a CP Grade 2 sheet is decreased; these failures were mainly due to extreme heating, leading to termination of the tests concerned. The main objective of the study is to gain a better understanding of the combined effects that the varied relative motions at the tool/sheet contact zone have on the process conditions.

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Keywords: Incremental sheet forming; Themomechanical demands; Titanium Grade2

1. Introduction

Titanium Grade 2 also known as CP Grade 2 is usually selected as the sheet material because of its outstanding corrosion resistance, particularly in applications where high strength is not required (given that its tensile strength is < 340 MPa). Forming temperature is a decisive factor affecting the processing of titanium alloys and is responsible for the phase changes in its microstructure. During the metal forming operation, the surface of the forming tool and

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of the deforming material are in direct contact with each other, and the friction at their interface plays a major role. Localised temperature gradient and deformation generate microstructural changes along the forming path of the workpiece [1]. As a result, non-uniform material properties can be produced over the workpiece, which in turn impacts on the quality and performance of the produced component.

In state-of-the-art of SPIF, it is particularly the mechanical forces and their dependency on process variables that have widely been researched. A limited attention has, however, been applied to the process thermal conditions [2]. According to some publications [3–5], it is presumed that the upper limit of a practical forming rate is governed by the maximum feed rate achievable by the CNC machine. Hussain et al.[6] studied the formability of CP Grade 2 in SPIF by running different forming strategies; they observed a significant rise in titanium temperature with increased feed rate, although they did not present details on the order of these temperatures. Furthermore they reported a decrease in the formability of titanium with an increase in the forming feed rate. It has to be stated, however, that their CNC machine was subjected to some constraints during testing, and accordingly experiments were performed using a non-rotating forming tool; this may have affected friction conditions at tool/sheet interface. Ambrogio et al. [4] investigated the effect of extreme feed rates on the CP Grade 2 and Ti6Al4V alloys. Instead of a conventional milling machine, they used a novel technique, mounting experimental apparatus on a CNC lathe to allow increased feasible speeds up to 600 m/min. They used a tool holder incorporating bearings to allow free tool rotation, with the workpiece clamped in the lathe spindle. They concluded that increasing the feed rate has a negligible effect on both the microstructure and the hardness of CP Grade 2. In their discussion the authors mentioned that there were signs of high forming temperatures, but they did not provide any details on the magnitude of these temperatures.

As summarised in the preceding discussion, the forming conditions (the non-rotating tool and the lathe machine with a rolling tool) described and implemented by Ambrogio et al. and Hussain et al. [4,6] deviate slightly from a standard SPIF process done typically on a milling machine. But to the knowledge of the authors of this paper, little information on the thermal demands of the SPIF process has been published, and there is even less information on the SPIF process involving titanium sheets. Quantitative knowledge of frictional heat and the forces at the tool/sheet interface is crucial for adequate design of the SPIF of CP Grade 2. The work presented in this paper fits into a broader study and series of experimental campaigns that have been directed toward understanding the correlation between the key design factors in SPIF and the process outcomes. The ultimate goal is to establish a process map for the SPIF of CP Grade 2 [7]. In this paper an experimental study has been performed in order to investigate the influences of the tool rotation, ω_t and feed rate, f_r on the thermo-mechanical loads in the SPIF of CP Grade 2 sheets.

2. Experimental setup and design

A summary of the experimental setup and process settings that have been used in the tool speed tests is given in this section. Figure 1(a) depicts a fixture developed to be attached to a force dynamometer and bolt-mounted onto the CNC table.

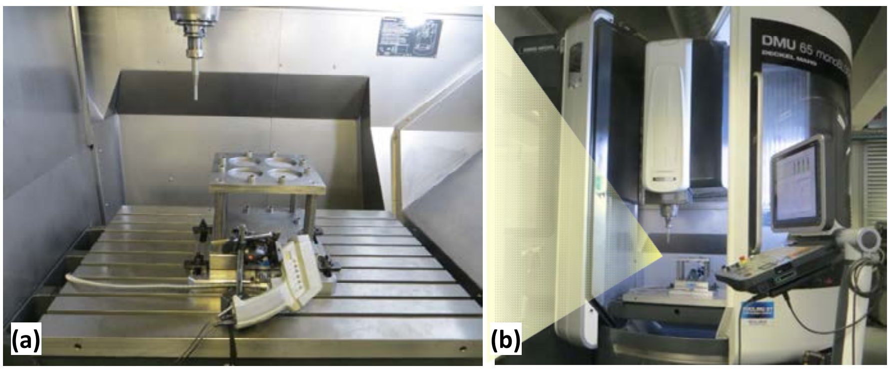

Figure 1: Depiction of the test platform: (a) the fixture, the dynamometer, and the IR-camera (b) the CNC machine