Engineering Fracture Mechanics 109 (2013) 262–272

Contents lists available at ScienceDirect

Engineering Fracture Mechanics

journal homepage: www.elsevier.com/locate/engfracmech

Influence of specimen width on the deformation and fracture behaviour of AA5182 sheets

G. Straffelini *, V. Fontanari, M. Zadra

Department of Industrial Engineering, Faculty of Engineering, University of Trento, via Mesiano 77, 38100 Trento, Italy

ARTICLE INFO

Article history:
Received 14 October 2011
Received in revised form 5 July 2013
Accepted 10 July 2013
Available online 17 July 2013

Keywords:
Al alloys
plastic deformation
Tensile ductility
Shear localisation
Stress triaxiality
Portevin-Le Chatelier effect

ABSTRACT

In this work, the influence of specimen width (in the range 6–15 mm) on the tensile deformation and fracture behaviour of AA5182 aluminium alloy sheets, characterised by the Portevin-Le Chatelier effect, was investigated. The experimental results showed that the elongation at necking and the plastic strain at fracture are influenced by the specimen geometry and, in particular, reached a maximum at a width of 12.5 mm. The experimental results are discussed on the basis of a finite element modelling of the tensile test. The material's constitutive behaviour was implemented following an approach that accounts for microstructural inhomogeneities by considering the material to be composed of a matrix (main component) and regions of slightly higher and lower strength. The plastic properties of the three microstructural constituents were represented by interpolating the tensile stress–strain curve using Voce's relationship. In this way, it was shown that the geometry of the specimen influences the onset and development of the stress triaxiality during plastic deformation, thus explaining the specimen width effect observed in the experimental results.

1. Introduction

Aluminium alloys have various applications in fields that require high specific strength, such as the automotive sector. Different investigations have been undertaken to extend the use of Al-based sheets in this sector, including their plastic formability and the improvement of joining technologies [1–4]. In particular, the study of Al-alloy sheet plastic deformation is of particular interest because the cold formability of these alloys is often limited by shear localisation, which reduces their ductility [5–7].

The plastic deformation of sheets is investigated by means of different tests, including the reference tensile test according to the ASTM B-02 557 standard. In a previous investigation, it was demonstrated that, due to necking, the stress state in the fracture region for AA5182 tensile specimens having a width of 12.5 mm and a thickness of 1.15 mm was in between uniaxial and plain strain conditions [8]. It is also well known that the evolution of stress triaxiality during plastic deformation strongly depends on the specimen geometry and should be properly taken into account during the design of experiments. In fact, the plastic deformation and fracture behaviour of metals are greatly affected by the local stress state which influences both the void nucleation stage and subsequent void growth and coalescence [9–12].

In addition, the strain hardening behaviour of Al alloys can be further influenced by the development of plastic instabilities such as the Portevin-Le Chatelier effect [13–15]. Such effect produces serrations in the stress–strain curve during strain

* Corresponding author.
E-mail address: giovanni.straffelini@ing.unitn.it (G. Straffelini).

0013-7944/$ - see front matter
http://dx.doi.org/10.1016/j.engfracmech.2013.07.007

Nomenclature

a, b, c, d	parameters of the Voce's relationship
α	constant in the Rice and Tracey relationship
C	material parameter in the Rice and Tracey relationship
σ_m, σ_{eq}	true mean stress, equivalent (von Mises) stress
T	stress triaxiality ratio
w	specimen width
w_0	initial specimen width
t	specimen thickness
t_0	initial specimen thickness
ε_1, ε_2, ε_3	true principal plastic strains
ε_{eq}	equivalent plastic strain
$\varepsilon_{eq,n}$	equivalent plastic strain for void nucleation
$\varepsilon_{eq,g}$	equivalent plastic strain for void growth

hardening that favour the development of localised necking. Following the early work of Marciniak et al. [16], a considerable effort has been devoted to predict the plastic instabilities and shear localisation accounting for the negative strain rate sensitivity using the finite element method (FEM). For example, Duan et al. [17] recently proposed a continuum solid mechanics approach to modelling, on the basis of a FE analysis, the strain hardening behaviour and shear strain localisation in Al alloys displaying the Portevin-Le Chatelier effect. The method focuses on the effect of microstructural inhomogeneity and considers the presence of randomly distributed soft and hard regions in the matrix which constitute the majority of the material. The method can be especially powerful for predicting the materials shear localisation and has since been successfully employed for determining the forming limit diagram of Al–Mg alloys [18].

In the present work, the influence of specimen width on the deformation and fracture behaviour of an AA5182 alloy was investigated. The observed plastic behaviour has been interpreted by combining a metallographic analysis of the fractured specimens at the necking region with a three-dimensional finite element analysis. Because the tensile stress–strain behaviour of this alloy is characterised by discontinuous plastic flow due to the Portervin-Le Chatelier effect, and the formability is limited by the onset of shear localisation, the approach proposed by Duan et al. [17] was adopted for the FE modelling. The aim of this work was to assess the suitability of this method in interpreting the role of specimen width on the evolution of tensile deformation and on the fracture behaviour of the alloy under study, and to provide additional information with regard to designing tensile tests for investigating the cold formability of this class of Al alloy.

2. Experimental characterisation

For the present investigation rolled sheets of alloy AA5182–0 (with a nominal chemical composition of 4.5 wt% Mg, 0.35 wt% Mn, wt% Fe 0.027, 0.08 wt% Si, 0.1% Ti) with a thickness of 1.15 mm were employed. The microstructure was characterised by a uniform distribution of intermetallic precipitates such as Al_3 (Fe, Mn) and Al_4 (Fe, Mn). The volume fraction of precipitates was found to be approximately 1.1% and the average grain size was 18 m [8].

Tensile tests were carried out at room temperature, using an Instron 4502 10 kN testing machine with a crosshead speed of 3 mm/min (initial strain rate of 6×10^{-4} s^{-1}). Tensile specimens having the same gage length (84 mm) and five different widths: 6, 8, 10, 12.5 and 15 mm, were machined in the transverse direction with respect to rolling. Three specimens were tested for each experimental configuration.

Metallographic samples were taken close to the fracture surface of the broken specimens and mounted in cold resin, grinded to grit 4000 with silicon carbide paper, polished with 3 m diamond paste with alcoholic lubricant and finally polished with a 0.04-m alumina suspension. The metallographic observations were carried out using a light microscope interfaced with an image analyser to obtain the pattern of true plastic principal strains in the region of rupture. Microhardness measurements were also taken close to the fracture surface using a Vickers indenter with a load of 0.1 N (HV 0.1). The fracture surfaces were observed with a scanning electron microscope (SEM).

The experimental true stress–true strain curves illustrative of tests carried out using the specimens with different widths are shown in Fig. 1. Irrespective of the specimen's width, a 0.2% offset yield stress of 138 MPa was obtained. As expected, all of the samples show a strain hardening behaviour after yielding characterised by the formation of the typical serrations due to the Portevin-Le Chatelier effect. Diffuse necking, localised necking and fracture occurred in very rapid succession: this is behaviour that is consistent with the slightly negative value of the strain rate sensitivity coefficient, which is defined as the slope of a plot of flow stress and strain rate (both in logarithmic scales [5]). Three tensile tests carried out at a constant strain rate of 0.1, 0.01 and 0.001 s^{-1}, yielded an average value of the strain rate sensitivity coefficient equal to -0.0172, which is in agreement with data in the literature [5].