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Effect of electropulse modification parameters on ingot macrostructure of Cu-Al-Ni shape memory alloys ①

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[Abstract] In order to improve ingot structure and to refine grain-size of Cu-Al-Ni shape memory alloys by means of electropulse modification, the effect of voltage, frequency and time of the pulse as well as the type of cooling mold on the macrostructure of ingot have been systematically studied. The results show that the above four parameters are important influencing factors on the ingot macrostructure. By appropriately adjusting the parameters, the macrostructure of polycrystalline Cu-Al-Ni ingot can be significantly improved and nearly fully equiaxied region of the ingot is obtained; the corresponding grain-size of the ingot can be dramatically reduced to less than 1/20 of that of unmodified.

[Key words] electropulsation parameters; Cu-Al-Ni; shape memory; macrostructure
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1 INTRODUCTION

It is known that the main obstacles to the application of polycrystalline Cu-Al-Ni alloys are coarse in grain-size and its concomitant intergranular fracture[1]. Although many attempts have been made in reducing grain-size of the alloys and in-deed there is some progress, there is not yet satisfactory way of grain-size refinement as to meet the demand of the application. Recently, WANG et al[2~5] have made a series of successful studies in reducing grain-size and modifying structure of ingots by using Electropulse Modification (EPM) on materials such as steels, cast iron, pure aluminum and Al-Cu alloys, and it is revealed that the EPM technique is an effective way. The technique has been utilized in the continuous production of square billets of steels[6]. Attention should be paid that because the pulsation treatment temperature is normally set at tens of degree higher than the liquidus point of the melt[7~9], the mechanism of pulsation treatment is not the classical "Electromagnetic Stirring Mechanism", rather is related with the "Clustering Theory of Atoms in Liquid Metals"; and the relevant "Joule Heat Effect" is negligible as the applying time of high electropulse is extremely short. The technique has been used in the fabrication of fine grain-sized Cu-Al-Ni alloys, and the relevant results such as macro- and microstructure analysis as well as shape memory performance have been reported in Ref.[10]. Recent extended research results of the effect of electropulse treatment parameters on the structures of ingots are summarized in this paper.

2 EXPERIMENTAL

All the raw materials, the nominal compositions of the alloys, the smelting facilities as well as the Electropulsation treatment devices were the same as that described in Ref.[10]. After the melts were formed at 1423 K (which is about 80 K higher than liquidus point) in furnace protected by nitrogen gas, the electropulse was applied onto the melts through two electrodes connected with self-made pulse supplier, with adjustment of pulse voltage, frequency, pulsation time. The treated smelts were poured into either sand molds or metal molds made of steel.

The ingots were cut with fret-saw along the longitudinal section, then carefully polished, and etched with fresh made 5 g $FeCl_3$ + 50 mL HCl + 100 mL H_2O solution. Macrostructures of the etched samples were observed and recorded with color scanner HP Scanjet 3400; the relevant microstructure analysis and the mean grain-size measurement were made under optical microscope.

3 RESULTS AND DISCUSSION

3.1 Effect of pulse voltage on structure of ingot

Fig. 1 is macrostructures of untreated ingot, treated ingots with pulse of 300 V, 600 V and 800 V (with same frequency of 2.5 Hz and same time of 60 s, cooled by metal mold), respectively. It can be seen that the pulse voltage plays a very important role

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in refining the grain-size and modifying the structure of ingot. With increasing pulse voltage, the typical three regions of ingot change distinctly in that the penetrating crystal region reduces greatly, while the range of central equiaxied-region increases remarkably. When pulse voltage reaches 600 V, nearly full equiaxied-region ingots can be obtained and the grain-size is reduced substantially. It is measured that the grain-size can be refined by EPM to less than 1/20 of untreated. It can be also found that the concentrated shrink of ingot reduced apparently.

According to the formation theory of ingot, the formation of a complete fine grain-size region of the ingot implies that nearly all the grains form simultaneously or within a very short time, that is to say the temperature difference of liquidus and solidus of the alloy is reduced after electropulsation.

Consequently the composition differences of both within one grain and between grains are diminished. The resultant influence of electropulsation treatment on composition is that the treatment increases the homogenization ability of the alloy's composition, both macro- and micro-structurally. Because of this, the concentrated shrink of the ingot can be reduced substantially, resulting in the usable percentage of ingot in further formation processing such as rolling and hot-forging is increased accordingly, and the cost of fabrication of the finished products of the alloy can be lowered thereafter.

Since all grains are formed almost simultaneously or within a very short tie, it is possible to enhance the mould filling ability, especially in the production of rods of big slenderness and relative thin and flat parts. This is of great importance to ensure the quality of products, and the poreness and looseness of ingot will be lower substantially.

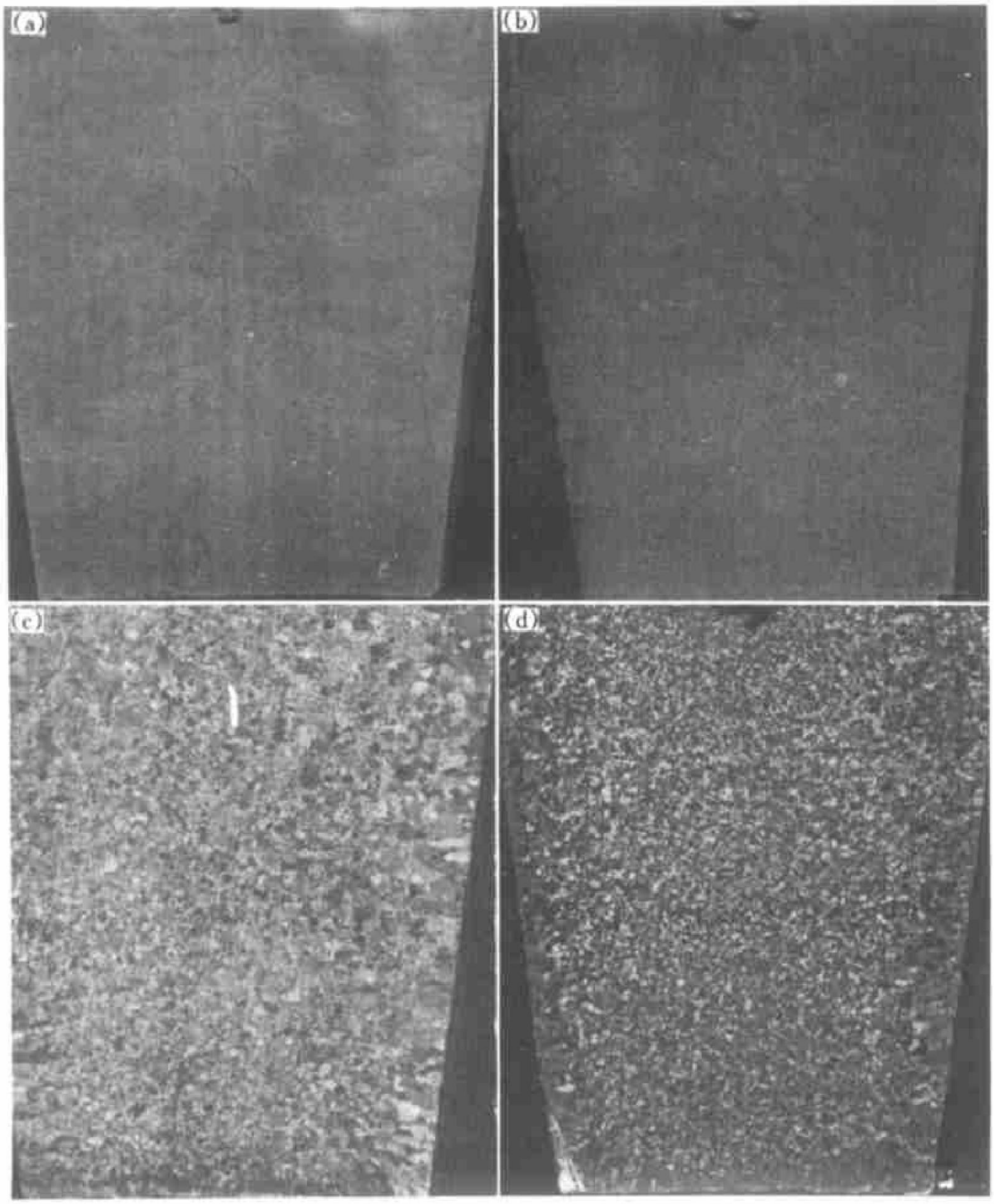

Fig. 1 Macrostructures of unmodified (a) and modified at 300 V (b), 600 V (c) and 800 V(d) with pulse frequency 2.5 Hz for 60 s, cooled by metal mold

As illustrated in Fig. 2, further microstructure analysis and mean grain-size measurement demonstrate that when the pulse voltage is between 600~800 V, the resultant refining effect is stable.

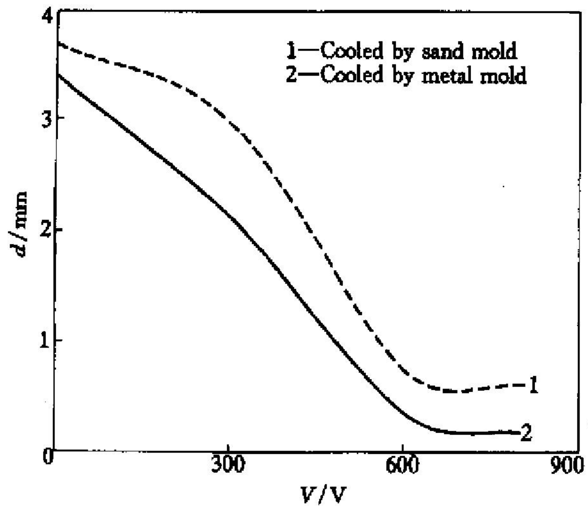

Fig. 2 Effect of pulse voltage (2.5Hz, 60s) on grain-size

Repeated experiments on effect of voltage on the distribution of three regions of ingot reveal that in order to realize effectively grain-size refining and modifying structure, it seems that there exists a value called "effective pulse voltage", which means only when the applied pulse voltage is larger than this value can effective grain-size refinement be realized. Thus in this respect, the effective pulse voltage is around 600V to the studied alloy. As for the exact physical meaning of this "effective pulse voltage", it needs to be investigated in detail by interested materials physicists.

3.2 Effect of pulse frequency on structure of ingot

Fig. 3 shows the macrostructure of ingot modified at 7.5Hz with the other same parameters as those in Fig. 1(d). Pulse frequency has great influence on structure of ingot. According to the experiences in other alloy systems[7,8], the frequencies of 2.5Hz, 5Hz and 7.5Hz are used for experiment. Fig. 4 demonstrates the effect of pulse frequency on mean grain-size of ingot. The frequency of 2.5Hz is an appropriate frequency in EPM treatment to the studied alloy. This is consistent with the fact that in DC (direct current) pulse welding, the structure of welding-line (or welded region) is quite fine when the pulse frequency of 2~3Hz is selected[11] although in the welding the high pulse time can be hundreds times longer than the present study case in each complete pulse cycle.

3.3 Effect of pulsation time on structure

Fig. 5 shows the macrostructure of ingot treated

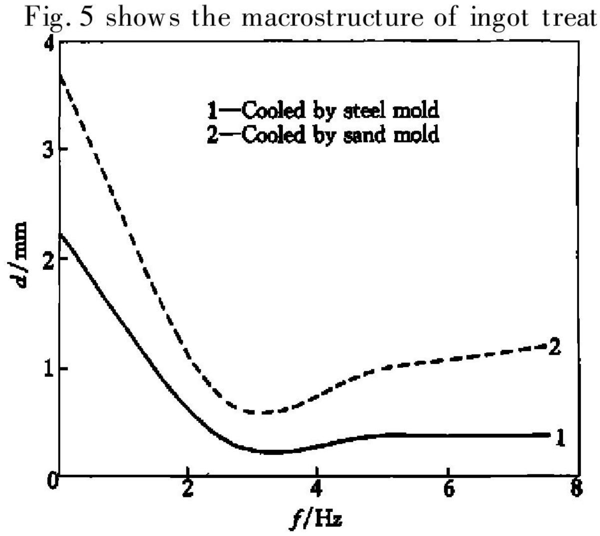

Fig. 4 Effect of pulse frequency on grain-size (at 600V, 60s)

Fig. 3 Macrostructure of modified at 800V, 2.5Hz for 60s, cooled by metal mold

Fig. 5 Structure of ingot cooled by metal mold after treatment of 600V, 2.5Hz for 120s

for 120s at other same parameters as those in Fig. 1(c). The pulsation time also has influence on the structure and the distribution of three typical regions of ingot. Increasing appropriately pulsation time can favor reducing the range of columnar region of ingot.

The evolution of mean grain-size of ingot with pulsation time is shown in Fig. 6, within the initial 60s of pulsation, the grain-size dramatically reduces with time and then gets to a stable value.

3.4 Influence of molds type on structure of ingot

Different cooling rates caused by different molds in solidification have important effect on the structure of ingots, as can be seen by comparing Fig. 7 with Fig. 1(c). Fig. 7 is the macrostructure of ingot treated at 600V, 2.5Hz for 60s and then cooled by sand mold. In the structure cooled by sand mold there is nearly one full coarse equiaxied-region and no columnar region is found, and the corresponding concentrated shrink region is large. However in the structure cooled by steel mold (Fig. 1(c)), the grain-size is much smaller and uniform, and the concentrated shrink region is very small.

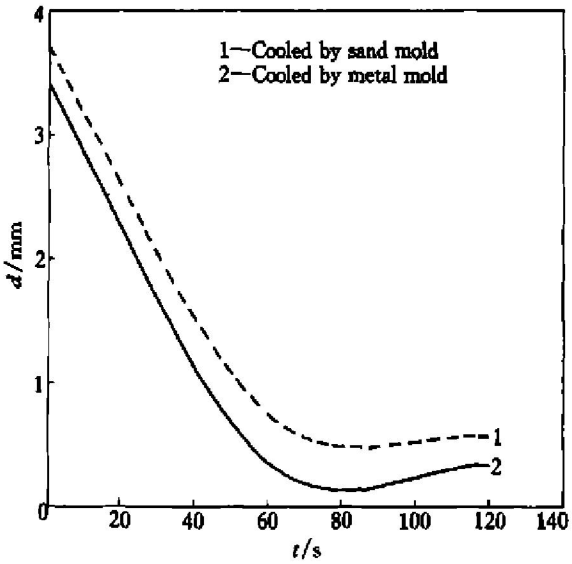

Fig. 6 Effect of EPM time on grain-size at 600V, 2.5Hz

Fig. 7 Structure of ingot cooled by sand mold after EPM at 600V, 2.5Hz for 60s

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