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Bendability and Fracture Behaviour of Heat-treatable Extruded Aluminium Alloys

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Three-point bending tests of extruded aluminium alloys have shown lower bendability when the bending axis is aligned with the extrusion direction compared to the transverse direction. In an attempt to explain the observed anisotropy in the mechanical behaviour, the microstructure of underaged and overaged fibrous extruded 7xxx aluminium alloys has been studied with respect to distribution of primary particles and fracture propagation. The microstructure of the deformed materials reveals different fracture mechanisms depending on the direction of the bending axis. These mechanisms are independent of the ageing condition, indicating that the grain morphology and alignment of primary particles give rise to the observed anisotropy.

Keywords: *Heat-treatable alloys, three-point bending, fracture*

1. Introduction

Uniaxial tensile testing is often used to determine the mechanical properties of metals. However, this type of test does not always give a good description of the deformation mode experienced by a component, either in fabrication or in use. Aluminium car bumper systems are formed into their final shape from extruded profiles by cold deformation. Thus in a collision, the ductility of the bumper system is important for optimal energy absorption. In this case, the three-point bending test is a suitable method for describing the mechanical properties.

For extruded profiles a lower bending angle has been observed when the bending axis is aligned with the extrusion direction compared to the transverse direction. This work will focus on the influence of primary particles and grain morphology on the fracture mechanisms of fibrous commercial 7xxx aluminium alloys exposed to three-point bending. A more thorough investigation of mechanical properties and texture has been reported elsewhere [1].

2. Materials and Experimental Procedure

Two 7xxx alloys have been studied in this work, namely AA7003 and AA7108, with alloy composition as given in Table 1. Both alloys were provided by Hydro Aluminium Structures Raufoss AS as plate-shaped extruded profiles with thickness and width of 3 mm and 180 mm, respectively.

Table 1 Alloy composition given in wt%

Alloy	Zn	Mg	Fe	Zr	Si	Cu	Mn	Cr	Ti	Al
7003	5.4-5.7	0.65-0.70	0.28	0.15-0.18	0.12	0.1	0.04	0.03	0.03	Bal
7108	5.4-5.7	1.15-1.25	0.28	0.15-0.18	0.12	0.1	0.04	0.03	0.03	Bal

The distribution of primary particles in the ED-ND plane and the TD-ND plane was investigated in the as-extruded AA7003 alloy using a Zeiss Gemini Supra 55 VP FESEM. The particle distribution is expected to be similar in the AA7108 alloy which has been subject to the rest of the investigations.

Specimens for three-point bending testing (60x60x3 mm^3) were machined from the AA7108 alloy. Two heat treatments were chosen, these were underaged and overaged conditions. Both were initially subjected to a solid solution heat treatment at 480ºC for 20 min followed by 24 h at room temperature and then given a two-step artificial ageing: 5 h at 100ºC followed by 5 h (underaged) or 24 h (overaged) at 150ºC.

Three-point plane-strain bending tests were performed with the bending axis along either the extrusion direction (ED) or the transverse direction (TD). This was performed in a Zwick testing machine according to guidelines proposed by Daimler Chrysler [2]. A constant vertical speed of 20 mm/min was chosen and the roll gap was two times the specimen thickness plus 0.2 mm. Force was logged as a function of vertical displacement, and the test was stopped when the force-displacement curve showed a significant drop. The bending angle was measured manually afterwards according to standard procedures [2]. A cut was made perpendicular to the bending axis and the microstructure and fracture propagation was examined by light optical microscopy.

3. Results

Both the alloys investigated have a fibrous microstructure with a recrystallized surface layer. For comparison the microstructure of the as-extruded alloys is shown in Fig. 1. The grain structure is similar in both, except that the surface layer of the AA7003 alloy in a) is somewhat thicker than for the AA7108 alloy in b).

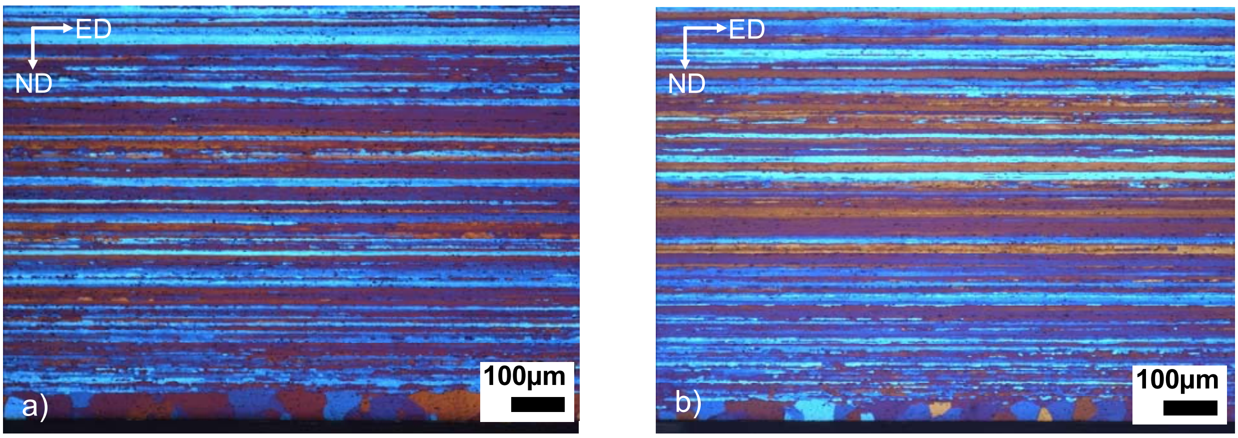

Fig. 1 Microstructure of the as-extruded material. a) AA7003 and b) AA7108. Both are showing a fibrous structure with a recrystallized surface layer.

The results from the three-point bending tests are given in Table 2 for the AA7108 alloy. The results indicate a higher bending angle with the bending axis along TD for both the tempers. This means that the alloy has better bendability when the bending stresses are aligned with the ED axis and thus with the fibrous microstructure. Both the bending angle and its standard deviation are higher for the overaged condition than for the underaged one with respect to the two directions.

Table 2 The measured bending angles after three-point bending of the AA7108

Temper	Direction of bending axis	Average bending angle [º]	Standard deviation [º]
underaged	ED	28	0.6
underaged	TD	37	1.7
overaged	ED	32	1.2
overaged	TD	46	4.9

The distribution of primary particles in the profiles is expected to be equal for the two alloys and is influenced by the extrusion process. The AA7003 alloy was investigated by SEM analysis with respect to the distribution of primary particles. Fig. 2 a) shows how the particles align like beads on a string, indicated by arrows, along the extrusion direction in the ND-ED plane. However, in the ND-TD plane the particles are more randomly distributed, i.e. the strings are perpendicular to this plane, see Fig. 2 b).

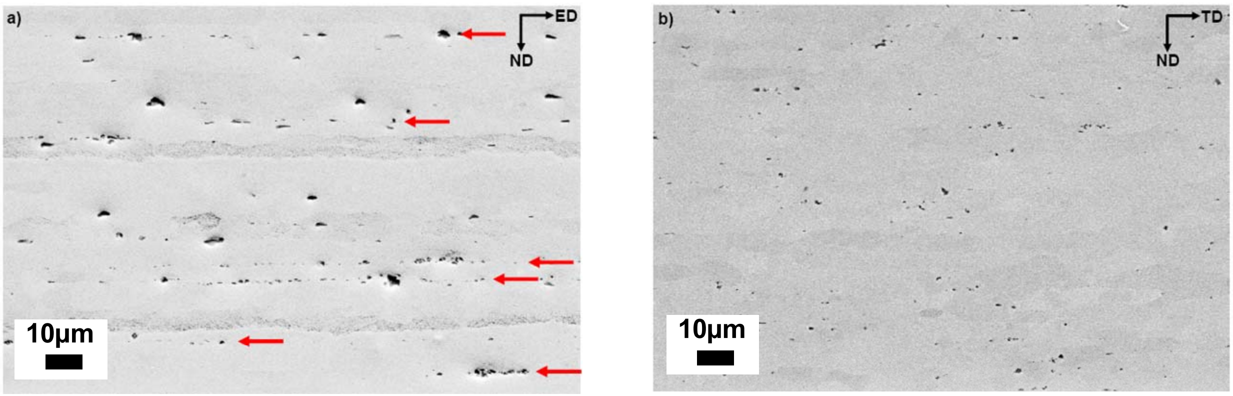

Fig. 2 Distribution of primary particles in an AA7003. In a) the particles are clearly aligned along the extrusion direction, while the particles are more randomly distributed in the TD-ND plane in b).

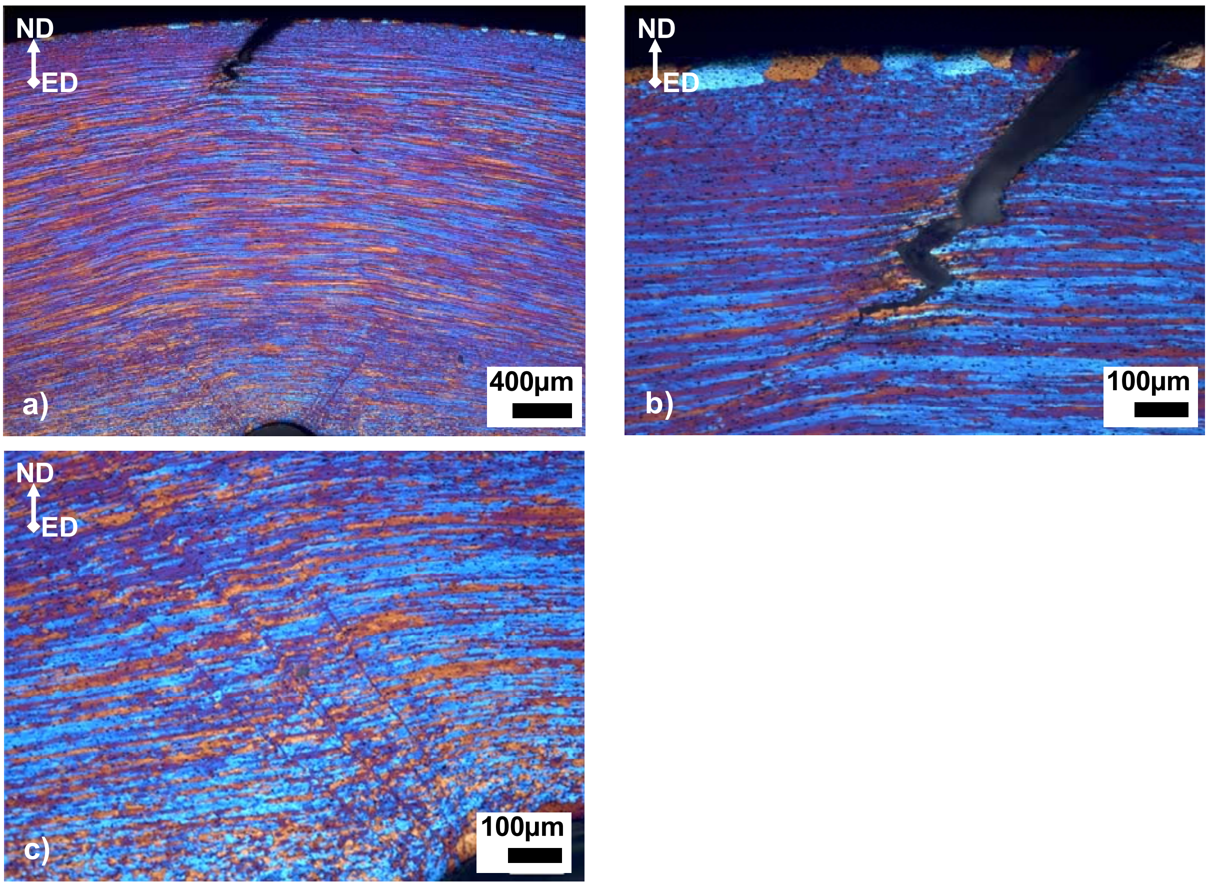

Fig. 1 Micrographs of the underaged AA7108 deformed with the bending axis along the extrusion direction: a) through-thickness overview, b) the crack propagation on the tension side and c) intense shear band formation on the compression side are seen.

The crack propagation was examined in the AA7108 alloy deformed by three-point bending for both the underaged and overaged conditions and with the bending axes along the ED and the TD. Fig. 3 and Fig. 4 show the microstructure of deformed underaged and overaged materials, respectively, when the bending axis is aligned with the ED. A closer look at the crack on the tension side in Fig. 3 b) reveals that the fracture at the surface of the sample is a transcrystalline shear fracture, and further into the material it turns into a mixture of intercrystalline and transcrystalline crack growth. On the compression side of the deformed sample, intense shear band formation is observed symmetrical around the bending axis, see Fig. 3 a) and c).

For the overaged condition with the bending axis in the ED, Fig. 4, the same trend is found as for the underaged condition. On the compression side intense shear bands are seen, Fig. 4 a). The fracture on the tension side has started as transcrystalline shear fracture at the surface and has turned into a combination of intercrystalline and transcrystalline crack growth as shown in Fig. 4 b).

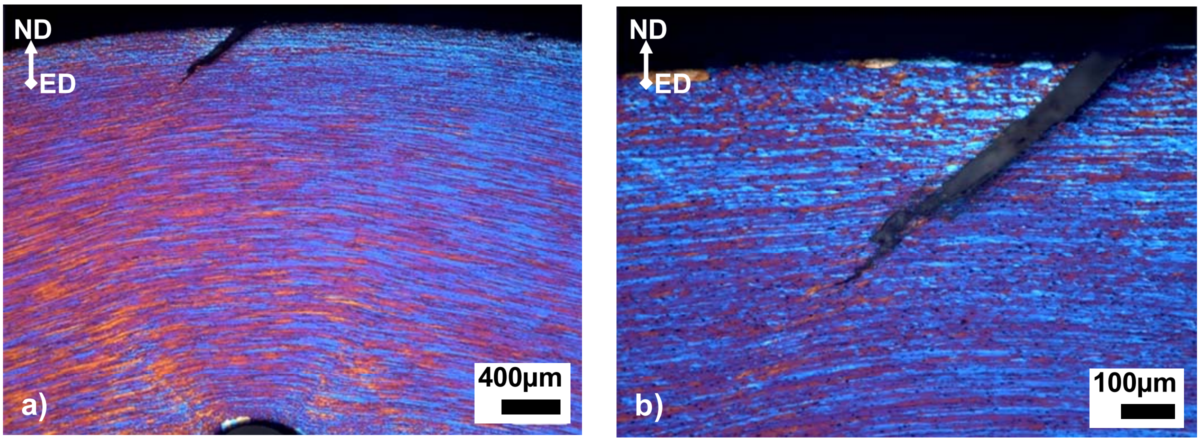

Fig. 2 Micrographs of the overaged AA7108 deformed with the bending axis along the extrusion direction: a) through-thickness overview showing intense shear band formation on the compression side and b) crack propagation on the tension side.

In Fig. 5 and Fig. 6 the crack propagation of the underaged and the overaged condition are shown, respectively, when the bending axis is aligned with the TD. None of these show shear band formation on the compression side. For both conditions the fracture on the tension side of the samples is a transcrystalline shear fracture. For the underaged condition only few shear bands are observed which are intense and narrow, Fig. 5 b), compared to the overaged condition, where deformation bands are seen in all the grains and the crack tip is broader, see Fig. 6 b).

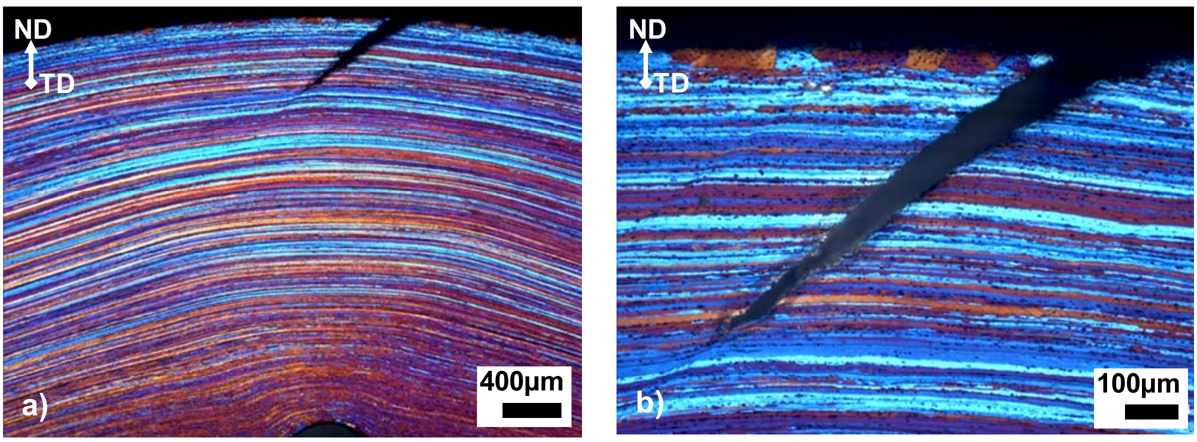

Fig. 3 Micrographs of the samples deformed with the bending axes along the transverse direction for the underaged condition: a) through-thickness overview and b) crack propagation in the shear band on the tension side.

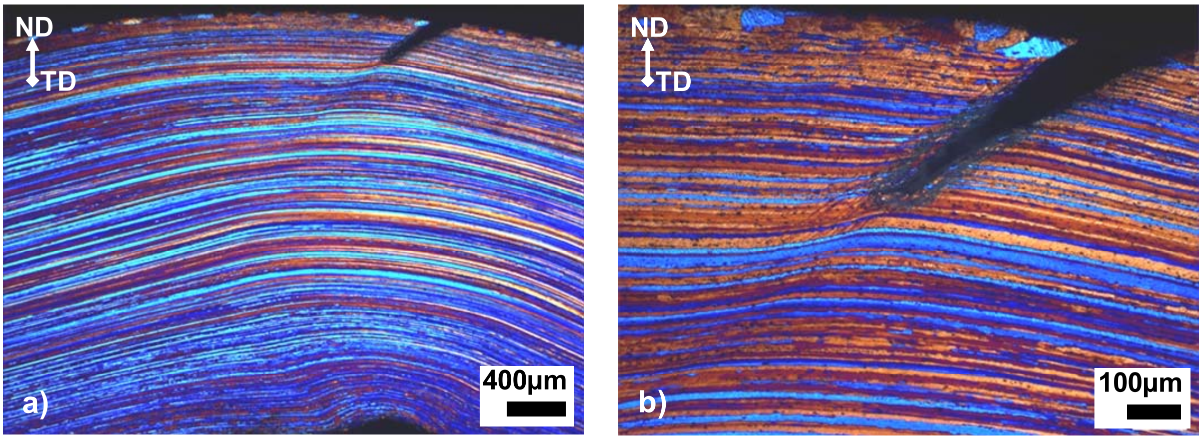

Fig. 4 Micrographs of the samples deformed with the bending axes along the transverse direction for the overaged condition: a) through-thickness overview and b) crack propagation in the shear band on the tension side and deformation bands.

4. Discussion

There is no doubt that strain localization in the form of shear band formation is the major failure initiation mechanism in three-point bending. Both Dao and Li [3] and Sarkar et al. [4] have concluded that roughening and grooves at the surface, typically at grain corners, work as initiation spots for the shear bands. Larger grain boundary precipitates have also been reported to cause initiation of shear banding inside the materials [3], which may explain the high density of deformation bands observed in the overaged condition in Fig. 6 b), where a coarsening of grain boundary precipitates is expected. A crystal-plasticity-based model for studying strain localization during bending has been presented by Dao and Li [3]. They have compared the effect of random texture and a typical deformation texture as well as the effect of a random distribution of particles. They found that the deformation texture increased the surface roughening and thereby increased the probability of shear band formation. This complies with the simulations made by Kuroda and Tvergaard [5] who have been studying the influence of the different texture components. Where Dao and Li have not taken into account the difference in bending axis, Kuroda and Tvergaard have included this in their investigation. They found that shear band formation on the compression side was more extended with the bending axis along the rolling direction for typical deformation textures. This is in agreement with the observations in the current work, where intense shear bands are seen on the compression side when the bending axis is aligned with the ED for both the tempers, Fig. 3 and Fig. 4. However, these shear bands on the compression side do not cause the material to fail.

It is more likely that the difference in bendability lies in the way the crack propagates. The reason to this must be found in the microstructure of the profile. The fibrous microstructure where the grains are elongated in the extrusion direction may work as reinforcement when the bending axis is along the TD. In this case the strings of particles are perpendicular to the bending axis and randomly distributed in the cross-section. When the shear bands are formed, most of the deformation is localized in the bands, i.e. ductile fracture occurs directly in the band. This is what may be observed in Fig. 5 and Fig. 6. However, when the bending axis is aligned along the ED, the fibre direction and the strings of particles run parallel with the bending axis. This weakens the material and makes it easier for the crack to follow a path that requires less energy, i.e. at first in the shear bands and then along grain boundaries and between particle strings. This may also be reflected in the bending results, Table 2, where the standard deviation is lower when the bending axis is aligned along ED, i.e. the material fail momentarily when a certain bending angle is reached due to intercrystalline failure.

5. Summary

Shear band formation is the major failure initiation mechanism for all the samples independent of temper and alignment of bending axis. The reason for the difference in bendability should be found in the microstructure of the extruded profiles. As a result of the extrusion process, primary particles are aligned like beads on a string along the extrusion direction. When the bending axis is aligned along the TD, the strings are perpendicular to the bending axis and the fibrous microstructure act as a reinforcement of the material. In this case the deformation is localized in the shear band. However, when the bending axis is aligned with ED, the fibre direction as well as the strings of particles run parallel to the bending axis leading to a combination of intercrystalline and transcrystalline crack growth.

References

[1] K. E. Snilsberg, I. Westermann, B. Holmedal, O.S. Hopperstad, Y. Langsrud and K. Marthinsen: Mater. Sci Forum, vol. 638-342 (2009), pp 487-492.
[2] H. Bold: *Plattchen-Biegeversuch*, Daimler Chrysler 2008.
[3] M. Dao and M. Li: Phil. Mag. A, vol. 81 (2001), pp. 1997-2020.
[4] J. Sarkar, T. R. G. Kutty, D. S. Wilkinson, J. D. Embury and D. J. Lloyd: Mater. Sci. Eng. A, vol 369 (2004), pp. 258-266.
[5] M. Kuroda and V. Tvergaard: Int. J. Plasticity, vol. 23 (2007), pp. 244-272.