USING COMPRESSION TESTS TO EVALUATE THE RECRYSTALLIZATION BEHAVIOUR UNDER REALISTIC STRAINING

Irene Høgset Hove[1], Bjørn Andersson[1] and Gaute Jensen[2]
1 SINTEF Materials Technology, P.O. BOX 124 Blindern, 0314 Oslo, Norway
2 Raufoss A/S, P.O. BOX 2, 2831 Raufoss, Norway

Abstract

Age hardenable alloys often recrystallize during solution heat treatment after a deformation, e.g. forging. The recrystallized grain size depends, in addition to structure parameters, on the strains caused by the plastic deformation. Several material properties depend on the grain size. It is therefore important to know how grain size is related to deformation. Information about this can be found by uniaxial compression tests. In this work we have shown that compression tests with realistic friction combined with finite element analysis give valuable information about the grain size/strain relationship. Several grain size/strain pairs have been found in each sample and the effect of deformation mode has been demonstrated.

Introduction

In forged products of complex geometry, the strains vary from very small to very high and the deformation mode varies. During solution heat treatment of age hardenable alloys this results in a large range of grain size/structure. To be able to control the recrystallized grain size after solution heat treatment, it is necessary to understand how the grain structure relates to the complex strain pattern.

This type of information can be found by uniaxial compression tests. One way, considered to be the conventional, is to refine the experiment so that the deformation becomes nearly homogeneous i. e. the global deformation is close to the local. The local grain size can therefore be an unknown approximation related to the global strain. The drawback is that a large number of tests must be performed, and a correct measurement and realistic strain situation cannot be obtained. With friction the deformation will be inhomogeneous [1] which results in an uneven grain size after recrystallization. In this work we will show how compression tests with realistic friction combined with finite element analysis is a useful method to obtain information about the relationship between local strain/deformation mode and grainsize after recrystallization.

Experimental and results

Compression test

In this work we have used a 7XXX alloy as an example. The alloy was extruded and annealed. The material did not recrystallize during the annealing. Cylindrical samples for compression tests were taken with the cylinder axis parallel to the extrusion direction. The samples were 15 mm high and had a diameter of 10 mm. The compression tests were conducted on a 25 T Instron Dynamic Test machine, model 1333. Rentax AM which is molybdenum disulphide based was used as lubricant.

The tests were conducted at room temperature. The ramspeed was constant during the testing, v=1,7 mm/s. This gave a strain rate varying from $\dot{\varepsilon}$=0,12 s^{-1} at the start to $\dot{\varepsilon}$=0,4 s^{-1} at the end for the largest deformations. Samples were deformed to different thicknesses, table I. The global strain is given by the thickness reduction, $\varepsilon_{global}=\ln(h/h_0)$.

Table I: Deformation of different samples.

Sample	Thickness, mm	Global strain, ε_{global}
S1	12,3	0,20
S2	9,5	0,46
S3	6,2	0,88
S4	4,0	1,32

Load and position were logged during testing and stress/strain curves calculated. The measured load has a friction part, which is small for small thickness reductions, but higher for larger thickness reductions. We assumed that $\sigma=K\varepsilon^n$, where σ=stress, ε=strain and K and n are constants. To subtract the friction part data from sample S1 and S2, where the friction part was very small, was used to find K and n. We found that K=392 MPa and n=0,19.

After deformation the samples were solution heat treated. The samples were cut longitudinally and one half was cold mounted in epofix. The samples were ground, polished and anodized. The grain structure was investigated in polarized light at a Reichert MeF3A light microscope. All the samples were recrystallized after the heat treatment. The grain size was uneven as seen in figure 1a. The grain size was small in the middle of the samples and large near the surface. In a zone about 30°-40° to the compression axis the grains were smaller than the surrounding. In all the three areas there was a great variation of grain size. The grain size was measured parallel to the compression surfaces with the lineal intercept method. Results from the grain size measurements are given in table II-IV and figure 4-5. In figure 1b the grain structure after solution heat treatment is shown for another 7XXX alloy. This material does not recrystallize during solution heat treatment. The elongated grains from extrusion clearly show the deformation pattern. The sample was compressed as S3.

Finite element analysis

A model for the compression test was made with the finite element program Abaqus [2]. In this model the material description is elastoplastic and the stress/strain curve found by the experimental compression is used as input. As yielding criterion Von Mises was used. To model the friction Coloumbs friction law was used. The friction constant was found in an earlier work [3] by fitting the friction law to the derivation of the stress/strain curve from material response ($\sigma=K\varepsilon^n$) and controlled by that the geometry changes were as predicted. μ=0,2 was found to be a reasonable value for the friction.

With this compression model all the 4 experimental tests were modelled. From the model stress and strain distributions are calculated. Figure 2 shows the distribution of equivalent plastic strain after ε_{global}= 0,88 (S3). Because of symmetry only 1/4 of the sample is drawn. There are large difference between the strains in different areas, varying from ε_{pl}=0,17 near the surface to ε_{pl}=1,44 in the middle. There is also a shear zone about 30°-40° to the compression axis.
Figure 3 shows a map of the shear strain.

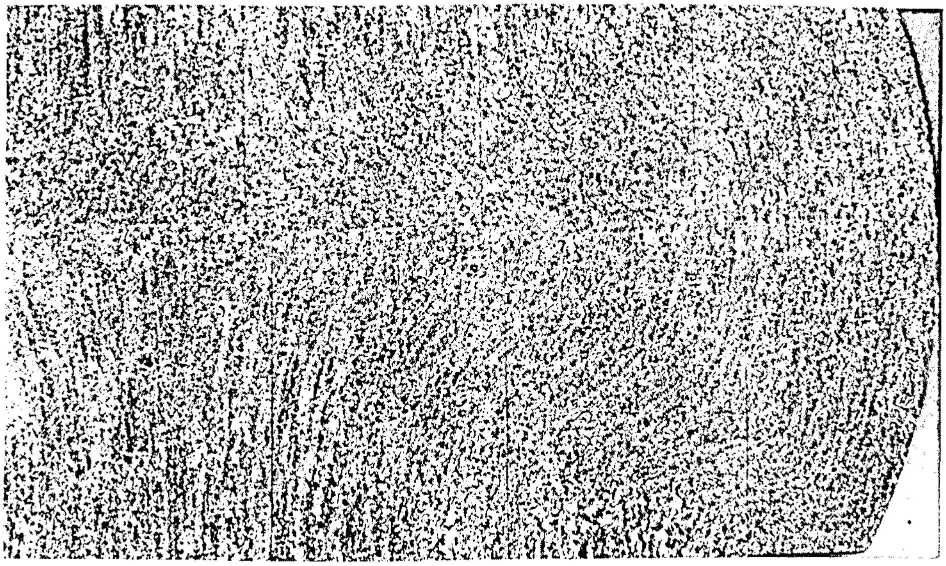

Figure 1a) Grain size in sample S3 after solution heat treatment.

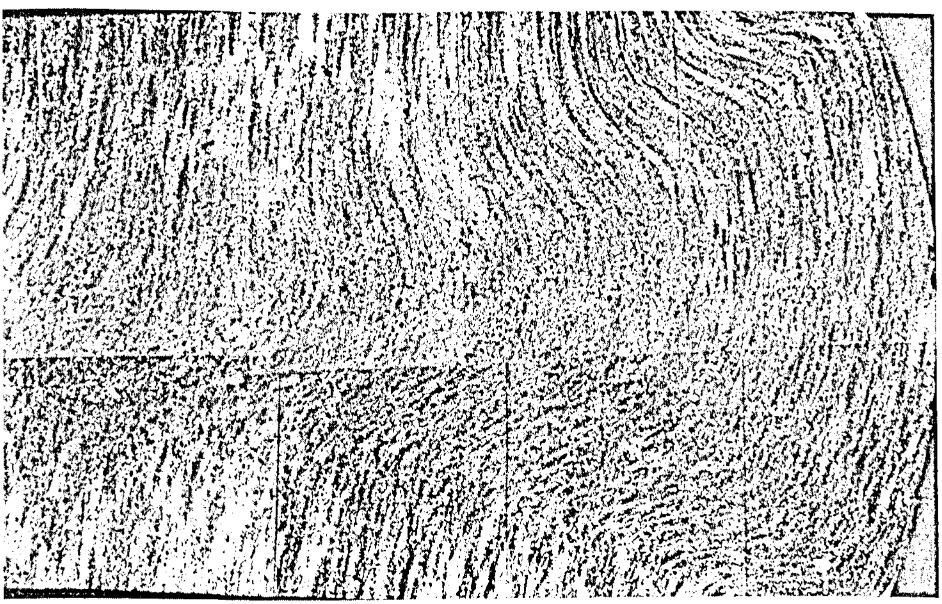

Figure 1b) Grain structure in a sample deformed as S3, but which did not recrystallized during solution heat treatment.

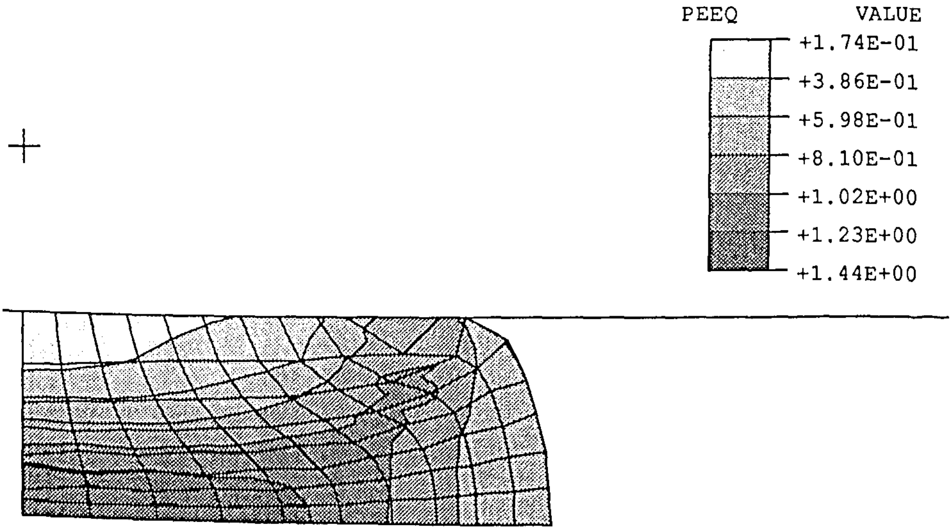

Figure 2: Distribution of equivalent plastic strain in sample S3.

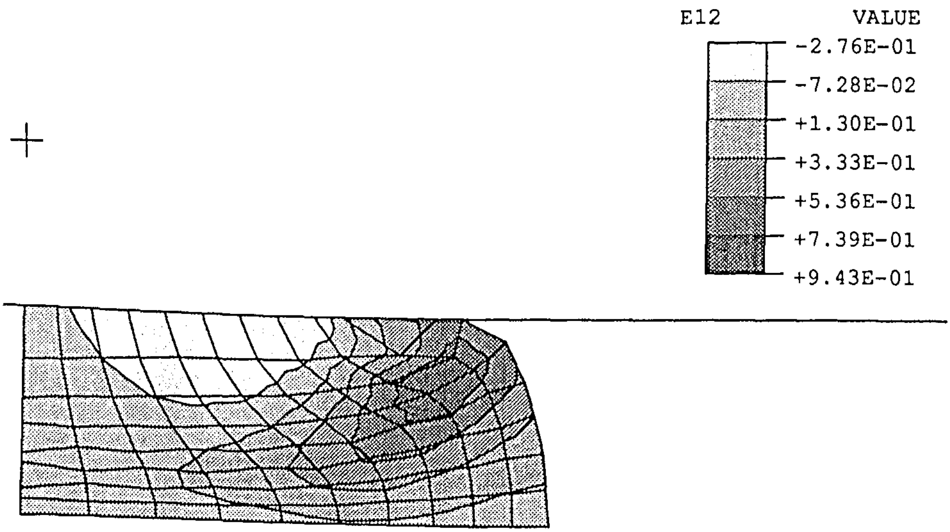

Figure 3: Distribution of shear strain in sample S3

Discussion

Comparison of strain maps and grain structure

Local strain related to grain size. By comparing the grain size in figure 1 and the strain map in figure 2 we see that the variation in grain size correlates to the pattern of material flow found by the simulation model. To perform a more thorough investigation of the grain size/strain relationship, we focused first at the middle of the samples. The grain size in the middle was measured in all the samples. The local strain was found from strain maps. The grain size, local strain and global strain are given in table II. As seen the local strain is nearly twice as the global in the middle. Consequently, if we did not know the local strain we could get the wrong grain size/strain relationship. Because it is not a strain of ε=0,88 that corresponds to a grain size of 20μm, but a strain like ε_{pl}=1,3 (table II). We also observed that the grain size decreased with increasing strain.

Table II: Grain size found in the middle of the samples with different global and local strains.

Sample	S1	S2	S3	S4
Grain size, μm	41±2,2	23±1,6	20±1,4	19±1,1
Global strain, ε_{global}	0,19	0,46	0,88	1,35
Local strain, ε_{pl}	0,3	0,8	1,3	2,0

Several strain /grain size pairs from each sample. Since the grain size and the local strain vary within the same sample it is possible to find several grain size/strain relationships in one sample. This is exemplified by comparing the grain structure and strain maps in three different areas: middle of the surface, the middle of the sample and the shear zone. The measured grain size and strain found from strain maps in the different areas in two samples, sample S3 and S4, are given in table III and table IV. All the measured grain sizes are summarised in figure 4. In each of the three areas (surface, middle and shear zone) the grain size decreased with increasing strain.

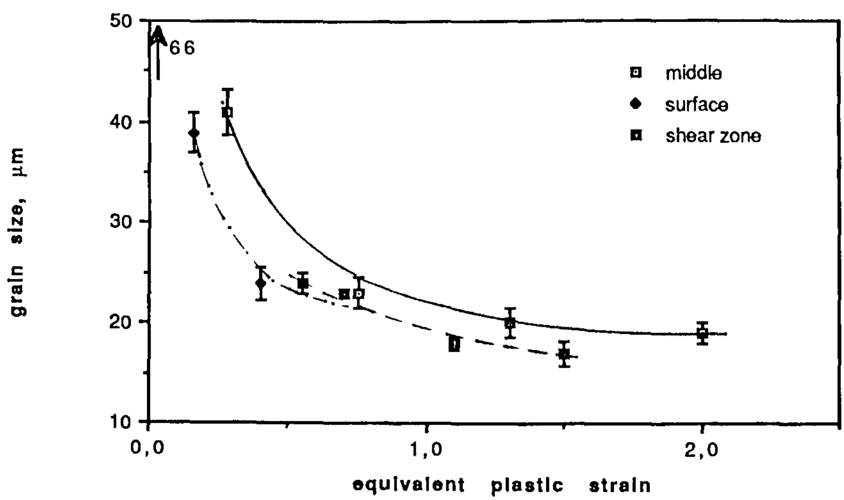

Figure 4: Grain size measured in different areas as function of local strain.

Table III: Measured grain size and local strain in different areas in sample S3

Area	Grain size	Local strain	Global strain
near surface	24±1,4	0,4	0,88
middle	20±1,4	1,3	0,88
shear zone	18±0,7	1,1	0,88

Table IV: Measured grain size and local strain in different areas in sample S4

Area	Grain size	Local strain	Global strain
near surface	23±0,4	0,7	1,35
middle	19±1,1	2,0	1,35
shear zone	17±1,2	1,5	1,35

The effect of deformation mode on grain size. The deformation mode is not the same in the whole sample. The deformation mode in the middle will for instance be different from the deformation mode in the shear zone. By using realistic friction it is therefore possible to study the effect of deformation mode on the grain size. The equivalent plastic strain in the middle is higher than in the shear zone, so we expect smaller grains in the middle than in the shear zone. But the results from the grain size measurements indicate that the grain size is smaller in the shear zone than in the middle, figure 4. This indicates that the deformation mode influence the grain size, i.e. for the same equivalent plastic strain the grain size will be smaller in the shear zone than in the middle. The effect of both equivalent plastic strain and shear strain on the grain size have been illustrated by a closer investigation of sample S3. The grain size has been measured in areas with the same equivalent plastic strain, but variable shear strain. The same has been done in areas with constant shear strain but variable equivalent plastic strain. In figure 5 the grain size as function of shear strain is plotted. The grain size decreased with increasing shear strain for constant equivalent plastic strain. In areas with constant shear strain the grain size decreased with increasing equivalent plastic strain.

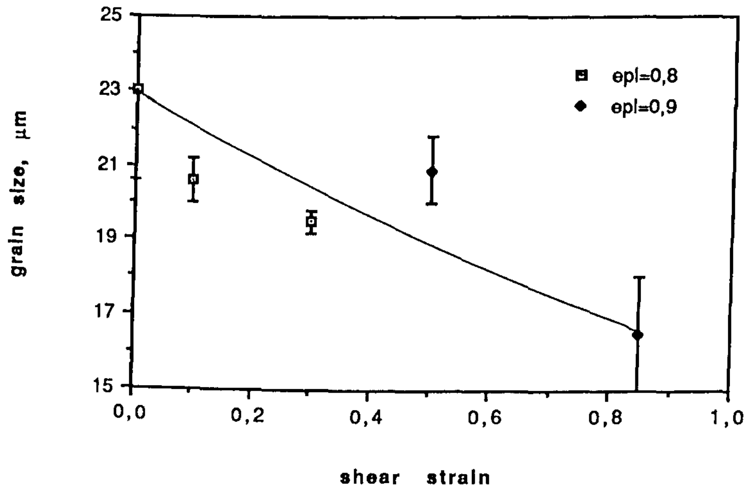

Figure 5: Grain size as function of shear strain.

The grain size also depends on the Zenerdrag caused by dispersoides, the heating rate and the solution heat treatment temperature. These parameters are held as constant as possible in this work.

Conclusion

We have shown that compression tests with realistic friction combined with finite element analysis give valuable information about the grain size/strain relationship. Several grain size/strain pairs have been found in each sample and the effect of deformation mode has been studied.

References

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