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Quasi-static and dynamic fracture of high-strength aluminium alloy

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Abstract

The quasi-static and dynamic fracture behaviour of the high-strength aluminium alloy AA7075-T651 was studied by material testing over a wide range of stress states and dynamic impact testing using different shapes of the projectile. Rolled plates of the aluminium alloy exhibited anisotropy owing to the complex, non-recrystallized microstructure. In the quasi-static tests, a marked influence of loading direction on the fracture strain was observed, in addition to the expected strong effect of the stress state. Fragmentation and delamination were observed in the impact tests within the impact zone of the plates. A metallurgical study showed the crack growth to be partly intergranular, along the grain boundaries or precipitation free zones, and partly transgranular by void formation around fine and coarse intermetallic particles.

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Keywords: Ductile fracture; anisotropy; intergranular fracture; precipiate free zones; delamination; fragmentation.

1. Introduction

High-strength aluminium alloys are interesting for use in lightweight protective structures owing to their high strength-to-density ratio (Børvik et al., 2010). However, in order to dissipate the kinetic energy from an impacting object or an explosion, the alloy should have sufficient ductility at the extremely high strain rates encountered under

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such loading scenarios. Age hardening alloys of the 6xxx and 7xxx series may have the sufficient strength for these applications but the ductility of these alloys is rather limited in the peak aged condition.

In age hardening aluminium alloys, the fracture behaviour is influenced by microstructural features such as texture, grain size and shape, precipitates, dispersoids and constituent particles, precipitate free zones and grain boundary precipitation. In particular, in alloys containing shearable precipitates and precipitation free zones adjacent to the grain boundaries, a competition between intergranular and transgranular crack growth typically occurs (Dumont et al., 2004).

In this paper, the quasi-static and dynamic fracture behaviour of the high-strength aluminium alloy AA7075-T651 is presented by summarizing the results of an extensive experimental study comprising material testing over a wide range of stress states along with dynamic impact testing using two different shapes of the projectiles to alter the failure mode (Børvik et al., 2010; Pedersen et al., 2011; Fourmeau et al., 2011, 2013).

2. Material

The AA7075-T651 material was delivered as rolled plates of 20 mm thickness. The nominal chemical composition is given Table 1, the main alloying elements being Zn, Mg and Cu. Based on data from the supplier AA7075-T651 has nominal yield and tensile strengths in the rolling direction equal to 505 and 570 MPa, respectively. Temper T651 implies that the alloy is slightly stretched and artificially aged to peak strength.

Table 1. Nominal chemical composition (weight %) of the AA7075-T651 aluminium alloy.

Al	Zn	Mg	Cu	Cr	Fe	Ti	Si	Mn	Others
Bal.	5.7	2.4	1.3	0.19	0.19	0.08	0.06	0.04	0.15

Tri-planar optical micrographs of the grain structure and the distribution of constituent particles are shown in Fig. 1. The grain structure is non-recrystallized with flat and elongated grains in the rolling plane. The grain size is 138 μm in the rolling direction (RD), 62 μm in the transverse direction (TD) and 11 μm in the normal direction (ND) of the plate (Fourmeau, 2014). The iron-based intermetallic constituent particles (Jordon et al., 2009) are broken-up and aligned in the RD due to the rolling process, and are expected to play an important role in defining the fracture characteristics of the alloy.

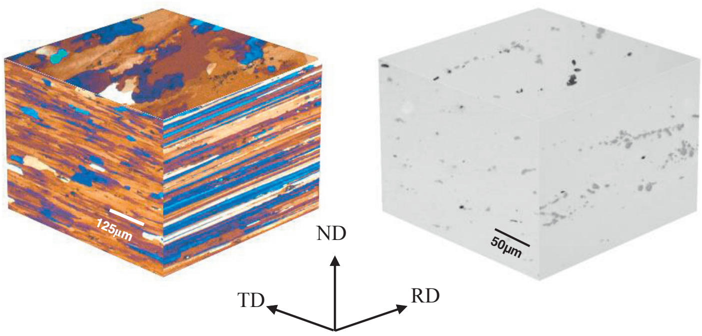

Fig. 1. Tri-planar optical micrographs: grain structure (left) and distribution of constituent particles (right) (Pedersen et al., 2011).

An important microstructural feature regarding fracture in age-hardening aluminium alloys is the precipitate free zones (PFZ) along the grain boundaries. The PFZs are created by the local depletion of vacancies to the grain boundaries, inhibiting the formation of fine hardening precipitates. In addition, a local solute depletion caused by heterogeneous precipitation of phases at the grain boundaries may occur. These two phenomena require atom mobility and occur therefore during the thermal treatment of the alloy. The cooling rate of the quenching operation influences the width of the PFZs for 7xxx alloys (Deschamps et al., 2009). Fig. 2 presents images from the transmission electron microscope (TEM) showing PFZs along high-angle and low-angle grain boundaries. The low-angle grain boundaries separate sub-grains created due to the large deformations during the rolling process. The