Institute for Materials Science and Welding (IWS)
Graz University of Technology, Austria

Hot deformation of AA6082 containing fine intermetallic inclusions

C. Poletti, C. Sommitsch

Institut für Werkstoffkunde und Schweißtechnik, Technische Universität Graz. Kopernikusgasse 24/I 8010 Graz

ABSTRACT

Hot deformation of a hot rolled Al-Mg-Si alloy is studied by means of compression tests carried out in a wide range of strain rates and between 300-550°C. The flow data obtained by using a Servotest machine are used in order to calculate the strain rate sensitivity value and constitutive equations. Low values of strain rate sensitivity (around 0.1 in the studied range) are related to dynamic recovery acting as the main restoration mechanism. This argument is also confirmed by correlating the subgrain size of recovered grains determined from EBSD measurements with both the Zener –Hollomon parameter and the stress values. At temperatures below 450°C, grain refinement is observed and to the presence of small Mg_2Si precipitates formed during the relative slow cooling in the hot rolling process. High values of the n exponent from the creep equation and of the apparent energy of activation compared to pure aluminium diffusion are related to the pinning of dislocations due to the high content of very fine Fe and Mn rich inclusions. The addition of a threshold stress value to the constitutive equation is needed and represent the pinning of dislocations at the fine inclusions. Growth and dissolution of Mg_2Si precipitates takes place at high temperatures.

Objective

The objective of this work is to study the deformation mechanisms that take place during the hot deformation of a hot rolled AA6082 aluminium alloy with large amount of intermetallic inclusions.

Experimental

The hot rolled plate is produced in 5 steps (starting T = 550°C) and homogenized at 500°C. Cylindrical samples are compressed using a Servotest machine between 300-550°C and 0.001 and 500 s^{-1} of strain rate. Some compression tests at specific deformation parameters are carried out with a Gleeble ® 1500 servohydraulic to freeze the microstructure in situ by water quenching. Samples are ground and polished and observed using SEM in the BSE mode. EBSD measurements are carried out by means of ESEM (FEG-ESEM) FEI device and TEM pictures to observe dislocations and subgrains.

Microstructure

The microstructure of the as received material consists on elongated not fully recrystallized grains, some of them present a substructure [6]. A large amount of intermetallic inclusions (Al-Fe-Mn-Si) are observed in withe and needle –like shape Mg_2Si precipitates in black (Fig.1).

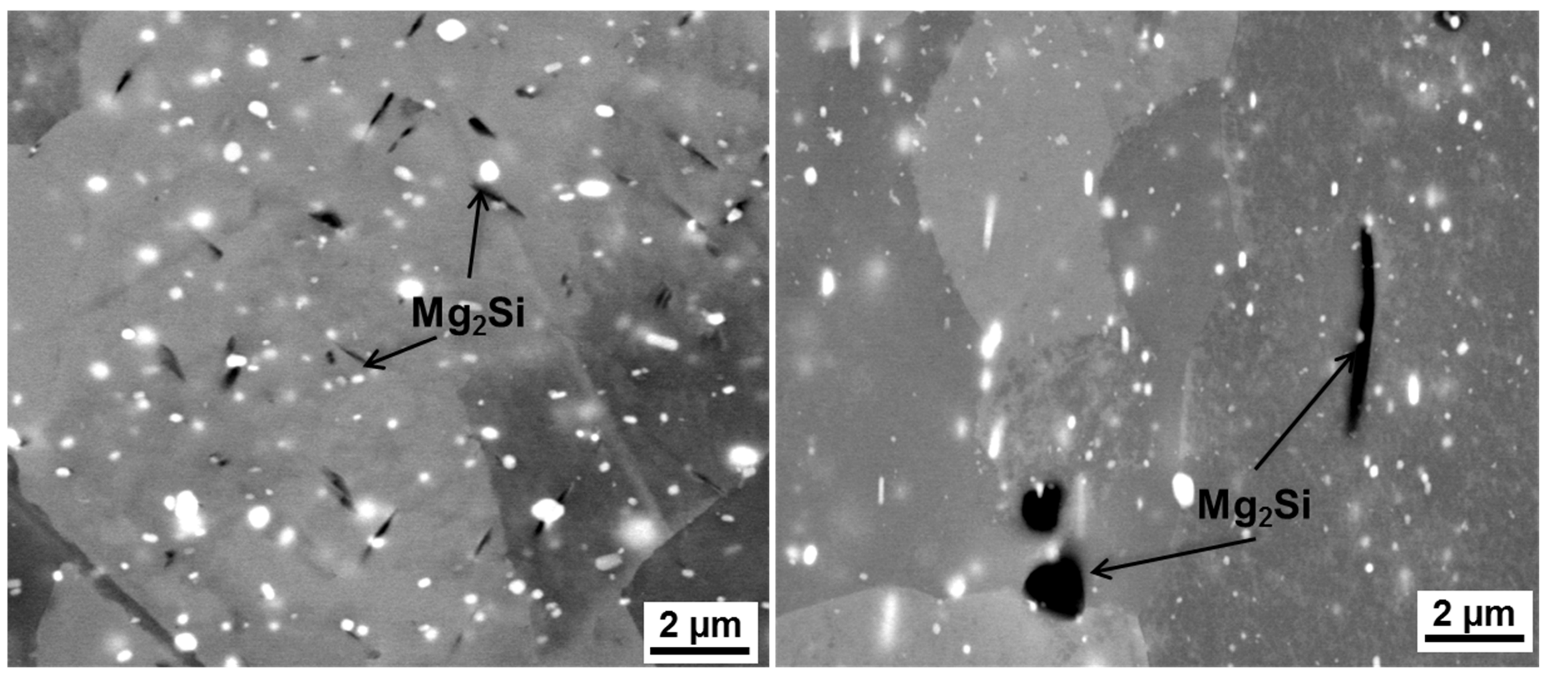


Fig. 1: SEM (BSE) picture in a) as received condition b) after heat treatment at 500°C/30 min.

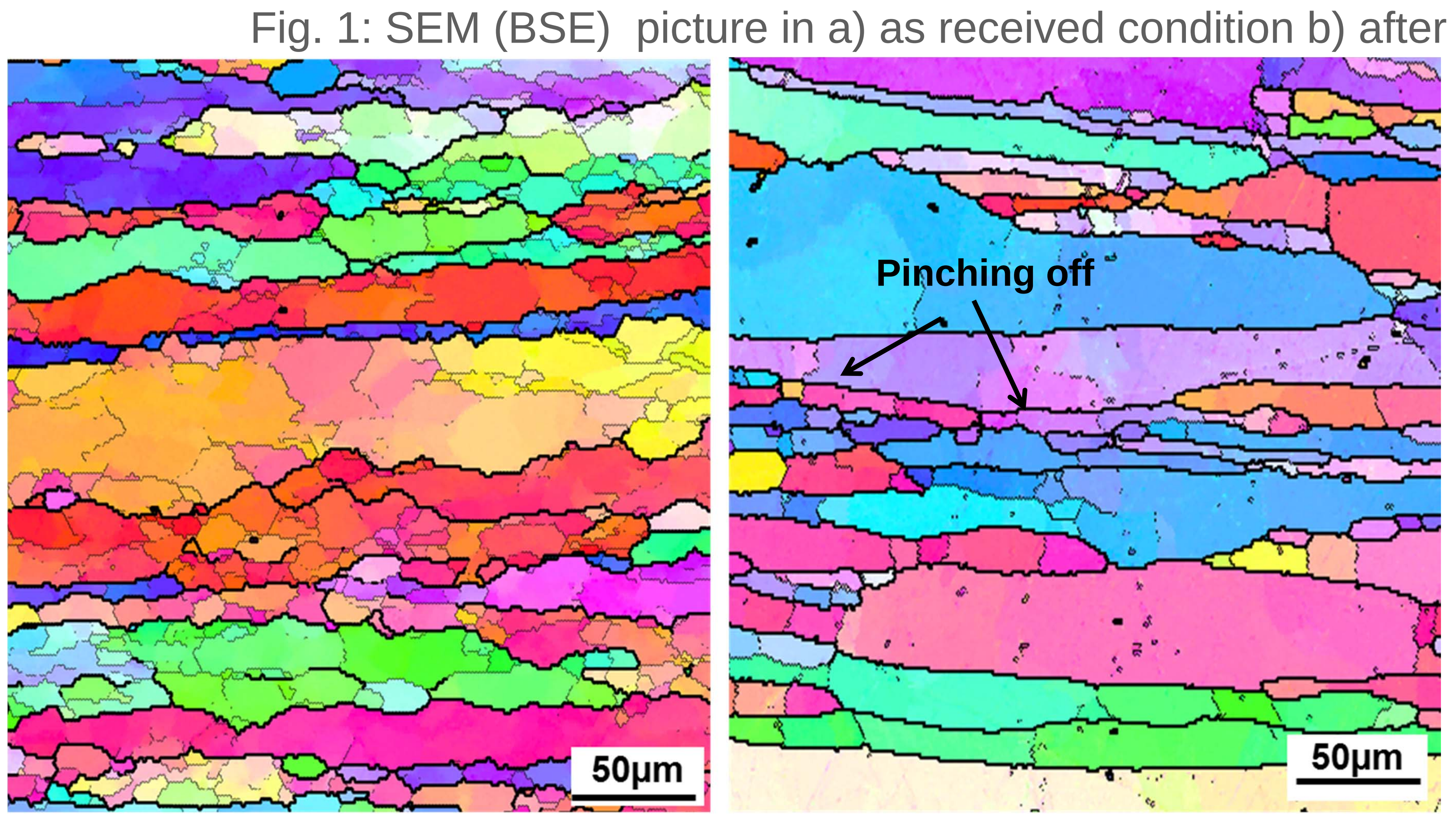


Fig. 2: EBSD measurements of samples deformed at a) 1s^{-1} and 550°C and b) 0.001s^{-1} and 500°C (grain boundaries black).

At large strains geometric dynamic recrystallization (gDRX) [2,3] takes place by pinching off of HAGB (Fig.2)

Intermetallic inclusions are refined during hot rolling and pin the dislocations during further hot deformation. Dislocations climb these inclusions and are further attracted to the particles even after passing through them (Fig.3). This was also observed for dispersion strengthened alloys [4]. Dynamic recovery is thus retarded, and a threshold stress is needed.

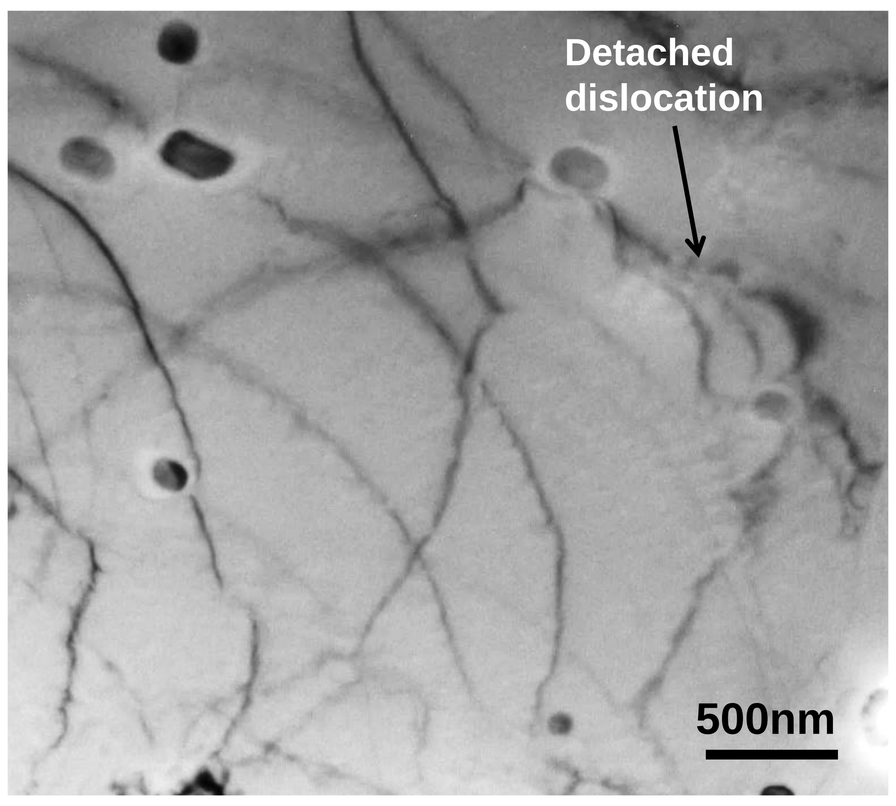


Fig. 3: TEM picture of a sample deformed at 500°C and 0.001 s^{-1}

Flow behaviour

The flow curves in Fig 4 show steady state after strain hardening. At high temperatures, some softening is observed at high strain rates

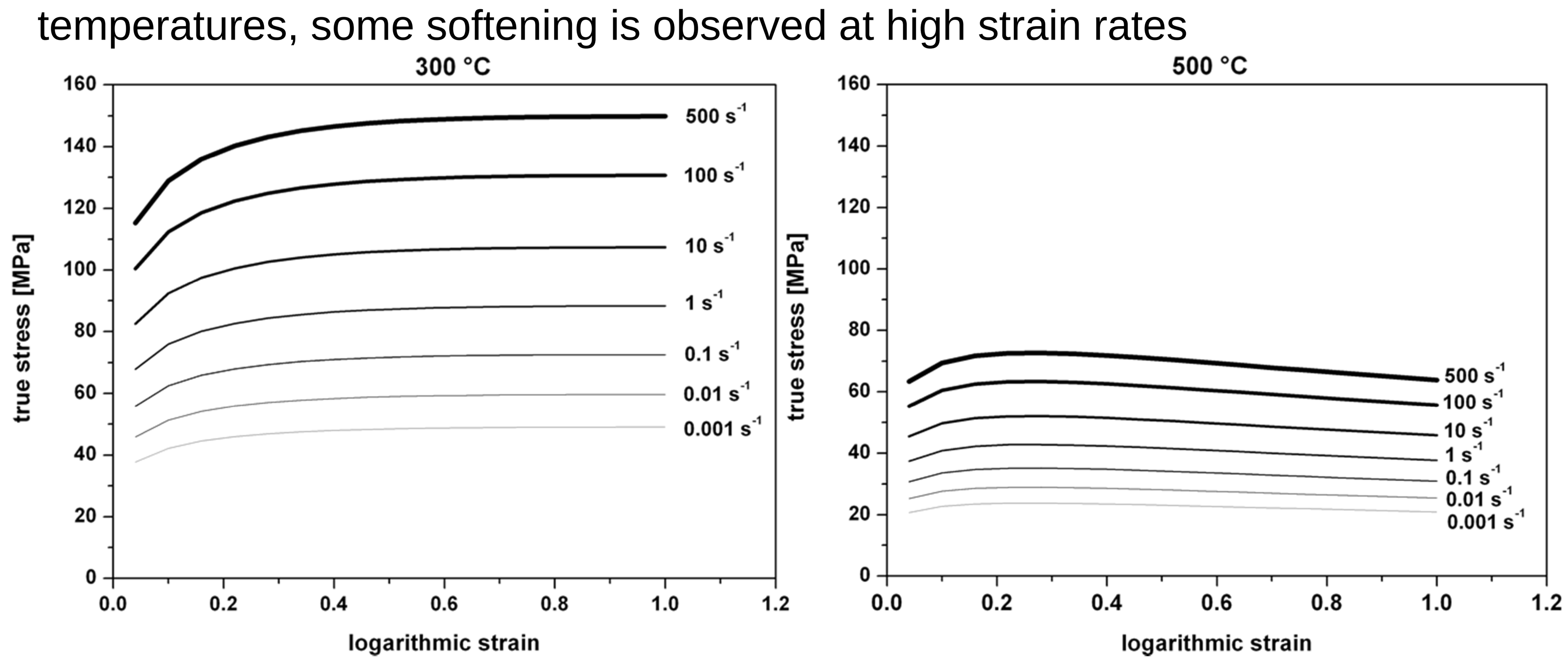


Fig. 4: Flow curves at different temperatures and strain rates

Constitutive equations

Constitutive equations relate the flow stress with the Z as follows [5]:

$$A_P\sigma^{n_P} = \dot{\varepsilon}\,exp(Q_P/RT) = Z_P \qquad \textbf{Eq.2}$$

$$A\,sinh(\alpha\sigma)^n = \dot{\varepsilon}\,exp(Q_P/RT) = Z \qquad \textbf{Eq.3}$$

A, b and *a* re material constants, P related to the power law, and the exponent *n* can be correlated to the deformation mechanism [6].

The ***n* = 11.7** for Eq. 2

Eq 3 can be written as:

$Z = 2.72 \times 10^{18} [sinh(0.005\sigma)]^{11.5}$

Q was found to be 159 kJ mol^{-1} K^{-1}.

If a threshold stress is included, then the Eq. 3 can be rewritten as:

$Z = 2.36 \times 10^{16} [sinh(0.005(\sigma - \sigma_0))]^8$

with σ_0 =10 MPa and Q = 145kJ/mol. The value of *n* = 8 is related to the invariant model.

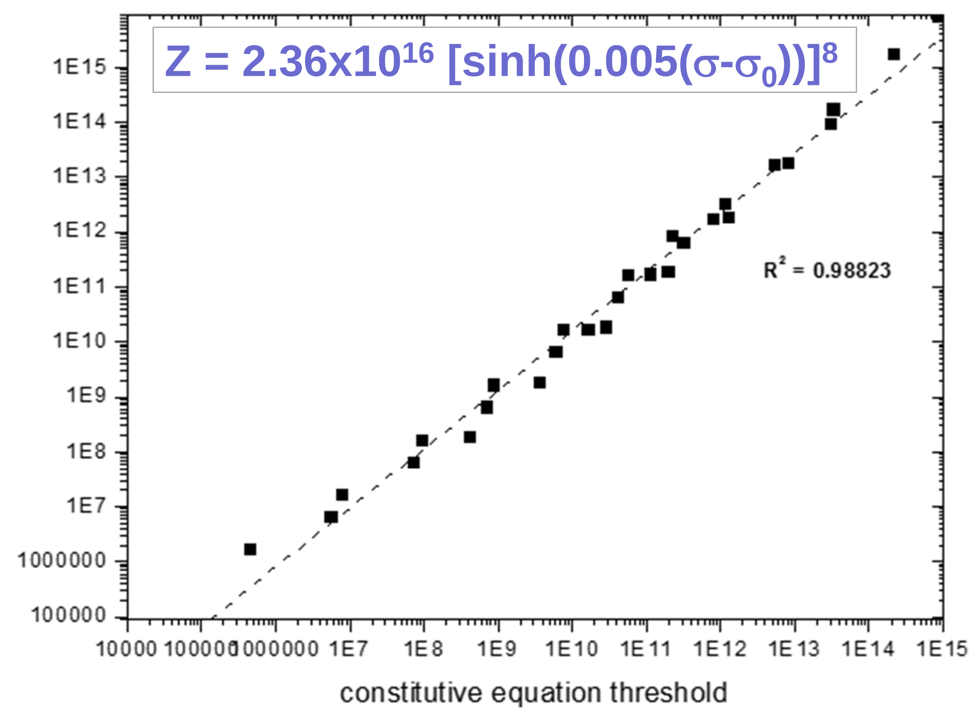
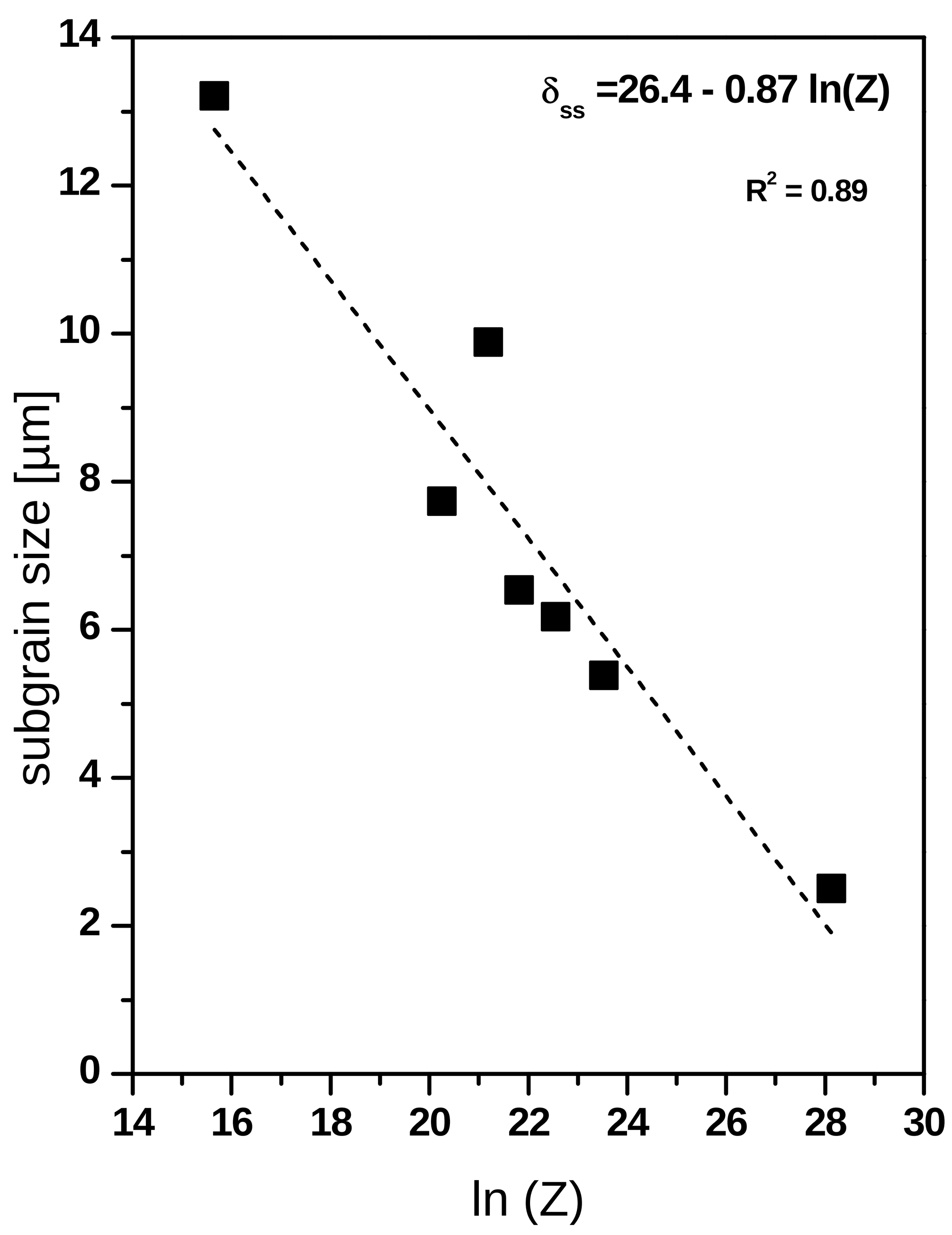


Fig. 5: Z correlates well with the Eq. 3 with threshold

Microstructural correlation



Dynamic recovery is the main restoration mechanism in the tested range, in agreement with the literature [1].

There is a good correlation of the subgrain size (δ_{ss}) with the lnZ (Fig. 6)

Fig. 6: Subgrain size developed during hot deformation as a function of lnZ

References

[1] H. J. McQueen, W. Blum. Mater Sci Eng A 290 1-2 (2000) 95
[2] M.D Drury, F.J. Humphreys. Acta Metall 34 (1986) 2259
[3] H.J. McQueen, J.K. Solberg, N. Ryum, E. Nes. Phil. Mag. A60 (1989) 473
[4] J. Rösler, R. Joos, E. Arzt. Metall Trans. 23A (1992) 1521
[5] C.M. Sellars, W.J. McG. Tegart. Acta Metall. 14 (1966) 1136
[6] N.E. Dowling. Mechanical Behaviour of Materials: Engineering Methods for Deformation, Fracture and Fatigue. 3rd edition 2007. Pearsons Prentice Hall

Acknowledgments

The authors would like to thank FWF (Austrian Science Fund) for funding project number [P22238-N22], AMAG for the provision of the material and USTEM (Vienna University of Technology) for the provision of the EBSD facilities and TEM pictures.