Smaller is stronger : an engineering induced size effect!

Smaller is Stronger: An engineering induced size effect!

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Introduction

Due to miniaturisation ever thinner metal components are being processed (Figure 1). Consequently, only a few crystals may be present, resulting often in dramatic changes in mechanical properties with decreasing dimensions, i.e. the so-called "size-effect".

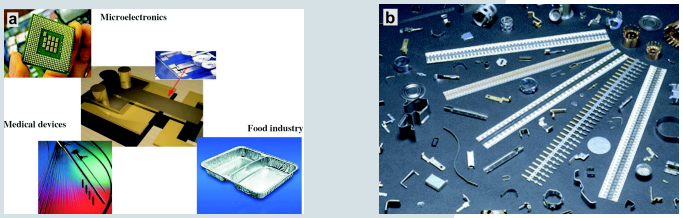

Figure 1: (a) Industrial applications (b) Micro-parts.

Objective

Investigation of the origin of size effects in thin metal sheets with through-thickness grains for decreasing number of grains across the width, using a model system: very pure Al sheets with a grain size to thickness ratio of 2.5, subjected to uniaxial tension.

Specimen preparation

A strain-anneal protocol is used to produce a reproducible microstructure with an average grain size of 800 μm and a pronounced Cube texture (Figure 2).

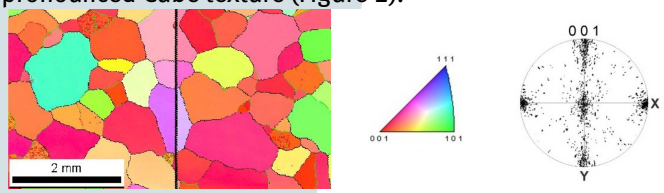

Figure 2: Microstructure and {001} pole figure of a recrystallised specimen.

From the recrystallised strips, test specimens are machined in two ways: by mechanical cut followed by grinding to final width and by direct laser-cut to final size. Finally, all specimens are annealed for 1 hour at 200 ^oC to relief internal stress.

Mechanical behaviour

Results for the uniaxial tension tests for both specimens types are shown in Figure 3. Both specimen types show a distinct size effect in the low-strain (< 0.02) region: narrow specimens are stronger!

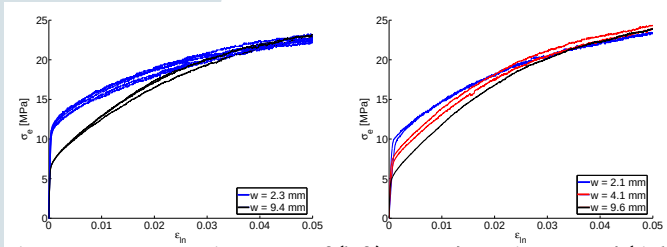

Figure 3: Stress-strain curves of (left) ground specimens and (right) laser-cut specimens.

To investigate the origin of this size effect, the specimens have been given an additional heat-treatment of 30 minutes at 600 ^oC (Figure 4).

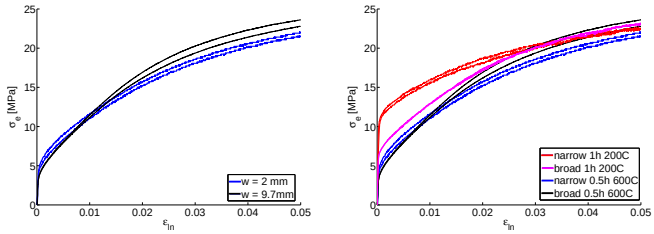

Figure 4:(left) Stress-strain curves of additional annealed specimens (right) 1 hour 200 ^oC vs 30 minutes 600 ^oC specimens.

For these specimens the smaller is stronger effect has decreased significantly, even though this additional annealing did not induce any (significant) changes in grain structure and orientation (Figure 5).

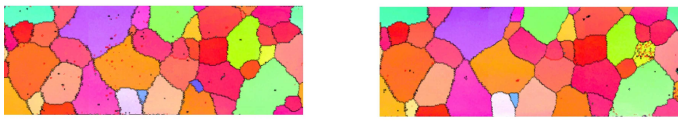

Figure 5: Microstructure evolution, before (left) and after (right) the additional 30 minutes 600 ^oC annealing.

An inhomogeneous microstructure or variations in Al-oxide surface layer are ruled out as possible origins of the size effect. The results indicate the presence of a stronger edge zone in the specimens (higher dislocation density or compressive residual stress?) as a generic result of machining.

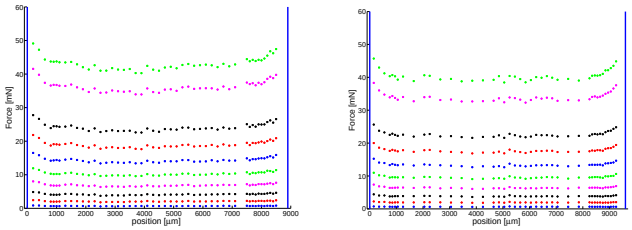

Figure 6:(left) Nano-indentation results at several indentation depths across the width of (left) a mechanically cut specimen and (right) a laser cut specimen.

The presence of a stronger edge zone has been investigated by nano-indentation experiments. The results for mechanically cut and laser cut specimens in as-cut state are presented in figure 6. As can be seen, an edge zone of approximately 2 mm and 1 mm exist for the mechanically cut and laser cut specimens respectively.

Conclusion

A "smaller is stronger" size effect, interesting for applications, has been observed and investigated, and has an engineering-induced origin.

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