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Experimental and numerical investigation on 6082 0 temper aluminium alloy cartridge tubes drawing

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ABSTRACT

In order to test and evaluate the drawing efficiency of 6082 0 temper aluminium alloy for cartridge tubes, both experimental and numerical analyses were conducted. The theoretical assessment validation was performed by overlapping the graph of stress triaxiality ratio vs. plastic strain and the graph of 6082 0 temper aluminium alloy fracture envelope for a zero Lode parameter. The numerical simulation in Ls-Dyna® gave the stress triaxiality ratio vs. plastic strain correlation. With the view to defining the constitutive material model and fracture envelope, both experimental determinations and numerical simulations for plane stress and plane strain specimens were performed (tensile, shear and compression tests for various samples). The simulation results were compared with the experimental observations. The possibility of using the concept of triaxiality for a constant Lode parameter and an isotropic elastic/plastic material model in the field of drawing was also considered.

1. Introduction

Manufacture of thin tubes for various applications by extrusion and drawing is a widespread technique in industry, due to its economic efficiency. Kumar and Agnihotri (2013), highlighted the importance of the analysis of the mechanical properties of a material subjected to cold drawing, required since its overstress may lead to flawed semi-products with non-steady shape or even broken semi-products. 6XXX series aluminium alloys are particularly used in this type of mechanical processing.

Previous studies in the field investigated extensively 5XXX series aluminium alloys, while the 6XXX series is still under research. For example, Spigarelli et al. (2003) demonstrated the high-temperature plasticity of 6082 aluminium alloy in a wide range of temperatures and strain rates. They analyzed the peak stress dependence on strain rate and temperature. Gea and Ramamurthy (1998) presented a numerical scheme for improving the drawability in the deep drawing of square shells by blank design optimization. They proved that predicting the onset of fracture failure and draw-in failure is required to enable the numerical scheme to work models. With respect to the 6082 aluminium mechanical properties and workability, very important studies were conducted, such as Airod et al. (2004), who made a comparison between the axisymmetric compression to flat rolling of 5083 and 6082 aluminium alloys. The values of the average flow stresses and the activation energies obtained after the laboratory flat rolling and the axisymmetric compression turned out to be comparable for these two alloys. However, the textures developed were different, due to a difference in the mechanisms controlling the plastic deformation and the recrystallization in each deformation technique for the tested alloys. As regards the axisymmetric compression, Airod et al. (2004), considered that giving information about some mechanical and physical parameters needed to simulate flat rolling can be a valuable technique, but not favorable enough to simulate the developed texture.

Further, Jansson et al. (2008) wrote a review study, where methods to describe the limiting strains in tube hydroforming have been evaluated. The classical Swift diffuse instability criterion was compared with the localisation criteria according to Hill and Marciniak and Kuczynski (MK), which are based on plastic instability considerations. Also, a numerical method with statistically distributed thickness was found to comply with the MK criterion in a plane stress case. Srinivasulu et al. (2012) carried out experiments to form annealed 6082 aluminium alloy tubular pre-forms into thin

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walled seamless tubes on CNC flow forming machine with a single roller. They thoroughly studied the effects of the process parameters on the dimensional characteristics and surface quality of flow formed tubes. Mohan et al. (2012) concluded that severe plastic deformation induced by equal channel angle pressing conducts to significant grain refinement, to obtain high strain rate super plasticity.

It is well known that aluminium alloys feature a series of particularities, such as anisotropy and the dependence of their mechanical properties on the triaxiality tension state, strain rate and temperature. These parameters, along with the procedures aimed at emphasizing these characteristics, are thoroughly presented in classic research papers, such as Kolsky (1949), approaching a method of determining the stress–strain relation of materials at very high loading rates on a modified Hopkinson pressure bar apparatus, Taylor (1948), targeting the dynamic yield stress, and giving methods for calculating a more probable value, Johnson and Cook (1985), offering a constitutive model and data for materials subjected to large strains, high strain rates and high temperatures, and evaluated by comparing the computational results with data from cylinder impact test, Johnson and Cook (1983), giving important data on metals submitted to various strain rates, stress and temperature, and Hancock and Mackenzie (1976), who discussed the application of ductile-fracture models of three low-alloys with particular reference to the effects of directionality and stress-state on the condition for flow localization to occur between holes.

Recent works revealed important data on the matter, such as Clausen et al. (2004), who targeted the dependence of fracture on strain rate, triaxiality and temperature, or Field et al. (2004), who studied various materials submitted to high rate shock. Mean stress was proven to play an important role in the fracture of metals by Bao and Wierzbicki (2005). Their numerical simulations with the cut-off value in fracture loci successfully captured the main features observed in tensile tests under hydrostatic pressure. Further, Wierzbicki et al. (2005) have shown the advantage of working with plane stress. Fracture loci for all seven cases considered during the study were constructed in the space of the equivalent fracture strain and the stress triaxiality. Bai and Wierzbicki (2008) highlighted that both the pressure effect and the effect of the third deviatoric stress invariant should be included in the constitutive description of a material. In their study, a general form of asymmetric metal plasticity, considering both the pressure sensitivity and the Lode dependence, is postulated and a calibration method for the new metal plasticity is discussed and subsequently validated. Next, Fourmeau et al. (2011) approached the influence of plastic anisotropy on the mechanical behavior of aluminium alloys under quasi-static loading conditions, and obtained an almost perfect fit between the numerical predictions and the experimental results.

The research on certain mechanical complex phenomena can be conducted by reinforcing the experimental data with numerical analyses based on finite element modeling (FEM). This approach results in a more detailed image of the phenomena that occur in the material during the stress process by facilitating either the development of constitutive laws (as stated by Brunig and Driemeier, 2007) or their improvement, as proved by Lee and Wierzbicki (2005), and lately by Lixandru et al. (2012), including thereby the identification of material fracture envelope. Moreover, FEM enables the investigation of strain and triaxiality stress states evolution in complex structures subjected to loads that induce major plastic strains.

In this context, the subject of the current paper addresses the possibility of manufacturing a product (cartridge tube subjected to interior pressure load) mainly by drawing. The studies focused on EN AW 6082 0 temper aluminium alloy, this alloy encoding particular properties in terms of workability by mechanical procedures. Given the particular nature of the process (major plastic strain at low strain rate), the influence of triaxiality stress ratio vs. the fracture limit of the 6082 0 temper aluminium alloy was studied. Also, the evolution of the stress triaxiality ratio was numerically looked into during an intermediate drawing stage of the semi-product under analysis. Although the Lode parameter is required when a fracture envelope is determined, in this particular application FEM proves that, when the aluminium exhibits important deformations, the Lode parameter is close to zero.

Fig. 1. Test samples.

2. Materials and methods

2.1. Materials

EN AW6082 alloy (AlSi1MgMn) is composed of a series of elements such as Si = 0.7–1.3%, Fe ≤ 0.5%, Cu ≤ 0.1%, Mn = 0.4–1%, Mg = 0.6–1.2%, Cr ≤ 0.255%, Zn ≤ 0.2%, Ti ≤ 0.1%, others ≤0.05% and Al = balance. The alloy under consideration was purchased from Color-Metal, and its chemical composition (from the chemical analysis bulletin) is: Si = 1.05%, Fe = 0.26%, Cu = 0.037%, Mn = 0.45%, Mg = 0.98%, Cr = 0.023%, Zn = 0.02%, Ti ≤ 0.028%, others ≤0.05% and Al = balance.

For the calibration of the constitutive model and the strain fracture limit for different values of the stress triaxiality ratio (aspects employed in modeling and assessing drawing reliability), samples were manufactured for tensile, shear and compression tests (Fig. 1).

2.2. Calibration of the constitutive model

The theoretical aspects of drawing concept comply with the theory of plastic flow. The mathematical relationships involved were synthesized by Hill (1998), and many others and refer to the increments of: volumetric elastic strain vs. volumetric stress (1), total strain vs. elastic strain and plastic strain (2), the variation of the elastic strain according to Hooke's law (3), plastic strain deviator vs. stress deviator (4) and von Mises yield function (5):

$$\mathrm{d}\varepsilon = \frac{\mathrm{d}\sigma}{K} \tag{1}$$

$$d\varepsilon_{ij} = d\varepsilon_{ij}^{e} + d\varepsilon_{ij}^{p} \tag{2}$$

$$\mathrm{d}\varepsilon_{ij}^{e} = \frac{1}{2G}\left(\mathrm{d}\sigma_{ij} - \frac{3\nu}{1+\nu}\delta_{ij}\mathrm{d}\sigma\right) \tag{3}$$

$$\mathrm{d}\varepsilon_{ij}^{p} = \mathrm{d}\lambda S_{ij} \tag{4}$$

$$J_2 - k^2 = 0 \tag{5}$$

where: $\mathrm{d}\varepsilon_{ij}$—total strain increment tensor component; $\mathrm{d}\varepsilon_{ij}^{e}$—elastic strain increment tensor component; $\mathrm{d}\varepsilon_{ij}^{p}$—plastic strain increment