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Electrically-Assisted Incremental Sheet Forming of Advanced High Strength Steels

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Abstract

In Electrically-Assisted Incremental Sheet Forming (EISF), the sheet specimen is locally heated by electrical current, which flows through the forming tool to the sheet specimen at their contact area, due to the well-known Joule heating effect. EISF Experiment was carried out on advanced high strength steel, DP1000. The maximum temperatures at the contact area between the forming tool and sheet specimen were monitored by an infrared camera and controlled through a feed-back control program during forming. Two DP1000 specimens were formed at the maximum temperatures of 600 °C and 800 °C. Both forming force and electrical current were recorded throughout the experiments. The effect of forming temperature on the forming force and required electrical current were analyzed. After the sheet specimens were cooled to room temperature, tensile specimens with reduced size were cut from the straight walls of the sheet specimens by electrical discharge machining, in order to investigate the effect of deformation at elevated temperatures on the post-deformation mechanical properties of the steel sheets.

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Keywords: Incremental sheet forming; electricity; elevated temperatures; advanced high strength steels; mechanical properties

1. Introduction

It has been reported that formability of sheet metals is significantly increased in ISF compared to conventional sheet forming, due to shear deformation mechanism [1], cyclic stretch-bending deformation [2], the superimposed pressure between the forming tool and workpiece, etc. [3]. High strength steels (e.g. DP1000), Ti alloys (e.g.

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Ti6Al4V), high strength Al alloys (e.g. 7000 series Al) etc. are difficult-to-form materials due to higher strength and lower formability at room temperature (RT) compared to mild steels and 5000/6000 Al alloys. In ISF at RT, the formability increase of these difficult-to-form materials is limited, and the issue of springback caused by high residual stresses in the workpieces of these materials is unavoidable when formed at RT. For example, Duflou et al. [4] and Al-Obaidi et al. [5] respectively reported that a Ti6Al4V cone specimen and a DP980 pyramid specimen formed at RT exhibited significant distortion after unclamping. Forming at elevated temperatures is a solution to both issues, since the formability and forming stresses of the difficult-to-form materials will be remarkably improved and reduced, respectively, as temperature increases, e.g. hot incremental sheet forming of high strength steels and Ti alloys [6][7], hot stamping of press hardened steel (PHS) (also known as boron bearing steel, e.g. 22MnB5) [8][9], and hence the geometrical accuracy of workpieces will be improved. Hot ISF has attracted increasing interest in the world in the last decade, and several approaches have been proposed to realize ISF at elevated temperatures, where workpieces can be heated by laser [4][10], electrical current [6][7][11], electrical pulse current [12], induction coil [5], or hot fluid [13] etc. In the laser heating and induction heating methods, the laser beam and the coil have to move synchronically with the forming tool. While only the method by electrical current heating does not require a special setup on the side against the forming tool and consequently is more flexible.

EISF of a high strength steel (DP1000) is conducted in this work and the effect of forming temperature on forming force, post-deformation mechanical properties etc. is presented and discussed.

2. Experimental details

The used material was a 1.0 mm thick dual phase steel with a strength class of 1000 MPa (DP1000). The initial phases of DP1000 are martensite and ferrite. Steel sheets were cut into 250 mm by 250 mm for EISF experiments. The designed shape of DP1000 specimens was square pyramids with a height of 23 mm, a wall angle of 25° (0.436 grad), and a bottom size of 75 mm × 75 mm, as illustrated in Figures 1 (a) and (b). EISF system developed at the Chair of Production Systems, Ruhr-University Bochum includes two KUKA robots (KR 360-1), electrical system, cooling system and control system. One of the two KUKA robots, hereafter designated as the master robot, held the semi-spherical ended forming tool having a radius of 6 mm and moved following a pre-programmed path. The second KUKA robot on the opposite side held an infrared camera and moved synchronously with the master robot to make sure the infrared camera always measured the temperature in the forming zone and monitored the maximum temperature in this zone. Two EISF experiments were conducted with forming temperatures of 600 °C and 800 °C. The tool paths for the square pyramid specimens were generated using CAMwork software and a self-developed Matlab code. After the EISF specimens were cooled to room temperature, six sub-size tensile specimens were cut from three of the four straight walls of each EISF specimen (Fig. 1a,c) by EDM, and then were tested on a universal tensile testing machine with the aid of digital image correlation (DIC) techniques. Samples with dimensions shown in Fig. 1d for optical metallographic observations were cut from one of the four straight walls.

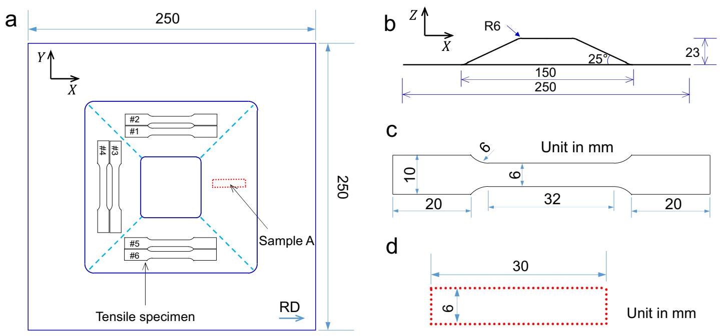

Fig. 1 (a) A plan view (XY-plane) and (b) a side view (XZ-plane) of the EISF specimen. (c) Dimensions of tensile specimens cut from the EISF specimens. (d) Dimensions of the sample A as illustrated in (a) for metallographic observation.