

## Creep Behavior of the Inconel 718 Superalloy

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**Keywords:** Inconel 718, creep, microstructural characterization.

**Abstract.** A superalloy is an alloy developed for elevated temperature service, where relatively severe mechanical stressing is encountered, and where high surface stability is frequently required. High temperature deformation of Ni-base superalloys is very important since the blades and discs of aero engine turbine, because need to work at elevated temperature for an expected long period. The nickel-base alloy Inconel 718 has being investigated because it is one of the most widely used superalloys. The objective of this work was to evaluate the creep behavior of the Inconel 718 focusing on the determination of the experimental parameters related to the primary and secondary creep states. Constant load creep tests were conducted with at 650, 675 and 700°C and the range of stress was from 625 to 814 MPa to according to ASTM E139 standard. The relation between primary creep time and steady-state creep rate, obeyed the equation for both atmospherics conditions at 650, 675 and 700°C. The microstructural characterization employing the technique of scanning electron microscopy has been a valuable tool for understanding the mechanisms of creep.

### Introduction

The behavior of metals and alloys during strain at high temperatures is complex and changes with thermomechanical processing parameters and working conditions.

The development of superalloys in the United States began around 1930, prompted by the need for materials with greater resistance to high temperature applications in jet engines. For the purpose of classification, we identified three main groups of superalloys: cobalt, nickel base and iron base, we consider the base alloy of nickel-iron a special group within the class of nickel [1].

Nickel-based superalloys are known since the 1930s, and used primarily in aerospace applications. These applications require a material with high mechanical strength, good resistance to fatigue and creep, good corrosion resistance and ability to operate continuously at high temperatures.

Inconel 718, a superalloy based on iron-nickel hardened by precipitation, is one of the most widely used superalloy that exhibits adequate resistance to creep, ductility and fatigue resistance above 650°C. Applications of these alloys range from disks of gas turbine projects to components used in the structures and cryogenic nuclear, screws and tools for setting high-strength components and aerospace projects, due to its excellent machinability and weldability [2].

Creep is the slow and continuous strain of a solid over time. Typically, the creep resistance of a solid is estimated by calculating the rate of deformation secondary and evaluated as a function of load or applied stress. Thus, there is a static load applied on a sample at elevated temperatures by measuring the deformation as a function of time [3]. Under the aspect applied to engineering, the

creep phenomenon has particular relevance to conditions that may occur in appreciable deformations in components operating at high temperatures for periods of time near the expected life of the material [4].

There are three kinds of mechanisms of fracture in metals:

- ductile materials usually fail as the result of nucleation, growth, and coalescence of microscopic voids that initiate at inclusions and second-phase particles.
- cleavage fracture involves separation along specific crystallographic planes (transgranular fracture).
- intergranular fracture, as its name implies, occurs when the grain boundaries are the preferred fracture path in the material [5].

The micromechanisms of fracture in various material systems are of obvious importance to materials scientists, because an understanding of microstructural events that lead to fracture is essential to the development of materials with optimum toughness [5].

The objective of this work was to evaluate the creep behavior of the Inconel 718 focusing on the determination of the experimental parameters related to the primary and secondary creep states. Constant load creep tests were conducted with at 650, 675 and 700°C and the range of stress was from 625 to 814 MPa to according to ASTM E139 standard. The microstructural characterization employing the technique of scanning electron microscopy has been a valuable tools for understanding the mechanisms of creep.

## Materials and Methods

The chosen material for the present study was the superalloy Inconel 718 which was provided by the company Villares SA (Sumaré-SP). The material had a melting furnace VIM, VAR remelting in heat treatment, homogenization, hot forging in open die for roughing, roughing hot rolling and hot rolling finish.

The chemical composition of superalloy is shown in the Table 1.

Table 1 – Chemical composition of superalloy Iconel 718.

Chemical elements	C	S	Mn	Co	Cr	Ni	Nb	Al	Ti	Mo
(%)	0,042	0,0028	0,01	0,02	18,56	52,97	5,61	0,07	1,95	2,69

Short-term creep tests were performed under constant load in a stress range from 625 to 814 MPa at temperatures 650, 675 and 700°C. Samples with a gage length of 18.5 mm and a diameter of 3.0 mm were used for all tests. The creep tests were performed according to ASTM E139 standard. The creep tests were performed in a furnaces belonging to the Instituto Tecnológico de Aeronáutica (ITA / DCTA), acquired from EMEC (The Electronic and Mechanical Engineering Co. Ltd.). The ovens are adapted electrical systems and controllers, developed by BSW Technology, Industry and Commerce Ltda. according to the requirements of ASTM E139/83 [6]. After creep's rupture, samples were prepared for the fractography analysis.

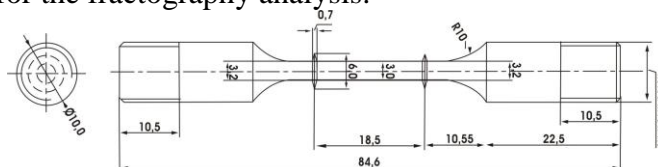


Figure 1. Schematic view of the specimen for creep test.

The preparation of samples for fractographic analysis by scanning electron microscopy followed the usual patterns of metallographic: the samples were cleaned with acetone in ultrasound for 10 minutes. The SEM images were obtained in the backscattering electron mode, whose main mechanism of contrast is related to differences in average atomic number between the phases present. Through the analysis by SEM the main characteristics of the fracture surfaces were studied.

## Results and Discussions

Figure 2 shows the creep curves of the Inconel 718 at 650°C and 700, 750 and 814 MPa, corresponding to the real strain  $\epsilon$  as function of time  $t$ .

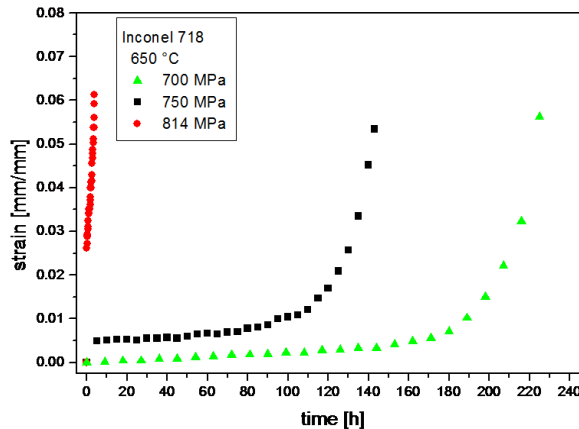


Figure 2. Creep curves of Inconel 718 at 650°C and stress conditions of 700, 750 and 814 MPa.

Figure 3 shows the creep curves of the Inconel 718 at 675°C and 670, 700 and 750 MPa, corresponding to the real strain  $\epsilon$  as function of time  $t$ .

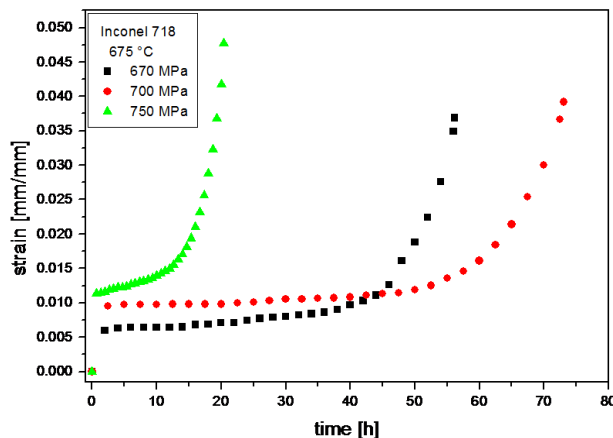


Figure 3. Creep curves of Inconel 718 at 675°C and stress conditions of 670, 700 and 750 MPa.

Figure 4 shows the creep curves of the Inconel 718 at 700°C and 625, 700 and 750 MPa, corresponding to the real strain  $\epsilon$  as function of time  $t$ .

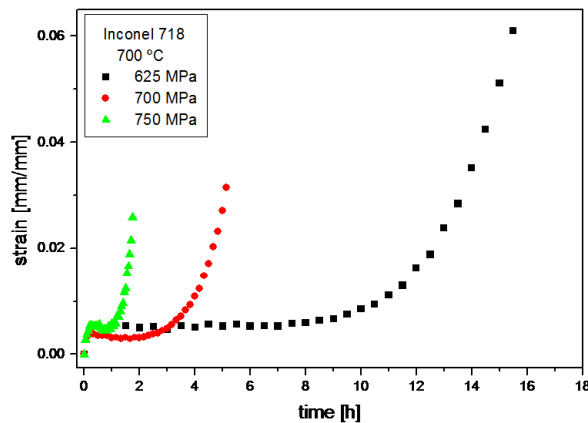


Figure 4. Creep curves of Inconel 718 at 700°C and stress conditions of 625, 700 and 750 MPa.

Figure 5 shows the creep curves of the Inconel 718 at 750 MPa and 650, 675 and 700°C, corresponding to the real strain  $\varepsilon$  as function of time  $t$ .

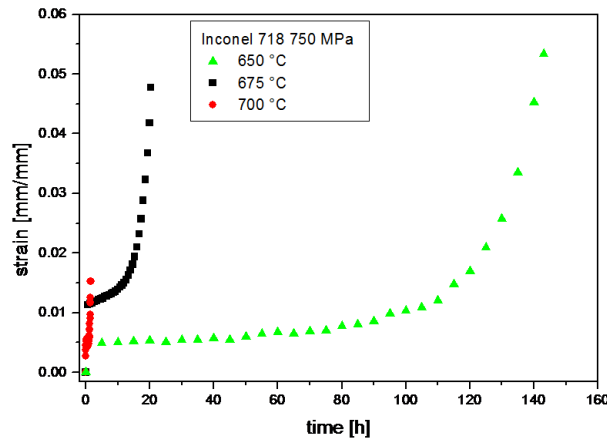


Figure 5. Creep curves of Inconel 718 at 750 MPa and temperature conditions of 650, 675 and 700°C.

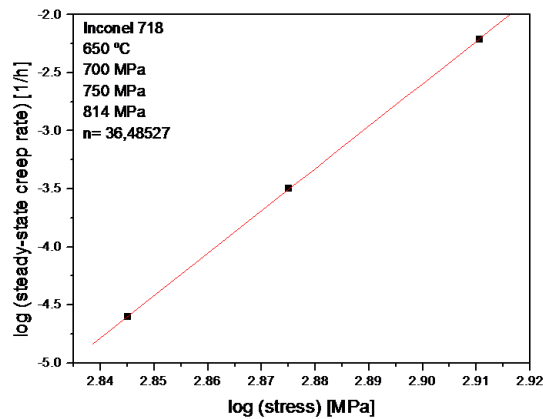


Figure 6. Stress dependence of steady-state creep rate at 650°C.

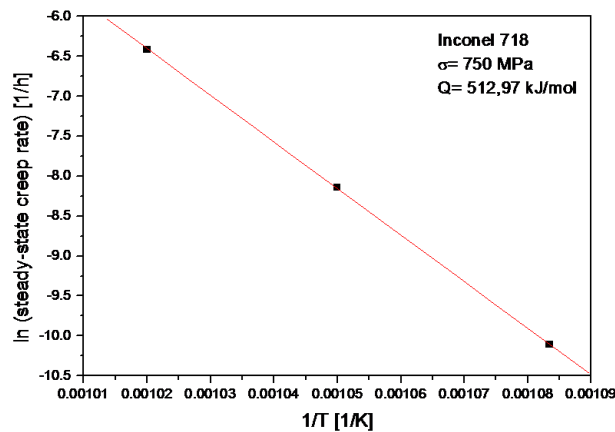


Figure 7. Activation energy dependence of steady-state creep rate at 750 MPa.

Table 2 shows the relationship of the main experimental parameters obtained at 650, 675 and 700°C from experimental curves. When  $\sigma$  is the applied stress,  $\dot{\varepsilon}_s$  is the steady state creep rate, obtained from the slope of the linear creep curve (secondary stage). The value of  $t_p$  is the constant relative time to primary time, obtained in the final stage of primary and / or in the beginning of secondary stage. The value  $t_f$  is the final time of fracture and  $\varepsilon_f$  correspond to the fracture strain.

TABLE 2. CREEP DATA

T (°C)	$\sigma$ (MPa)	$t_p$ (h)	$\dot{\epsilon}_s$ (1/h)	$t_f$ (h)	$\epsilon_f$ (mm/mm)
650	700	9.0	0.000024	225	0.0562
	750	6.00	0.0000406	92.70	0.0604
	814	0.25	0.00616	4.00	0.0612
675	670	4	0.00008	56.15	0.0369
	700	2.50	0.00004	73.07	0.0392
	750	0.67	0.00033	20.38	0.0477
700	625	1.5	0.00019	16.28	0.0807
	700	0.33	0.0009	5.10	0.0314
	750	0.05	0.0016	1.70	0.0258

It can be noted from Table 2 that the samples present the lowest values of steady state rate ( $\dot{\epsilon}_s$ ), constant relative time to primary time ( $t_p$ ) and the fracture strain ( $\epsilon_f$ ) when they were tested in lower temperature and stress condition. It can be noted too that the steady state rate ( $\dot{\epsilon}_s$ ) increased with the increment of stress for the same temperature condition.

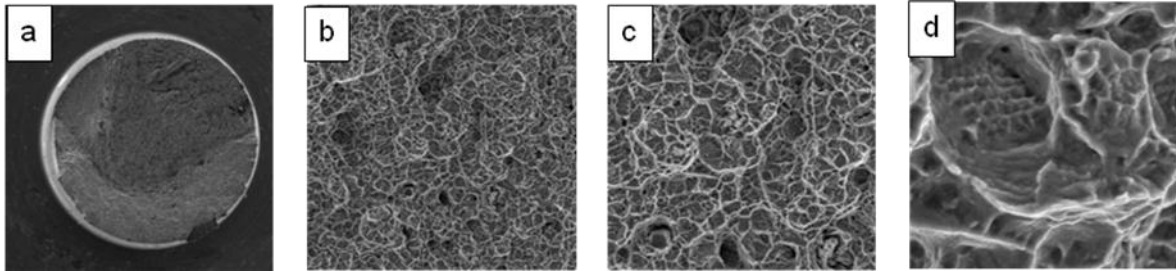


Figure 8. Fractography of Inconel 718 after creep test at 650°C and 750 MPa: a) overview; b) center; c) center; d) center.

It is observed in Fig. 8 that for a temperature of 650°C the fracture is ductile. The fractographs show dimpled fracture surfaces that are typical of microvoid coalescence.

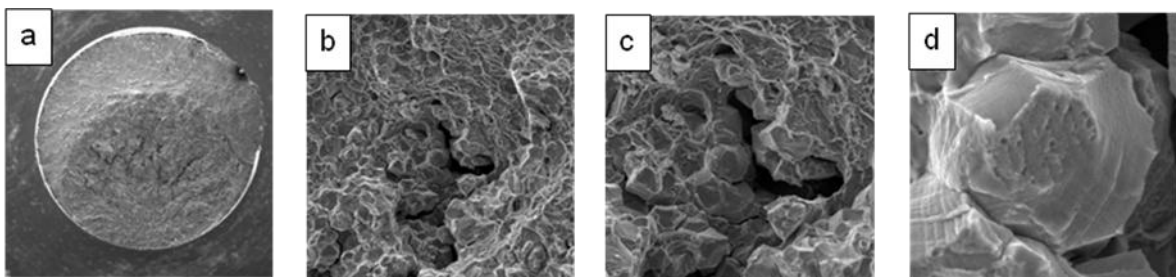


Figure 9. Fractography of Inconel 718 after creep test at 675°C and 750 MPa: a) overview; b) center; c) center; d) center.

With increasing temperature to 675°C there is a small change in fracture behavior of Inconel 718. It is observed in the Fig. 9 an intergranular fracture.

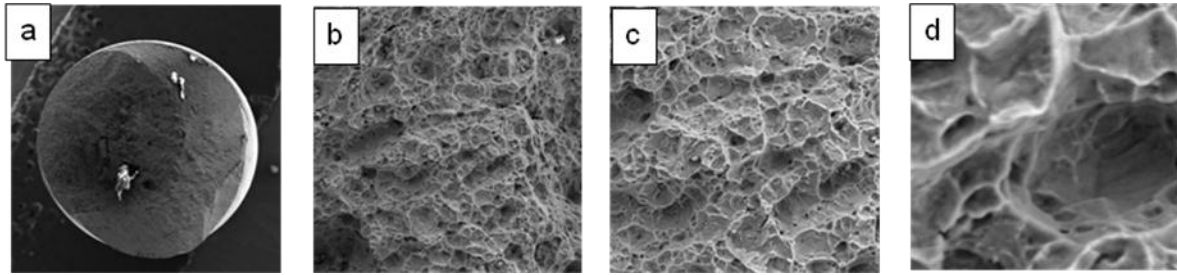


Figure 10. Fractography of Inconel 718 after creep test at 700°C and 750MPa: a) overview; b) center; c) center; d) center.

At 700°C it is observed in Fig. 10 that the fracture is ductile. The fractographs show dimpled fracture surfaces that are typical of microvoid coalescence.

### Conclusions

Creep curves in Figs. 2, 3 and 4 show an Inconel 718 normal curve of creep stages consisting of primary, secondary and tertiary well defined.

The results presented in Table 2 show the highest values of  $t_p$  and the reduction of the steady-state creep rate for smaller stresses, demonstrating the higher creep resistance at smaller temperatures and stresses. Analysis of the stress exponent value ( $n = 36.48527$ ) and activation energy ( $Q_c = 512.97$ ) in Figs. 6 and 7 respectively, suggests that the creep mechanism at 650°C is consistent with the dislocation climb one. It can be concluded from images of scanning electron microscopy that depending on the working temperature Inconel 718 can have two types of fracture: ductile fracture at 650°C and 700°C, and intergranular type fracture at 675°C.

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