Deviating mechanical behaviour of sheet metal with a thickness of about the crystallite size

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Introduction

Due to miniaturisation, for instance in the electronic industry, ever thinner metal sheets are being processed (figure 1). Consequently, only a few crystals may be present within the thickness of the sheet.

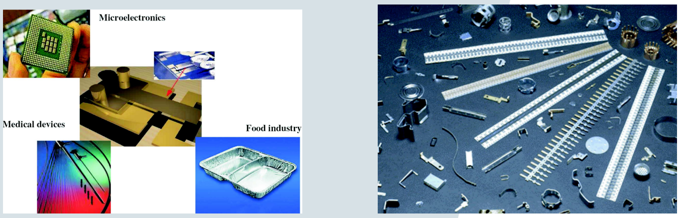

Figure 1 *(a) Industrial applications (b) Micro-parts.*

Objective

The subject of this poster is the mechanical behaviour of plate specimens with varying thickness (t) and grainsize (d_s), all having initially the same texture and a low dislocation density. In this work the ratio between thickness and grain size (λ_s) is less than two, in literature [1, 2] most research was only done for λ_s larger than two.

Microstructure

Typical grain structures and {001} pole figures of the specimens, having different grain sizes and thickness, are shown in figure 2. The specimens have a regular grain structure and a $\{001\}\langle 100\rangle$ cube texture; the strength and sharpness of the textures of the different specimens are very much the same.

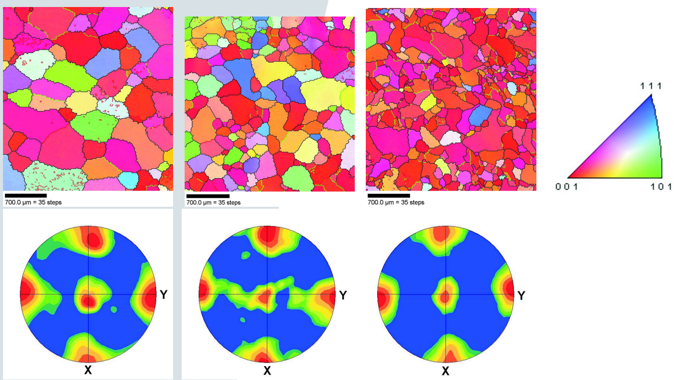

Figure 2 *Grain structures and {001} pole figures of several specimens; crystallographic directions parallel to the tensile direction coloured according to the indicated inverse pole figure.*

Results

The stress-strain curves, shown in figure 3(a), were measured using a Kammrath&Weiss 10 kN micro tensile stage equipped with an 500 N loadcell. The true stress versus λ_s, at a true strain of 0.05 and 0.1, is shown in figure 3(b) . As can be observed, the stress does only slightly increase for $\lambda_s < 1$ and increases significantly for $\lambda_s > 1$.

For $\lambda_s < 1$, the specimens can be considered as a two dimensional arrangement of grains, there are only "vertical" grain boundaries. All crystals have two free surfaces, the deformation and rotation of the central parts of the crystals, are almost not obstructed.

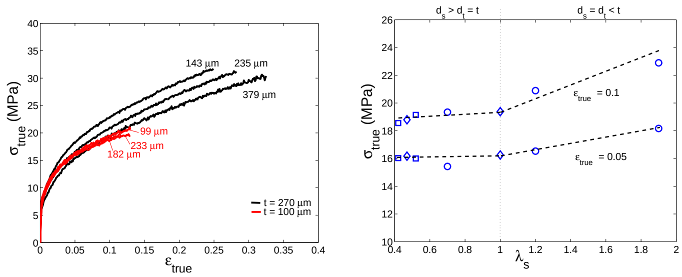

Figure 3 *(a) Mean tensile curves; thickness (t) and grain size (d_s) are depicted in figure (b) True stress versus λ_s for all series at a true strain of 0.05 and 0.1 (d_t is grain size in thickness direction).*

The reason for the increase in strength beyond $\lambda_s > 1$ is that "horizontal" grain boundaries are introduced into the material. As a result, crystal deformation and rotation becomes significantly more constraint, the strength of the material increases significantly.
The effect of grain size refinement on the flow stress for bulk material is described by the Hall-Petch relation, the stress is linearly proportional to the grain size.

Hall-Petch relation:

$$\sigma(\epsilon) = \sigma_0(\epsilon) + k(\epsilon)d^{-1/2}$$

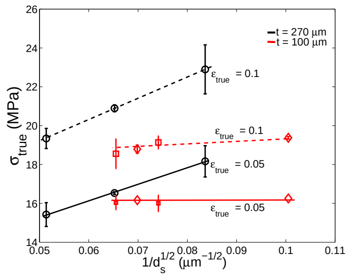

Figure 4 *True stress versus* $1/\sqrt{d_s}$.

The flow stress, for a specific grain size and strain (deformation), and slopes are different for specimens with different thickness as is shown in figure 4. From this, one can conclude that the Hall-Petch relation is no longer valid. In Hall-Petch type relations, if they exist anyhow for specimens with $\lambda_s < 3$, parameters will be different for different λ_s.

Future work

Investigate the grain statistics effect, using specimens with constant grain size and varying geometry, in the range of $1 < \lambda_s < 8$.

References:

[1] Miyazaki, S. Shibata, K. Fujita, H.: Acta Metallurgica, Vol. 27, p. 855-862, 1978.

[2] Kals, R.T.A. Eckstein, R.: Journal Materials Processing Technology, Vol. 103, p. 95-101, 2000.

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