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Cyclic hardening behavior of roller hemming in the case of aluminum alloy sheets

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ABSTRACT

A method to investigate the cyclic hardening behavior of roller hemming in the case of aluminum alloy sheets is described in this approach. Roller hemming hardening behaviors are studied with numerical simulation. The minimum sets of uniaxial experiments are established for the determination of accurate constitutive parameters. A special specimen holder, together with modified uniaxial specimens with two side fins is used in uniaxial tension and compression tests to determine combined hardening parameters. The material parameters are verified by pre-hemming roll-in/out data. It is also demonstrated that the combined hardening parameters derived from the minimum set of uniaxial tests with the aid of special specimen holder and modified specimens are accurate and believable.

1. Introduction

Hemming is used to attach one sheet metal part to another especially in automotive panels such as doors, hoods and deck-lids [1]. Roller hemming is a relatively new joining process. In the place of traditional hemming tabletop, a roller is guided by a robot along the hemmed line and progressively bends the flanged height along the part [2].

Previous studies mostly focus on tabletop hemming. Muderrisoglu et al. [3] analyzed influences of flanging parameters on roll-in/out of 1050 aluminum alloy tabletop hemming. Zhang et al. [4,5] investigated into the mechanism of tabletop hemming warp and recoil. Livatyali et al. [6–8] studied the effects of flanging and hemming parameters on tabletop hemming quality through simulation and experiments. The studies in 2000 concerned flanging die corner radius, pre-hem path, pre-hem stroke and final-hemming force on warp/recoil and roll-in/out for flat surface-straight edge hemming. In 2002, the most accurate and effective finite element modeling method and commercial code for the straight flanging process was determined. In 2004, forming defects, roll and warp, in hemming of mild steel sheets with flat surface–convex edge geometry, are experimentally investigated. The study showed that the influence of the contour radius on roll-in/out was relatively stronger than other parameters. Lin et al. [9] presented maximum surface plastic strain as a hemming fracture criterion.

As for roller hemming process, Thuillier et al. [10,11] focused on the finite element simulation of roller hemming process of an Al–Mg alloy on roll-in/out. The accuracy of the model was verified by comparison with tabletop hemming. Roller hemming experiments were not realized.

However, the cyclic hardening parameters were determined through simple shear [12] and cyclic bending [13] tests. We are not quite sure whether the cyclic shear and bending stress–strain responses can be identified with those under in-plane tension and compression.

This paper presents a study on the cyclic hardening behavior of roller hemming in the case of aluminum alloy sheets. First, the finite element model of roller hemming is established. Special specimen holder and modified uniaxial specimens are used for uniaxial tension and compression tests. The combined hardening parameters derived from the uniaxial tension and compression tests are verified by the pre-hemming roll-in/out data. Finally, the cyclic hardening behavior of roller hemming of aluminum alloy is studied based on simulation results.

2. Modeling of the roll hemming process

The aluminum alloy sheet 6061-T6 (chemical composition in wt.%, see Table 1) is considered in the present investigation, which exhibits only weak anisotropic behavior.

A phenomenological constitutive model with an isotropic yield criterion, a non-linear kinematic hardening rule and the associated flow rule for 6061-T6 roller hemming is presented in this section.

The yield criterion which defines the elastic domain is written in the form

$$f(\sigma_{ij}) = \sigma_{eq} - \sigma_y(\bar{\varepsilon}_p) \leqslant 0 \tag{1}$$

where $\sigma_y(\bar{\varepsilon}_p)$ defines the yield stress in the form

$$\sigma_y(\bar{\varepsilon}_p) = \sigma_{y0} + R(\bar{\varepsilon}_p) \tag{2}$$

where σ_{y0} is the initial yield stress, $\bar{\varepsilon}_p$ is accumulated effective plastic strain with the definition

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