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On the strengthening mechanisms of 18 carat yellow gold and its mechanical behaviour

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Abstract

In order to contribute to a better understanding of the mechanical properties of gold alloys this paper investigates the mechanical behaviour of an 18 carat yellow alloy; the strain hardening behaviour during a tensile test was measured in the annealed as well as in different cold-work conditions. In addition, the contribution of different strengthening mechanisms is discussed on the basis of current results and of data reported in literature. In particular, the contributions of grain size refinement and copper solid solution alloying in improving the mechanical strength of gold alloys were quantified.

Keywords: Gold alloys; Mechanical behaviour; Strengthening mechanisms; Strain hardening

1. Introduction

The mechanical properties of jewellery and the microstructure of the precious alloy they are made with are, very rarely taken into account; additionally the effect of the manufacturing technology on the final properties or the effect of the properties of the raw material on the technical and economical feasibility of the production technology chosen are usually not even considered on an industrial scale, when the design and the production of an item of jewellery are to be planned [1].

However, even when some attempts are made at benefiting from an engineering approach, difficulties are frequently encountered, most often because materials data is not available, complete or, in some instances, accurate, and because metallurgical knowledge of the interrelationship among processing technologies, microstructure, and properties has not been established except on a phenomenological basis.

Some excellent research [2–5] recently involved investigation of the metallurgical principles at the basis of the hardening of low-carat gold. The strengthening mechanisms, and in particular the precipitation hardening in almost pure gold with only small amounts of some selected alloying elements, were investigated mainly for the purpose of developing high hardness, high strength and wear-resistant low-alloyed gold for the growing markets in the Middle and Far East.

In 1990 a noteworthy effort was made to organize the available mechanical properties of some commonly used alloys [6]; since then, only one additional paper [1] assembled a relatively complete set of mechanical properties for different carat alloys. In other cases published mechanical properties are generally incomplete, usually refer only to the hardness and never take into account the strain hardening behaviour, i.e. the complete stress–strain relationship during a monoaxial tensile test, necessary for finite element simulation of the deformation processes.

In this paper the mechanical behaviour of an 18 carat yellow alloy (18 ct Y) was investigated, the strain hardening behaviour was measured in different cold-work conditions. In addition, the contribution of different hardening mechanisms is discussed on the basis of current results and of data reported in literature.

2. Experimental procedures

A 0.85-mm diameter commercial gold wire, 18 ct Y of nominal weight composition 750% Au, 180% Ag, 70% Cu, was used as the base material, the delivery condition, according to the purchaser information, was fully annealed and 25% cold worked. The wire was then further drawn with a total cold-work reduction of nearly 50% and 70%, with no intermediate annealing. As-received and cold-worked wires were also heat-treated at var-

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ious temperatures, in the range 250–750 °C, for 15 min. Anneal heat treatment was carried out at different temperatures in order to indicate the minimum temperatures for recovery and recrystallization; different grain sizes were also obtained at increasing anneal temperature to assess the contribution of grain size to strengthening.

Tensile tests were carried out by means of an INSTRON mod. 3366 testing machine, at room temperature, under displacement control and at a crosshead speed of 1 mm/min; three tensile tests were carried out for each experimental condition. The linear best fit of a log–log plot of the true stress σ_{tr}–true strain ε_{tr} data between 0.2 yield point and maximum load was used to calculate the strain hardening exponent n of the equation $\sigma_{tr} = k\varepsilon_{tr}^{n}$, as a measure of the hardening capacity in the plastic regime.

A microstructure examination was carried out on polished and etched surfaces, a chromia–hydrocloridric acid mixture was used as etchant medium. Grain size was measured according to the ASTM E 112 standard; the mean grain diameter was used as a measure of grain size instead of the ASTM grain size number in order to establish a physical relationship with heat treatment parameters.

3. Results and discussion

3.1. Cold-work hardening strengthening mechanism

The effect of cold-work reduction on tensile strength of the 18 ct Y alloy used in this investigation is reported in Fig. 1. Some results from literatures [1,6] are also reported in the same figure for the sake of comparison. 22 ct Y [1] is a yellow gold with unspecified chemical composition; 22 ct Y [6] is a yellow gold with 55‰ Ag and 28‰ Cu; 18 ct R [1] is a red gold with unspecified chemical composition; 18 ct Y* [6] is a yellow gold with 125‰ Ag and 125‰ Cu. In the data as-received wire corresponds to 25% cold work, while 0% cold-work results were obtained with both as-received wire and 70% cold-worked wire, after annealing at 550 °C for 15 min.

As expected, both the yield and tensile strength increase, as does their ratio that tends to approach unity. The same effects are

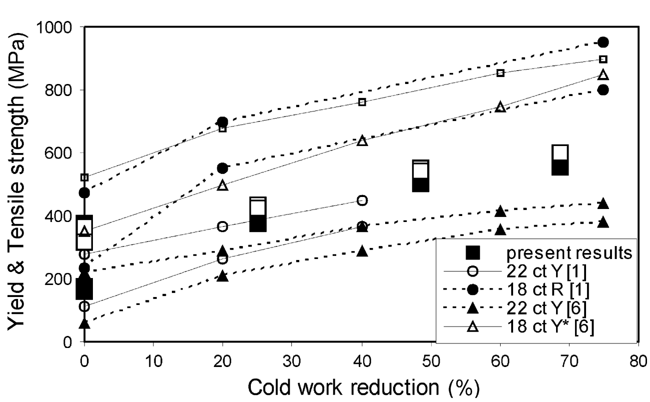

Fig. 1. Effect of cold-work reduction on yield and tensile strength (current 18 ct Y gold yield and tensile strength = closed and open points, respectively; for the other gold alloys the respective lower and higher lines represent yield and tensile strength).

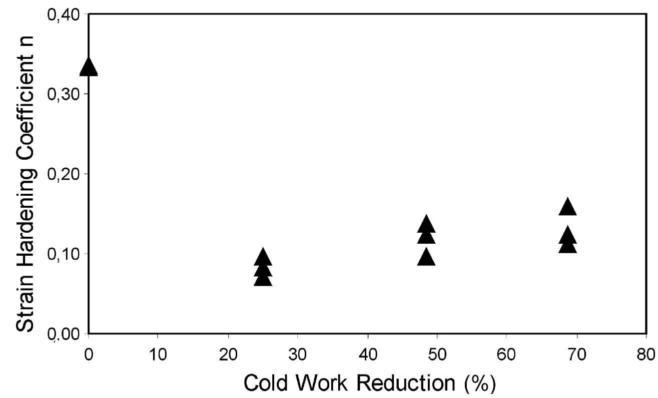

Fig. 2. Effect of an increasing amount of cold work on the strain hardening coefficient n in the tensile test.

in fact observed in the other results from literature reported in the figure. A notable difference (about 180 MPa in yield strength) is observed between present results (18 ct Y) and those of the 18 ct Y* from literature [6]; this difference is discussed later on, when the effect of solid solution strengthening will be considered, on the basis of the different copper content of the investigated 18 ct Y alloy (70‰) and the published 18 ct Y* alloy (125‰).

The slight difference between the published results for the 22 ct Y alloys may be the result of a difference in copper content with respect to the nominal alloy chemical composition, as well as a difference in the initial grain size, whose effect is discussed later on in the paper.

As a general trend, it can also be observed that when increasing the alloying content, i.e. with decreasing caratage, the strength of the alloys increases; furthermore the effect of cold working is different from alloy to alloy, i.e. in the case of the 18 ct Y* alloy [6] the increase in yield and tensile strength is almost comparable, while for other alloys the yield strength increases more readily than tensile strength, especially in the initial stages of hardening.

Fig. 2 shows the strain hardening exponent n values for the tested 18 ct Y alloy both in the annealed condition and when increasing cold work. It can be observed that n shows a first noticeable decrease after the initial cold-work reduction and then undergoes a moderate increase when increasing cold-work reduction. Correspondingly the reduction of the area measured on broken tensile specimens decreases from 90% to 80%.

Indeed the relationship between n and cold-work reduction most probably deserves to be investigated in greater detail depth in order to be fully understood.

As well known strain hardening is attributed to the interaction of dislocations with other dislocations and with other barriers to their motion through the lattice. In the early stages of plastic deformation the slip is essentially on primary glide planes and the dislocations form coplanar arrays. As deformation proceeds, the cross-slip takes place and multiplication processes operate. The cold-worked structure forms high-dislocation-density regions which soon develop into the cell walls of a cellular substructure. The cell structure is usually well developed at strains of around 10% [7] and this could be the reason for the initial decrease of n at increasing cold-work reduction.