# Mechanical properties and precipitation energy of the Cu–Al–Ag (5.4% Al–5.2% Ag) alloy

A. T. ADORNO, M. CILENSE
*Instituto de Química-UNESP, Araraquara, SP, Brazil*

W. GARLIPP
*Escola de Engenharia-USP, São Carlos, SP, Brazil*

The Cu–Al–Ag (5.4% Al–5.2% Ag) alloy has some characteristics, such as high plasticity, good workability, brightness and high-corrosion resistance [1, 2], that seem to justify a more detailed study of its properties. Furthermore, at this composition the alloy is susceptible to ageing after quench, above 740° C [2].

Although fairly well studied [3], this alloy has some practical application and so it is interesting to obtain a better understanding of its mechanical properties.

The ingots of the alloy were hot rolled to 1.0 mm thickness and cut in plates 10.0 mm long and 6.0 mm wide. These samples were heated at 750° C for 1 h and then quenched in water at 0° C. The samples were then submitted to an isochronic ageing treatment for 1 h, at temperatures of 351, 400, 425, 454, 475, 502, 523, 553, 576 and 599° C, respectively, for each one of the samples. The hardness measurements were then made on these plates, using a Metaval Carl Zeiss metalographic microscope, with a microhardness meter.

Fig. 1 shows the isochronic ageing curve and the hardness changes with ageing temperature, with a maximum at about 420° C. Fig. 2 shows the influence of temperature and ageing time on the hardness of the alloy, quenched from 750° C, where the maxima correspond to short times for high temperatures and long times for the lower ones.

All curves in Fig. 2 show a stationary period depending on the temperature. This corresponds to an incubation or induction period of 120 min at 361° C and 10 min at 460° C. After this initial period the hardness increases until the maximum is reached,

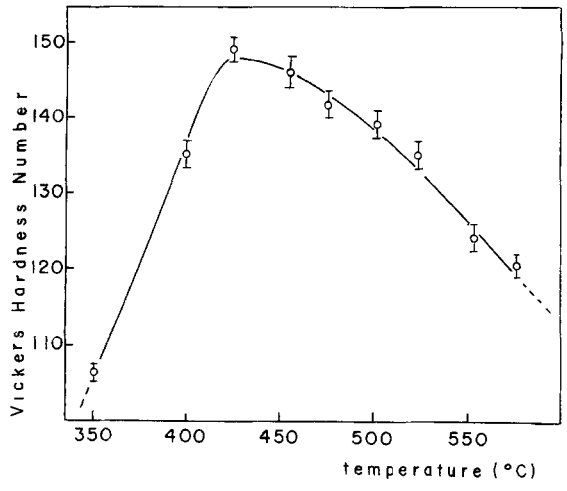


*Figure 1* Influence of the isochronic ageing temperature on alloy hardness. Samples quenched from 750° C.

which is also greater the lower the ageing temperature. These curves suggest an analytical form, such as the Johnson–Mehl equation [4] to describe the precipitate growth process, that increases the alloy hardness

$$\ln \frac{H_\infty - H_0}{H_\infty - H_t} = (kT)^n \qquad (1)$$

where $H_0$, $H_t$ and $H_\infty$ are, respectively, the hardness values at the induction period, at a time, $t$, from the intitial ageing time, and at the maximum hardness, corresponding to the critical diameter of the precipitate, beyond which it becomes incoherent with the matrix. Table I shows their values at different test temperatures.

The substitution of the values of $H_t$ from Fig. 2, into Equation 1 gives the values of $n$ and $k$ listed in Table II. The substitution of the values from Table II into Equation 1 gives the curves of Fig. 2, which include the induction period and essentially reproduce the experimental curves. From the $k$ values, for the various temperatures, the activation energy of the process was found to be $E_a = (120 \pm 14)\,\mathrm{kJ\,mol^{-1}}$.

The curves in Fig. 2 seem to indicate that the particles of the precipitate, which are probably responsible for the increase in the hardness of the alloy, become more numerous the lower the ageing temperature, and that they reach a critical size in a time that is shorter the higher the ageing temperature. These results are in agreement with those obtained by Panseri and Leoni [2] for an alloy with 6.0% Al–4.0% Ag. Furthermore, data from X-ray diffraction for the alloy used in our work seem to indicate the presence of a Ag–Al compound in the annealed samples and not in the quenched ones, which seems to support the assumption that the precipitation of a silver-rich phase increases the alloy hardness.

These curves also show the fitting of the Johnson–Mehl function with the kinetic process, up to maximum hardness.

The different values obtained for $n$ seem to be related to the various possibilities for nucleation: in

TABLE I

| $T$ (° C) | $H_\infty$ | $H_\infty - H_0$ |
|---|---|---|
| 361 ± 1 | 172.5 ± 0.5 | 64.5 ± 0.8 |
| 398 ± 1 | 171.5 ± 0.5 | 63.7 ± 0.8 |
| 440 ± 1 | 164.1 ± 0.5 | 42.9 ± 0.8 |
| 460 ± 1 | 153.8 ± 0.5 | 30.1 ± 0.8 |

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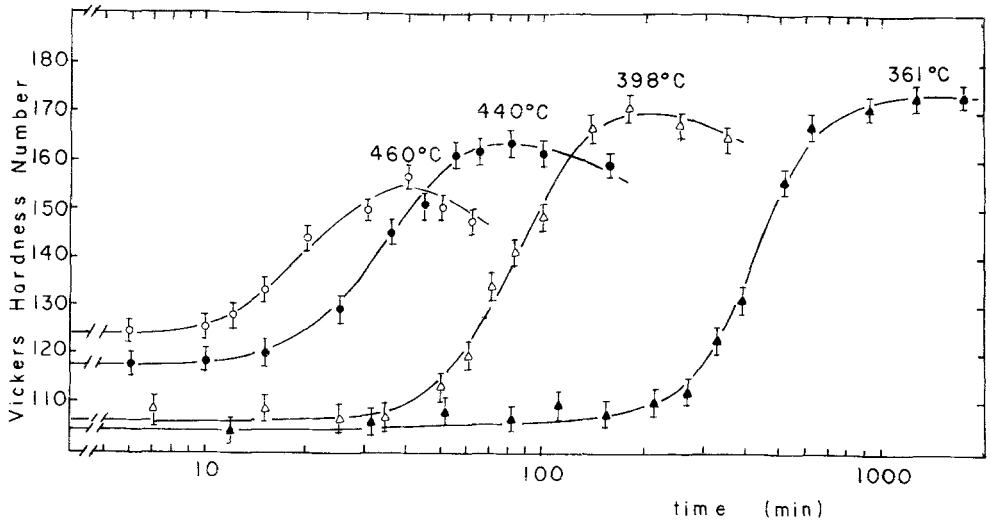


*Figure 2* Influence of the temperature and ageing time on alloy hardness. Samples quenched from 750° C.

the grain, at grain-boundary surfaces, at grain edges and at grain corners [5]. The values from Table II refer to long periods of time, when peak hardness is reached, and correspond to the limit of the influence of the precipitate in the alloy hardness.

The changes in the values of $n$ with increasing temperatures from 361° C can be interpreted by considering the constant volume nucleation rate, $J$, increasing with temperature ($n = 4.0 \pm 0.5$), decreasing and tending to zero ($n = 3.1 \pm 0.4$), but with a perturbation given by the mixed nucleation at grain edges and grain corners ($n = 2.6 \pm 0.3$) at the transition temperature between 398 and 460° C. This influence then apparently ceases and the volume nucleation decreases ($n = 3.5 \pm 0.4$).

TABLE II

| $T$ (° C) | $n$ | $k$ (min$^{-1}$) |
|---|---|---|
| 361 ± 1 | 4.0 ± 0.5 | 0.0020 ± 0.0002 |
| 398 ± 1 | 3.1 ± 0.4 | 0.0098 ± 0.0012 |
| 440 ± 1 | 2.6 ± 0.3 | 0.0244 ± 0.0021 |
| 460 ± 1 | 3.5 ± 0.4 | 0.0480 ± 0.0058 |

## Acknowledgements

The authors thank CNPq (Procs. 408401/85 and 300965/83) for financial support.

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*Received 7 July*
*and accepted 23 July 1986*