DYNAMIC STRAIN AGEING EFFECTS IN AN EXTRUDED AA7030 ALLOY SUBJECTED TO TENSILE DEFORMATION

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ABSTRACT

Dynamic strain ageing (DSA) is a well-known phenomenon in a number of alloying systems, including the AA7XXX series aluminium alloys. The physical origin is the repeated pinning and un-pinning of moving dislocations by diffusing solute atoms and the phenomenon is thus highly temperature and strain rate dependent. In the present work, the DSA manifestation in extruded AA7030 (Al-5.4Zn-1.2Mg) was extensively characterized as a function of temperature, strain rate and heat treatment, using constant cross-head velocity tensile tests. The temperature was varied between -20 and +60°C at strain rates of 10^{-4} and 10^{-3} s^{-1} in both the solution treated and peak-aged condition. Serrated flow, or the Portevin-Le Chatelier (PLC) effect, was observed in both tempers under most conditions. The serrations were much more pronounced in the solution treated condition and the appearance clearly different from the peak-aged temper. In the latter case small type B serrations persist throughout the specimen life, often interrupted at regular intervals by larger type A serrations. In the solution treated samples type A or B serrations of small amplitudes precedes the type D serrations appearing at high and medium strains. When using strain rate change tests a clear influence of previous deformation can be seen, manifested as super positioning of serrations in the tensile curves. In the solution treated condition, inverse temperature and strain rate dependence of both the flow stress and ductility was observed as a consequence of DSA. None of this occurred in the peak-aged samples.

1 INTRODUCTION

In many alloying systems containing diffusing solute atoms in solid solution a dislocation-solute interaction termed dynamic strain ageing (DSA) can take place. The mechanism behind DSA is the repeated pinning and unpinning of moving dislocations by mobile solute atoms (McCormick [1]). Due to the physical nature of this interaction, the extent of it is highly dependent on temperature and strain rate through the mechanisms of diffusion and thermal activation. Dynamic strain ageing can cause numerous detrimental effects on the mechanical behaviour such as loss of ductility, localized strain, increased stresses and inverse temperature and strain rate dependence of the flow stress as well as aesthetic problems with surface effects (Robinson and Shaw [2]). Another observable manifestation is the Portevin-Le Châtelier (PLC) effect, or serrated flow. The phenomenon is closely related to the yield point behaviour and Lüders band formation in mild steels. Another relevant phenomenon is dynamic precipitation (DP) where deformation induced vacancies facilitate precipitation of small coherent particles, such as GP-zones (Deschamps *et al.* [3]). This process consumes both vacancies and solute atoms and can thus present an obstacle for the DSA process (Pink [4] and Pink and Webernig [5]).

Al-alloys are generally most susceptible to DSA at ambient temperatures which is why they have been investigated rather extensively. The present investigation concerns the influence of DSA on the mechanical properties of AA7030 under tensile deformation. This alloy has earlier been shown by Fjeldly and Roven [6] to exhibit serrated flow and negative strain rate sensitivity (SRS) in the solution treated condition and the aim here is to more extensively characterize the material for further investigations into the cyclic (LCF) properties, such as stress evolution and fatigue life as well as crack propagation and fracture properties, and their relation to DSA. This is an area where little work has been done, with the exception of super alloys and pressure vessel steels.

2 EXPERIMENTAL

2.1 Material

The material was supplied by Norsk Hydro in the form of 150 mm wide plates, extruded at 10 m/min at 550°C and air cooled, with a thickness of 5 mm. The nominal composition is given in table 1. The microstructure was recrystallized due to the low Zr content with an average grain size of 110 µm (ASTM grain size number 3-4) and only a small elongation of the grains in the longitudinal direction was observed. A texture analysis of extruded AA7030 has been performed by Fjeldly and Roven [6], and it was shown to have a recrystallization texture. The material was to be tested in two different states, solution treated and peak aged. Solution treatment was performed at 480°C for 30 min, followed by immediate water quenching and ageing to peak hardness at 120°C for 24 h. Due to the extremely unstable solution treated state there was a need to stabilize the microstructure. The main reason for this was to plan for later LCF tests using the same conditions. Ageing tests showed an increase of almost 60% in the hardness of the solution treated material if aged for 8 h at room temperature, an approximate duration of an LCF test. To rationalize, the samples were aged at room temperature for 24 h before testing to obtain a more stable state. Although no longer strictly true, this state will still be referred to as solution treated.

Table 1: Composition of AA7030 as provided by Norsk Hydro.

Element	**Al**	**Si**	**Fe**	**Cu**	**Mg**	**Zn**	**Zr**
Weight %	Bal.	0.08	0.16	0.27	1.19	5.39	0.03

2.2 Tests

An Instron 8032 servohydraulic tensile testing rig equipped with a temperature chamber was used to perform the tensile tests. Constant cross-head velocities corresponding to nominal strain rates of 10^{-4} and 10^{-3} s^{-1} were used and the tests were performed at -20°C, room temperature and 60°C. Furthermore, strain rate change tests were performed with $\dot{\varepsilon}_1 \rightarrow \dot{\varepsilon}_2$ as $10^{-4} \rightarrow 10^{-3}$ s^{-1} at an approximate strain of 1.5%, as $10^{-3} \rightarrow 10^{-4}$ at 3% strain and as $10^{-4} \rightarrow 10^{-2}$ s^{-1} at 4.5% strain.

3 RESULTS

3.1 Tensile tests

The $R_{p0.2}$ and R_m values from the tensile tests are presented in figure 1. The results are very much in agreement with what is expected, i.e. normal temperature and strain rate dependence of the flow stress in the peak aged condition, and inverse in the solution treated.

Also the temperature dependence of the ductility, here measured as reduction of area (figure 2), shows the same behaviour. The solution treated samples show decreasing RA values with increasing temperature while the peak aged exhibit the normal behaviour. The strain rate dependence on the other hand is somewhat different. The inverse behaviour is seen in the solution treated state as expected, however the same trend is observed in the peak aged condition, except at 60°C.

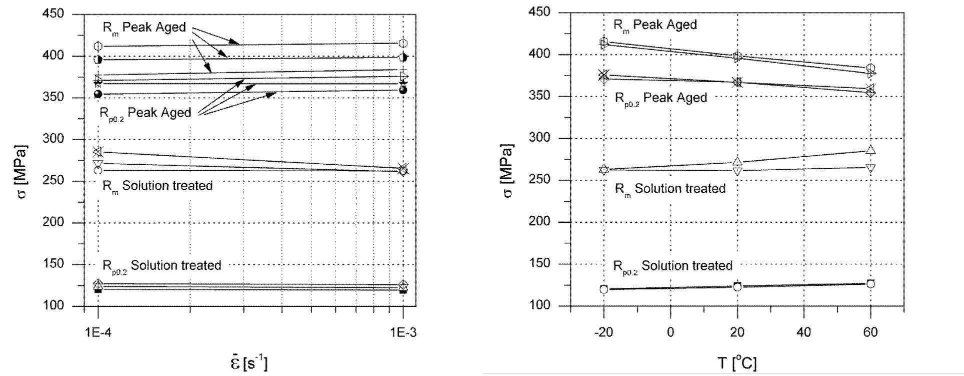

Figure 1: $R_{p0.2}$ and R_m values from tensile tests. All tests are performed at different strain rates and temperatures, although the individual parameters are not indicated in the figure. The combined influence is further dealt with in the section on SRS.

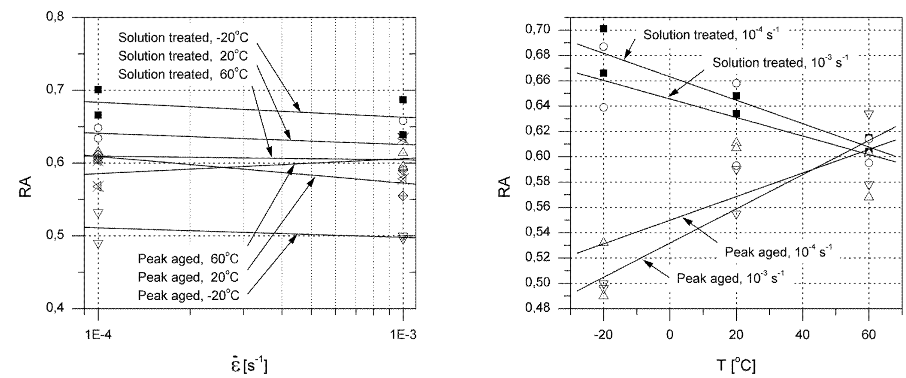

Figure 2: Reduction of area. The added straight lines show the general trends.

3.2 Serrations

Serrated flow, or the PLC effect, was observed in all samples under most conditions, although markedly different between the tempers. In the peak aged state small type B (see Robinson and Shaw [2] for identification of serration types) serrations persisted throughout the specimen life, in many cases interrupted at regular intervals by larger type A serrations. The magnitude and frequency varied, as can be seen from figure 3. The serrations in the solution treated condition were much more pronounced and of clearly different type. Small type A or B serrations of small amplitudes precedes the type D serrations, see figure 4, appearing at high and medium strains. These kinds of serrations have not been reported earlier for this material and are therefore probably a result of the stabilized solution treated state of the material. However in an article by Fjeldly and Roven [6] clear traces of type D serrations could be seen in solution treated AA7030, although this was not commented on by the authors. The type D serrations are associated with the formation of

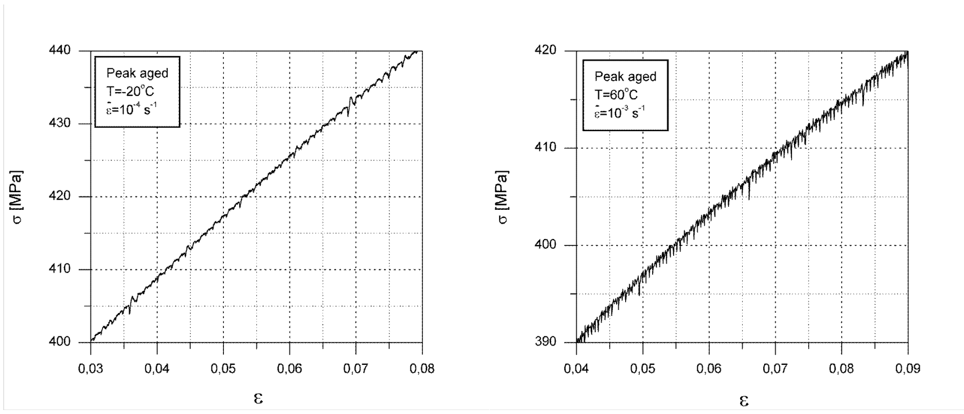

Figure 3: Stress-strain curves for peak aged samples.

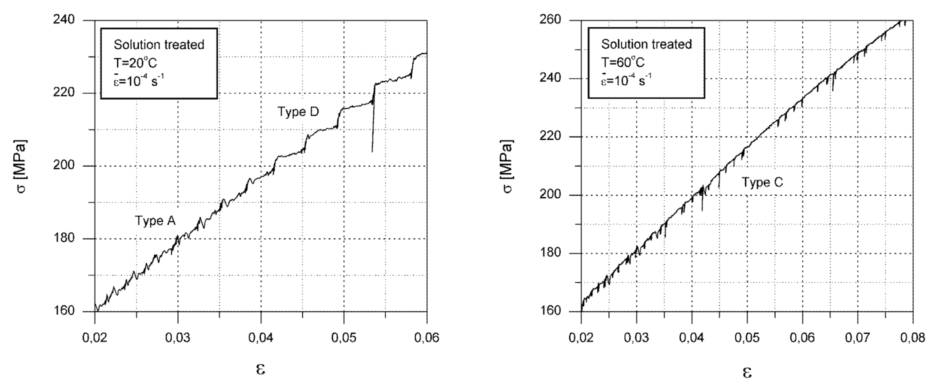

Figure 4: Stress-strain curves for solution treated samples.

moving deformation bands, and these were extensively investigated in terms of localized strain and band velocity using double extensometers (Hörnqvist and Karlsson [7]). At low strain rate and high temperature the serration type changes to type C (figure 4) where the stress level drops below the general stress-strain curve but never rises above.

3.3 Strain Rate Sensitivity

The strain rate sensitivity, in the form of m from eqn (1), was measured at the different strain rate changes.

$$m = \frac{\Delta \ln \sigma}{\Delta \ln \dot{\varepsilon}} \tag{1}$$

The results are presented in figure 5. As expected, negative values of m were observed in the solution treated state and positive in the peak aged.

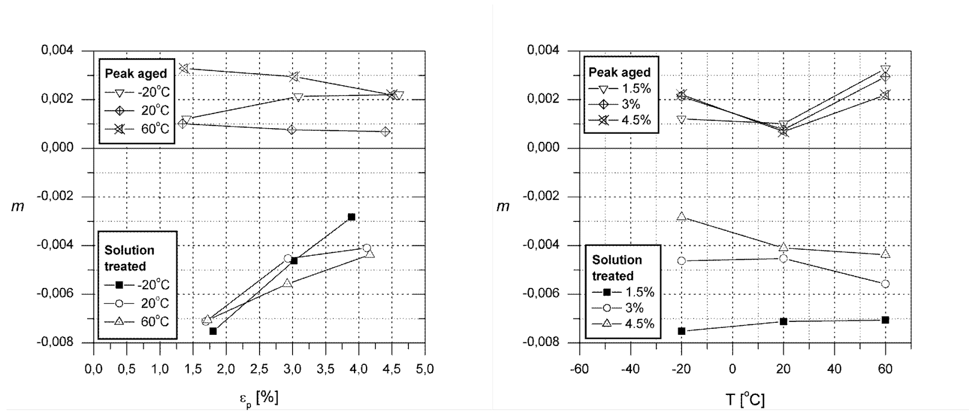

Figure 5: Strain rate sensitivity.

The peak aged samples showed a minimum in the SRS at room temperature. This suggests that there is a suitable balance between the thermally activated obstacle surmounting process and the diffusivity of solute atoms to achieve dislocation pinning, at least to a small extent. The decrease in *m* with increasing strain may be explained by increased diffusivity due to deformation induced vacancies, although this is contradicted by the inverse trend in the samples tested at -20°C.

In the solution treated samples a clear trend of increasing *m* with increasing strain was observed, although the values remained negative. This is probably an indication of deformation (and in the case of the 60°C samples also temperature) induced precipitation due to the unstable solution treated microstructure. Pink [3] and Pink and Webernig [4] provide a more extensive investigation into the relationship between DSA and precipitation in Al5Zn1Mg alloys. The consumption of vacancies and solute atoms counteracts the pinning process necessary for DSA by decreasing solute content and diffusivity. The magnitude of the SRS increases with temperature, indicating that the increased diffusivity promotes a more efficient DSA process.

Another effect noted from the strain rate change tests is the superpositioning of serration types when a strain rate change is performed. The serrations after a change in strain rate commonly consist of the same serrations as in the corresponding monotonic tensile test, with the serrations associated with the preceding deformation rate superposed.

4 SUMMARY

The aim of the study is to prepare for further investigation of dynamic strain ageing and its relation to fatigue behaviour. The focus is therefore directed towards the suitability of AA7030 for this purpose, especially in the peak aged condition because this is the most common temper in industry.

The solution treated specimens show the recognized signs of DSA under all employed conditions. In the peak aged condition the signs are fewer and weaker. Serrated yielding however is still observed although different from that in the solution treated samples. Further indications of DSA are the temperature dependence of the strain rate sensitivity and the inverse temperature dependence of the ductility. All this indicates that DSA is active and so there is a continued interest in the cyclic behaviour of this alloy. The results can generally be summarized in the following points:

1. AA7030 provides an interesting candidate for further investigation into the relation between cyclic behaviour and DSA. The main signs of DSA observed were serrated

yielding in both solution treated and peak aged condition and negative strain rate sensitivity as well as inverse temperature and strain rate dependence of the flow stress and ductility in the solution treated state.

2. Dynamic and temperature induced precipitation can play a significant role in the development of the DSA manifestations.
3. Type D serrations, associated with moving bands of localized deformation, were observed under all conditions in the solution treated state. This has not been reported earlier for this material, although traces can be seen in other articles. The distinct serrations developed here are most likely a result of the stabilized solution treated state (24 h ageing at room temperature).

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