Recrystallization of a Cold-rolled Ni-30%Cu Alloy Cast

By Masanori Kiyoshige*, Toshimi Yamane**
and Junzo Takahashi**

The values of activation energy for recrystallization were obtained in hot forged or cold rolled Ni-30%Cu alloy ingot by isothermal annealing. The values obtained were as follows:

64500±900 cal/mol for the ST specimen,
67000±900 cal/mol for the CT specimen,
56000±900 cal/mol for the CR specimen,
65500±900 cal/mol for the ER specimen.

ST: Hot forged and recrystallized before cold rolling
CT: Columnar axis was perpendicular with the cold rolling direction
CR: Columnar axis was parallel with the cold rolling direction
ER: Equiaxed zone of ingot

(Received October 19, 1974)

I. Introduction

Liu⁽¹⁾ and Liu and Hibbard⁽²⁾ clarified that, in various *fcc* metals, the recrystallization temperatures and recrystallization texture were varied depending on the orientations of cold rolled crystals. Many researchers have studied the correlation between crystal orientations before recrystallization and kinetics of recrystallization. In many cases ingots have columnar and equiaxial structures and are hot-worked to eliminate the cast structures by recrystallization. But few studies have dealt with the effect of the cast structures on recrystallization, despite the fact that it is important to investigate the recrystallization kinetics of the cast structures from the point of view of metallurgical engineering.

The purpose of this research is to clarify the effect of the cast structures on the activation

energy of recrystallization using a Ni-30%Cu alloy which is the basic component of Monel metal of practical importance.

II. Experimental Procedure

The specimen was prepared by melting 99.9% nickel and 99.6% copper in an alumina crucible in an evacuated induction furnace and cast into a metal mold.

The ingot was homogenized at 900°C for 16 hr, but the cast structure was still retained. Table 1 shows the chemical composition of an ingot after homogenization. There is no difference in chemical composition among the parts of the cast structure.

Then, as shown in Fig. 1, several specimens were taken from the columnar zone and the equiaxed zone (ER) whose average grain diameter was 0.66 mm ϕ . Photograph 1 shows the macrostructure of each specimen. For the CT specimen, the rolling direction was perpendicular to the columnar axis and that of the CR specimen was parallel to the columnar axis. On the other hand, the standard specimen (ST)

* Technical Research Laboratory, Kawasaki Heavy Industries, Ltd., Akashi 673, Japan.

** Department of Metallurgy, Osaka University, Suita 565, Japan.

Table 1 Chemical composition of Ni-Cu alloy (wt%).

C	Si	Mn	P	S	Fe	Al	Ti	Cu	Ni
0.004	<0.01	0.003	<0.001	0.001	0.028	0.265	<0.01	31.17	Bal.

Fig. 1 Location of specimens.

Photo. 1 Macrostructures of specimens before rolling.

CT: rolling direction $\perp$ columnar axis.CR: rolling direction $\parallel$ columnar axis

ER: equiaxed zone.

was taken from the equiaxed zone, hot forged at 1000°C and annealed at 900°C for 16 hr. The average grain diameter was $0.11\text{ mm}\phi$.

These specimens were cold rolled by 90% reduction, isothermally annealed at temperatures between 525 and 650°C , and cooled in water. A micro-Vickers hardness tester was

used under a load of 1 kg.

III. Experimental Results

Figures 2, 3, 4 and 5 show the changes in hardness with the isothermal annealing time for the specimens investigated. The order of the time required for half recrystallization was $\text{CT} > \text{ER} > \text{ST} > \text{CR}$ in the case of annealing at 650°C and $\text{CR} > \text{CT} > \text{ER} > \text{ST}$ in the case of annealing at 550°C .

Figure 6 shows the relation between the hardness change and the recrystallization fraction obtained by measuring the area of recrystallized grains in the CT specimen by optical microscopy.

From this linear relationship, the hardness changes in Figs. 2, 3, 4 and 5 are replotted in

Fig. 2 Change in hardness with isothermal annealing time for 90% cold-rolled Ni-30%Cu alloy hot forged and annealed (ST).

Fig. 3 Change in hardness with isothermal annealing time in 90% cold-rolled Ni-30%Cu alloy taken from columnar zone: rolling direction $\perp$ columnar axis (CT).

Fig. 4 Change in hardness with isothermal annealing time in 90% cold-rolled Ni-30%Cu alloy taken from columnar zone: rolling direction // columnar axis (CR).

Fig. 5 Change in hardness with isothermal annealing time in 90% cold-rolled Ni-30%Cu alloy taken from the equiaxed zone (ER).

Fig. 6 Relationship between the fraction of recrystallized grains and the hardness change for 90% cold rolled Ni-30%Cu alloy (CT) in isothermal annealing.

Fig. 7 as the changes in the fraction of recrystallized grains.

Figure 8 indicates the relation between the time required for recrystallization and the reciprocal of annealing temperature ($^{\circ}\text{K}$). (f denotes the fraction of recrystallized grains.)

By means of the least squares method, the values of activation energy⁽³⁾⁽⁴⁾ were derived;

64500 ± 900 cal/mol for the ST specimen,

67000 ± 900 cal/mol for the CT specimen,

56000 ± 900 cal/mol for the CR specimen,

65500 ± 900 cal/mol for the ER specimen.

Fig. 7 The fraction of recrystallization vs annealing time for 90% cold-rolled Ni-30%Cu alloy.

ST: hot forged and annealed; CT: columnar zone of ingot, rolling direction $\perp$ columnar axis; CR: columnar zone of ingot, rolling direction // columnar axis; ER: equiaxed zone of ingot.

Fig. 8 Relation between time required for recrystallization and the reciprocal of annealing temperature.

IV. Discussion

It is known⁽⁵⁾ that recrystallization is not a single process but consists of several processes during annealing at comparatively low temperatures. Otherwise, recrystallization during

annealing at comparatively high temperatures can be looked upon as a single stage process⁽³⁾⁽⁴⁾.

Liu and Hibbard⁽²⁾ have recognized that there is the difference in recrystallization kinetics between $(110)\langle 11\bar{2} \rangle$ and $(3\bar{5}8)\langle 3\bar{5}2 \rangle$ of cold worked single *fcc* crystals. The mechanism has not been made clear yet, but a similar conclusion may be applied to the cast structures. It is interesting to note that the activation energy for the CR specimen is small. This phenomenon may be related to the anisotropy due to the rolling texture. Laue X-ray diffraction revealed that about 80% of the columnar axes were parallel with the $\langle 100 \rangle$ direction within 5° , and 20% of the columnar axes were inclined to a maximum of 24° to the $\langle 100 \rangle$ direction.

REFERENCES

- (1) Y. C. Liu: Trans. AIME, **209** (1957), 1017.
- (2) Y. C. Liu and W. R. Hibbard: Trans. AIME, **197** (1957), 672.
- (3) T. Yamane: Trans. JIM, **4** (1963), 242.
- (4) T. Yamane: Trans. JIM, **10** (1969), 341.
- (5) G. Mima and Y. Ogino: J. Inst. Metals, **96** (1968), 49.