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Study on QTi3.5-10graphite slurry①

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Abstract: QTi3.5-10graphite(mass fraction, %) slurry was prepared using electromagnetic-mechanical stirring technology. The distribution of graphite particles in QTi3.5-10graphite slurry was studied using cold quenching method. The results show that solid fraction of QTi3.5-10graphite slurry increases with the decreasing stirring temperature. There is a linear relationship between solid fraction and stirring temperature. With increasing solid fraction, the rising of graphite particles in slurry is restricted gradually. When the solid fraction is larger than 42.5%, the rising of graphite particles in slurry can be controlled, and QTi3.5-10graphite slurry with uniform distribution of graphite particles can be prepared.

Key words: QTi3.5; electromagnetic-mechanical stirring; graphite particles; solid fraction

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1 INTRODUCTION

Copper-graphite is an ideal material for the slide of locomotive electricity-catching bow[1]. Graphite has excellent lubricating property[2]. Copper alloy such as yellow brass, bronze has perfect electrical conductivity[3]. Therefore, copper-graphite has a very wide application in slide-electrical field[4].

However, the properties of copper alloy and graphite are very different. The density of copper alloy (about 8.8×10^{-3} kg/m^3) is much larger than that of graphite (about 2.2×10^{-3} kg/m^3), and the freezing range of the former about 875－1 085 ℃ is much lower than that of the latter 3 700 ℃[5]. Graphite particles are always buoyed by copper alloy liquid, and it is very difficult for graphite particles to distribute evenly in molten copper alloy.

At present, the available way to realize the uniform distribution of graphite particles in copper alloy matrix is powder metallurgy method[6]. However, this method includes too many working operations such as powder manufacturing, powder mixing, high temperature sintering and wastes too much energy. The cost of product is very high. Furthermore, too more cavities in copper alloy matrix deteriorate the properties. Thus the application of this material is limited. Therefore, a new method to realize the uniform distribution of graphite particles in copper alloy matrix should be developed.

In this work, QTi3.5-10graphite slurry was prepared using electromagnetic-mechanical stirring technology. The distribution of graphite particles in QTi3.5-10graphite slurry was studied and the condition for preparing QTi3.5-10graphite slurry with uniform distribution of graphite particles was obtained.

2 EXPERIMENTAL

The materials used in this experiment is QTi3.5 and the graphite particles size is about 60 μm. QTi3.5 is a copper alloy which contains 3.5%－4.0% Ti, and less than 0.5% impurity (As, Sb, Sn, Si, Al, Pb, P, Fe, Bi, Zn, Mn). Its freezing range is about 890－1 070 ℃(Fig. 1)[7], and the density is about 8.8×10^{-3} kg/m^3.

The experimental procedures were as follows:

1) Preparing QTi3.5 liquid. The temperature of the liquid was 1 200 ℃. The liquid must be degassed.

2) Preparing QTi3.5-10graphite slurry. Fig. 2 shows the diagram of QTi3.5-10graphite slurry-making apparatus (being patent). It includes three main parts, such as electromagnetic stirrer, mechanical uniform device and graphite crucible. Electromagnetic

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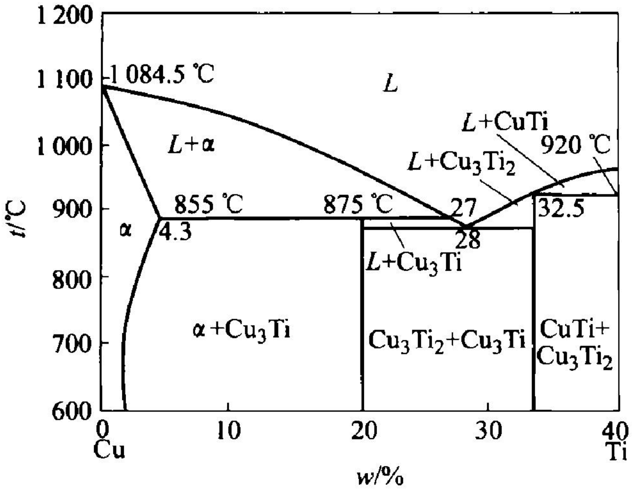

Fig. 1 Cu-Ti binary equilibrium diagram

stirrer is made up of three couples of electric poles which distribute around the crucible evenly. Its main role is to break up the dendritic crystal in the process of solidification by circular motion of slurry. Its power is 10 kW. Mechanical uniform device is a fluid director designed specially. It can move up and down by using an assistant electric device. Its main role is to enlarge the stirring intensity and to accelerate the deconcentration of graphite particles in the whole crucible. Graphite crucible is a temperature-adjusting container. There are holes in its wall evenly. These holes contain heaters and coolers so as to adjust the temperature of slurry. There is a hole at the bottom of the crucible. Its role is to let out the slurry. Because the solidus-liquidus interval of QTi3. 5 is 180 ℃, the solid fraction (volume fraction) of slurry is mainly controlled by stirring temperature. The process of making QTi3. 5-10graphite slurry was as follows: first, the crucible was preheated up to 1 000 ℃ by using the heaters. After the QTi3. 5 liquid (1 200 ℃) and 60 μm graphite particles were put into the crucible, the upper cover was overlaid and Ar gas was inlet through the gas pipe in order to prevent the liquid and graphite particles from oxidizing. Then, the electromagnetic stirrer and the mechanical uniform device were switched on and the cooling mediator was pumped into the cooling pipe to cool the liquid until down to the required temperature. The heaters were switched on to keep the temperature stable by adjusting the current. The precision of temperature was ± 0. 5 ℃. After a certain time of stirring at constant temperature, the slurry with required solid fraction could be prepared. In this experiment, the stirring time was 20 min.

3) Cold quenching experiment[8]. After the slurry was prepared, the spigot was opened and the slurry at the bottom of crucible was let out into water, and the structure of slurry could be reserved directly after cold quenching.

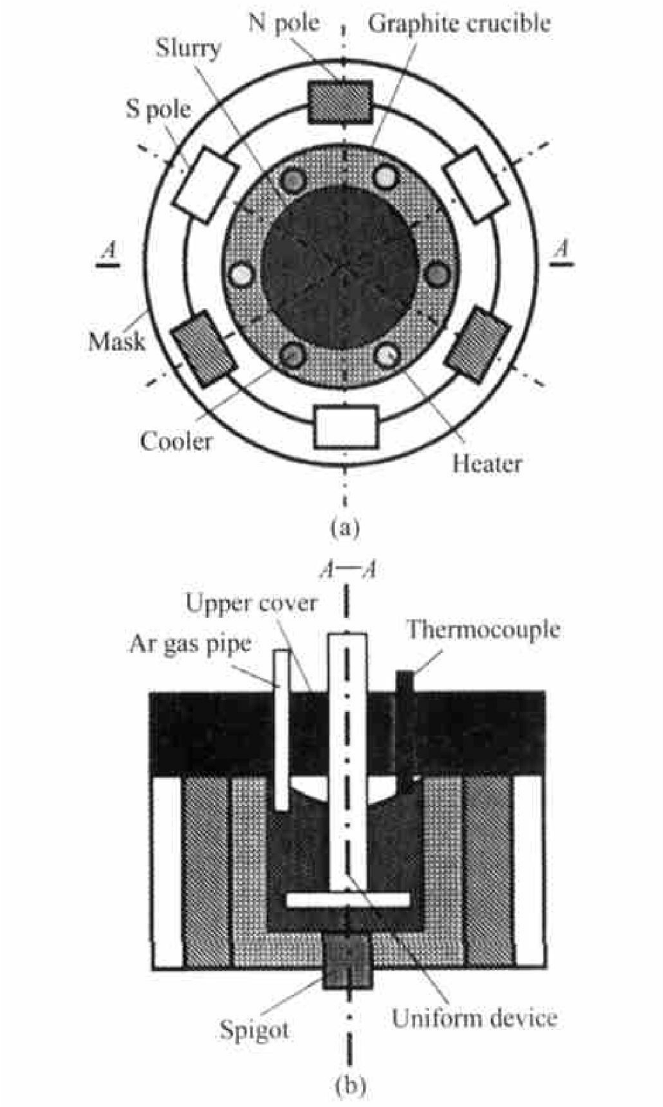

Fig. 2 Diagram of QTi3. 5-10graphite slurry-making apparatus

4) Conduct SEM experiment to determine the solid fraction of slurry and the distribution of graphite particles in slurry.

3 RESULTS AND DISCUSSION

3. 1 Relationship between solid fraction and stirring temperature of QTi3. 5-10graphite slurry

When the temperature of a metal is lower than its melting point, dendritic crystal can be formed and the proportion of this solid metal to the whole metal is called solid fraction[9]. Under the action of stirring, the dendritic crystal will be broken up and gradually change into solid particles which distribute in the liquid metal uniformly. So the metal becomes slurry[10]. Table 1 indicates the experimental data of the solid fraction of QTi3. 5-10graphite slurry at different stirring temperatures. After theoretical regression analysis, the regression equation about solid fraction of QTi3. 5-10graphite slurry and stirring temperature is

Table 1 Solid volume fraction and stirring temperature

Sample No.	Solid volume fraction/ %	Stirring temperature/ ℃
1	0	1 070
2	3.5	1 065
3	5.2	1 060
4	8.0	1 055
5	11.1	1 050
6	16.1	1 045
7	18.6	1 040
8	24.3	1 035
9	26.1	1 030
10	28.4	1 025
11	34.3	1 020
12	36.6	1 015
13	41.5	1 010
14	44.7	1005
15	48.7	1 000
16	53.1	995
17	56.2	990
18	57.1	985
19	61.3	980

$$f_s = 753.9 - 0.706\, t \qquad (1)$$

where f_s is solid fraction; t is stirring temperature. The regression coefficient R_1 is 0.998 88, and this proves that Eqn. (1) gives a correct relationship between solid fraction and stirring temperature of QTi3.5-10graphite slurry.

3.2 Distribution of graphite particles in QTi3.5-10graphite slurry

The difference of density between graphite and QTi3.5 will result in the rising of graphite particles in molten QTi3.5-10graphite. The nearer to the bottom of slurry, the less the graphite particles. If the distribution of graphite particles in the whole slurry is uniform, the quantity of graphite particles at the bottom of slurry will be 10%. Therefore, the content of graphite particles in slurry at the bottom of crucible was used to determine the distribution of graphite particles in QTi3.5-10graphite slurry. The nearer to 10% of graphite particles, the more uniform the distribution of graphite particles in the whole slurry. The experimental data are listed in Table 2. It can be seen that, with increasing solid fraction of QTi3.5-10graphite slurry, the content of graphite particles increases gradually, namely, the rising of graphite particles is restricted constantly. When the solid fraction was larger than 42.5%, the content of graphite particles is 10% basically. It can be seen that when the solid fraction of QTi3.5-10graphite slurry is larger than 42.5%, the rising of graphite particles is removed, and the graphite particles can distribute evenly in the QTi3.5-10graphite slurry.

Table 2 Solid volume fraction and content of graphite particles

Sample No.	Solid volume fraction/ %	Content of graphite particles/ %
1	0	0
2	2.5	0
3	5.0	0.5
4	7.5	1.0
5	10.0	1.7
6	12.5	2.4
7	15.0	3.2
8	17.5	3.7
9	20.0	4.3
10	22.5	4.8
11	25.0	5.2
12	27.5	5.8
13	30.0	6.6
14	32.5	7.8
15	35.0	8.6
16	37.5	9.1
17	40.0	9.8
18	42.5	10.0
19	45.0	10.0
20	47.5	10.0
21	50.0	10.0

3.3 Discussion

Under the action of strong electromagnetic-mechanical stirring, graphite particles can get enough additional energy to realize the distribution in molten QTi3.5. This additional energy ΔE is[11]

$$\Delta E = \sum_{i=1}^{n} \Delta E_i \qquad (2)$$

where ΔE_i represents additional surface energy, additional potential energy, additional kinetic energy and additional buoyancy energy, respectively. However, graphite particles will move up to the top of molten QTi3.5 because of the difference of density between graphite and QTi3. 5. The velocity V is [12]

$$V = \alpha(\rho_1 - \rho_2) \cdot r^2 / \eta \quad (3)$$

where α is a coefficient; ρ_1 is the density of QTi3. 5; ρ_2 is the density of graphite; η is the viscosity of molten QTi3. 5.

From Eqn. (3), it can be seen that, the smaller the viscosity of molten QTi3. 5, the larger the velocity. It is well known that, the higher the temperature of molten metal, the smaller the viscosity[13]. For QTi3. 5-10graphite slurry, when the solid fraction is zero, the temperature is the highest (1 070 ℃), the viscosity is the smallest, and the rising velocity of graphite particles is the largest. Therefore, no graphite particles existed at the bottom of slurry stably.

However, when the solid fraction is larger than zero, with increasing solid fraction, the temperature decreases, the viscosity increases, and the rising velocity of graphite particles decreases gradually. Furthermore, more and more primary QTi3. 5 solid particles in slurry hinder the vertical motion of graphite particles. Therefore, the rising of graphite particles is limited continuously, and the content of graphite particles at the bottom of slurry increases gradually. When the solid fraction reaches about 42. 5%, the large viscosity and the surrounded primary QTi3. 5 solid particles restrict the rising of graphite particles completely. Thus the content of graphite particles at the bottom of slurry reaches its largest value of 10%, and graphite particles distribute in the slurry evenly. Fig. 3 shows the stereoscan photograph of the sample whose solid fraction is 42. 5%. The dark parts are graphite particles, the white parts are primary QTi3. 5 solid particles. It can be seen that the distribution of graphite particles and the primary QTi3. 5 solid particles are relatively uniform. This illustrates that uniform QTi3. 5-10graphite slurry can be prepared by using electromagnetic-mechanical stirring technology.

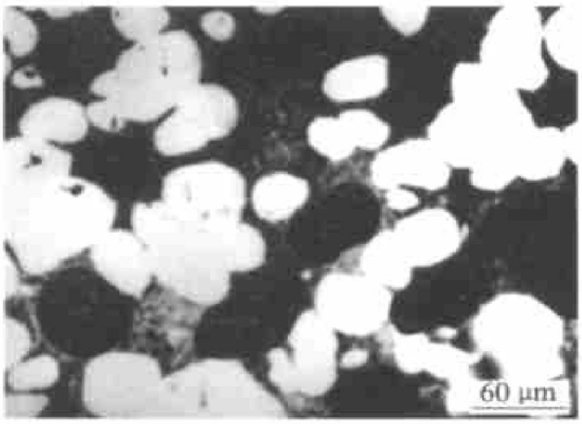

Fig. 3 Structure of slurry

4 CONCLUSIONS

1) For QTi3. 5-10graphite, slurry can be prepared by electromagnetic-mechanical stirring technology. The relationship between solid fraction and stirring temperature is

$f_s = 753.9 - 0.706t$

2) With increasing solid fraction of QTi3. 5-10graphite slurry, the rising of graphite particles in slurry reduces gradually. When the solid fraction is larger than 42. 5%, graphite particles can distribute evenly in QTi3. 5-10graphite slurry. This establishes a useful basis for semi-solid processing of QTi3. 5-10graphite.

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