

# EFFECT OF STANDARD HEAT TREATMENT ON TENSILE AND CREEP PROPERTIES OF INCONEL 718

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## Abstract

The effect of standard heat treatment on tensile and creep properties of nickel-base superalloy, Inconel 718 was investigated. Solution treatment was applied on the as-received material at 980°C for 1 hour before water quenched followed by double aging treatments at 720°C and 621°C for 8 hours, respectively and then cooled in air. Standard heat treatment was significantly improved the tensile strength and creep rupture properties. However, the ductility of heat treated material drastically reduced compared to the as-received material. Precipitations of gamma prime ( $\gamma'$ ), gamma double prime ( $\gamma''$ ) and long needle-like delta ( $\delta$ ) phase observed preferably at the grain boundary and transgranular which restricted the grain growth and block grain boundary sliding are believed to be the reasons for increase in mechanical properties of Inconel 718.

**Keywords:** Heat treatment, tensile, creep, precipitation, Inconel 718

## 1. Introduction

Nickel-based superalloy is one of the most promising high temperature strength materials for extreme condition of high temperature and stress applications [1]. Some of examples nickel-based superalloy are Nimonic, Udimet, Waspaloy, Astroloy, Hastelloy and Inconel. They have been used in variety of industries such as aerospace, chemical processing, marine engineering, nuclear reactor, etc. Among them Inconel is the most popular material and has many grades depend on the applications such as Inconel 738 and Inconel 718. Besides retaining its mechanical strength under high temperature conditions, the advantages of these alloys are resistant to thermal fatigue, oxidation and corrosion, and forging and brazing ability [2]. Inconel 738 is commonly used for turbine blade in power generation and design to operate at temperature of about 1000°C. The application of Inconel 718 is focused on the turbine disc of steam turbine power generation that operates at much lower temperature than that of Inconel 738. The strength of nickel-based superalloys is promoted by the precipitation of secondary phases (e.g. gamma prime and double-prime) into the metal matrix through the heat treatment process. The most commonly applied heat treatment for Inconel is standard heat treatment process. However, most of the studies of the effect of precipitation of secondary phases were focused on Inconel 738. Therefore, in this study, the effect of standard heat treatment processes for nickel-based superalloys i.e. the solid solution treatment and aging processes on tensile and creep properties of Inconel 718 were investigated.

## 2. Experimental

The nickel-base superalloy used in this study was a 105 cm diameter round bar billet Inconel 718. The chemical composition of the material used is shown in Table 1. The specimens for tensile and creep tests were prepared according to the ASTM E8M-08 standard [3]. The specimen with the details of its geometry is presented in Fig. 1 with 3 mm thickness. To compared the as received and precipitation hardened materials, the standard heat treatment process was introduced to the samples. Samples were annealed at 980°C for 1 hour before quenched in water. Samples were then gone through double aging treatment process at 720°C and 621°C for 8 hours, respectively. Finally, the samples were cooled in air until reached room temperature. The schematic diagram of the standard heat treatment process is shown in Fig. 2.

Table 1. Composition of Inconel 718.

Element	Ni	C	Fe	Cr	Cu	Mo	Co	Mn	Al	Nb	Ti	Si
%	55.83	0.033	15.507	17.58	0.0293	3.522	0.238	0.005	1.032	5.189	1.1033	0.08

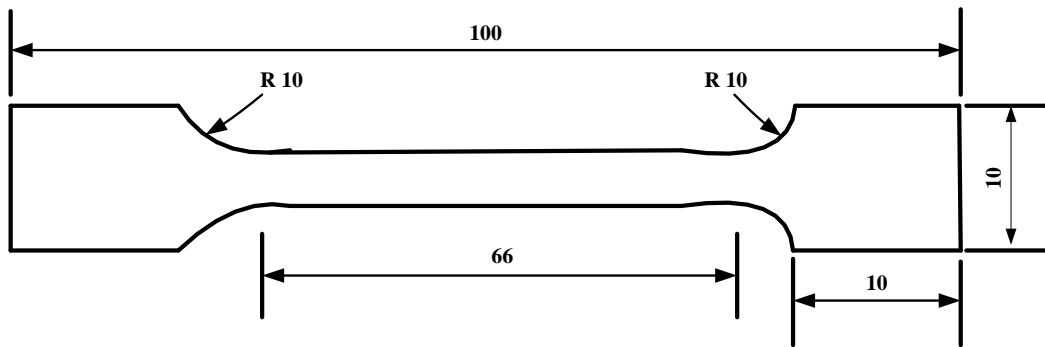


Figure 1: Test specimen dimension (in mm).

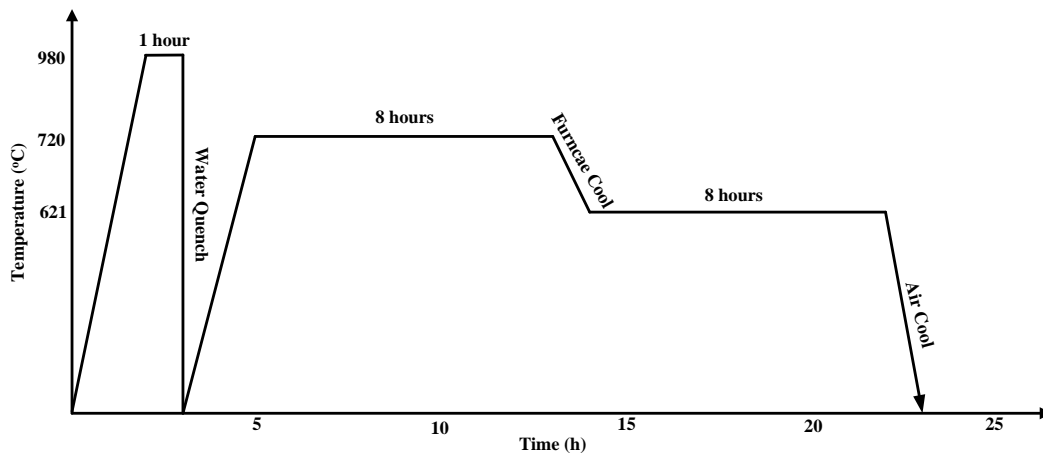


Figure 2: Heat treatment scheme.

Metallographic sections were prepared using standard mechanical polishing procedure. Samples were then etched using Kalling reagent no. 2 with 5 gram  $\text{CuCl}_2$ , 100 ml hydrochloric acid and 100 ml ethanol. The morphology characterization was studied by means of optical microscopy. Before tensile and creep tests were performed, the effect of standard heat treatment on hardness was investigated using Rockwell hardness tester. Ten points were measured for each sample and the average was taken as the representative hardness of the material before and after heat treatment. Tensile properties of Inconel 718 were investigated in accordance to ASTM standards E21-05 [4]. The tests were performed at room and elevated temperature of  $550^\circ\text{C}$  and  $650^\circ\text{C}$ , respectively. Several creep tests on heat treated samples were performed at different temperatures and stress levels according to ASTM E139 standard [5]. The creep tests were performed at elevated temperatures of  $550^\circ\text{C}$  and  $650^\circ\text{C}$  (half of melting temperature). The test load was determined from the previous tensile test results. The test load was decided to be 70% of the ultimate tensile strength at the above test temperatures. To determine the effect of load level on the creep properties of Inconel 718, 90% load of ultimate tensile strength was performed at  $650^\circ\text{C}$ . Creep curves (strain vs. time) were plotted for comparison. All the mentioned tests were carried out using a computer-controlled universal testing machine Zwick/Roell Z030 (30 kN) equipped with a high-temperature furnace Maytec HTO-08/1 ( $1000^\circ\text{C}$ ) and a high-temperature extensometer Maytec LVDT.

### 3. Results and Discussion

#### 3.1 Microstructures

The microstructure of the as received and heat treated are shown in Fig. 3. Microstructure of Inconel 718 shows that carbides and needle-like  $\delta$  phase present in both conditions. Carbides in the as received samples were distributed evenly throughout its matrix and along grain boundary but in the heat treated samples it becomes accumulated and increased in size. Similar observation results were obtained by C. M. Kuo et. al. for Inconel 718 [2]. There was no sign of  $\gamma'$  and  $\gamma''$  precipitates in the as received materials. However the heat treated sample showed some precipitations of  $\gamma'$  and  $\gamma''$  deposited at grain boundary. A needle-like structure ( $\delta$  phase) were observed precipitated near the grain boundaries. It is believed that the present of the precipitates restrict the grain boundary movement, sliding and control grain growth. The average grain size for the as received was 28.5  $\mu\text{m}$ . After the heat treatment the average grain size reduced to 16.2  $\mu\text{m}$ .

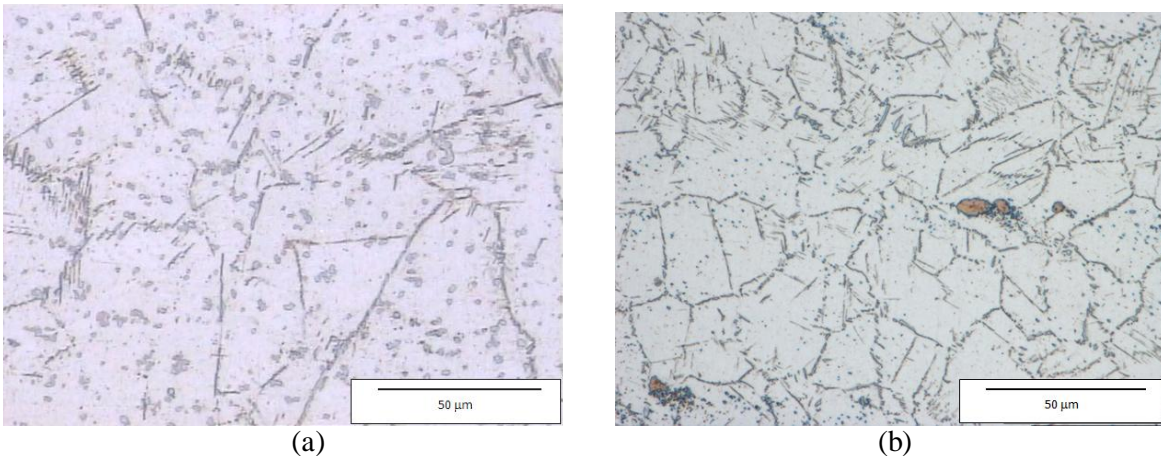


Figure 3: Microstructure of Inconel 718 by optical microscopy. (a) as received, (b) heat treated.

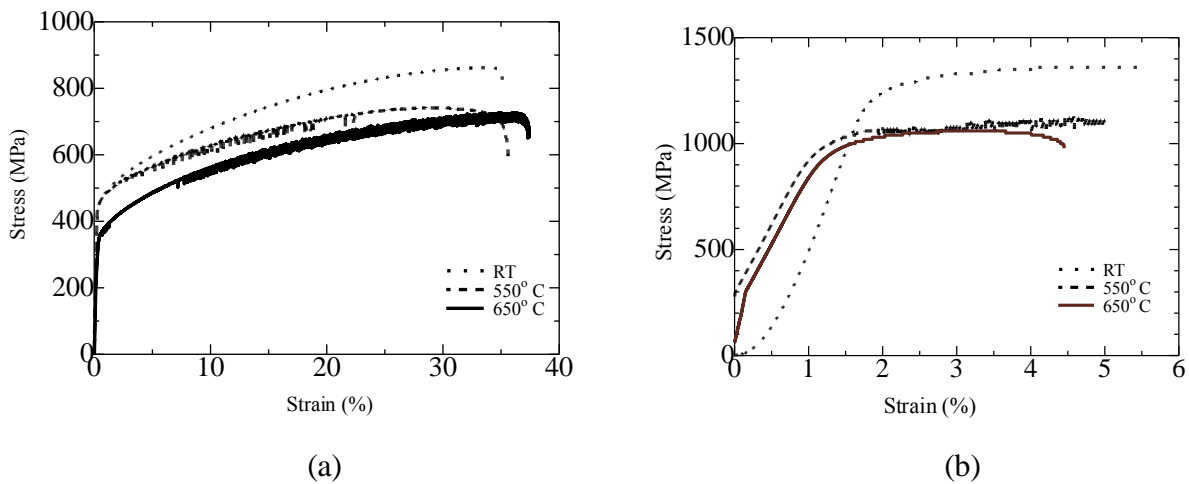


Figure 4: Effect of temperature on the stress–strain behaviour of the tension specimens (a) as received, (b) heat treated.

#### 3.2. Hardness

The hardness for the as received and heat treated Inconel 718 was HRB 100 and 113, respectively. From the result it shows that the hardness was increased by the standard heat treatment. It is believed that the increased in hardness was due to precipitation of  $\gamma'$ ,  $\gamma''$  and  $\delta$  phase in the heat treated sample. The refinement of grain size was also a probable reason for the increase in hardness.

### 3.3. Tensile properties

Figure 4 shows the stress-strain diagrams of the as received and heat treated Inconel 718 at different temperature levels. The figure shows that both samples demonstrated the highest strength at room temperature. However, the heat treated material showed a superior strength compared to that of the as received material. The tensile strength at elevated temperatures of 550°C and 650°C were slightly deteriorated for both materials. Beside strength, significant difference was observed in the elongation. The elongation of heat treated samples drastically reduced to 4 to 5% only compared to that of the as received materials which exhibited more than 30% elongation. The significant increased in tensile strength is suspected due to the present of  $\gamma'$ ,  $\gamma''$  and  $\delta$  precipitates which pinned the movement of grain boundary and sliding. However, the present of these precipitates caused the material to become harder and brittle. The tensile properties of tested Inconel 718 are summarized in Table 2.

### 3.4. Creep tests

Figure 5 shows the creep curves of standard heat treated Inconel 718 at 550°C and 650°C and at 70% and 90% load level of ultimate tensile strength. The result showed that the creep rate for 550°C-70% UTS was the lowest compared to the other two conditions. The increase in temperature to 650°C increased significantly the second stage creep rate from  $7.95 \times 10^{-9} \text{ s}^{-1}$  to  $2.1 \times 10^{-7} \text{ s}^{-1}$ . Moreover, the increase in load from 70% to 90% UTS significantly accelerated the creep rate at 650°C. The 650°C-90% UTS samples fracture only after 44 minutes of test.

Table 2: Mechanical properties of Inconel 718 at various temperatures

	Temperature	Yield stress $\sigma_{0.2}$ (MPa)	Ultimate tensile strength $\sigma_{uts}$ (MPa)	Elongation $\epsilon$ (%)
As received	RT	456	862	35.2
	550°C	454	739	36.4
	650°C	358	727	37.6
Heat treated	RT	1240	1360	5.5
	550°C	508	1140	5.1
	650°C	498	1060	4.4

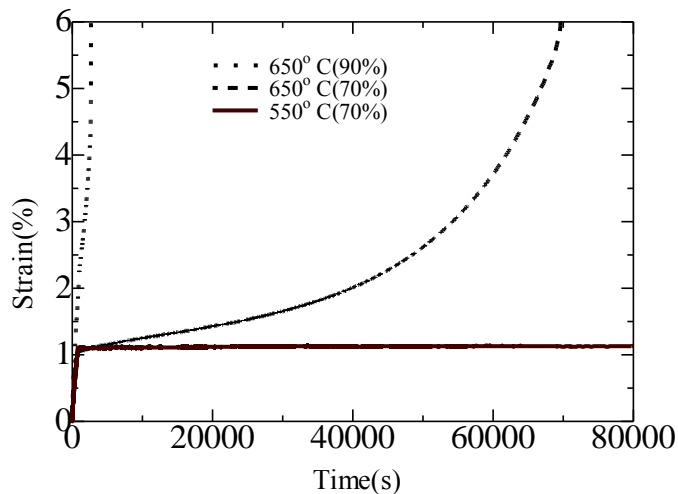


Figure 5: Creep tests at different load and temperature for heat treated.

#### 4. Conclusion

Based on the results the following conclusions were made:

1. Standard heat treatment precipitates  $\gamma'$ ,  $\gamma''$  and  $\delta$  phase in the matrix of Inconel 718.
2. Second phase precipitates were responsible for the increased in tensile strength but reduced the ductility of heat treated Inconel 718.
3. Increased in temperature to above half of melting temperature increased the creep rate and further accelerated by the increased in load applied.

#### 5. Acknowledgement

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