

EFFECTS OF MAGNESIUM ON NIOBIUM SEGREGATION

AND IMPACT TOUGHNESS IN CAST ALLOY 718

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Abstract

A program has been conducted on the effects of Mg in cast alloy 718. The results show that small amounts of Mg improves impact toughness and decreases Nb segregation by decreasing secondary dendrite arm spacing which results in less and smaller interdendritic Laves and MC eutectics. Small amounts of Mg produce a more spheroidal as well as a more dispersive MC phase. Impact toughness was found to be related to the refinement of interdendritic segregation of Nb which affects the size, quantity and morphology of Laves and MC phases.

Introduction

The unique effects of Mg have been determined for many wrought superalloys. Mg has been shown to improve the creep properties and particularly the high temperature ductility due to refinement of the grain boundary carbides and equilibrium segregation. Mg also reduces the detrimental effect of S.

Effects of Mg in cast superalloys have recently been investigated and results indicate that Mg improves solidification behaviors and structures. Mg segregates to phase boundaries and refines the interdendritic MC carbides and γ eutectic as well as decreasing the quantity of γ eutectic.

A program to study the effect of Mg in cast alloy 718 was conducted. The purpose of this study was to study the effects of Mg on the segregation behavior of Nb and the morphology distribution of primary Laves and MC carbides. This paper presents the effects of Mg on impact toughness and segregation of Nb in cast alloy 718.

Experimental Procedure

Seven heats of alloy 718 with various contents of Mg were prepared. The materials used for first cycle tests were commercial alloy 718 without Mg (Alloy A) and with Mg of 0.0026% (Alloy B). The content of Nb is as high as 5.25%. The 718 materials used for the second cycle testing have a lower Nb content (~ 4.75%) and varying amounts of Mg (0.000%, 0.0016%, 0.0084% and 0.011%, respectively). Investment cast specimens were used for testing. The pour temperature was 1420-1450°C, and the mold temperature was 820-840°C. The heat treatment for first cycle tests was 1100°C/1 hr/AC + 980°C/1 hr/AC + 720°C/16 hr/AC. The heat treatment for the second cycle tests was 1100°C/1 hrs/AC + 970°C/2 hrs/AC + 720°C/8 hrs/AC to 620°C/18 hrs/AC.

The morphology of Laves and MC eutectic in alloys with various contents of Mg was characterized. Fracture surface were investigated by SEM to determine the effects of Mg. Quantitative measurements of Laves and MC particles were carried out. Both electron microprobe and EDS analyses were also used in this program. Impact tests were primarily used to follow the resultant structural changes on toughness.

Experimental Results and Discussion

The results of the impact tests show that Mg increases significantly the impact toughness as shown in Table I. Impact toughness increases with Mg content as illustrated in Figure 1.

Microstructural studies show that Mg additions have no influence on grain size, but decreases the secondary dendritic arm spacing as shown in Figure 2.

Table I. Impact Toughness of Cast alloy 718 with Various Contents of Mg.

| Alloy | Mg% | Ak J/cm ² | Alloy | Mg% | Ak J/cm ² |
|-------|--------|----------------------|-------|--------|----------------------|
| A | 0.000 | 32.5 | 13 | 0.000 | 30.2 |
| B | 0.0062 | 55.1 | 7 | 0.0016 | 49.8 |
| | | | 8 | 0.0041 | 54.9 |
| | | | 9 | 0.0084 | 58.1 |
| | | | 10 | 0.011 | 69.1 |

As a result, the interdendritic precipitates of Laves and MC eutectic is decreased. Figure 3 shows the typical dendritic MC microstructure and Laves eutectic for alloys without Mg and with Mg. Figure 3 illustrates the decrease of Nb segregation with Mg. Figure 4 indicates that Mg makes MC particles finer and more spheroidal. The results of quantitative analysis indicate that the average diameter and average length/width ratio of MC particles is decreased with Mg. The average number of MC particles in a visual field is increased, but the total amount of MC carbide is not changed by Mg addition of 0.0062% as shown in Table II. The average composition of MC as determined by electrochemical phase analysis techniques is as about 0.65 Cb, 0.12 Ti, 0.08 Ni, 0.06 Cr, 0.05 Fe.

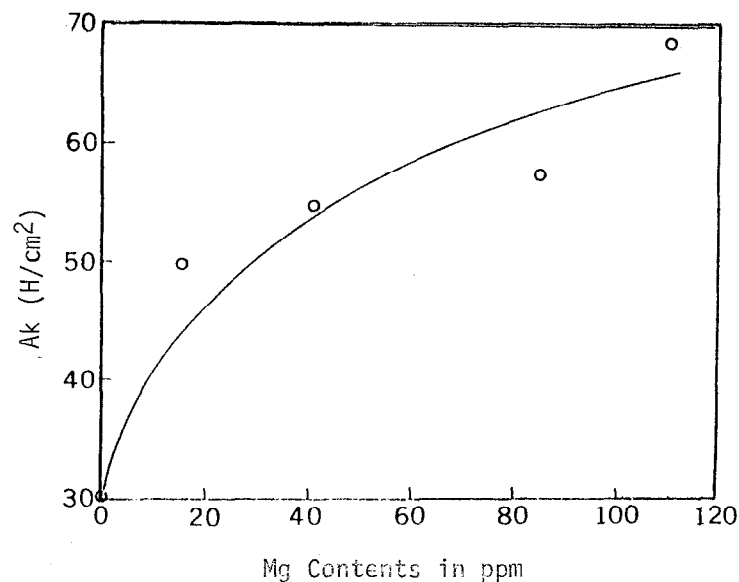


Figure 1. Effects of Mg addition on impact toughness in cast alloy 718.

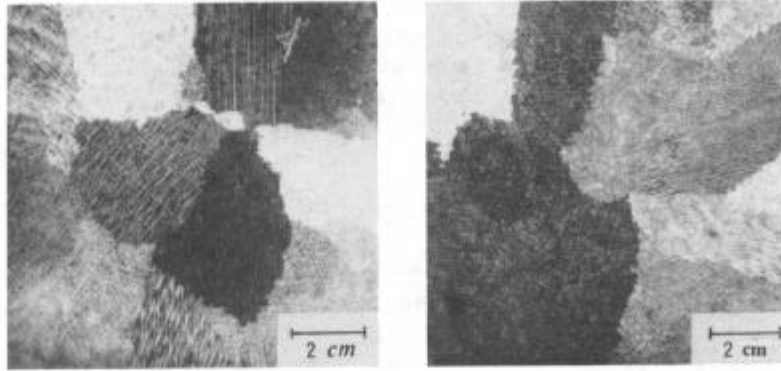


Figure 2. Grain size of cast alloy 718.
 (a) Alloy without Mg; (b) Alloy with Mg.

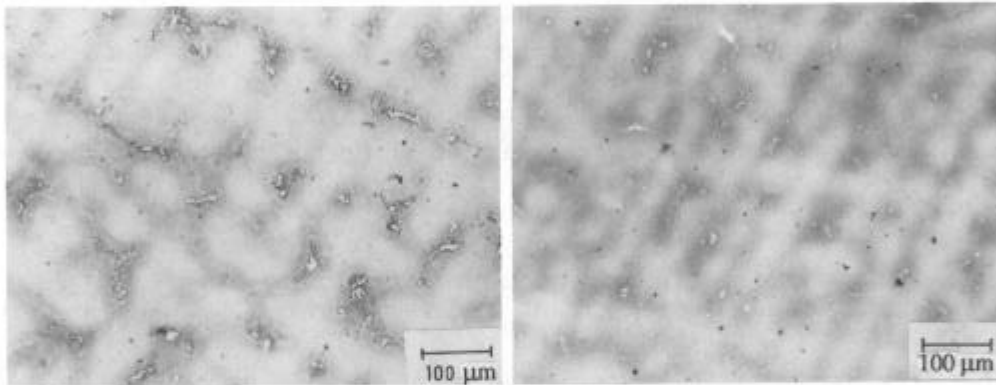


Figure 3. Effects of Mg addition on dendritic microstructure and Laves eutectic in cast alloy 718. (a) Alloy without Mg; (b) Alloy in Mg.

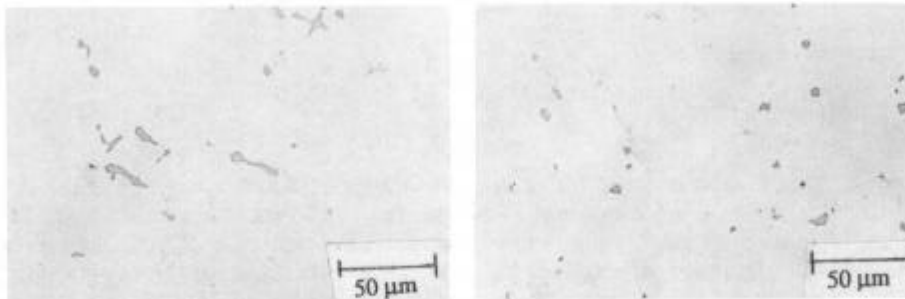


Figure 4. The morphology of MC particles in cast alloy 718. (a) Alloy without Mg; (b) Alloy with Mg.

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Table II. Effects of Mg Addition on the Character of MC Particles in Cast alloy 718.

| Alloy | Total amount* | Average diameter μm | Average length/width | Average # of MC |
|-------|---------------|--------------------------------|----------------------|-----------------|
| A | 1.055 | 4.31 | 1.56 | 38.2 |
| B | 1.028 | 3.66 | 1.46 | 56.0 |

*as measured by electrochemical phase analysis technique.

A quantitative analysis was also carried out for Laves phases. The results show that the quantity of Laves eutectic decreases with the increase of Mg content as shown in Figure 5.

These results indicate that very small amounts of Mg addition, such as 0.002%, significantly influences the impact toughness and the distribution of interdendritic Laves and MC particles. As the amount of Mg addition increases, the effect become gradual. When the amount of Mg addition is too high, the MC particles coarsen again as shown in Figure 6. A optimal range of Mg addition is determined to be ~ 0.004 - 0.008%.

A comprehensive study of the fracture surfaces and microcracks indicates that cracks always form at the interfaces of interdendritic MC and Laves particles and propagate along interdendritically as shown in Figures 7 and 8.

The broken particles in the fracture surface are MC particles whose composition is 0.87 Cb, 0.10 Ti of 0.01 C and 0.02 Ni. In Figure 7 and 8, it can be seen that the MC and Laves particles in the alloy without Mg are drastically fractured but only slightly in the alloy with Mg. It is believed that the improvement of impact toughness is associated with the improvement of MC and Laves eutectic. The relationship between impact toughness and area of Laves particles is similar to that of Figure. 5. The impact toughness is directly proportional to the average area of Laves particles as given by.

$$Ak = 91.03 - 2.52 A \quad R = -0.9943$$

where Ak = impact toughness
A = area of Laves particles %
R = regression coefficient

The existence of interdendritic MC and Laves eutectic in cast alloy 718 is the result of the segregation of Nb. When a large amount of Nb segregates to interdendritic areas, MC carbide and Laves eutectics form in large amounts. Conversely, the decrease of primary Laves and MC eutectic indicates a decrease of Nb segregation. The decrease of Nb segregation by Mg additions has been found by electron microprobe analysis. The results are summarized in Figure 9. It indicates that at the optimum content of Mg the segregation of Nb and Ti decreases. During the homogenization at 1150°C/24 hrs, the Nb and Ti contents become more homogeneous. The results indicate that small additions of Mg decrease initial cast segregation which shortens the homogenization cycle.

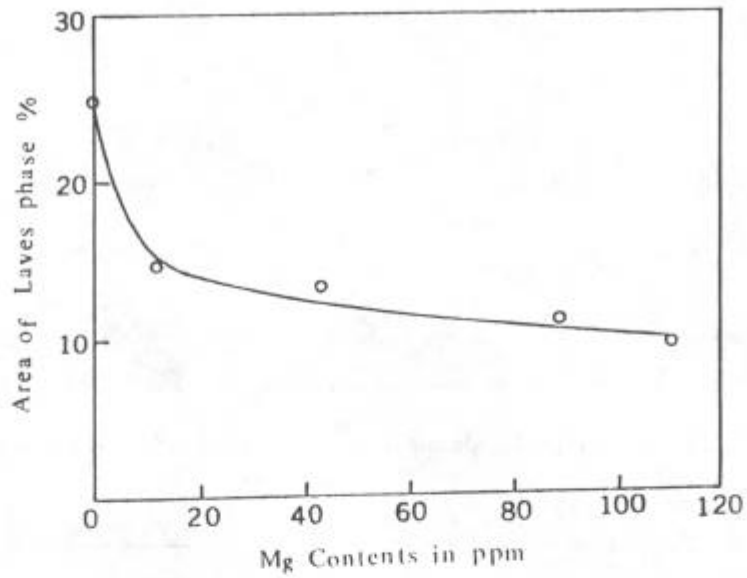


Figure 5. Effect of Mg contents on the quantity of laves eutectic in cast alloy 718.

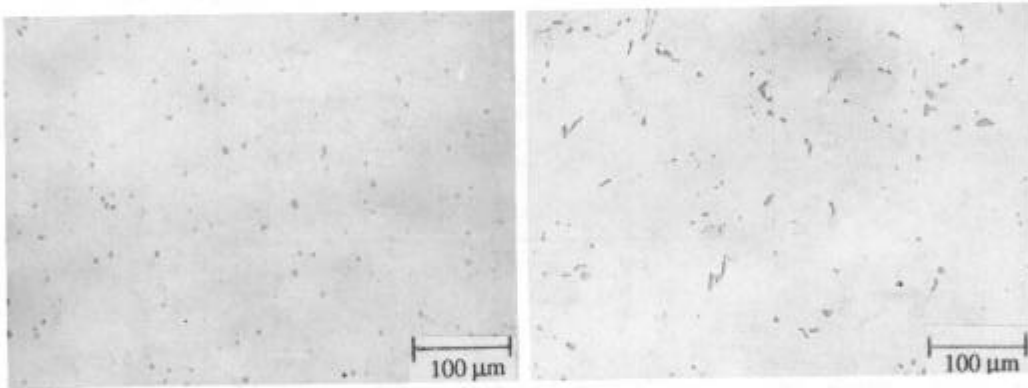


Figure 6. Effects of too high content of Mg on MC particles in cast alloy 718. (a) Alloy with Mg of 0.0084%; (b) Alloy with Mg of 0.011%.

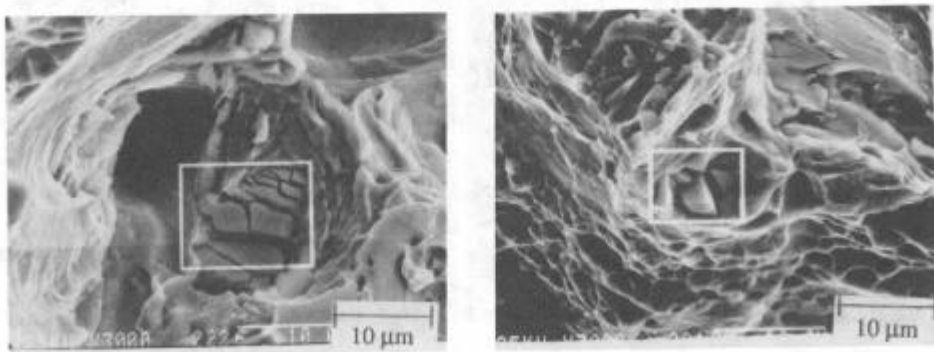


Figure 7. Morphology of MC particles in fracture surface. (a) Alloy without Mg; (b) Alloy with Mg.

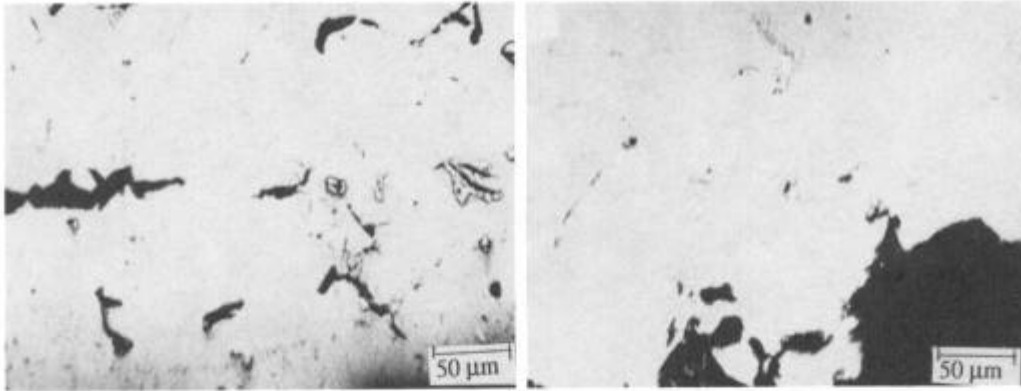


Figure 8. Microcracks in impact samples. (a) Alloy without Mg; (b) Alloy with Mg.

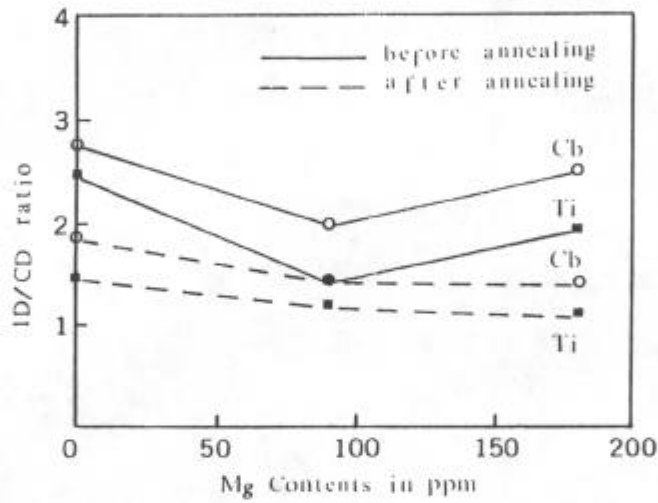


Figure 9. Effect of Mg addition on Cb and Ti segregation IC/CD is concentration in interdendrite/concentration in center of dendrite.

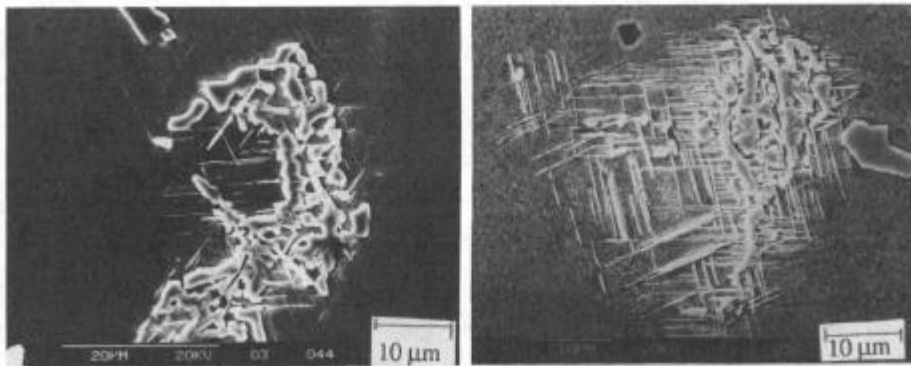


Figure 10. Effects of Mg on δ plates around the Laves islands in cast alloy 718. (a) Alloy without Mg; (b) Alloy with Mg.

The amount of δ plates found around the Laves island is related to the degree of Nb segregation. Figure 10 indicates that as the Mg content increases and the Laves particle decreases, the amount of δ plates around the Laves islands increases. This occurs because the amount of Nb necessary for Laves formation is too low but the Nb content is high enough for δ plate formation. The δ plates can be eliminated by homogenization much easier than the Laves islands.

Conclusions

1. Mg additions increase the impact toughness of cast alloy 718 due to the decrease of interdendritic MC and Laves eutectic.
2. Mg addition decreases and refines the interdendritic segregation of Nb and Ti which permits shorter homogenization cycles.