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Repetition bend properties of Cu–Cr and Cu–Cr–Sn alloys

TOSHIMI YAMANE, MASATOSHI YASUNAGA, KEIICHI HIRAO
Department of Materials Science and Engineering, Faculty of Engineering, Osaka University, Yamadaoka, Suita, Osaka 565, Japan

SHINSUKE YAMASAKI, KEIZO KAZAMA
Central Research Laboratory, Sumitomo Metal Mining Co. Ltd, 18-15 3-chome, Nakakokubun, Ichikawa 272, Japan

KOSEI YOSHIDA, RIKIO TAKEDA, MINORU HIRATANI
Sumitomo Metal Mining Copper and Brass Sales Co. Ltd, Shinaoyama West Building, no. 1156, 1-chome, minamiaoyama, Minatoku, Tokyo 107, Japan

Repetition numbers of bending of Cu–0.81 wt% Cr, Cu–0.81 wt% Cr–0.14 wt% Sn and Cu–0.26 wt% Cr–0.10 wt% Sn alloys were investigated. After solution treatment, the first two types of copper alloys have a primary chromium phase; this is not so in the last alloy. The primary chromium phase does not influence the repetition numbers of bending of cold-rolled specimens; the repetition numbers of bending of specimens aged at 723 K for 1.8×10^3 sec after cold rolling are higher than those of cold-rolled specimens. The cause of this is considered to be a recovery of work-hardening during ageing.

1. Introduction

Cu–Cr alloys exhibit properties of high tensile strength, high electric conductivity [1] and age hardening [2]. Recently, Ishida *et al.* [3] have reported that the addition of tin to Cu–Cr alloys makes the diffusion of chromium slow, and delays the high-temperature precipitation of chromium from a supersaturated solid solution [4]. The Cu–Cr–Sn alloys are used as lead-frame materials for integrated circuit (IC) packages [4]. The high strength of the Cu–Cr–Sn alloys can be obtained by work hardening and precipitation hardening. An important repetition number of bending is estimated by the test method mentioned in MIL–STD [5]. The repetition number of bending is expected to be more than 3 [6, 7].

The purpose of this work was to investigate the relationship between repetition numbers of bending and cold rolling or cold rolling plus ageing on the Cu–Cr and Cu–Cr–Sn alloys.

2. Experimental details

Three types of copper alloys were prepared from copper, chromium and tin of 99.99% purity in a high-frequency induction-melting furnace. Ingots (about 5 kg) of the alloys were hot rolled to 12.5 mm thickness. Then, these alloy plates were rolled at room temperature to various thicknesses, 0.3 to 12.5 mm. All plates of various thicknesses were heated at 1223 K, then quenched in water (solution treatment), and rolled to 0.3 mm thickness at room temperature. The chemical compositions of the copper alloy plates were Cu–0.81 wt% Cr, Cu–0.81 wt% Cr–0.14 wt% Sn, and Cu–0.26 wt% Cr–0.10 wt% Sn. After solution treatment, the first two alloys had primary chromium phase particles in the matrix, but this was not observed in the last alloy.

Tensile and bending test specimens were punched using a blanking tool die from the 0.3 mm thick plates. The shape and dimensions of the punched tensile and bending test specimens are shown in Fig. 1, and the relationship between the longitudinal axis of the specimens and the rolling direction is shown in Fig. 2. The alloy plates were rolled in the same rolling direction, but only one Cu–0.81 wt% Cr–0.14 wt% Sn alloy plate, 12.5 mm thick, was cross rolled pass-by-pass.

Repetition bending test specimens were fastened by upper and lower chucks as shown in Fig. 1. A total hanging load of 479 g including the lower chuck weight, was applied by the lower chuck. The repetition

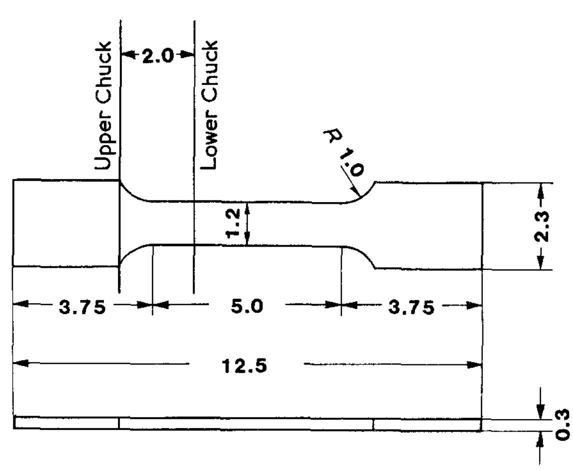

Figure 1 Shape and dimensions of repetition bending test and tensile test specimens.

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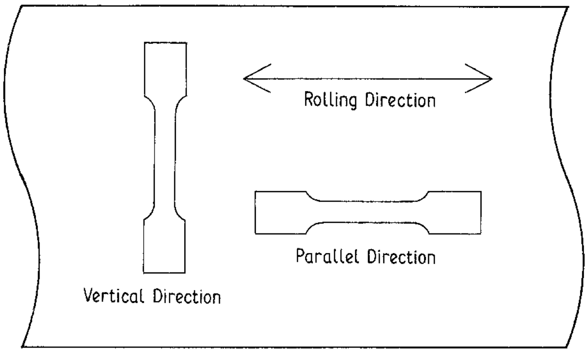


Figure 2 Relationship between rolling direction and longitudinal axis of specimen. Parallel direction: rolling direction is parallel to longitudinal axis of specimen. Vertical direction: rolling direction is vertical to longitudinal axis of specimen.

bending specimens were initially vertical and the upper chuck was rotated to 90° at a bending speed of $45° \sec^{-1}$ and turned back to the initial position. This bending was repeated until the specimens were broken. A repetition number of bending was obtained as an average value of 12 time repetition bending tests.

Tensile tests were performed at the engineering strain rate of $2 \times 10^{-4} \sec^{-1}$.

Transmission electron microscope observation was performed using Hitachi HU-11B. Specimens for transmission observation were electropolished at the voltage of 40 V, and an electric current of 10 mA mm^{-2} in a solution of HNO_3 + 10 $CuNO_3$ 10 weight + 30 CH_4OH parts by weight.

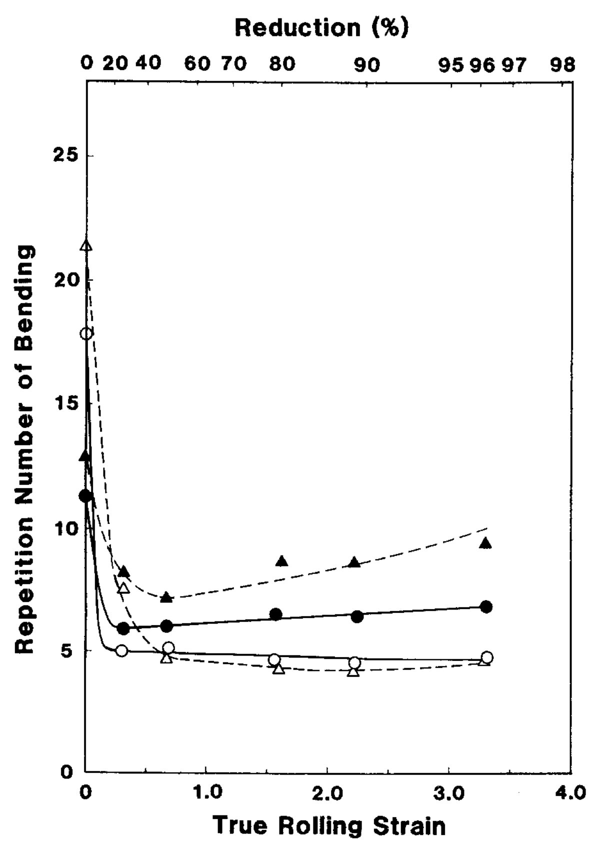


Figure 3 Repetition number of bending as a function of cold rolling strain $\varepsilon = \ln (h_0/h)$, where h_0 initial plate thickness, h plate thickness after cold rolling. Reduction $[(h_0 - h)/h] \times 100$; solution treated (1223 K) before cold rolling; ageing at 723 K for 1.8×10^3 sec; alloy, Cu–0.81 wt % Cr. Open symbols, roll only; solid symbols, roll and age. (○, ●) Parallel direction; (△, ▲) vertical direction.

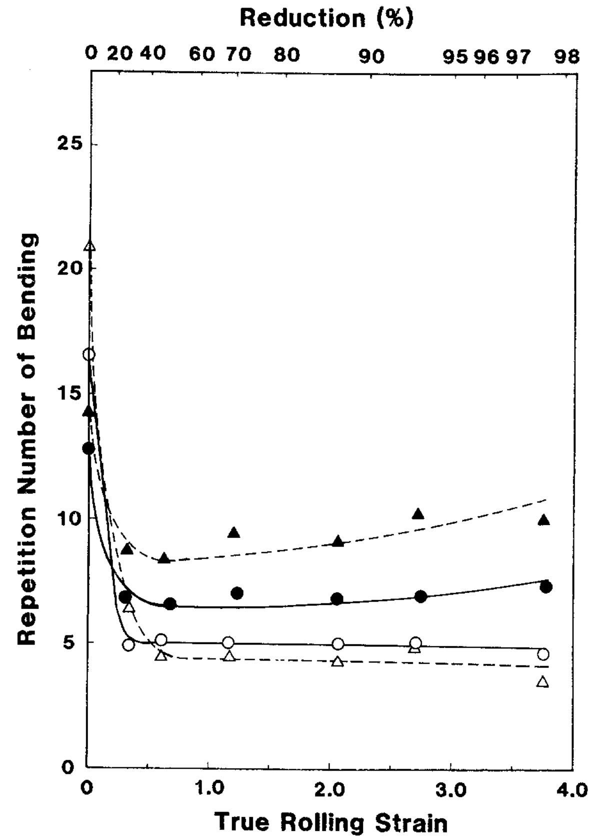


Figure 4 Repetition number of bending as a function of cold-rolling strain (see Fig. 3 caption). Alloy: Cu–0.81 wt %Cr–0.14 wt % Sn.

3. Experimental results

3.1. Repetition bending test results

Figs 3 to 5 show changes of repetition numbers of bending as a function of cold rolling strain. Solution-treated specimens, and specimens aged after solution

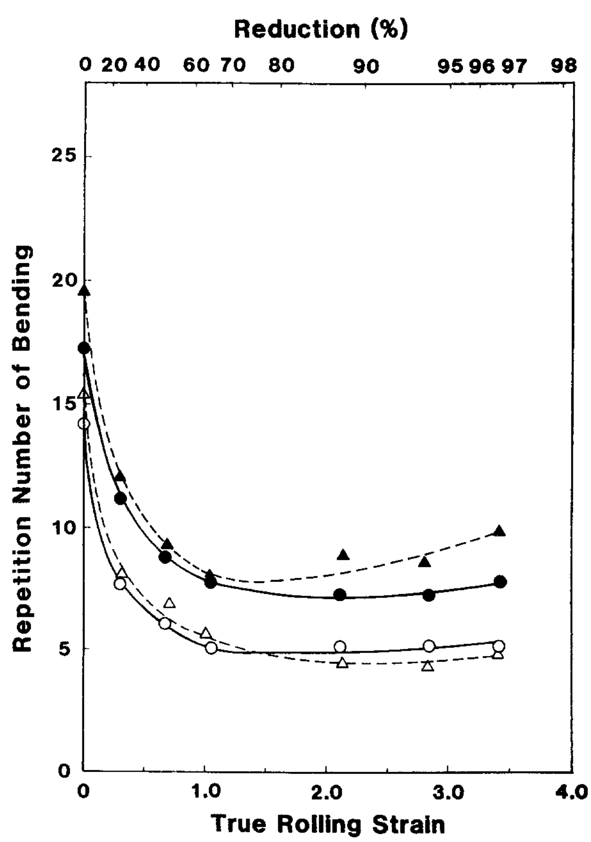


Figure 5 Repetition number of bending as a function of cold-rolling strain (see Fig. 3 caption). Alloy: Cu–0.26 wt % Cr–0.10 wt % Sn.

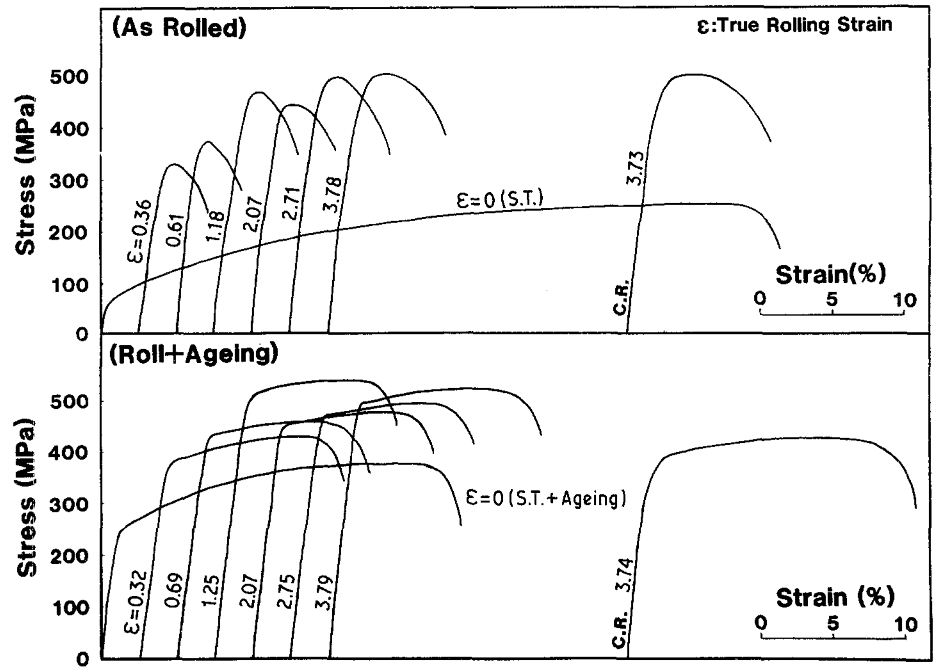


Figure 6 Stress–strain curves of Cu–0.81 wt % Cr–0.14 wt % Sn alloy. Specimens are rolled in the parallel direction. S.T., as solution treated; aged at 723 K for 1.7×10^3 sec; $\varepsilon = \ln (h_0/h)$; C.R., cross rolling.

treatment, have repetition numbers of bending higher than 10, but they decrease after cold rolling. Cold-rolled specimens have similar values in the parallel direction (rolling direction parallel to longitudinal axis of specimen) and in the vertical direction (rolling direction vertical to longitudinal axis of specimen). Aged specimens after cold rolling have higher values than the simply cold-rolled specimens, and the repetition numbers of bending in the parallel direction are lower than those of the vertical direction. This tendency is seen in all types of specimen.

3.2. Tensile test results

Figs 6 and 7 show stress (load/initial cross-sectional area of specimen)–strain [(gauge length after tension – initial gauge length)/(initial gauge length) × 100] curves in the parallel direction and the vertical direction of the Cu–0.81 wt % Cr–0.14 wt % Sn alloy. Cross-rolled specimens have middle tensile strength and fracture elongation between those rolled in the parallel direction and those rolled in the vertical direction. From these stress–strain curves, the fracture elongation and yield strength (0.2% offset) are plotted in Figs 8 to 13). The fracture elongation of cold-rolled specimens is higher than that of aged specimens, and the fracture elongation of the aged specimens rolled in the parallel direction is higher than that rolled in the vertical direction. The same tendency is seen in yield strength, but the aged specimens rolled in the vertical direction have higher yield strength

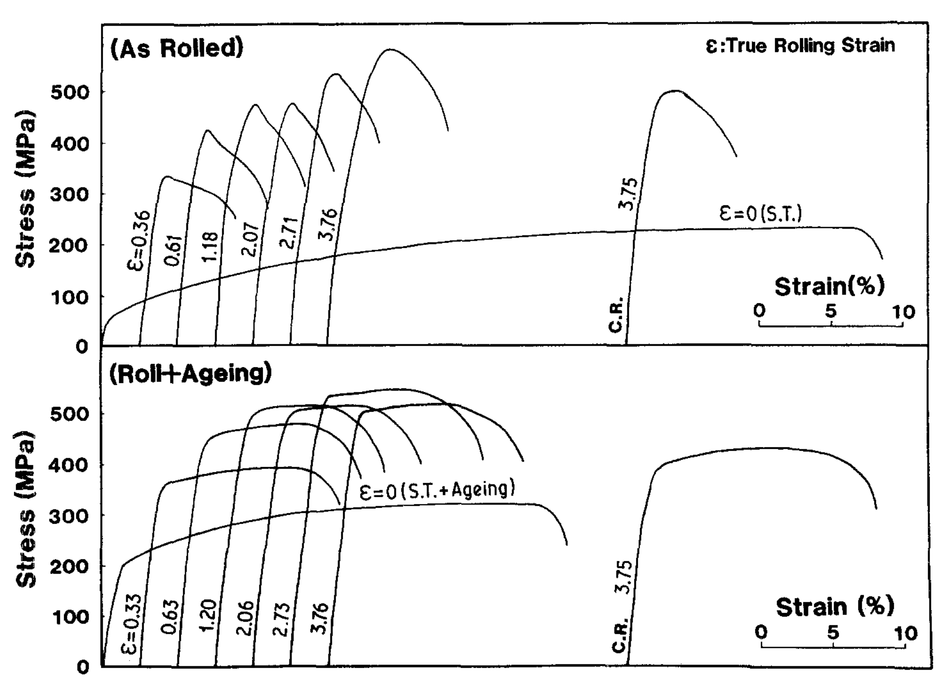


Figure 7 Stress–strain curves of Cu–0.81 wt % Cr–0.14 wt % Sn alloy. Specimens are rolled in the vertical direction. S.T., as solution treated; aged at 723 K for 1.7×10^3 sec; $\varepsilon = \ln (h_0/h)$; C.R., cross rolling.

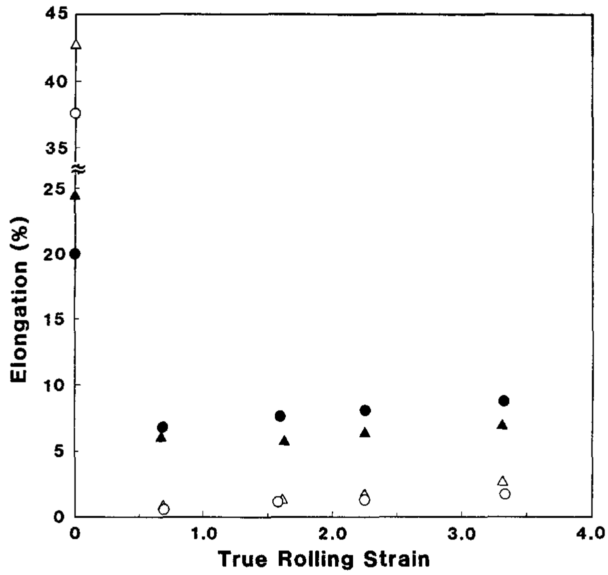


Figure 8 Relationship between fracture elongation and rolling strain on Cu–0.81 wt % Cr alloy cold rolled (open symbols), and aged after cold rolling (solid symbols). (○, ●) Parallel direction, (△, ▲) vertical direction.

than that of the specimens rolled in the parallel direction.

3.3. Transmission electron microscope observation

Fig. 14 shows transmission electron micrographs of the Cu–0.81 wt % Cr–0.14 wt % Sn alloy. A primary chromium phase particle can be observed in the specimen solution treated, but the primary chromium phase particles are elongated by cold rolling ($\varepsilon = 0.288$, 1.109) and substructures in the matrix where crystallization is not observed.

4. Discussion

The repetition numbers of bending decrease with cold rolling strain. This is due to work hardening of the matrix. The repetition numbers of bending of the aged specimens are higher than those of the rolled speci-

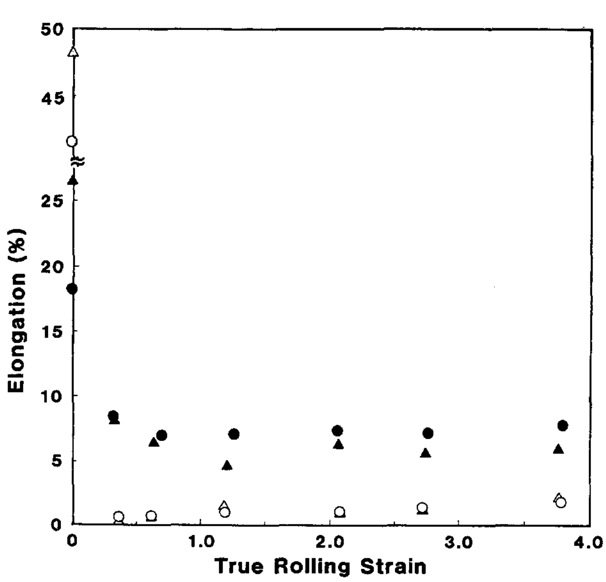


Figure 9 Relation between fracture elongation and rolling strain on Cu–0.81 wt % Cr–0.14 wt % Sn alloy cold rolled, and aged after cold rolling. For key, see Fig. 8 caption.

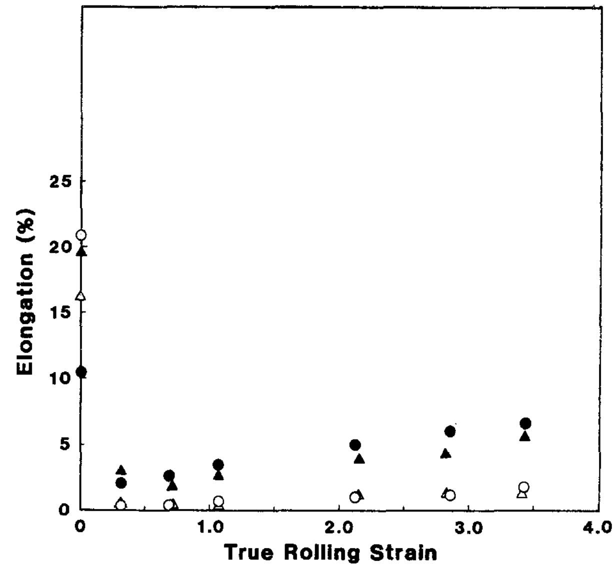


Figure 10 Relation between fracture elongation and rolling strain on Cu–0.26 wt % Cr–0.10 wt % Sn alloy cold rolled, and aged after cold rolling. For key, see Fig. 8 caption.

mens. This might be due to annealing recovery of work hardening, and because these specimens are not recrystallized during ageing at 723 K. The solution-treated C–0.26 wt % Cr–0.10 wt % Sn specimens have no primary chromium phase as known from the Cu–Cr–Sn phase diagram [8]. As seen in Figs 3 to 5, the

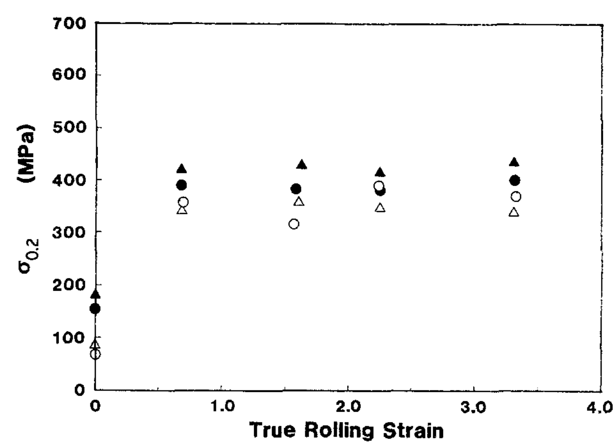


Figure 11 Relation between yield stress (0.2% offset) and rolling strain on Cu–0.81 wt % Cr alloy. For key, see Fig. 8 caption.

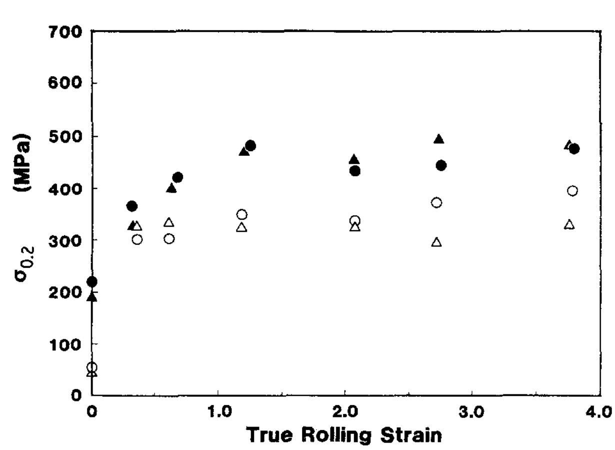


Figure 12 Relation between yield stress (0.2% offset) and rolling strain on Cu–0.81 wt % Cr–0.14 wt % Sn alloy. For key, see Fig. 8 caption.

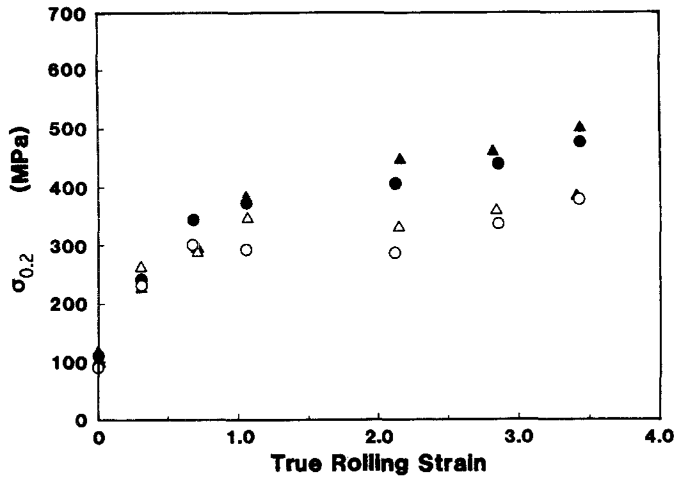


Figure 13 Relation between yield stress (0.2% offset) and rolling strain on Cu–0.26 wt %–0.10 wt % Sn alloy. For key, see Fig. 8 caption.

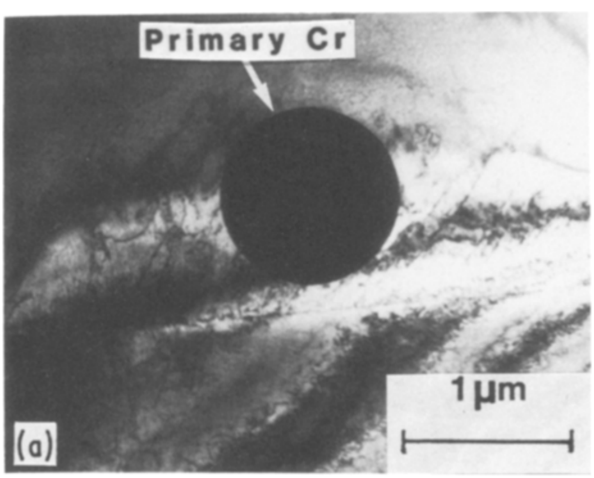
repetition numbers of bending are virtually uninfluenced by the existence of the primary chromium phase and texture of cold rolling, but they are influenced by the precipitation of chromium from the solid solution, because the repetition numbers of bending of the specimens after ageing in the parallel direction are smaller than those in the vertical direction. The Cu–0.26 wt % Cr–0.1 wt % Sn alloy aged after cold rolling, which has no primary chromium phase, has higher repetition numbers of bending than those of the cold-rolled specimens at the same rolling strain, so that it can be concluded that the primary chromium phase has only a small influence on the repetition numbers of bending. [2 1 0] (1 1 0) is the rolling texture of the copper alloys as shown in Fig. 15. The repetition numbers of the Cu–0.26 wt % Cr–1.10 wt % Sn alloy aged in the vertical direction are higher than those aged in the parallel direction. This might correspond to the rolling texture.

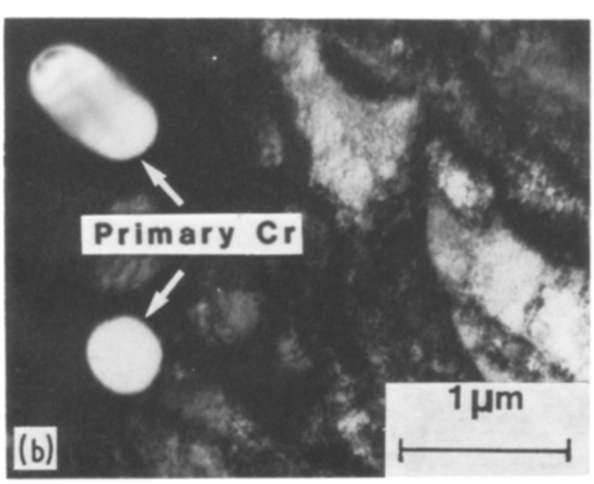
4. Conclusions

1. Repetition numbers of bending of Cu–0.81 wt % Cr, Cu–0.81 wt % Cr–0.14 wt % Sn and Cu–0.26 wt % Cr–0.10 wt % Sn alloys cold rolled after solution treatment are 4 to 5 and independent of rolling strain over 20%.

2. Repetition numbers of bending of the specimens aged at 723 K after cold rolling are higher than those of the cold-rolled specimens, and those rolled in the vertical direction are higher than those in the parallel direction.

3. The primary chromium phase does not influence repetition numbers of bending.





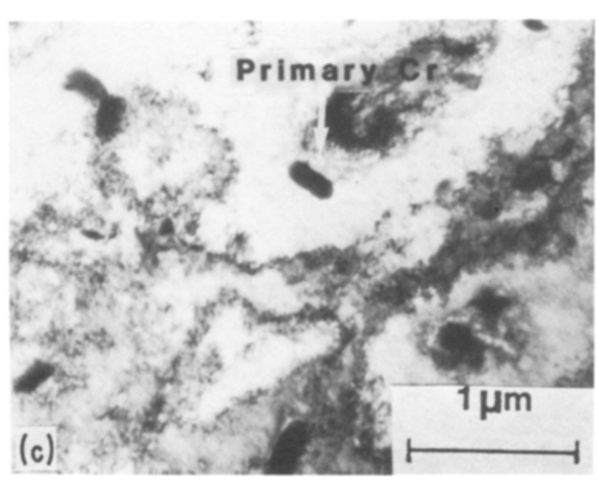


Figure 14 Transmission electron micrographs of Cu–0.81 wt % Cr–0.14 wt % Sn alloy. (a) Solution treatment + ageing, $\varepsilon = 0$. (b) 25% roll + ageing, $\varepsilon = 0.288$. (c) 67% roll + ageing, $\varepsilon = 1.109$. $\varepsilon = \ln (h_0/h)$.

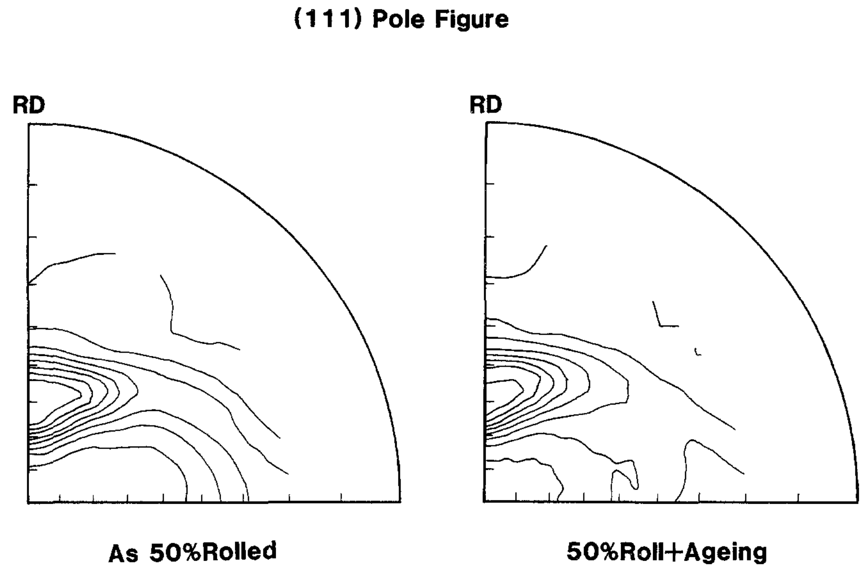


Figure 15 Textures of Cu–0.81 wt % Cr–0.14 wt % Sn alloy cold rolled 50%, and aged at 723 K for 1.8×10^3 sec after cold rolling 50%.

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