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Processing technology for C194 alloy sheet and strip

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Abstract: To optimize processes for stable commercial production of C194 alloy sheet and strip, several key steps were investigated. Various procedure and the parameters for melt purifying, finishing rolling temperature, split aging parameters, and water cooling capacity during casting and hot rolling were analyzed. The results imply that shield gas atmosphere along with alloying element of Mg and Ce help greatly on purifying the melt. C194 alloy sheet and strip with finishing rolling temperature higher than 750 ℃ and split aging treatment at 550 ℃, 2 h+450 ℃, 2 h can obtain excellent integrity properties. The cooling capacity during casting and on-line quenching after hot rolling are also key factors influencing the quality of C194 alloy sheet and strip.

Key words: C194 alloy; finishing rolling temperature; split aging

1 Introduction

Copper alloys are major materials for lead frame usage because they possess excellent combination properties. Four alloy systems (Cu-Fe-P[1−2], Cu-Ni-Si [3−4], Cu-Cr-Zr[5] and Cu-Ag) share about 80% of the market for metal lead frames. Among the 77 brands of copper alloys in use for lead frames, Cu-Fe-P alloys make up about 65% of the market[6−7]. C194, which belongs to the Cu-Fe-P alloy system, is a moderate strength and conductivity alloy, with the following service performance: tensile strength 450−500 MPa and electrical conductivity 65% IACS[8−10].

Mass production of C194 plates and strips is, however, usually limited by such questions: ineligibility of hardness, inadequate softening temperature, poor presentation quality and oversized dimensional tolerances

In the present work, the processes of melt purifying, finishing rolling temperature, aging process and cooling capacity for both casting and hot roll operations were investigated. Recommendations for technological parameters were given for the commercial processing of C194 copper alloys.

2 Experimental

As-casting C194 ingots were fabricated using a medium-frequency induction furnace. Protective atmosphere was used during the casting process. Alloying elements of Fe and P were charged by using the intermediate alloys of Cu-Fe and Cu-P, while magnesium (Mg) and rare earth metals were charged by using element Mg and Ce. C194 alloy ingots (70 mm×190 mm×800 mm) were hot and cold rolled. C194 alloy sheet were age treated using a vertical furnace with a shielding atmosphere. Inductive coupled plasma emission spectrometer(ICP) was used to analyze alloying compositions of the copper alloys. NIKON 200 optical microscope was used to observe the morphology and microstructure. The analytical transmission electron microscopy (TEM) observation was conducted using a JEM-200CX transmission electron microscope operating at 200 kV. The TEM disc foils were reduced by electro-thinning.

The chemical composition of C194 alloys is listed in Table 1. According to the various chemical compositions, the ingots were marked as sample 1, 2 and 3 (Table 1).

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Table 1 Chemical composition of C194 alloys (mass fraction, %)

Sample	Fe	P	Zn	Mg
1	2.20−2.40	0.1−0.2	0.02−0.04	−
2	2.20−2.40	0.1−0.2	0.02−0.04	0.03−0.05
3	2.20−2.40	0.1−0.2	0.02−0.04	0.03−0.05

Sample	Cr	Ce	Cu
1	−	−	Bal.
2	0.03−0.05	0.05−0.10	Bal.
3	0.03−0.05	0.10−0.20	Bal.

3 Results and discussion

3.1 Effect of shielding gas on quality of C194 alloy ingots

The microstructures of C194 alloy ingots with various casting and purifying technique are shown in Fig.1. The average grain size of sample 1 ranges from 100 to 300 μm (Fig.1(a)). Refined grain and microstructures are obtained after alloying with Mg and Ce elements during the casting process as shown in samples 2 and 3. The refined grain size of samples 2 and 3 are 80−120 μm (Fig.1(b)) and 50−100 μm (Fig.1(c)) respectively. Fig.1(d) shows the columnar crystals achieved by lowering the cooling velocity during the continuous casting process.

The cast quality of ingots greatly influences the final service performance of alloys. Purification of melt is the primary requirement for high quality cast ingots. It is necessary to pay close attention to the processes of deoxygenization and slag removal.

Application of shielding gas during casting process reduces slag quantity and the slag removal is easier and more complete. Alloying with the elements of Mg and Ce purified the melt more effectively.

Low-melting elements such as P (44 ℃), Pb (327 ℃) and Bi (271 ℃) are considered to deteriorate the property of copper alloys. Ce is an active element that is apt to form intermetallic compounds with these impurities. The intermetallic compound usually possess higher melting point than the element itself, such as the Ce_3Pb (1 200 ℃) and $BiCe_3$ (1 400 ℃). The removing of low-melting impurities contributes to improving the softening temperature of copper alloys[11−14].

Being grain refining elements, Mg and Ce significantly refine the grain size. As shown in Fig.1, grains are refined after alloying with elements of Ce and Mg under the same casting processing parameters (see Fig.1(a)−(c)).

3.2 Influence of finishing rolling temperature on properties of C194 alloy

Finishing rolling temperature influences the properties of C194 alloy. The properties of C194 alloy with various finish rolling temperatures are listed in Table 2. The results indicate that higher finishing rolling temperatures are helpful to obtaining better combination properties.

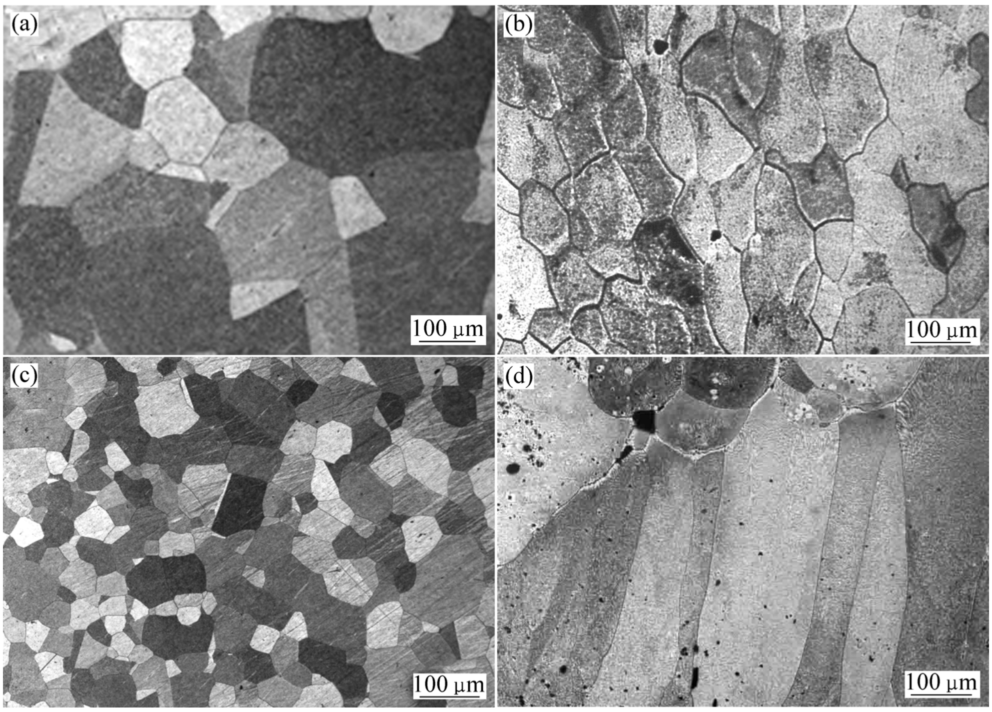

Fig.1 Microstructures of C194 alloy ingots: (a) Equiaxed grain for sample 1; (b) Equiaxed grain for sample 2; (c) Equiaxed grain for sample 3; (d) Columnar crystals achieved by lower cooling velocity

Table 2 Combination properties of C194 alloy with various finishing rolling temperatures

Finish temperature/ ℃	Hardness (HV)	Elongation/ %	Tensile strength/ MPa	Conductivity IACS/%
600−650	156	6.4	517	65.4
＞750	161	6.9	540	68.5

General phase diagrams of Cu-Fe system indicate that the solubility of Fe in Cu is about 1.5% at 750 ℃ and 0.5% at 650 ℃. Thus, finishing rolling at 750 ℃ will remarkably improve the solid solubility of Fe element in Cu than that at 650 ℃. We suggest a finish temperature higher than 750 ℃ with immediate on-line quenching. Higher solubility of Fe in the Cu matrix improves the homogeneous distribution of precipitated particle phases during the aging treatment.

A higher finishing temperature is also helpful to avoid the tearing tendencies. A pilot-scale test indicates that hot rolling finishing at 750 ℃ will effectively avoid the formation of hot cracks. However, the cracks occur frequently when hot rolling at or lower than 600 ℃.

Combination properties of C194 alloys with different finishing rolling temperatures suggest that, higher temperature (＞750 ℃) obviously contributes to improve the tensile strength, hardness and conductivity properties (Table 2). The disqualification of C194 alloys usually connects with the instability of hardness and the lower softening temperature. Besides, the rolling cracks obtained with lower finishing temperatures cause the reduction yields and push costs. Thus, the improved performances are significant for C194 alloys.

3.3 Effect of split aging process on combination properties of C194 alloy

Aging parameters influence obviously the combination properties of C194 alloy[15].

According to the differential scanning calorimetry (DSC) curves of C194 alloys, the precipitation occurs primarily at 445−550 ℃ (Fig.2). Two aging processes for C194 alloy were studied. Process A is split aging at 550 ℃ and 450 ℃ for 2 h respectively, process B is single aging at 500 ℃ for 4 h.

Split aging at 550 ℃ for 2 h and then at 450 ℃ for 2 h lead to more precipitation. As shown in Fig.3, the volume fraction and the distribution density of the C194 strip aged with process A (Fig.3(a)) are visibly higher than those found with process B (Fig.3(b)).

The conductivity of C194 alloy strips aged by process A was 68% IACS; however, process B resulted in only 60% IACS. The average hardness is 161 HV (process A) and HV 148 (process B) respectively. Test data indicate that after split aging at 550 ℃ for 2 h followed by 450 ℃ for 2 h, C194 alloy strips possess better integrity properties.

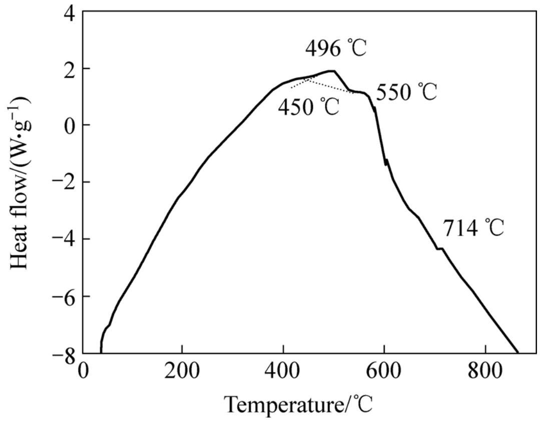

Fig.2 DSC curves of C194 alloy with a heating rate of 10 ℃/min

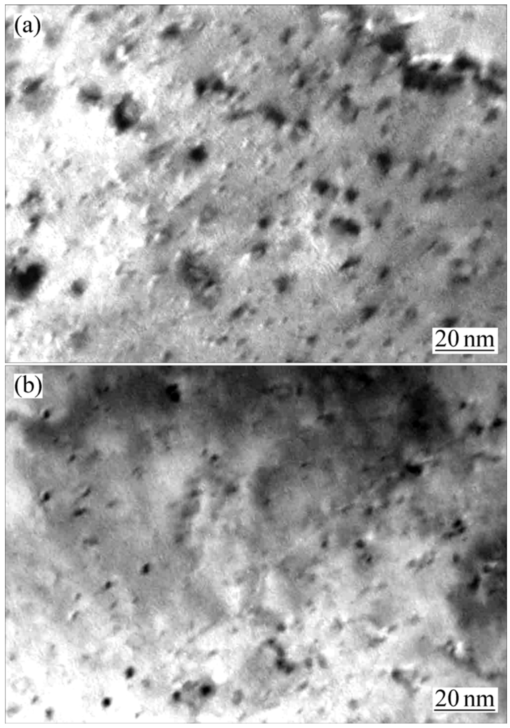

Fig.3 Microstructures of C194 strip aged at 550 ℃, 2 h+450 ℃, 2 h(a) and 500 ℃, 4 h(b)

3.4 Effect of cooling capacity on properties of C194 alloy

Refined grain is generally considered helpful to improve the mechanical properties of most alloys. Lower cooling capacity usually forms columnar crystals (see Fig.1(d)). By optimizing the cooling parameters during semi-continuous casting, ingots with equiaxed crystals can be obtained (Fig.1(a)−(c)).

Quenching capacity influences greatly the combination properties of C194 strips. Pilot-scale testing results indicate that high quenching equipment is necessary to obtain refined microstructure for C194 alloys. By regulating of the cooling capacity, the microstructure of C194 alloys can be controlled during both casting and rolling processes.

4 Conclusions

1) Ideal finishing rolling temperature for C194 alloys is higher than 750 ℃, and the preferred split aging parameter is 550 ℃, 2h+450 ℃, 2 h.

2) Melt purifying technology is very important to produce a high quality of C194 sheets and strips. Alloying with elements of Mg and Ce elements can effectively purify the melt.

3) To further enhance melt purifying, gas shield technology is recommended during the casting process.

4) Cooling capacity during casting and on-line quenching after hot rolling significantly influences the quality of C194 alloy.

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