Precipitation Behavior of γ″ in Severely Plastic Deformed Ni-base Alloys

Il-Ho Kim[a] and S. I. Kwun[b]

Division of Materials Science and Engineering, Korea University, Seoul 136-701, Korea
[a]gsystem@hanmail.net, [b]sookkwun@korea.ac.kr

Abstract

The precipitation behaviors of γ″(Ni_3Nb) in four Ni-base alloys were investigated. The four alloys were forged Ni20Cr20Fe5Nb alloy, mechanically alloyed Ni20Cr20Fe5Nb alloy, IN 718 alloy and ECAPed(equal channel angular pressing) IN 718 alloy. Aging treatment was employed at either 600℃ or 720℃ for 20 hrs. The TEM observation and hardness test were performed to identify the formation of γ″. The precipitation of γ″ was noticed after aging at 600℃ for 20 hrs in the mechanically alloyed Ni20Cr20Fe5Nb alloy and ECAPed IN 718 alloy, while it was observed after aging at 720℃ for 20 hrs in the forged Ni20Cr20Fe5Nb alloy and IN 718 alloy before ECAP. The lower aging temperature for γ″ precipitation in the mechanically alloyed Ni20Cr20Fe5Nb alloy and ECAPed IN 718 alloy than in the forged Ni20Cr20Fe5Nb alloy and IN 718 alloy before ECAP appeared to be due to the severe plastic deformation which occurred during mechanical alloying or ECAP.

Keywords : γ″precipitate, plastic deformation, mechanical alloying, ECAP, Ni-base alloy

1. Introduction

IN 718 alloy has been used for structural applications such as airplane components, nuclear power generators and industrial gas turbines[1,2]. This alloy is a wrought type Ni-based superalloy, whose strength is enhanced by the formation of γ′(Ni_3(Al, Ti)) and γ″(Ni_3Nb) precipitates[3]. However, the major contribution to the precipitation strengthening in this alloy is derived from the γ″precipitates, as the volume fraction of γ″ precipitates is four times larger than that of γ′ precipitates[4]. Through the addition of Ni, Cr, Fe, and Nb, which are the main chemical compositions of IN 718 alloy, Ni20Cr20Fe5Nb alloys were fabricated by forging or mechanical alloying. In this study, the influences of the severe plastic deformation which occurred during mechanical alloying or ECAP on the precipitation temperature of the γ″ phases were investigated by microstructural observation and the hardness test.

2. Experimental and Results

Table 1 shows the nominal and chemical compositions of alloys used in this study. In present study, four different alloys are hereafter referred to as Alloy 1, Alloy 2, Alloy 3 and Alloy 4, respectively. Alloy 1 is Ni20Cr20Fe5Nb alloy which was fabricated by forging at 1150℃ after casting by induction melting. Alloy 2 is Ni20Cr20Fe5Nb alloy fabricated by the mechanical alloying method. The mechanical alloying process was performed for 30 hrs in an attrition mill and the alloy powders were subsequently consolidated at 1100℃ by SPS(spark plasma sintering) with a holding time of 5min. Alloys 3 and 4 are commercial IN 718 alloy before and after ECAP (equal channel angular pressing), respectively. The ECAP mold had an intersecting angle of 135° (Φ=135°) and a curvature angle of 45° (Ψ=45°). The specimen used for ECAP was a bar with dimensions of 5mm x 5mm x 40mm. During each pass, the specimen was rotated by 90 degrees always in the same direction (route Bc) and this process was repeated for a total of 8 passes. The Vickers hardness was measured under a load of 200g for 15sec. OM and TEM observations were performed to compare the microstructures before and after the aging treatment. In order to compare the changes of the lattice strains during the mechanical alloying or ECAP process, the Williamson-Hall method was used[5].

Table 1. Nominal composition of Ni20Cr20Fe5Nb alloy and chemical composition of IN 718 alloy (wt.%).

Sample	Ni	Fe	Cr	Si	Mo	Co	Nb	Ti	Al	Mn	C
NCFN	Bal.	20.00	20.00				5.00				
IN 718	Bal.	18.20	17.76	0.07	3.01	0.35	5.21	1.01	0.43	0.07	0.02

Fig. 1 shows the changes in hardness of the four alloys before and after the aging treatment at 600℃ or 720℃. In comparing the hardness of the alloys with the same chemical composition, the hardnesses of the alloy fabricated by mechanical alloying and the alloy subjected to ECAP, viz. Alloy 2 and Alloy 4, respectively, were higher than those of the alloy that was forged and the alloy not subjected to ECAP, viz. Alloy 1 or Alloy 3, respectively. The hardnesses of Alloys 1 and 3 were not changed

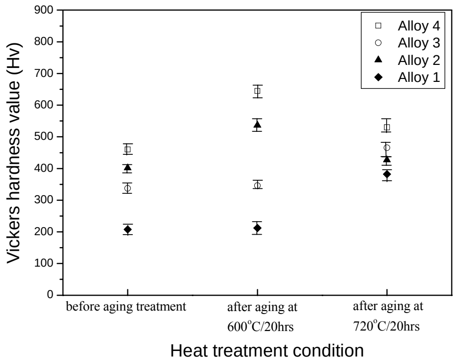

Fig. 1. Hardness changes of the four alloys before and after aging treatment.

significantly after aging at 600℃, but they were increased after aging at 720℃. However, the hardnesses of Alloys 2 and 4 were increased after aging at 600℃, while they were not significantly changed after aging at 720℃, as compared with those of the alloys before aging. Fig. 2 shows the TTT curve for IN 718 alloy. The aging condition for 20 hrs at 600℃(△2) is in the γ region, whereas the aging condition for 20 hrs at 720℃(○1) is in the region where γ″ can be formed[6]. Accordingly, it is thought that the increase in the hardness of Alloys 1 and 3 after aging at 720℃ was derived from the precipitation of γ″. However, it was noteworthy that the hardnesses of Alloys 2 and 4 were increased after aging at 600℃, even though the aging condition was not in the region where γ″ can be formed.

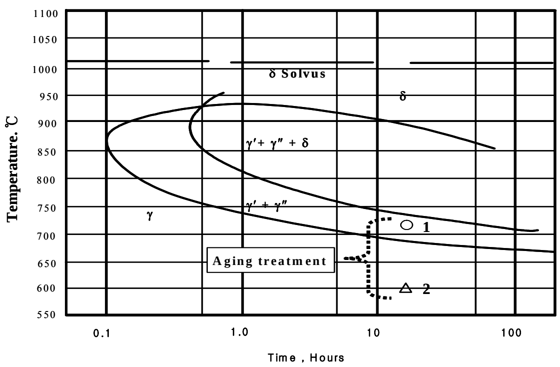

Fig. 2. Time Temperature Transformation Curve for IN 718 alloy[6].

The grain sizes of Alloys 1 and 3 were about 100 ㎛, and ultra-fine grains with sized of less than 200nm were observed in both Alloys 2 and 4, suggesting that the grains were refined due to severe plastic deformation during the mechanical alloying or ECAP process. Only γ (matrix) without γ″ was observed after aging at 600℃ of Alloys 1 and 3. However, the presence of γ″ precipitates was confirmed in the Alloys 2 and 4. Therefore, the increase in the hardnesses of Alloys 2 and 4 after aging at 600℃ could be attributed mainly to the formation of these γ″ precipitates. Consequently, it was found that the aging temperature for the formation of γ″ in Alloy 3 or 4 was lower than that in the forged alloy or IN 718 alloy before ECAP. After aging at 720℃, large amounts of γ″ precipitates were formed in Alloys 1 and 3, whereas δ(Ni_3Nb)precipitates were observed in Alloys 2 and 4. From these results, it was found that the precipitation behaviors of Alloys 1 and 3 coincided with the TTT curve, whereas those of Alloys 2 and 4 did not. It can be inferred from this that the temperatures required for precipitation in Alloys 2 and 4, which were fabricated by mechanical alloying and ECAP, respectively, were lowered compared to those of Alloys 1 and 3, which were fabricated without any plastic deformation occurring.

3. Summary

In the comparison of the precipitation behavior in Ni20Cr20Fe5Nb alloy fabricated by forging or mechanical alloying, and IN 718 alloy before and after ECAP, several significant results were obtained. The formation temperature of γ″ and δ precipitates in the mechanically alloyed Ni20Cr20Fe5Nb alloy was lower than that in the forged one. Moreover, the formation temperature of γ″ and δ precipitates in the IN 718 alloy was lower after 8 passes of ECAP than before ECAP. From the above results, it was found that the severe plastic deformation by mechanical alloying and ECAP lowered the formation temperature of the γ″ and δ precipitates.

4. References

1. D. Fournier and A. Pineu : Met. Trans. Vol. 8A (1977), p. 1095
2. R. P. Jewett and J. A. Halchak : Superalloy718, 625 and Various Derivatives., ed. E. A. Loria, TMS. (1991), p. 749
3. C. Slama and M. Abdellaoui : J. Alloy Compd. Vol. 306 (2000), p. 277
4. M. Sundararaman, P. Mukhopadhyay and S. Banarjee : Met. Trans. Vol. 19A (1988), p. 453
5. R. Vivekanandan and T. R. N. Kutty : Powder Technol. Vol. 57 (1989), p. 181
6. O. B. Armida, J. F. Radavich : Superalloy718, 625 and Various Derivatives., ed. E. A. Loria, TMS. (1991), p. 325
7. L. Zhenhua, C. Xianhua and S. G. Qianqian : Mater. Lett. Vol. 59 (2005), p. 705