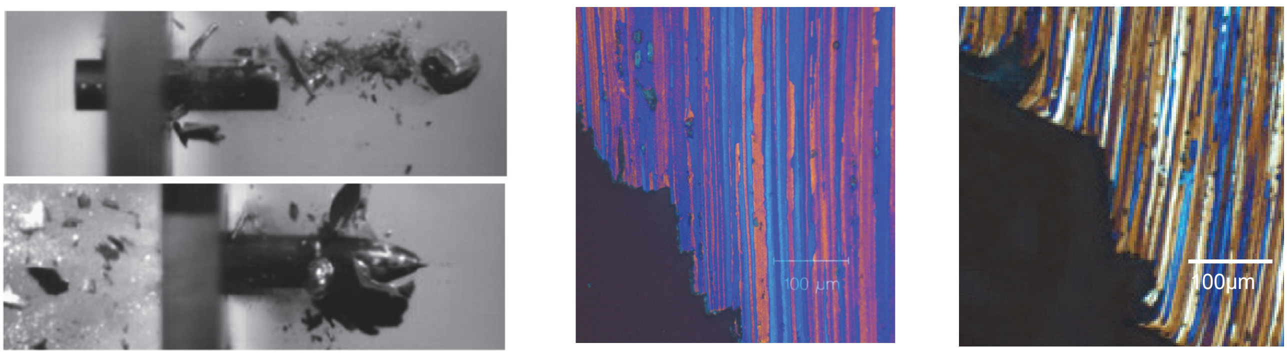
ANISOTROPIC FRACTURE OF QUASI-BRITTLE ALUMINIUM ALLOY

Odd Sture Hopperstad[* a)], Tore Børvik[*], Marion Fourmeau[*,**], Ketill O Pedersen[***] & Ahmed Benallal[**]
[*] *Structural Impact Laboratory, Norwegian University of Science and Technology, 7491 Trondheim, Norway*
[**]*LMT-Cachan, ENS de Cachan/CNRS/UPMC/PRES Universud, 94235 Cachan cedex, France*
[***]*SINTEF Materials & Chemistry, 7465 Trondheim, Norway*

Summary Plate impact tests were conducted for the high-strength aluminium alloy 7075 in temper T651. Fragmentation was observed in the impact zone of the targets. An extensive experimental study on the stress-strain behaviour and fracture characteristics of the material showed that the material is markedly anisotropic due to its complex microstructure, and that the quasi-brittle behaviour in the impact tests was due to intergranular fracture. The fracture strain was found to exhibit an intricate dependence of stress state and loading direction.

INTRODUCTION

Plate impact tests with blunt and ogival projectiles have been carried out in a compressed gas-gun on 20 mm thick plates of the high-strength aluminium alloy AA7075 in T651 temper [1]. It was found that the alloy behaved rather brittle during impact, and severe fragmentation and delamination of the target in the impact zone were detected (Figure 1a). The stress-strain behaviour of the material was characterized by tension and compression tests, and an isotropic thermoelastic–thermoviscoplastic constitutive model and a ductile fracture criterion were determined. All impact tests were analysed using the explicit solver of the non-linear finite element code LS-DYNA. The global failure modes were captured reasonably well in the simulations, while some deviations between the numerical and experimental ballistic limit velocities were ascribed to the observed fragmentation and delamination of the target. These phenomena are difficult to model accurately in finite element simulations. To improve the accuracy of the simulations, it is necessary to establish a better understanding of the physical mechanisms leading to the quasi-brittle behaviour and more advanced constitutive models and fracture criteria that are capable of describing the observed phenomena.



a) b) c)

Figure 1: a) Fragmentation of target during impact with blunt and ogival projectiles. b) Fracture mode in quasi-static uniaxial tension test. c) Fracture mode in plate impact test with ogival projectile.

METALLURGICAL STUDY

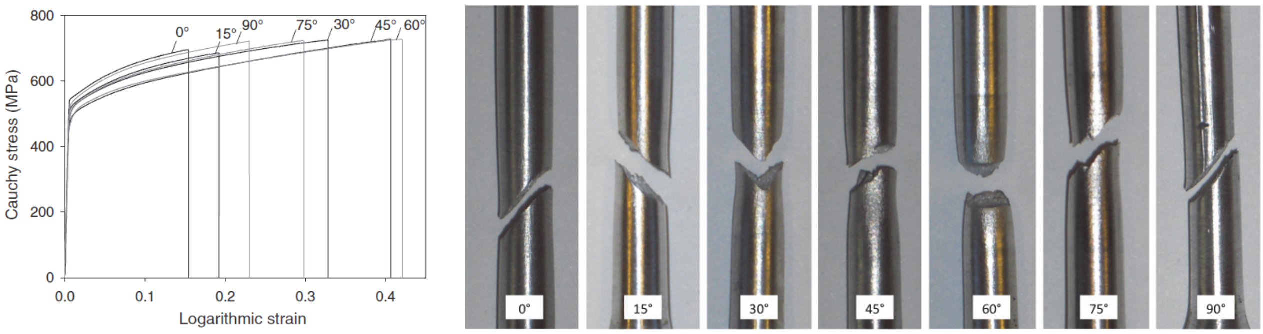
To reveal the mechanisms responsible for the quasi-brittle behaviour observed in the impact tests, the fracture characteristics of the aluminium alloy AA7075-T651 were investigated for quasi-static and dynamic loading conditions and different stress states [2]. The fracture surfaces obtained in tensile tests on smooth and notched axisymmetric specimens and compression tests on cylindrical specimens were compared to the fracture surfaces resulting from projectile impact with blunt and ogival projectiles. The fracture surfaces obtained in tests with smooth axisymmetric specimens indicated that the crack growth was partly intergranular along the grain boundaries or precipitation free zones and partly transgranular by void formation around fine and coarse intermetallic particles (Figure 1b). When the stress triaxiality was increased by the introduction of a notch in the tensile specimen, delamination along the grain boundaries in the rolling plane was observed perpendicular to the primary crack. In through-thickness compression tests, the crack propagated within an intense shear band that was orientated about 45° with respect to the load axis. The primary failure modes of the target plate during impact were adiabatic shear banding for blunt projectiles and ductile hole-enlargement for ogival projectiles. Delamination and fragmentation of the plates occurred for both loading cases,

a) Corresponding author. Email: odd.hopperstad@ntnu.no.

but were stronger for the ogival projectile (Figure 1c). The delamination in the rolling plane was attributed to intergranular fracture caused by tensile stresses occurring during the penetration event.

PLASTIC ANISOTROPY

To study the plastic anisotropy of the AA7075-T651 alloy, material tests were carried out at different orientations to the rolling direction of the rolled plate using various specimens providing a wide range of stress states [3]. A laser system was used to measure the diameter reduction of the specimens to fracture. The marked plastic anisotropy in uniaxial tension is illustrated in Figure 2a, which shows stress-strain curves to fracture from tests at different in-plane orientations. The Yld2004-18p yield function [4] was identified using the available test data and was found to accurately describe the plastic anisotropy of the material. Numerical simulations of the material tests showed that an accurate description of the plastic anisotropy is important to correctly predict the stress state of the specimens, such as the notch-strengthening effect in notched axisymmetric tensile specimens. Since the identification of fracture criteria often relies on a combined use of experimental data and numerical simulations, a good representation of the plastic anisotropy is of the greatest importance also for the modelling of ductile fracture in textured aluminium alloys.



a) b)

Figure 2: a) Stress-strain curves to fracture from uniaxial tension tests at different in-plane orientations with respect to the rolling direction of the plate. b) Fracture modes in the same tests as in a).

FRACTURE ANISOTROPY

The fracture strains and failure modes of AA7075-T651 were found to vary strongly with the stress state, but also with the loading direction. The remarkable variation of the fracture strain and the failure mode with loading direction is illustrated in Figure 2a) and b), respectively. As an example, at 60° the fracture strain is almost three times larger than in the rolling direction. It is seen that a large value of the fracture strain coincides with the cup-and-cone failure mode, while a small value is related to the shear failure mode. Numerical simulations using the anisotropic Yld2004-18p yield function were performed to obtain local values of stresses and strains to fracture for the various specimens. Owing to the heterogeneous stress and strain fields in the specimens at fracture, it was very difficult to determine accurately the location of fracture inside the specimen and thus the fracture strain. The problem is that it is not certain that fracture occurs at the location of maximum plastic strain, since the stress state varies considerably across the fracture surface.

CONCLUSIONS

The fracture behaviour of the high-strength, quasi-brittle aluminium alloys AA7075-T651 has been investigated experimentally and numerically. The complex microstructure of the material, including the crystallographic texture, the particle distribution and the precipitate-free zones, leads to very complicated fracture behaviour, which strongly depends on the loading direction as well as the stress state. The study shows that establishing a fracture criterion for this class of materials is a demanding task owing to the fracture anisotropy resulting from the complexity of the microstructure.

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