THE EFFECT OF COOLING RATE OF SOLIDIFICATION ON MICROSTRUCTURE AND ALLOY ELEMENT SEGREGATION OF AS CAST ALLOY 718

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Abstract

In this study, several solidification cooling rates of alloy 718 were obtained using different pouring and mould temperature combinations. Secondary dendrite arm spacing, grain size and the volume fraction of Laves phase formed at different solidification cooling rate were systematically observed. The relationships of secondary dendrite arm spacing, grain size and volume fraction of Laves phase with the cooling rate were set up by measurement and data treatment. These relationships possess semi-quantitative significance within the condition of this study, which can be used to predict the secondary dendrite arm spacing, grain size and volume fraction of Laves phase when knowing the solidification cooling rate of alloy 718.

The extent of effect of the solidification cooling rate on the porosity and the morphology of Laves phase for alloy 718 also were obtained by metallographic analysis. The alloy element distribution in Laves phase and in dendritic core region were measured by energy spectral analyzing electron microscope. Some quantitative conceptions about the relationship of the microstructure with the solidification cooling rate for as cast alloy 718 have been achieved.

Introduction

The relationships between microstructures and mechanical properties for cast alloy 718 have been discussd by many investigators. But the relationships of microstructure with solidification cooling rate about the alloy have not been reported. Along with the development of computer simulative technique, it will be able to estimate the solidification cooling rate of any part for a large structural casting before practical pouring. Therefore ,if the relationships of the microstructure and solidification cooling rate of certain part of a casting has been obtained, it is possible to predict the mechanical properties of the casting.

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Experimental Procedures

Cast samples of alloy718 were prepared with investment cast process . The composition of the alloy is, in weight percent, :52.7Ni, 19.1Fe, 18.46Cr, 5.14Nb, 2.87Mo, 0.95Ti, 0.55Al, 0.15Si, 0.042C.The pouring conditions for various cast samples are shown in Table I.and the shape of samples are shown in Fig.1.and Fig. 2. Prior to pouring, thermocouples were installed in central location within the mold cavities to obtain the solidification cooling rate data.

Table I Experimental Casting Processes

Sample	Pouring Temperature, ℃	Mould Temperature, ℃
15#	1350—1400	<600
1# (including ladder-shape sample)	1400—1450	<600
14#	1400—1450	>800
10#	1450—1500	<600
6# (including ladder-shape sample)	1450—1500	>800

Note: (1) Samples were all standard φ5 mm investment casting close to net shape,

also including ladder-shape samples for 1# and 6#.

(2) Standard heat treatment were carried out for all samples as follows:

homogenization: 1095℃, 2 hrs, air cool;

solution: 954℃, 1 hrs, air cool;

precipitation: 720℃, 8 hrs, furnace cool (50℃/h) to 620℃, 8 hrs, air cool.

(3) Ladder-shape samples were used for segregation analysis.

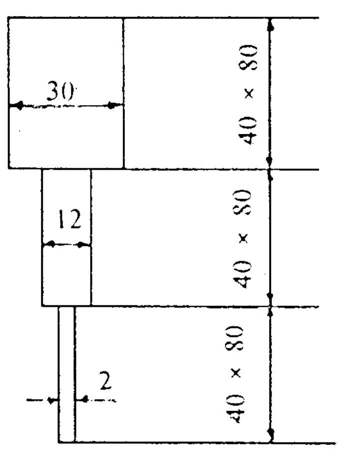


Fig.1 Sketch of ladder-shape sample

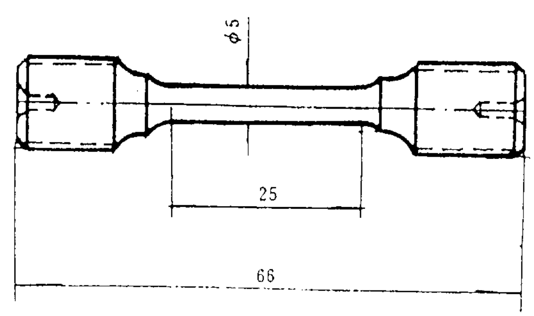


Fig.2 Sketch of casting net shape sample

Etching agent used for metallographic examinations was: 16g CrO_3+10mlH_2SO_4+70mlH_3PO. Etching agent used for macrostruture: examinations was: $HCl:H_2O_2=3:1$. Observation and analysis of the microstruture were carried out by optical micrographs and scanning electron microscope equipped with secondary electron and X-ray energy dispersion detectors (SEM—EDAX).

Results and Discussion

Several solidification cooling rates of cast alloy 718 were measured practically and the data were presented in Table II.

Table II The Average Solidification Cooling Rates of Cast Alloy 718 Samples by Some Cast Processes

Sample	1# Ladder-Shape (12 mm Thick)	6# Ladder-Shape (12 mm Thick)	6#
V,°C/min	23.1	12.1	8.1

Secondary dendrite arm spacing of the alloy samples by different cast processes was examined by metallographic method. The results were given in Table III.

Table III Secondary Dendrite Arm Spacing of the Samples Cast in Different Samples

Sample	15#	1#	14#	10#	6#	1# Ladder-Shape (12mm Thick)	1# Ladder-Shape (30mm Thick)	6# Ladder-Shape (12mm Thick)	6# Ladder-Shape (30mm Thick)
d_2,cm	0.0357	0.0394	0.0431	0.0520	0.0732	0.0510	0.0545	0.0637	0.0710

Generally, the relation equation of secondary dendrite arm spacing with solidification cooling rate corresponds to:[1]

$$d_2=kv^{-1/3} \tag{1}$$

Where:

d_2: secondary dendrite arm spacing;
v: solidification cooling rate,
k: constant about the alloy.

On the basis of the average solidification cooling rates (v) of alloy718 in Table II and the secondary dendrite arm spacing (d_2), corresponding number of sample in Table III, the constant k may be calculated by using equation (1):

$$k=0.146$$

Therefore, equation (1) becomes:

$$d_2=0.146v^{-1/3} \tag{2}$$

Then, put the measured data of secondary dendrite arm spacing (in Table III) into equation (2), the solidification cooling rate of various cast processes were obtained and showed in Table IV.

Table IV Solidification Cooling Rates of Various Cast Processes

Sample	15#	1#	14#	10#	1# Ladder-Shape (30mm Thick)	6# Ladder-Shape (30mm Thick)
V℃/min	134	71	39.6	22.6	19.6	8.9

The above data can be treated into a curve presenting the relationship of the secondary dendrite arm spacing with the solidification cooling rate (see Fig. 3).

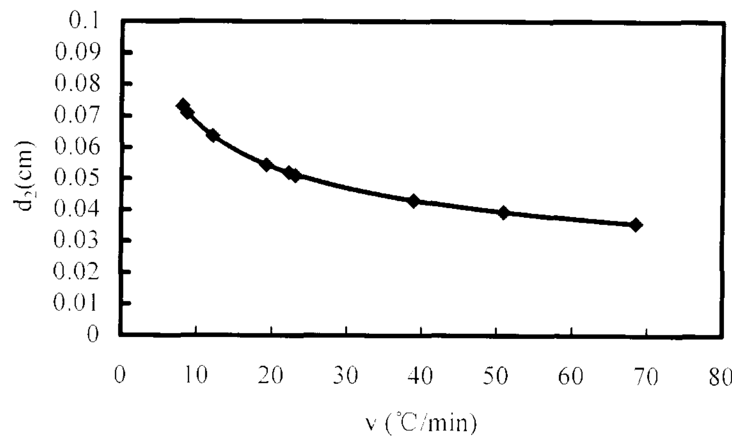


Fig. 3 Relationship of the secondary dendrite arm spacing with the solidification cooling rate

The effect of average solidification cooling rate on grain fineness is presented in Fig. 4. It showed that the grain size increased remarkably with the decrease of solidification cooling rate .The relationship can be described as following equation:

$$G=1.0196e^{0.0656V} \tag{3}$$

Where:

G: grain size;

V: solidification cooling rate

It should be noticed that, at the same solidification cooling rate, the composition variation within the allowance of alloy 718 will result in the grain size changing. In addition, the value of the constant **k** calculated from the secondary dendrite arm spacing also will be different owing to the same reason.

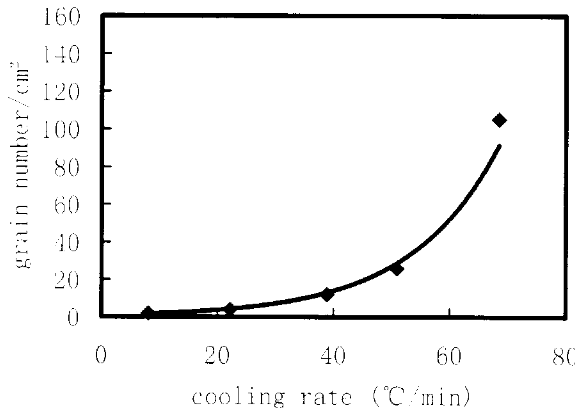


Fig. 4. The effect of average solidification cooling rate on grain fineness

The effect of average solidification cooling rate on the volume fraction of Laves phase was shown in Fig.5. Apparently, the volume fraction of Laves phase of the alloy increased remarkably with average solidification cooling rate decreasine .The relationship accords with the following empirical equation:

$$F=-0.4388\ln(v)+2.3075 \quad (4)$$

Where:

F: volume fraction of Laves phase;

V: solidification cooling rate

As the result of the alloy composition variation, the volume fraction and the morphology of Laves phase will vary (see Fig..5 and Fig.7).

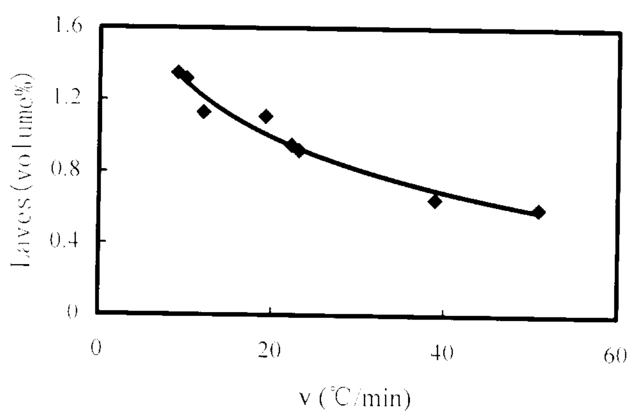


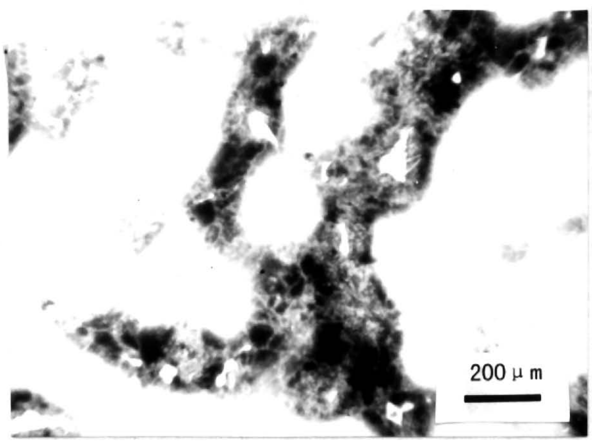
Fig.5 The effect of average solidification cooling rate on volume fraction of Laves phase

The different extent of porosity would form at various solidification cooling rate. The typical examples were presented in Fig. 6. It is well known that the solidification cooling rate only is one of the factors to influence the forming of porosity. The other factors will be discussed elsewhere.

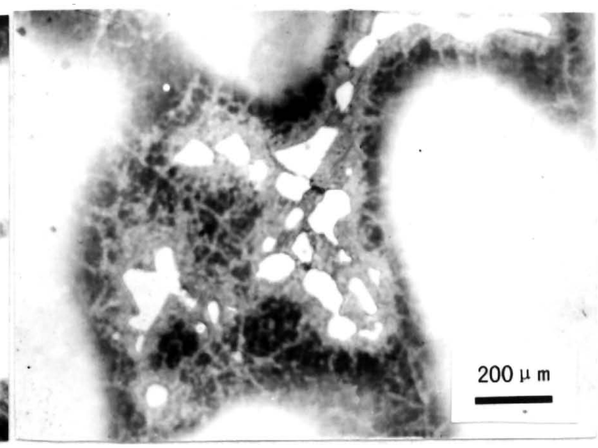
68.5℃/min 50.9℃/min 8.7℃/min

Fig..6 Extent of porosity formed at different solidification rate

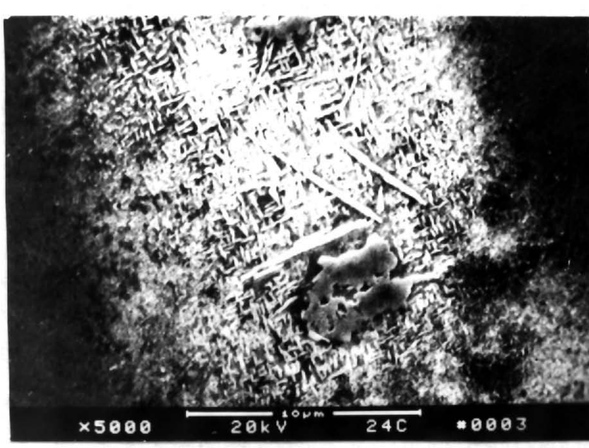
The effect of average solidification cooling rate on the morphology of Laves phase was shown in Fig. 7. From Fig. 7 it can be seen that the morphology of Laves phase has changed from honeycomb into large bulk with the decrease of solidification cooling rate ranging from 68.5℃/min to 8.7℃/min.



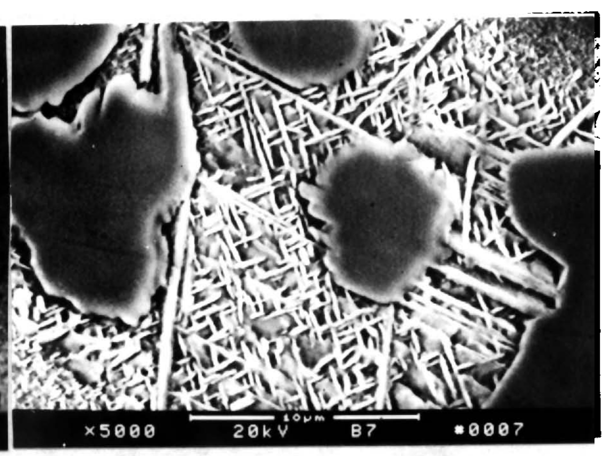
a) 68.5℃/min



b) 8.7℃/min



c) 68.5℃/min



d) 8.7℃/min

Fig. 7 Morphology of Laves phase formed at different solidification cooling rate

The effect of average solidification cooling rate on the alloy elements distributions in dendritic core region and in Laves phase (interdendritic region) were presented in Fig. 8 and Fig. 9 respectively.

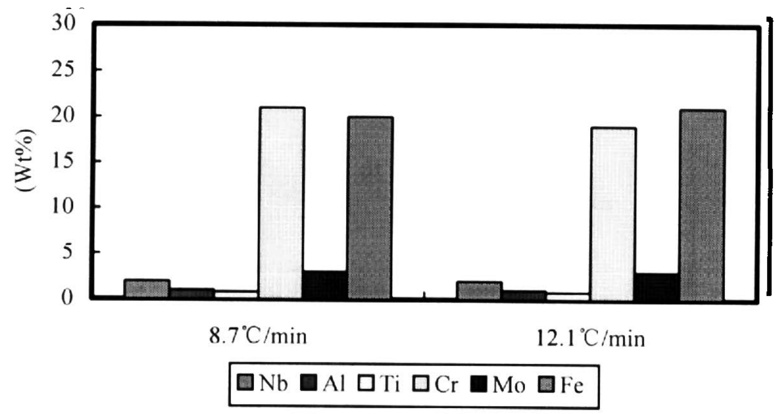


Fig. 8 The effect of average solidification cooling rate on the alloy elements distribution in dendritic core region

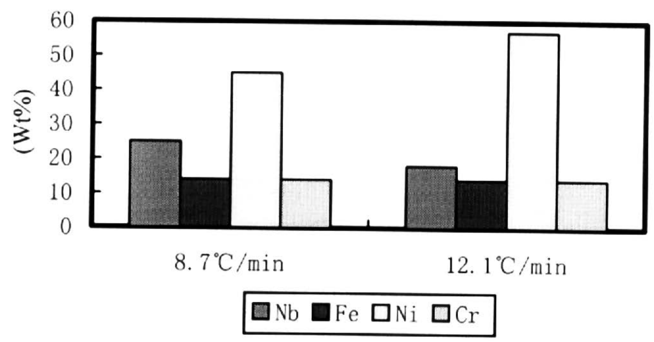


Fig. 9 The effect of average solidification cooling rate on the alloy elements distribution in Laves phase

Conclusions

1.The solidification cooling rate (v) strongly affects the secondary dendrite arm spacing(d_2). the grain size(G) and the volume fraction of Laves phase(F) for cast alloy 718. The relationgships of d_2. G and F with v may be summarized as following equations:

$$d_2=0.146v^{-1/3}$$

$$G=1.0196e^{0.0656v}$$

$$F=-0.4388\ln(v)+2.3075$$

2..The extent of porosity and the morphology of Laves phase for the alloy vary with the average solidification cooling rate from 68.5℃/min to 8.7℃/min were remarkably different.

3.The change of alloy elements distribution in dendritic core region ,with the solidification cooling rate increasing from 8.7℃/min to 12.1℃/min, was lighter than that in Laves phase (in interdendritic region).

References

1 Merton C.Flemings, ed.,:Solidification Processing, (McGraw – Hill Series in Materials science and Engineering, 1974)