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# Evolution of mechanical properties in a 7075 Al-alloy subject to natural ageing

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ABSTRACT

A series of mechanical tests was used to characterise the evolution of yield strengths, *r*-values and work hardening during the natural ageing of a commercial 7075 aluminium alloy. The results show that there is a significant underlying change in anisotropy between the original O-condition and solution heat treated tempers. In the absence of recrystallisation, the abrupt change in anisotropy appears to have been caused by the modification of the precipitate during the solution heat treatment. The degree of induced anisotropy remained constant throughout the natural ageing process from 15 to 120 min. A series of phenomenological functions is presented for the purpose of interpolation between the original test data points. These empirical functions are shown to predict the yield behaviour of the naturally aged material within the observed experimental scatter.

## 1. Introduction

The commercial Al–Zn–Mg–Cu (7075) alloy is used extensively in the aerospace industry for the fabrication of structural components including C-section fuselage frames for subsonic designs [1] and honeycomb frame panels for transonic designs [2]. The C-section frames are typically fabricated from sheet using various production processes including fluid cell press forming. Due to the strains induced in the forming of the frame, especially in the small radius bends, it is not possible to manufacture these parts in the final T62 temper. Instead, following removal of the blanks using a CNC milling process, the blanks are solution heat treated, stored in a freezer to arrest the ageing process and then formed in the 'as-quenched' (W-temper) condition. Typical production procedures often mean that the parts can be formed anywhere from 30 to 100 min following removal from the freezer. In order to make informed design and production process decisions, a more complete picture of the material behaviour in the W temper is required [1].

The physical changes during the natural ageing of 7075 are reasonably well understood. A comprehensive study of the dissolution kinetics was presented by Papazian [3], where cold work was also shown to influence the precipitation kinetics. Further work by Ayer et al. [4] characterised the phases present following solution heat treatment and artificial ageing. Following a solution heat treatment and rapid quench, a Super Saturated Solid Solution (SSSS) is created. During the initial stages of natural ageing only spherical coherent Guinier Preston (GP) zones form uniformly throughout the matrix. The volume fraction and radius of the GP zones then increases in a near linear fashion as the natural ageing process develops, with a corresponding increase in yield strength [5]. Many factors influence the nucleation and growth of the GP zones including heterogeneities at grain boundaries [6], dislocation density driven by prior cold work [7] and cold working during natural ageing [5].

Characterising the mechanical behaviour of 7075 aluminium has been the focus of several researchers. The impact of cold work from rolling and subsequent annealing on the mechanical properties of 7075 aluminium has been documented by Tajally and Emadoddin [8]. Solution heat treatment and natural ageing was not considered in this work. Staley [9] Analysed the mechanical and physical changes in both 7075 and 7050, but failed to capture the yield strength changes below 1 h nor characterise the anisotropy. Later work by Koch and Kolijn [10] and also by Chemingui et al. [11] analysed the changes in mechanical and physical properties for Al–Zn–Mg alloys subject to two stage artificial ageing without considering natural ageing.

Barlat and Vasudevan [12] characterised the mechanical properties of 7075 sheet material subjected to solution heat treatment and artificial ageing to both an underaged and overaged condition. A series of mechanical tests provided insight regarding the sheet metal formability and yield behaviour. Nevertheless, the work is limited to considering only the rolling and transverse directions along with biaxial yield testing without consideration of natural ageing. In addition, the biaxial yield point was determined by fitting a curve to the data above 5% equivalent strain before back extrapolation to 0.2%, which is a less reliable way to determine

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the biaxial yield point. Another artificial ageing study of 7075 by Kandil et al. [13] provided direct relationships between the ageing kinetics and observed hardness changes without reference to the underlying anisotropy. More recent work by Pedersen et al. [14] analysed the natural and artificial ageing of 7030 extrusions, but no biaxial test data was provided.

None of the above studies provides sufficient data in the first 100 min of natural ageing for the description of underlying anisotropy and evolution of mechanical properties in commercial 7075. This work presents an extensive set of mechanical properties for commercial 7075 sheet material following 15–120 min of natural ageing. A series of functions are also suggested for the interpolation of the experimental data sets.

## 2. Mechanical test programme

The material under consideration is a commercial grade 7075-O Al-clad aluminium alloy, 1.27 mm thickness, manufactured to SAE AMS-QQ-A-250/13. The nominal 4% cladding layer on each side is a non-heat treatable 7072 alloy.

Production specifications require that the solution heat treated sheet components are formed within a time limit of 100 min following removal from the freezer storage. In order to capture the full range of material property evolution over this time frame, ageing times of 15, 30, 60, 90 and 120 min were investigated.

All specimens were machined using a CNC milling cutter and heat treated at 465 °C for 35 min followed by a glycol quench in a single batch operation. To stall ageing, the specimens were then stored at −30 °C. In addition, all tests were conducted within a 24 h time frame from quenching to minimise any risk of natural ageing of the specimens.

### 2.1. Tensile testing

Batches of tensile test specimens were removed at 0°, 15°, 30°, 45°, 60°, 75° and 90° from the rolling direction with three repeats in each direction. For the five natural ageing times this gave a total of 105 specimens. The dog-bone specimen dimensions were based on recommendations in ASTM: E8/E8M-11, with a 75 mm parallel gauge length and a width of 12.5 mm in the reduced width section and an overall length of 200 mm. Each specimen was tested on an Instron 5500R tensile testing machine at a rate of 1.27 mm/min until 1% engineering strain at which point the speed was increased to 6.35 mm/min until fracture. Extensive serrated yielding observed during the test programme precluded the use of strain rate control. The crosshead rates approximate to strain rates of $280 \times 10^{-6}\ \mathrm{s}^{-1}$ and $1.35 \times 10^{-3}\ \mathrm{s}^{-1}$. The change in strain rate ensured that the test was complete within approximately two minutes rather, than 10 min, thus minimising any ageing effects during the test. The longitudinal and transverse strains were measured throughout the test using a 2620-600 dynamic (25 mm gauge length) and 2640-010 transverse extensometer respectively. Instron Merlin software was used to record the data throughout the test.

### 2.2. Biaxial yield testing

The biaxial tests were conducted using an hydraulic bulge test facility combined with an extensometer spherometer device outlined by Leacock [15]. The hydraulic pressure is created with a fully enclosed, lubricated cylindrical polyurethane punch (diameter 101.6 mm), 60 durometer shore hardness. The soft rubber deforms easily, providing a quasi-hydrostatic pressure in the enclosed tooling [16]. The applied load was measured over the 101.6 mm diameter, thus giving the pressure. The surface strain and radius of curvature for the bulged specimen surface was measured using the aforementioned contacting extensometer spherometer [17]. All measurements were recorded using LabVIEW. The entire test facility was mounted on an Instron 5500R. Hydraulic clamping pressure was used to hold the periphery of the specimen. Tests were then conducted at a constant crosshead speed of 15 mm/min, stopping at a peak load of 50 kN. A constant crosshead speed will result in a non-linear increase in the strain rate, however the objective of this test was the determination of yield, not the work hardening. The approximate strain rate measured from the test was $1.5 \times 10^{-3}\ \mathrm{s}^{-1}$. It has also been shown that constant strain rates are only critical for strains greater than 0.1 [18].

## 3. Results and discussion

A complete summary of the uniaxial yield strengths (defined as 0.2% proof) along with the uniaxial *r*-values for both virgin O-condition and solution heat treated material can be found in Table 1. The *r*-value given in Table 1 is defined as

$$r = \frac{-\varepsilon_w^p}{\varepsilon_l^p + \varepsilon_w^p} \qquad (1)$$

where $\varepsilon_w^p$ is the plastic strain in the width direction, $\varepsilon_l^p$ is the plastic strain in the longitudinal direction. The biaxial yield strengths (defined as 0.2% proof) for the O-condition and solution heat treated

**Table 1**
Summary of uniaxial yield strengths and *r*-values.

| Temper | Angle (°) | $\sigma_{yield}$ (MPa) | $\sigma_{yield}$ STD (MPa) | *r*-val | *r*-val STD |
|---|---|---|---|---|---|
| O-Con. | 0 | 89.0 | 1.8 | 0.877 | 0.069 |
| O-Con. | 15 | 87.4 | 2.4 | 0.916 | 0.058 |
| O-Con. | 30 | 87.6 | 1.4 | 0.914 | 0.022 |
| O-Con. | 45 | 86.5 | 1.7 | 0.972 | 0.025 |
| O-Con. | 60 | 87.7 | 2.8 | 0.928 | 0.020 |
| O-Con. | 75 | 88.3 | 1.4 | 0.836 | 0.078 |
| O-Con. | 90 | 88.1 | 2.2 | 0.752 | 0.099 |
| W-15 | 0 | 137.1 | 0.9 | 0.829 | 0.041 |
| W-15 | 15 | 132.7 | 0.7 | 0.857 | 0.076 |
| W-15 | 30 | 138.6 | 0.8 | 0.617 | 0.036 |
| W-15 | 45 | 131.7 | 0.5 | 0.693 | 0.021 |
| W-15 | 60 | 122.9 | 1.0 | 0.599 | 0.029 |
| W-15 | 75 | 133.3 | 1.2 | 1.162 | 0.353 |
| W-15 | 90 | 142.2 | 0.5 | 1.994 | 0.227 |
| W-30 | 0 | 140.7 | 1.6 | 0.938 | 0.151 |
| W-30 | 15 | 136.8 | 1.7 | 1.078 | 0.429 |
| W-30 | 30 | 143.6 | 0.6 | 0.598 | 0.034 |
| W-30 | 45 | 137.7 | 0.9 | 0.773 | 0.050 |
| W-30 | 60 | 128.6 | 1.2 | 0.581 | 0.013 |
| W-30 | 75 | 138.5 | 2.7 | 0.845 | 0.090 |
| W-30 | 90 | 149.8 | 2.3 | 1.731 | 0.115 |
| W-60 | 0 | 146.2 | 0.3 | 1.031 | 0.055 |
| W-60 | 15 | 143.3 | 1.3 | 1.015 | 0.372 |
| W-60 | 30 | 152.9 | 1.2 | 0.585 | 0.041 |
| W-60 | 45 | 143.9 | 1.7 | 0.686 | 0.017 |
| W-60 | 60 | 134.8 | 0.7 | 0.590 | 0.022 |
| W-60 | 75 | 144.8 | 1.7 | 0.766 | 0.014 |
| W-60 | 90 | 154.2 | 0.6 | 1.658 | 0.091 |
| W-90 | 0 | 150.1 | 0.7 | 0.856 | 0.162 |
| W-90 | 15 | 152.1 | 0.8 | 0.897 | 0.063 |
| W-90 | 30 | 159.2 | 2.0 | 0.560 | 0.053 |
| W-90 | 45 | 151.6 | 1.0 | 0.745 | 0.047 |
| W-90 | 60 | 140.9 | 0.8 | 0.597 | 0.041 |
| W-90 | 75 | 152.4 | 1.4 | 0.799 | 0.067 |
| W-90 | 90 | 164.0 | 1.5 | 1.781 | 0.109 |
| W-120 | 0 | 158.3 | 2.2 | 0.921 | 0.139 |
| W-120 | 15 | 156.8 | 1.4 | 0.779 | 0.038 |
| W-120 | 30 | 165.5 | 0.9 | 0.608 | 0.035 |
| W-120 | 45 | 157.4 | 1.8 | 0.759 | 0.012 |
| W-120 | 60 | 146.1 | 0.2 | 0.565 | 0.018 |
| W-120 | 75 | 159.3 | 0.7 | 0.772 | 0.055 |
| W-120 | 90 | 169.5 | 1.5 | 1.657 | 0.117 |