

## Smaller is stronger : an engineering induced size effect!

**Citation for published version (APA):**

Janssen, P. J. M., Keijser, de, T. H., Hoefnagels, J. P. M., & Geers, M. G. D. (2006). *Smaller is stronger : an engineering induced size effect!*. Poster session presented at Mate Poster Award 2006 : 11th Annual Poster Contest.

**Document status and date:**

Published: 01/01/2006

**Document Version:**

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

**Please check the document version of this publication:**

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

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# 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".

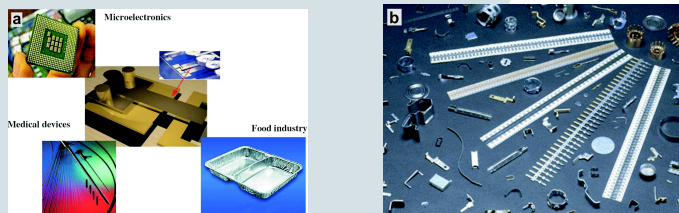


Figure 1: (a) Industrial applications (b) Micro-parts.

## 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  $\mu\text{m}$  and a pronounced Cube texture (Figure 2).

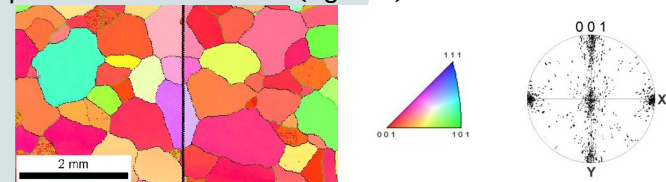


Figure 2: Microstructure and {001} pole figure of a recrystallised specimen.

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  $^{\circ}\text{C}$  to relief internal stress.

## Mechanical behaviour

Results for the uniaxial tension tests for both specimen 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!

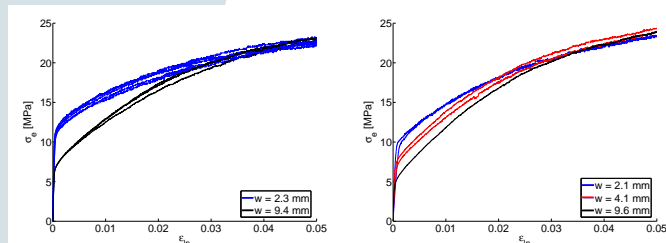


Figure 3: Stress-strain curves of (left) ground specimens and (right) laser-cut specimens.

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To investigate the origin of this size effect, the specimens have been given an additional heat-treatment of 30 minutes at 600  $^{\circ}\text{C}$  (Figure 4).

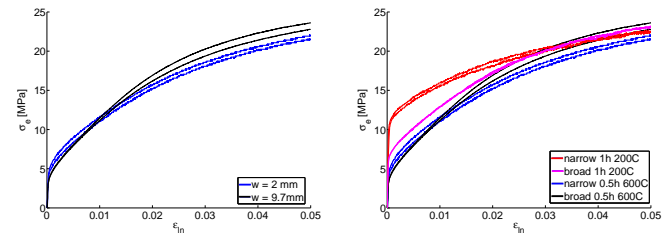


Figure 4: (left) Stress-strain curves of additional annealed specimens (right) 1 hour 200  $^{\circ}\text{C}$  vs 30 minutes 600  $^{\circ}\text{C}$  specimens.

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).

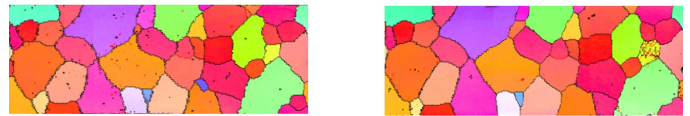


Figure 5: Microstructure evolution, before (left) and after (right) the additional 30 minutes 600  $^{\circ}\text{C}$  annealing.

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.

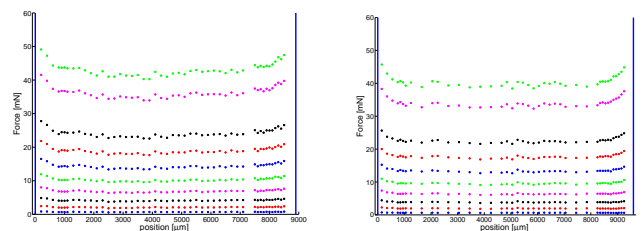


Figure 6: (left) Nano-indentation results at several indentation depths across the width of (left) a mechanically cut specimen and (right) a laser cut specimen.

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.