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Effect of prior cold work on age hardening of Cu–4Ti–1Cr alloy

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Abstract

The influence of cold rolling to 50, 75 and 90% reduction on the age hardening behaviour of Cu–4Ti–1Cr alloy has been investigated by hardness and tensile tests and optical as well as transmission electron microscopy. Hardness of Cu–4Ti–1Cr alloy increased from 222 Hv in solution treated condition to 416 Hv with 90% cold work and peak aging. Cold deformation reduced the peak aging temperature from 450 °C for the undeformed alloy to 400 °C for cold deformed alloys. The yield strength (YS) and ultimate tensile strength (UTS) of the alloy with 90% cold work followed by peak aging at 400 °C were found to be 1165 and 1248 MPa, respectively. The microstructure of the deformed alloy exhibited elongated grains and deformation bands. The maximum strength on peak aging was obtained due to precipitation of ordered, metastable and coherent β^{l}, Cu_4Ti phase in addition to high dislocation density and deformation twins. Overageing of the alloy resulted in reduced hardness and strength due to the formation of incoherent and equilibrium β, Cu_3Ti phase in the form of cellular structure. However, the morphology of the discontinuous precipitation was changed to globular shape with high deformation.

Keywords: Cu–4Ti–1Cr alloy; Precipitation hardening; Prior cold work; Tensile properties; β^{l}; Cu_4Ti phase; Discontinuous precipitation

1. Introduction

The worldwide research acknowledged that binary Cu–Ti alloys could serve as a substitute for expensive and toxic Cu–Be–Co alloys. An extensive research was carried out by several researchers on the mechanisms of spinodal decomposition and precipitation strengthening in Cu–Ti alloys [1–7]. Nagarjuna et al. have studied the structure–property correlations of Cu–Ti alloys in various conditions, viz., solution treatment, solution treatment and aging, and solution treatment, cold work and aging [8,9]. It was reported that compositional modulations would occur during solution treatment itself in Cu–Ti alloys containing Ti ≥4.0 wt% and age hardening takes place by the formation of metastable β^{l}, Cu_4Ti phase in both deformed and undeformed alloys. The tensile properties of these alloys approached those of Cu–Be–Co alloys [8,9].

Our earlier studies [10,11] on the addition of 1 wt% cadmium to Cu–Ti alloy revealed that the tensile properties of the alloy increased considerably in solution treated condition due to substitutional solid solution strengthening. The tensile properties of ternary Cu–Ti–Cd alloy were also comparable to those of Cu–Be–Co alloy in undeformed condition. The strengthening mechanism and microstructure of Cu–Ti–Cd alloy were similar to that of binary Cu–Ti alloys. Prior cold work increased the tensile properties considerably, but no microstructural changes were reported in Cu–Ti–Cd alloys during peak aging. The strengthening mechanisms of cold worked Cu–Ti–Cd alloys were also similar to undeformed condition [12,13].

Our recent studies on Cu–Ti alloys with 1 wt% chromium addition revealed that the tensile properties of Cu–Ti–Cr alloys increased considerably during peak aging after solution treatment [14]. Age hardening in these alloys was similar to binary Cu–Ti alloys. However, little work has been

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reported on the effects of prior cold work on age hardening of Cu–Ti–Cr alloys. Therefore, the present work was undertaken with the aim of filling this gap and generates necessary data on Cu–4Ti–1Cr alloy. This paper presents results on the effects of prior cold work on Cu–4Ti–1Cr alloy illustrating strength properties, microstructure and strengthening mechanism.

2. Experimental procedure

A Cu–Ti–Cr alloy was prepared with the aimed composition of 4 wt% Ti, 1 wt% Cr and Cu as balance. A 30 kg melt of the alloy was made using pure metals, viz. oxygen-free high conductivity copper (Cu > 99.9%), titanium (Ti > 99.9%) and chromium (Cr > 99.8%) as charge and melting the same in graphite crucible of STOKES vacuum induction melting (VIM) furnace. The liquid alloy was poured into and cast in a graphite mould. The ingot was homogenized at 850 °C for 24 h and analysed for its composition. The analysis report confirmed the composition to be 4.09 Ti, 0.98 Cr and balance copper. The ingot was subsequently hot forged and rolled after soaking at 850 °C to obtain 10 mm thick flats and rods of 12 mm diameter. After solutionizing at 860 °C for 2 h, the samples were given different amounts of deformation viz., 50, 75 and 90% at room temperature. Vickers hardness at 10 kg load was measured after aging the deformed samples at 400, 450 and 500 °C to establish peak aging time and temperature.

Flat tensile specimens were prepared as per the ASTM-E8M standards from the solution treated + cold deformed + aged alloy and tested at room temperature using INSTRON universal tensile testing machine. Optical microstructure of the alloy in solution treated + cold deformed + aged condition was observed after mechanical polishing and etching. A solution of 10 g $K_2Cr_2O_7$, 5 ml H_2SO_4, few drops of HCl and 95 ml distilled water was used as an etchant.

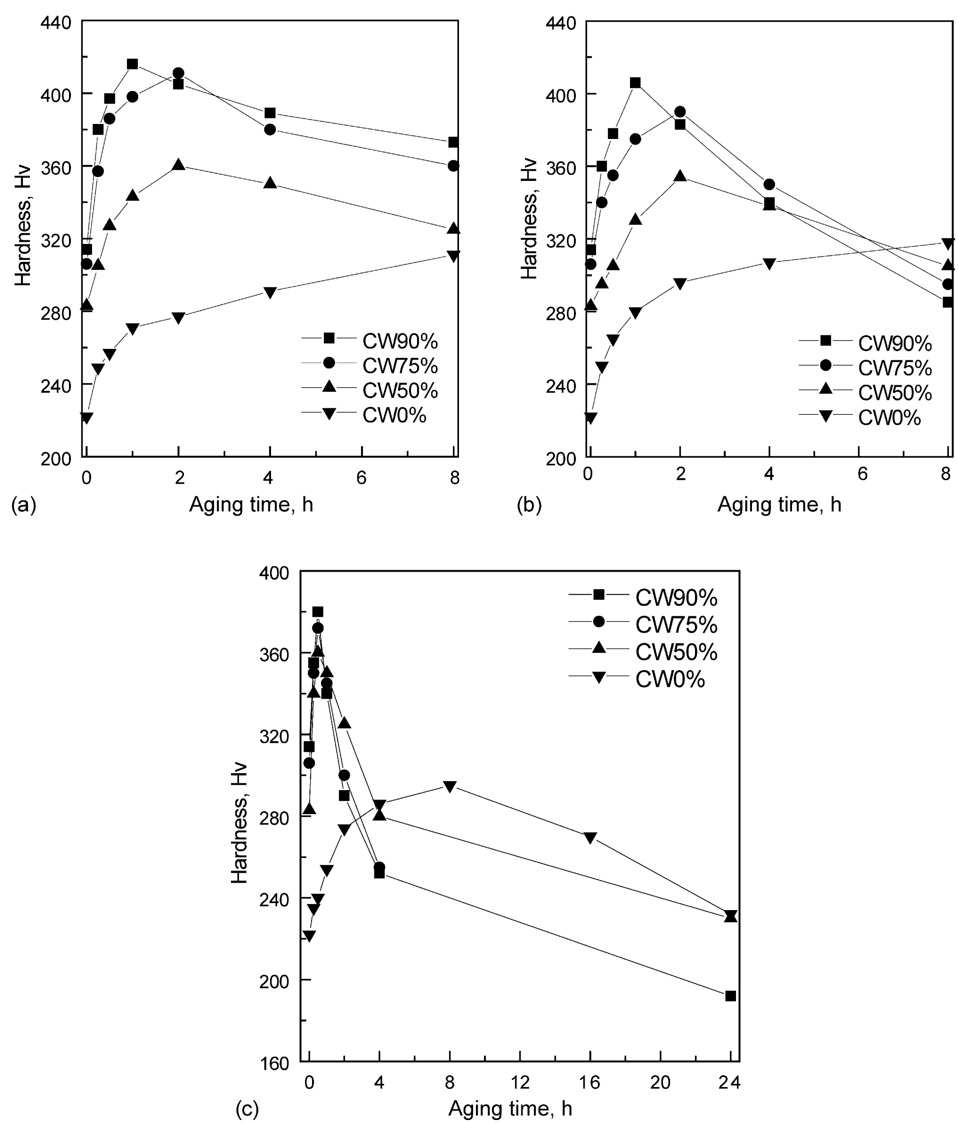

Fig. 1. Effect of prior cold work on hardness during aging of Cu–4Ti–1Cr alloy at (a) 400 °C (b) 450 °C and (c) 500 °C.