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Influence of Microstructure on the Folding Behavior of Crash Relevant Aluminum Extrusion Parts

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Abstract

Aluminum, especially extrusions of the 6xxx series, has considerable potential to make cars lighter and thus more economical. Over time, requirements have been changed to higher strength for profiles with lower wall thickness including, in particular, better energy absorbing behavior. Crash relevant aluminum parts in aluminum spaceframe constructions should have high mechanical properties combined with highest energy absorption capability. Such parts absorb energy by controlled folding.

Until now, the factors of influence on the folding behavior are not completely clarified. Possible factors are microstructure parameters such as grain size, grain structure and phase structure.

Therefore the TRIMET Aluminium SE investigated the correlation between the folding behavior and various microstructure parameters. This paper describes material, the heat treatment experiments for varying the microstructure und the correlations between the folding behavior and the microstructure. Finally conclusions and recommendations for optimizing the folding behavior are described.

Introduction

Crash relevant aluminum extrusion parts for space frame constructions require high mechanical properties in combination with an optimal capability for energy absorption. Well controlled failure with even folding should give the best energy absorber performance. Therefore the folding behavior is one design criteria for material, process and component development in the automotive industry.

Up till now the influencing factors for the folding behavior are not really clarified. Besides the material composition especially for high strength aluminum profiles, [1], the factors of influence could be microstructure parameters like grain size, grain structure, phase composition or phase structure.

Target of this project was to investigate the correlations between the folding behavior of crash relevant aluminum profiles and different formations of the microstructure, especially the grain size and grain structure.

Therefore different microstructure formations were generated in aluminum profiles. These different profile conditions were analyzed concerning the folding behavior and the correlations between folding behavior and microstructure.

Experimentals

The profiles investigated are produced with a 6xxx-alloy, which is typical for crash relevant automotive profiles. The alloy is an EN AW 6060. The analysis can be found in Table I.

Table I. Analysis of the EN AW 6060 profiles

Element	Si	Mg	Cu	Mn	Fe
wt-%	0.53	0.54	0.20	0.03	0.19

The profile and a folded profile are visible in Figure 1 and Figure 2. The length of the profiles used for the folding tests is 300mm. The folding test is a slow folding test according to the Volkswagen AG TL116, [2].

- Length of specimen: 300mm
- Deformation: 200mm
- Deformation speed: 100mm/min

The analysis of this crush test is a visual examination of surface, folding and cracks. For the analysis of the crush tests in this project all cracks were counted and summed up. This included even small cracks, which are acceptable according to TL116, [2].

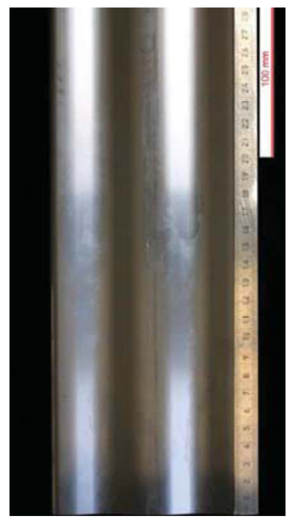

Figure 1. Profile

Figure 2. Profile before and after the crush test.

Microstructure

In this project different microstructure formations were investigated. The most important variations are profiles in condition:

1. (as delivered after extrusion (T1),)
2. heat treated (T6)
3. special heat treatment for coarse grain structure, without solution heat treatment and artificial ageing
4. special heat treatment for coarse grain structure, heat treated (T6)

For the third microstructure variation a treatment had to be found to generate a coarse grain structure all over the profile. The best grain structure was reached with a heat treatment of 580°C over 22h. At high solution heat treatment temperatures above 550°C most of the Mg_2Si-precipitations are solved and the degree of dispersion declines due to coagulation. Hence the force on the grain boundaries is lower and the crystallites can grow through migration of the grain boundaries, [3]. A multitude of trials showed that temperatures below 580°C results in uneven grain growth.

This treatment of 580°C/22h yields a relatively even, coarse grain structure, Figure 4, which is adequate contrary to the original state, Figure 5. Folding behavior thus obtained should clearly differ between the microstructure variations, if the grain size has significant influence on the folding behavior.

The solution heat treatments of both T6-varations were carried out at 540°C/120min cooled down in water. Afterwards an artificial ageing at 215°C/120min were carried out followed by air cooling.

For all heat treated variations homogeneous spread precipitations could be achieved, Figure 3.

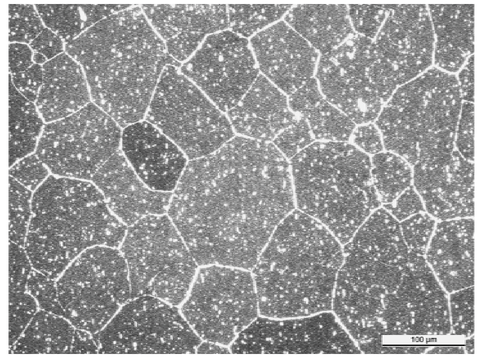

Figure 3. Homogeneous secondary precipitations of a normal heat treated profile (variation 2); etched.

The data in Table II show that the hardness is nearly the same for the both microstructure variations although the grain size and structure is very different. Therefore the folding behavior should not be influenced by the hardness and the strength respectively.

Table II. Brinell hardness of the different microstructure formations before and after the artificial ageing.

Variation	1, before artificial ageing	2, after artificial ageing	3, before artificial ageing	4, after artificial ageing
Hardness [HBW]	54	74.6	54.4	75

Figure 4. Profile microstructure after a heat treatment with 580°C/22h (variation 4).

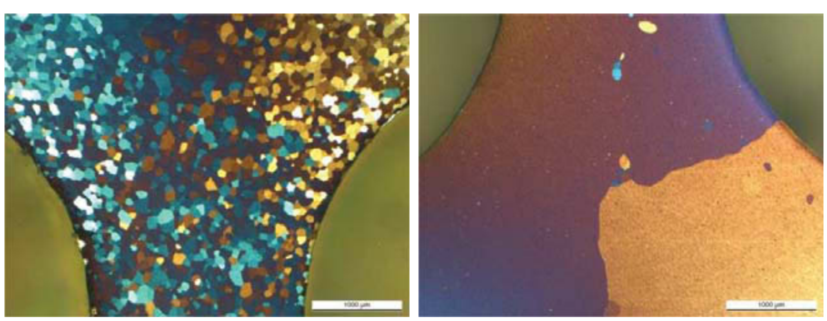

Figure 5. Profile microstructure; left: original grain structure (variation 2); right: coarse grain structure after grain growth by heat treatment (variation 4).

Folding Behavior

For this analysis typical cracks like visible in Figure 6 are counted and summed up. The folding behavior was rated visually. The analysis of the crush tests can be found in Figure 7 and examples for the folding of the profiles are shown in Figure 8.

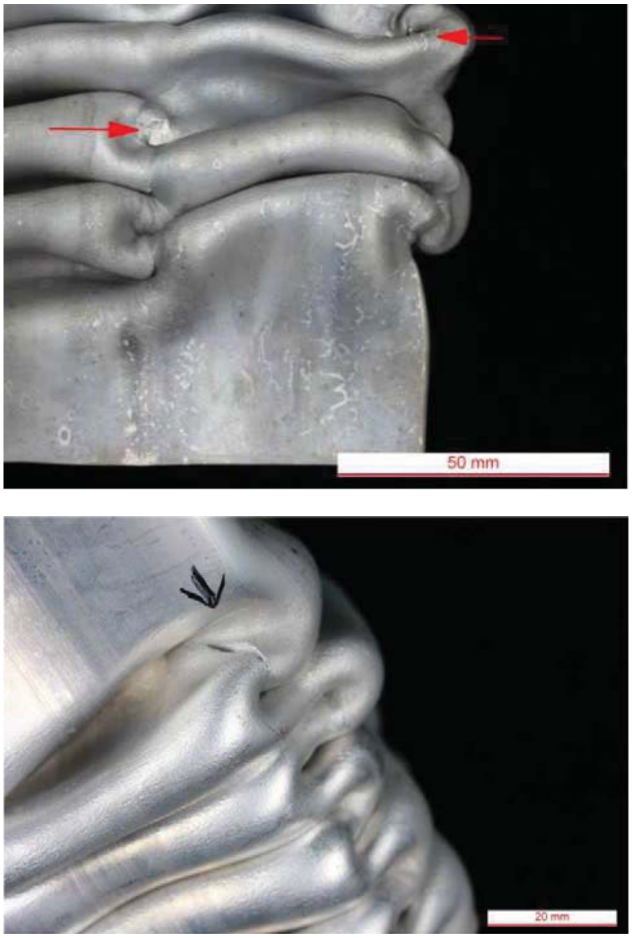

Figure 6. Examples for typical failures after a crush test.

The abbreviated summary of the folding behavior of the different profile types during the crush tests is:

Variation 1:
The profiles are folded well and evenly.

Variation 2:
The profiles are folded well and evenly, too. The folds are marginally smaller. The number of cracks is increased.

Variation 3:
With all profiles of variation 3 a bad and uneven folding can be determined. The crushed profiles have significantly more cracks and the folds are unevenly spread over the profile.

Variation 4:
After solution heat treatment and artificial ageing the profiles with coarse grain structure can be folded marginally better. But in comparison to profiles of variation 2 the folds are more uneven. Additionally all these profiles contain many more cracks than the profiles of variation 3.

Subsequently the cracks of the samples were analyzed by SEM for a classification of the crack types. Pictures of the cracks of profiles with a small grain, Figure 9, show shear-marks, a typical attribute for a ductile forced fracture together with an advanced, high plastic deformation. The conclusion from the crack structure and alignment is that the material cracked transcrystalline over shear planes. The cracks are deformation-rich cracks, [5].

In contrast, the surface of the cracks of those profiles with a coarse grain structure, visible in Figure 10, is much smoother and has no shear-marks. The fracture surface is typical for a low-deformation cleavage fracture. Such cracks are found rarely for cubic face-centered metals, [5]. Normally such cracks can be found if the crystallographic slip planes and especially a cross slip is blocked by dislocations. Before cracking there are high tensions caused by the accumulation of dislocations. The cracks in Figure 10 show that there were low plastic deformations while cracking.

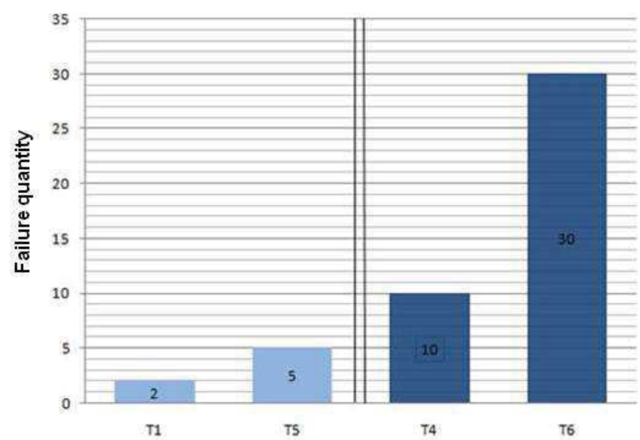

Figure 7. Mean failure quantities of the crushed profiles; left: normal grain structure; right: coarse grain structure.

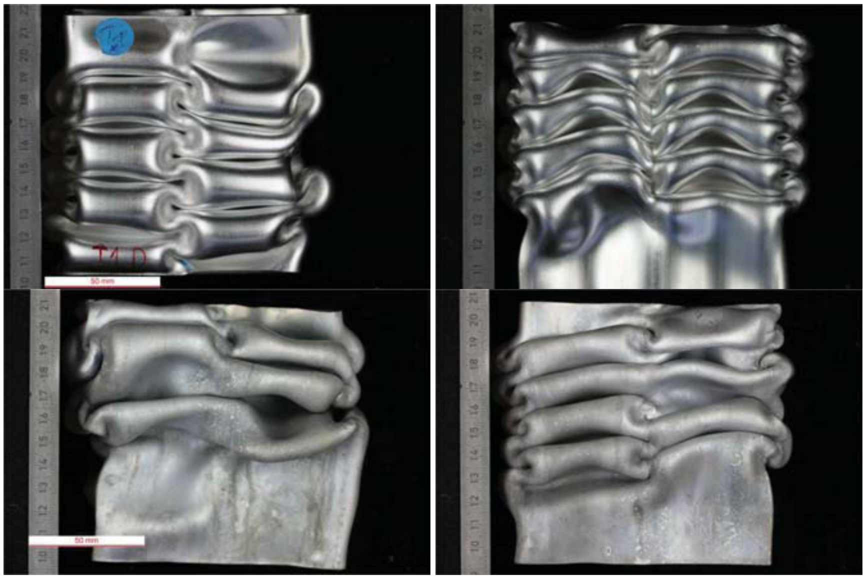

Figure 8. Examples for folded profiles. The different folding behavior is clearly visible. Above left: variation 1; above right: variation 2; bottom left: variation 3; bottom right: variation 4.

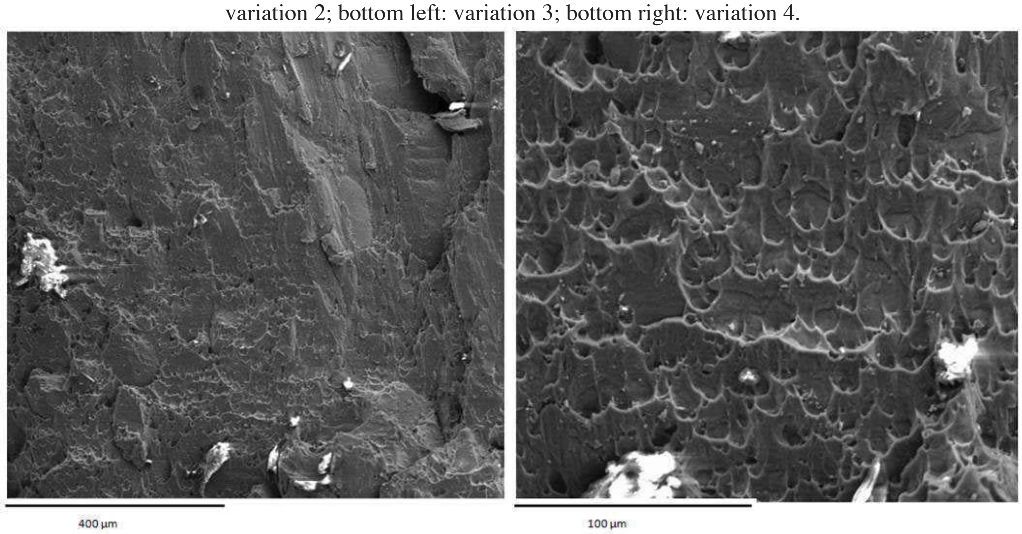

Figure 9. Fracture surface from a specimen with normal grain size and structure (variation 2).

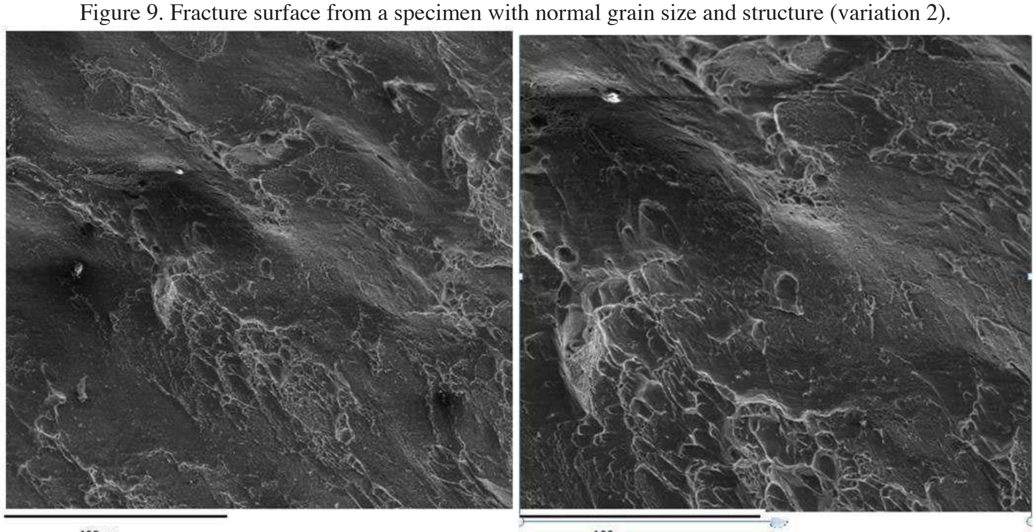

Figure 10. Fracture surface from a specimen with coarse grain size and structure (variation 4).

Conclusions

The results of this study show that the grain size of crush relevant extrusion parts has an important influence on the folding behavior. The main conclusion is:

- a microstructure with a small grain size improves the folding behavior of crush relevant profiles significantly,

Dislocations and their movement seem to have an important influence and are affected positively by a fine microstructure. Additionally the crack initiation is hindered by a small grain size, because of the higher fracture toughness. As a consequence, the course of the dislocations is grows longer. The movement of the dislocations will slide, not only on parallel gliding planes, but change the gliding plane to different orientated gliding planes. A picture of the gliding planes activated by impact loading is visible in Figure 11. The dislocation lines move on ±45°-planes and activate new gliding planes in adjacent grains.
To that effect, the cumulated route of the dislocations is very high and enables a high deformation of the extrusion part.
The number of grains per mm^3 should be one of the crucial factors on the folding behavior of crush relevant extrusion parts.

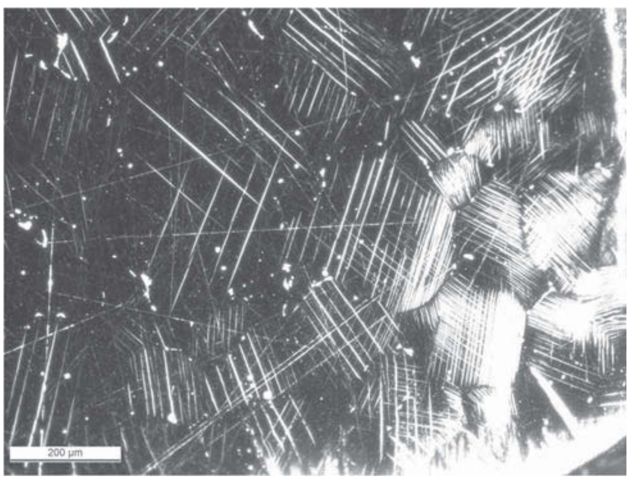

Figure 11. Picture of different active gliding planes in the microstructure of a profile specimen.

Furthermore it could be expected that microstructure parameter like phase type and formation have an additional effect on the folding behavior, even if the grain structure seems to have the most important influence.
Complementary results from the practical production experience support this conclusion.

Outlook

To prove and to assure the results of this project additional experiments and investigations should be carried out. On the one hand, different grain sizes should be produced by using different extrusion parameters to avoid the influence of the heat treatment for the grain coarsening. These profiles have to be analyzed concerning their folding behavior, too. On the other hand, influence of the grain structure along the profile section, especially the shell zone, on the folding behavior has to be investigated.

In a final step, understanding the influence of non-globulitic grains caused by a not recristallized microstructure on the folding behavior, could be an essential step forward to high performance extrusion parts for space frame constructions.

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