Creep of dilute zinc–copper alloys

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A series of zinc–copper alloys containing up to 2.0 wt% Cu have been prepared and tested in creep under constant load at temperatures up to 200°C. A metallographic study has also been made of the crept specimens. The creep resistance of Zn is shown to increase as the Cu content is raised, although the creep strength increment is small above 1 wt% Cu. Ageing the alloys also improves the creep strength, but precipitation during creep can generate voids which may lead to premature failure. The effect of increasing the Cu content is to make slip and grain-boundary sliding progressively more difficult, and to raise \( \Delta H_{\text{c}} \), the apparent activation energy for creep. A higher copper content also enables a low value of the stress exponent to persist to higher creep stresses.

1. Introduction

In spite of the importance of the wrought Zn–Cu alloys, little systematic work appears to have been undertaken to establish the relationship between their microstructure and mechanical properties. The room temperature tensile properties of these alloys have been studied [1], and no dramatic age-hardening response was observed, although discontinuous precipitation of the \( \varepsilon \)-phase appears to contribute a small aggregate hardening effect in alloys of higher (\( \sim 2.5 \) wt%) copper content.

The aim of the present work was to investigate the creep behaviour of these alloys at temperatures between room temperature and 200°C, and to attempt to correlate these properties with the microstructures observed.

2. Experimental methods

2.1. Alloys and specimens

8.5 kg casts of four alloys of compositions listed in Table I were prepared. Each ingot was hot-rolled at 250°C to a thickness of 9.5 mm, and finish rolling was carried out at 100°C by a number of passes to a final thickness of 0.75 mm. The width of the final sheets was 125 mm, and from these the test-pieces were produced by blanking with a die and punch with their axis parallel to the rolling direction: the gauge dimensions were 21.19 mm in length and 4.25 mm in width.

2.2. Heat-treatment

Heat-treatments above 200°C were performed in a salt bath, and those below 200°C were carried out in an oil bath. Details of the solution heat-treatment and the resulting grain sizes are given in Table I. A subscript notation is used in describing the ageing heat-treatment: namely 1.6\( \text{200,100} \); the base (1.6) represents the weight % Cu, the first subscript (200) the ageing temperature in °C and the second subscript (100)
the ageing time in hours. An alloy without subscripts refers to the solution-annealed condition.

2.3. Creep testing
The specimens were tested in air in a dead-loading creep rig, employing an LVDT for strain measurement which gave a strain sensitivity of \( \pm 10^{-4} \). Tests were conducted at room temperature, 100, 150 and 200°C, which represent values of 0.42, 0.54, 0.61 and 0.68 \( T_m \) for pure zinc. A number of crept specimens were examined by optical microscopy; details of the metallographic technique have been given elsewhere [1].

3. Results
3.1. Stress sensitivity
The effect of stress on the secondary creep rate can be seen from Fig. 1a to d, in which \( \log \sigma \) versus \( \log \dot{\varepsilon}_s \) is plotted for the four alloys. The individual curves correspond to the different test temperatures. In Fig. 1c creep data for the aged 1.6% Cu alloy are also given; when these aged alloys were tested at 150 or 200°C, the specimens exhibited tertiary creep from the beginning of the test, so the curves corresponding to these results are shown dashed. The 2% Cu alloy tested at 150 and 200°C also showed wholly tertiary creep, and thus are shown as dashed lines in Fig. 1d since a true \( \dot{\varepsilon}_s \) could not be assessed. In Figs. 1c and d, the creep rate plotted for the dashed curves is that observed at the commencement of the test.

3.2. The effect of temperature
The influence of temperature on the secondary creep rate can be examined by plotting \( \dot{\varepsilon}_s \) versus \( 1/T \) for a chosen stress. From the slopes of the individual curves, the apparent activation energies may be calculated for each alloy. The data obtained by this approach are shown in Fig. 2.

3.3. Metallography of crept specimens
Since deformation modes are strain-rate dependent, in order to examine the effect of composition in this context, a comparison has been made of the different alloys after creep at approximately \( 10^{-3} \) h\(^{-1} \) to a total strain of \( \sim 4\% \). This was effected by examining the surface of crept specimens which had been metallographically prepared before a creep test.

The solution-treated alloys, crept at room temperature, show a change in deformation behaviour with increasing copper content. Thus