EFFECT OF MICROSTRUCTURE ON MECHANICAL PROPERTIES OF INCONEL 718 ALLOY

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Synopsis

By conducting a material test using Inconel 718 materials different in microstructure, an effect of microstructure difference on mechanical properties was investigated. In addition, re-solution heat treatment was applied, and change of the microstructure and precipitates was observed. The test was made using materials having a laminar and a uniform grained microstructure. In a high temperature tension and a high temperature hardness test, marked difference was not observed. In a fatigue test, the uniform grained material showed somewhat preferable value at low cycle side. In a impact test, the uniform grained material showed about three times as much value as that of the laminar material, showing significant difference. As a result of precipitate analysis, it was shown that large-sized angular precipitates were carbide or nitride, and small-sized round precipitates were δ or Laves phase. Besides, though due to application of re-solution heat treatment, grain growth and some disappearance of small-sized precipitates occurred, segregation of composition itself hardly improved.

1. Introduction

Since Inconel 718 has favorable strength up to high temperature and excellent corrosion resistance, it is used for a wide range of application such as rocket engines, springs in fuel assemblies, etc. However, owing to manufacturing difficulty, a microstructure in delivered materials varied widely, and a noticeable laminar microstructure was found in some heat lots.

Therefore, from viewpoints of quality, it is necessary to make clear the relationship between microstructures and mechanical properties. In this report, difference in mechanical properties caused by difference in microstructures was investigated by conducting a high temperature tension test, a high temperature hardness test, an impact test, a fatigue test and precipitate analysis by SEM, EPMA, AES, AEM and EDS. Change of microstructures and precipitates due to re-solution heat treatment was also studied.

2. Experimental method

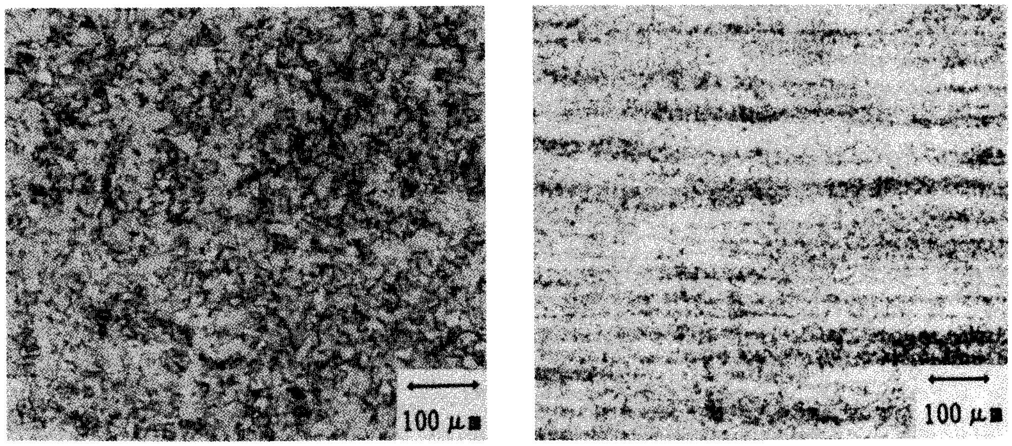
2.1 Specimens

Chemical composition and microstructure photos of Inconel 718 used in this investigation are shown in Table 1 and Fig. 1, respectively. As regards a mechanical properties test, comparison was made using materials having a laminar and a uniform grained microstructure. AMS 5596C[1)] is used as a standard for quality of Inconel 718 plate.

Specimens provided for a mechanical property test were taken out in a rolling direction from 200mm × 23mm × 4mm plate on which aging treatment had been applied.

Table 1 Chemical composition

	C	Si	Mn	P	S	Ni + Co	Cr	Mo	B	Co	Cu	Al	Ti	Nb + Ta	Fe
Uniform	.03	.18	.11	.008	.001	54.03	18.35	2.99	.002	.03	.06	.43	1.00	4.95	Bal.
Laminer	.04	.30	.13	.013	.003	52.98	18.33	3.08	.002	.22	.21	.62	.92	5.19	Bal.



Uniform Laminer

Fig.1 Microstructure Photos.

2.2 Mechanical property test

(1) Tension test

Measurement is made at a room temperature, 350℃ and 600℃, using a 5t－tension tester with 800℃ max. electric furnace.

(2) Hardness test

Measurement is made at a room temperature, 300℃, 500℃, and 650℃, using a 10kgf－Vickers hardness tester with 1,200℃ max. high temperature furnace,

(3) Impact test

Measurement is made at a room temperature, using a 30kgf.m Charpy impact tester.

(4) Fatigue test

Measurement is made at a room temperature, using a 5t servotype fatigue tester. Fatigue cycles are applied and effected by 4 points bending－double deflection. Smooth surface and notched specimens are provided.

Number of cycles : 10^6 (max)

Rate of cycles : 120－240 c.p.m.

2.3 Precipitate analysis

Qualitative analysis is made on precipitates by Electron Probe Micro Analyzer (EPMA), Auges electron Microscope (AES), Analytical Electron Micoroscope (AEM) and Energy Dispersive Spectroscopy (EDS) observation, after Scanning Electron Microscope (SEM) observation.

2.4 Re－solution heat treatment test

Using 3 kinds of materials having different microstructure with each other, re－solution heat treatment of 954℃×1 hr and 1,000℃×1 hr is carried out, and then microstructure observation and SEM & Energy Dispersive Spectroscopy (BEI) analysis are carried out.

3. Results and discussion

3.1 Mechanical property test

(1) Tension test

In Fig. 2, tensile strength, yield strength and elongation measured at each temperature are shown. Though the difference between both test materials is hardly seen at room temperature and 350℃, tensile strength of laminar material becomes lower at 650℃ than uniform material. However, this discrepancy falls within allowable range (ASTM 596C), it cannot be said to be significant.

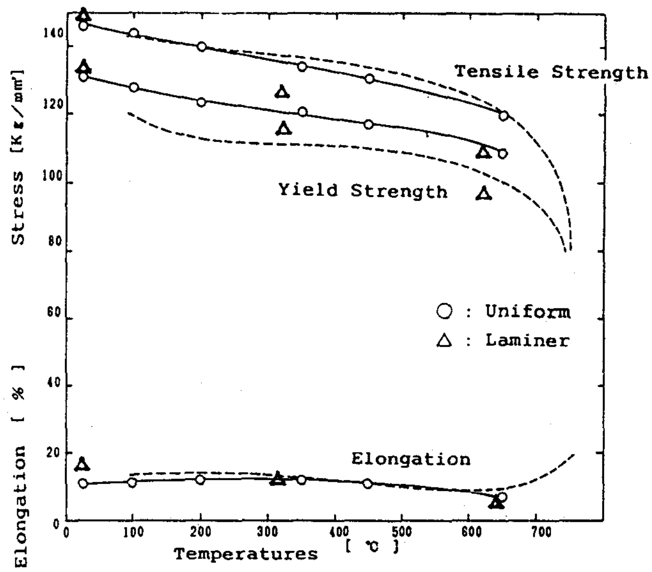


Fig. 2 High temperature tension test result.
Dotted line extracted from Huntington alloys company's data [2)]

(2) Hardness test

Fig. 3 shows the results of high temperature hardness test. Approximately the same value is shown by both uniform and laminar materials. Hardness on the laminar zones with and without fine precipitates was measured using a micro－Vickers hardness tester. The value on the laminar zone with fine precipitates was 1.3～1.5 times higher than that of precipitates－free zone.

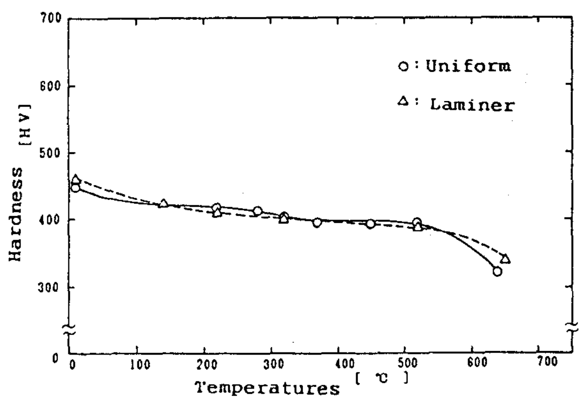


Fig.3 Hardness - Temperatures curves.

(3) Impact test

Measured value is listed in Table 2. In aging heat treated condition, the uniform material showed around 4 times higher value than that of the laminar material. And in solution heat treated condition, the uniform material showed around 3 times higher value. From these results, it is suggested that this difference in impact value arises not from aging heat treatment, but from difference between materials, that is, difference in microstructures.
When measurement was made on specimens sampled in a transverse direction, around 6 times difference was detected between the laminar and the uniform material in solution heat treated condition (Table 3).

Table 2 Charpy impact test results.

Impact Value : (kgfm/cm²)

		Solution heat treated		Aging heat treated	
Sampling direction \ Sample		Uniform	Laminer	Uniform	Laminer
Rolling direction	No. 1	20. 4	7. 5	8. 2	2. 0
	No. 2	20. 1	7. 2	8. 1	2. 1
	No. 3	20. 9	7. 4	8. 2	2. 7
	No. 4	20. 8	7. 3	8. 2	2. 6
	No. 5	20. 8	7. 7	8. 1	2. 0
	Average	20. 6	7. 4	8. 2	2. 3

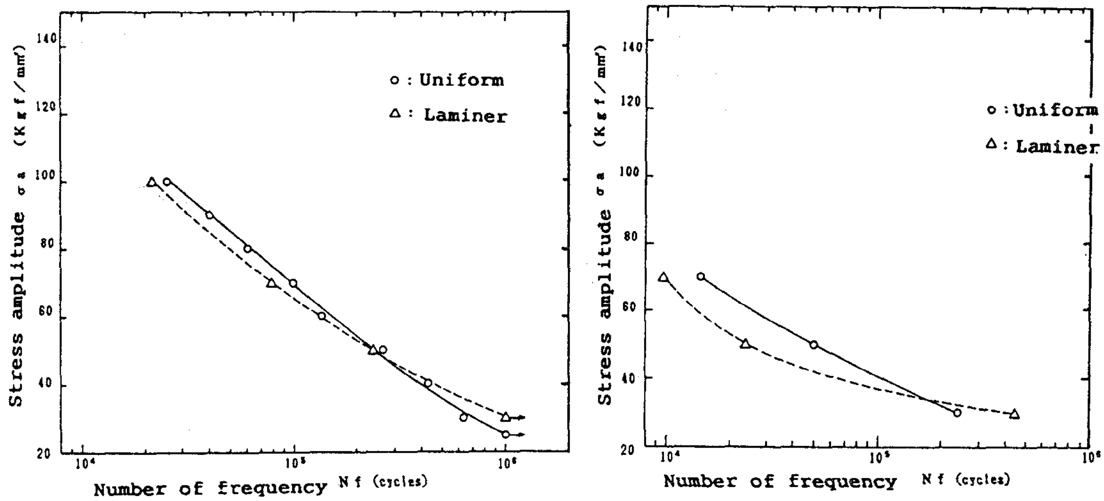
Table 3 Charpy impact test results.

Impact Value : (kgfm/cm²)

		Solution heat treated		Aging heat treated	
Sampling direction \ Sample		Uniform	Laminer	Uniform	Laminer
Trans verse direction	No. 1	16. 8	2. 6	6. -1	2. 0
	No. 2	16. 5	2. 6	6. 3	1. 9
	Average	16. 7	2. 6	6. 2	2. 0

(4) Fatigue test

Results on smooth and notched specimens are shown in Fig. 4 (a) and 4 (b), respectively. Though uniform material shows somewhat good tendency at low cycle side, difference between both materials is hardly seen at 2×10^6 cycles or more.

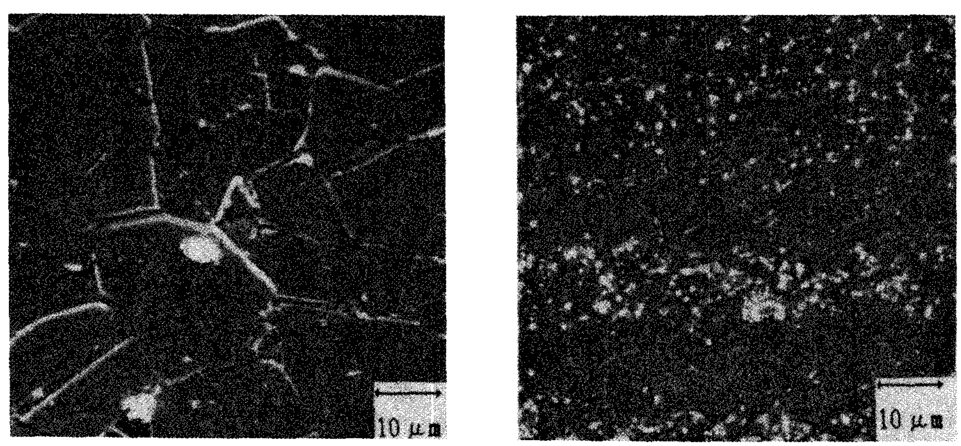


(a) Smooth specimen (b) Notched specimen

Fig. 4 Fatigue test results

3.2 Precipitate analysis

The analysis was made on materials chemically etched (by HCl $+HNO_3+CuCl_2$) after buff polising. SEM photos of respective material are shown in Fig. 5. It is learned that in the uniform mateial, large-sized angular precipitates are found sporadically and in the laminar material, small-sized precipitates with around μm in size is distributed in band-like besides the large-sized angular precipitates.



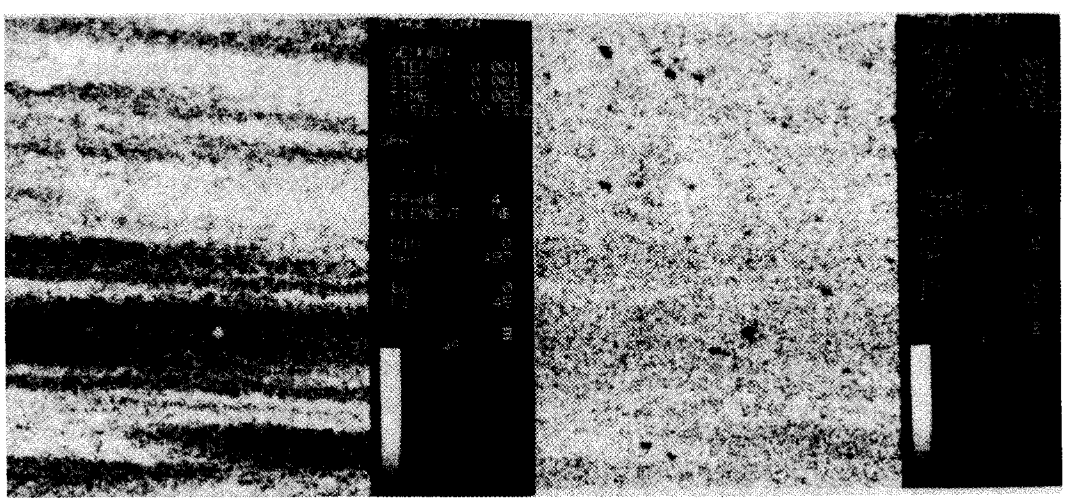
Uniform Laminer

Fig.5 SEM photos

These large-and small-sized precipitates were analyzed by use of EPMA, AES, AEM and EDS methods. It was shown that the large-sized precipitates were carbide or nitride composed of Nb, Ti (C, N), and the small-sized precipitates were Fe_2Ti type Laves or δ phase (seen Table 4.). When macroscopic analysis was made by a mapping analyzer, band-like segregation of Nb and Mo was measured (seen Fig. 6). In case of laminar material, it is supposed that grain growth was obstructed due to segregation of small-sized precipitates, resulting in formation of laminar microstructure.

Table 4. Chemical compound supposed from measurement results

Company	Measuring machinery	Small-sized precipitates	Large-sized precipitates
NFI	EPMA	Mo much contained (Laves phase containing Mo)	Ti, Nb much contained (nitride of Ti and Nb)
Toray	AES	Approximately the same as matrix	Nb and C much contained (carbide of Nb)
B&W [3]	AEM	Fe_2Ti type Laves phase	CaS prominent
	EDS	The same as in AEM	NbC, TiC
	EPMA	Nb and Mo much contained, Fe and Cr less contained (only compared to matrix)	



Nb Mo

Fig.6 Mapping analyzer photos.

3.3 Re－solution heat treatment test

By applying re－solution heat treatment of 954℃ (recommended in ASTM 5596C) and 1,000℃×1 hr on 3 kinds of materials having different microstructures, change of microstructures and precipitates was investigated. Relations between the microstructure and the composition were analyzed by observing BEI. The results are summarized Fig. 7.

At 954℃, their change was hardly found, but at 1,000℃ grain growth and some disappearance of small sized precipitate were shown. According to Keisen et al.,[4] it is said that δ phase dissolves at from 982℃ to 1,038℃, and Laves phase does not dissolve up to 1,093℃. In addition, Muzyka et al.[5] reported that the δ phase is dominant under temperatures of 982℃ or less and cause to suppress the grain growth of 718 alloy. These shows that these small－sized precipitates have higher possibility to be δ phase. However, it is shown by BEI that while grain growth and disappearance of precipitates occur, composition segregation hardly improves. In order to improve this segregation, it seems to be necessary that re－solution heat treatment temperature is raised higher or its treatment time is made longer.

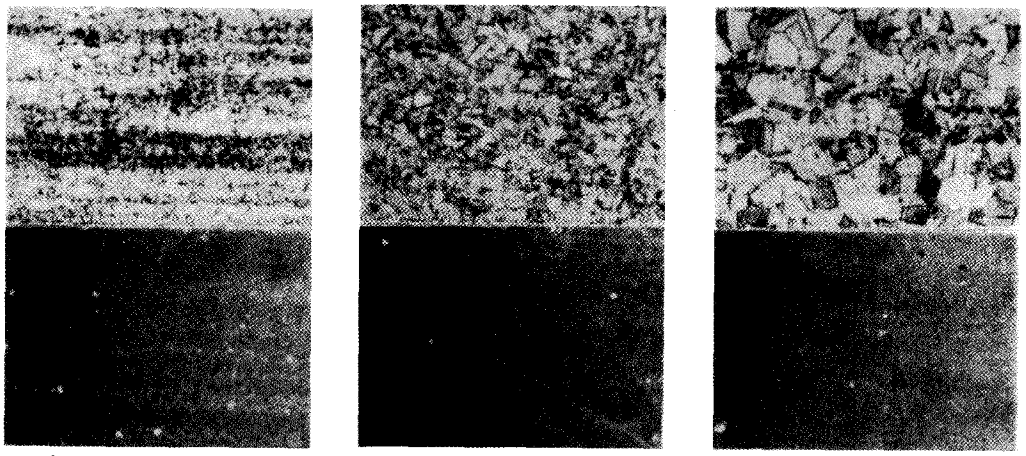
4. Summary

We have investigated relationship between microstructures and mechanical properties of Inconel 718, and obtained the follwings.

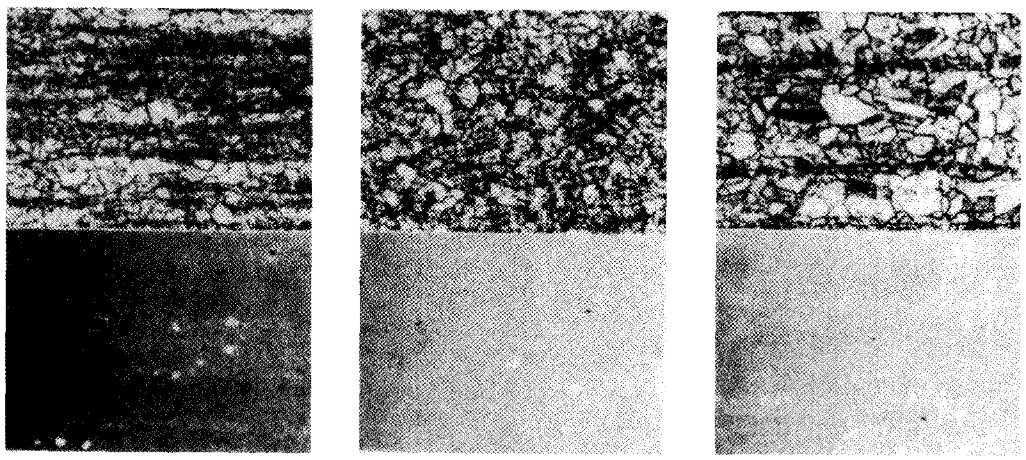
(1) Difference of mechanical properties between a laminar and a uniform microstructure is not made clear by a tension, a hardness and a fatigue test, but its significant difference can be obtained by an impact test.

(2) According to precipitate analysis, it can be considered the grain growth of the laminar materials was controlled by small precipitates as Laves or δ phase.

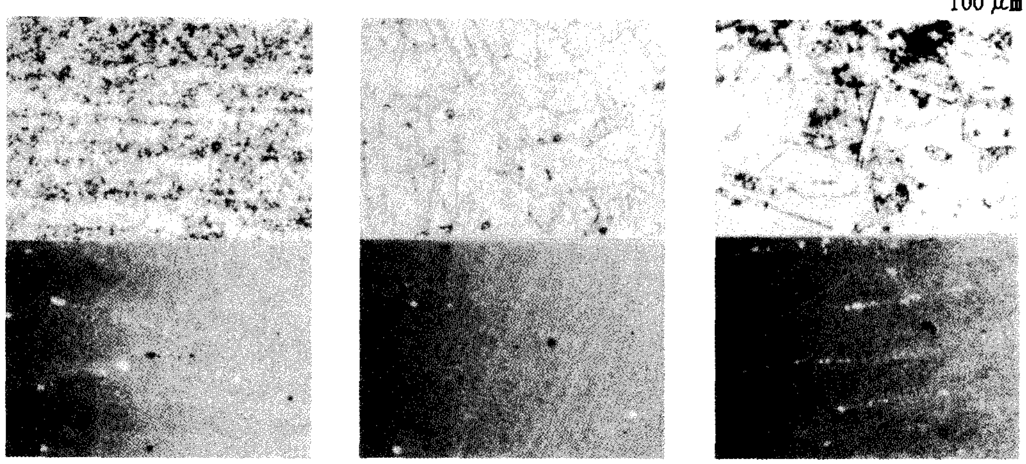
(3) By application of 1,000℃×1 hr re－solution heat treatment, though grain growth and disappearance of small－sized precipitates occur, composition segregation is not improved.



Solution heat treated　　100 μm



Re − solution heat treated at 954℃　　100 μm



Re − solution heat treated at 1,000℃　　100 μm

Laminar　　Uniform　　Semi uniform

Fig. 7　Photos on microstructural change caused by re − solution heat treated.

Upper side : metallograph.　Lower side : BEI

References

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3. L. W. Sarver, Babcock & Wilcox a Mcdermott Company Alliance Research Center letter report.

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5. D. R. Muzyka and G. N. Maniar, " Effects of solution Treating Temperature and Microstructure on the Properties of Hot Rolled 718 Alloy ", Metal Eng. Quar., 9, 4 (November 1969), pp23~26.