

Ni₃Al Precipitation Behavior in the Two-Phase (NiAl+Ni₃Al) Alloy

Jong-Hoon Lee*, Sang-Yul Lee**, Zin-Hyung Lee***, and Hak-Min Kim*

*Material Engineering Department, Korea Institute of Machinery and Metals, KyungNam, Korea, **Department of Materials Engineering, Hankuk Aviation University, KyungKiDo, Korea, ***Department of Materials Engineering, Korea Advanced Institute of Science and Technology, DaeJeon, Korea

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ABSTRACT

The toughness of brittle intermetallics has been improved by controlling the morphologies of the Ni₃Al through the solution and aging treatment in (NiAl+Ni₃Al) two-phase alloy. In this study, changes in the Ni₃Al morphologies were attempted through variation of the heat treatment conditions. The microstructure was examined using optical and scanning electron microscopy and the phase was characterized by X-ray diffraction analysis. Our results indicated that the precipitation of the homogeneous and randomly-oriented Ni₃Al during the final aging treatment could be made possible by performing an isothermal transformation of NiAl- (B2) to Ni₅Al₃ single phase prior to the final aging treatment in Ni-34at.%Al alloy.

1. INTRODUCTION

Since polycrystalline NiAl alloy exhibits extreme brittleness at room temperature /1/, extensive works by many investigators have been focused on the improvement of toughness of polycrystalline NiAl alloy by second phase reinforcement /2,3/. Improvement in the fracture toughness in Ni-36at.%Al alloy through the precipitation of rod-type Ni₃Al in over-saturated NiAl- (B2) phase was reported by Russell *et al.* /4/. In their work a series of heat-treatments involving a solution treatment at 1300°C, quenching into a fluidized bed at 430°C for 2 min, and then up-quenching to the aging temperature of 875°C were performed to avoid the formation of the martensite. Also, Ochiai *et al.* /5,6/

have found the superplasticity in the two-phase (NiAl+Ni₃Al) alloy which showed the lamellar microstructure formed by the conventional quenching from the solution treatment temperature and aging treatment /5/.

In this study, the microstructural variations in the Ni-34at.%Al alloy by solution and aging treatment have been investigated.

2. EXPERIMENTAL

Ni-34at.%Al alloys were prepared by a vacuum arc melting process. All specimens were cut into 30×50×10 mm³ size and were heat-treated with three different cycles, as described below;

Cycle A: Solution treatment at 1300°C for 14 hr/water quenching + aging at 800°C for 20 hr

Cycle B: Solution treatment at 1300°C for 14 hr/forced air cooling + aging at 800°C for 20 hr

Cycle C: Solution treatment at 1300°C for 14 hr/quenching into a salt bath at 530°C for 5 hr + aging at 800°C for 20 hr

The microstructure was examined using optical microscopy and SEM and the phases were characterized by the X-ray diffraction.

3. RESULTS AND DISCUSSION

The Ni-34at.%Al alloy was found to be completely transformed into NiAl- phase by the solution treatment

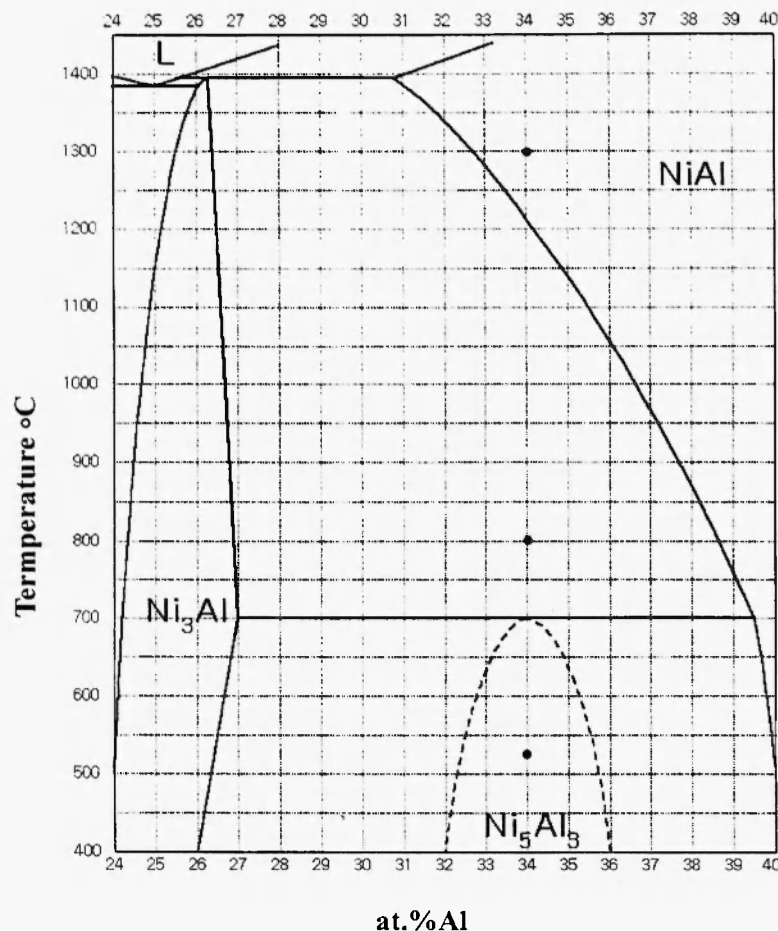


Fig. 1: Ni-Al phase diagram

at 1300°C, as shown in Fig. 1. Following the heat treatment cycle A, quenching from the solution treatment temperature made the NiAl- phase (B2 structure) transform into martensite completely, as shown in Fig 2(a). On subsequent aging at 800°C the martensite transformed into the lamellar structure of NiAl and Ni₃Al by precipitating Ni₃Al in the relatively coarse and lath-like martensite plates (see Fig 2(b)).

By following the heat treatment cycle B, a different microstructure resulted. As the alloy was cooled from the solution temperature by the forced air cooling method, the randomly-oriented fine martensite plates and some Ni₃Al precipitated during cooling were observed as shown in Fig 2(c). Fig. 2(d) shows the microstructure after the aging treatment. The Ni₃Al precipitates with homogeneous distribution and random orientation, relevant to the previous martensite

morphology, were observed at the subsequent aging treatment and some coarse Ni₃Al precipitated during the cooling from the solution temperature was also found in cycle B. This result indicated that the morphology and distribution of Ni₃Al precipitates on subsequent aging treatment were strongly dependent upon the previous martensite morphology which was decided by the cooling rate from the solution treatment.

A microstructure similar to Fig. 2(d) using a different heat treatment process was reported by Russell *et al.* [4]. In their work, in order to suppress the martensite transformation of the solution-treated NiAl-phase, the Ni-36at.%Al alloy was quenched into the fluidized bed at 430°C for 2 min, inducing the formation of the over-saturated NiAl- matrix. The precipitation of the rod type Ni₃Al occurred from this over-saturated NiAl- matrix on the subsequent aging treatment at the

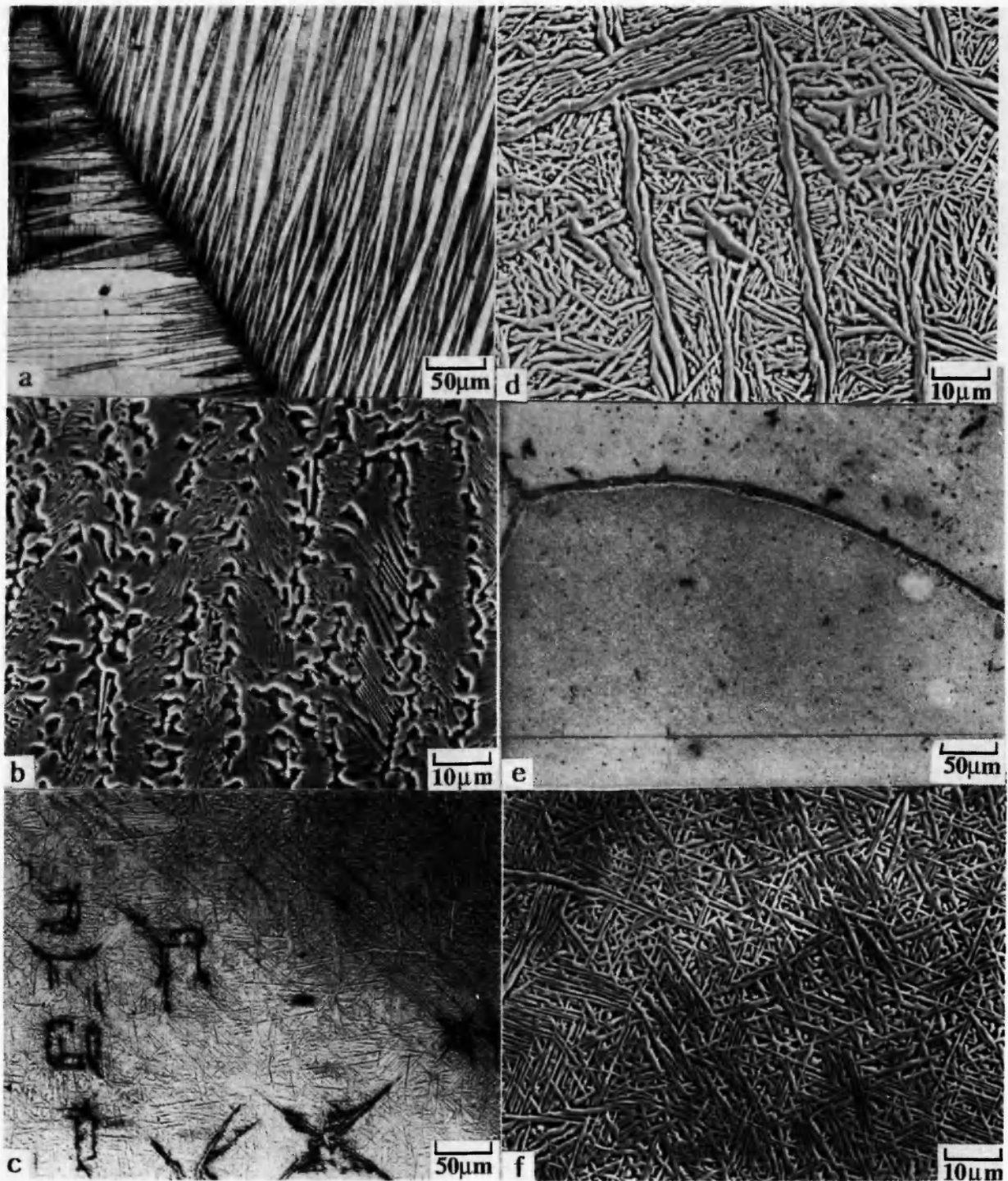


Fig. 2: Microstructure of Ni-34at.%Al alloy after the heat treatment at
 (a) 1300°C/14hr/W.Q/
 (b) 1300°C/14hr/W.Q + 800°C/20hr/A.C
 (c) 1300°C/14hr/F.A.C
 (d) 1300°C/14hr/F.A.C + 800°C/20hr/A.C
 (e) 1300°C/14hr 530°C/5hr/W.Q
 (f) 1300°C/14hr 530°C/5hr/W.Q + 800°C/20hr/A.C

up-quenched temperature of 875°C

According to the heat treatment cycle C, Ni-34at.%Al alloys were solution-treated and quenched into a salt bath at 530°C, which is above the *M_s* temperature of this alloy [6], and then were held isothermally for 5 hr to avoid the martensite transformation. After the isothermal transformation at 530°C for 5 hr and water quenching, a single phase without the precipitation of Ni₃Al was observed, as shown in Fig 2(e), and the X-ray diffraction results in Fig 3 showed that this phase was Ni₅Al₃ phase. The formation of the Ni₅Al₃ phase after the isothermal treatment at 530°C is expected from the equilibrium phase diagram in Fig. 1. As this Ni₅Al₃ single phase was aged at 800°C, the homogeneous and randomly-oriented precipitates of Ni₃Al appeared in the transformed NiAl matrix, as shown in Fig 2(f). The morphology of the Ni₃Al precipitates formed from the heat treatment cycle C was generally similar to that from the B cycle, but the coarse Ni₃Al precipitates, which were often observed in the B cycle, were not found in the C cycle.

The phase transformations with three different heat-treatment cycles in Ni-34at.%Al alloy could be clearly understood through the schematic continuous cooling transformation curve as shown in Fig 4. The A cycle is thought to be a typical heat treatment process

for the precipitation of the lamellar Ni₃Al phase in the martensitic-transformed NiAl with coarse plates after the final aging treatment. The B cycle is principally similar to the A cycle but the cooling rate of the B cycle seems relatively slower than that of the A cycle. Therefore, in the case of the B cycle, the coarse rod-shaped Ni₃Al is expected to precipitate partially in the NiAl- matrix during the cooling from solution treatment temperature and the remainder of the NiAl-phase transformed to the martensite, showing the morphology of the fine and randomly oriented plates in comparison with that from the A cycle. On further aging treatment, Ni₃Al phases precipitated in these fine martensite plates, resulting in a mixture of the coarse and fine precipitates of Ni₃Al. On the other hand, during the heat treatment cycle C, the isothermal transformation process was performed slightly over the *M_s* temperature to obtain the Ni₅Al₃ single phase without martensite formation. When the Ni₅Al₃ single phase was aged at 800°C Ni₃Al precipitates generally similar to that from the heat treatment cycle B were obtained. However, the coarse precipitates of Ni₃Al, which were often found in the heat treatment cycle B, were not found in the heat treatment cycle C. Therefore, it is noted that the precipitation of the homogeneous and randomly-oriented Ni₃Al during the final aging

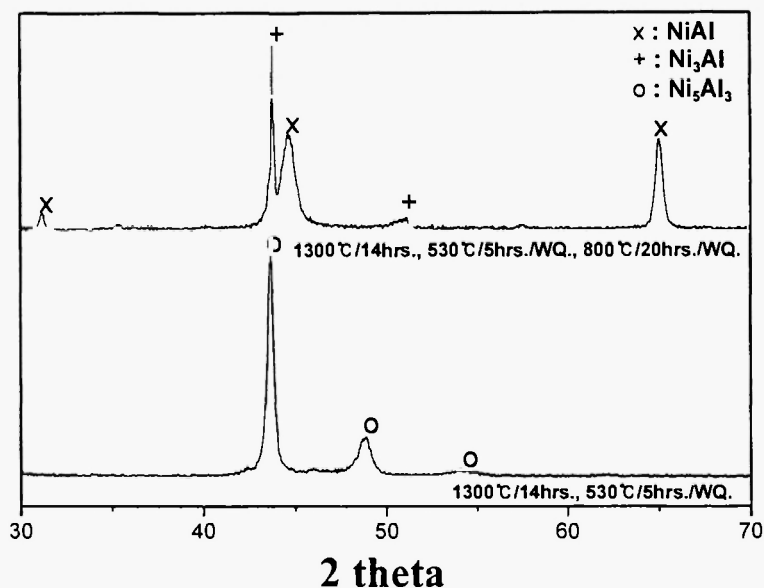


Fig. 3: Results from X-ray diffraction analysis on the Ni-34at.%Al alloy after solution treatment at 1300°C for 14 hr and quenching into a salt bath at 530°C for 5 hr

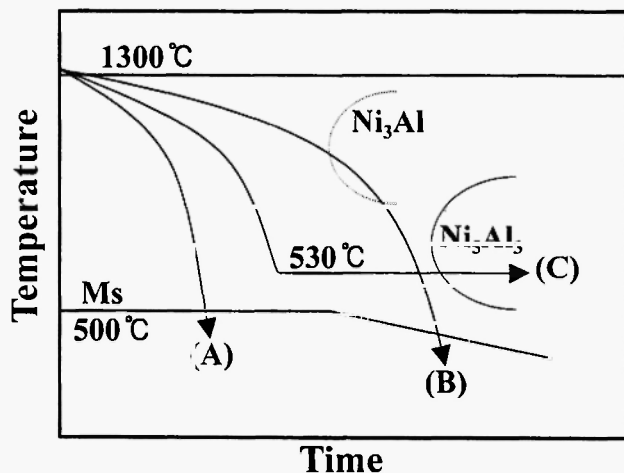


Fig. 4: Schematic illustration of continuous cooling transformation curve showing the three different heat treatment cycles

treatment could be feasible by performing an isothermal transformation of NiAl- to Ni_5Al_3 single phase prior to the final aging treatment.

3. CONCLUSIONS

In Ni-34at.%Al alloy, the martensitic morphologies of NiAl phase were affected by the cooling rate from

solution treatment temperature and, subsequently the morphologies of Ni_3Al precipitates during the aging treatment were also varied accordingly.

The NiAl- phase transformed to the Ni_5Al_3 single phase by the isothermal treatment at 530°C after quenching into a salt bath from the solution treatment temperature at 1300°C and, the homogeneous and randomly-oriented precipitates of Ni_3Al with the needle-like shape could be obtained by the aging treatment of the Ni_5Al_3 single phase at 800°C . Improvement of toughness of the (NiAl+ Ni_3Al) intermetallics was expected from this morphological variation of the Ni_3Al phase.

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