ANISOTROPY OF THE FRACTURE TOUGHNESS IN AGED INCONEL 718

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INTRODUCTION

INCONEL 718 is a widely used material for applications at temperatures up to 650°C. Many research groups have studied the properties of INCONEL 718 at different conditions[1,2]. It is known that, after several thousand hours at 650 °C, INCONEL 718 shows roughly a 75% decrease in the Charpy V-notch impact energy[3]. However, any anisotropic characteristics of this steel have not been investigated in adequate detail. Consequently, in order to maintain the integrity of the components, it is important to clarify the orientation dependence of the mechanical properties of INCONEL 718.

The techniques that provide at least qualitative information on a possible orientation dependence of the mechanical properties of the materials concerned could be the hardness measurement, the small punch (SP) test technique developed at Ames Laboratory[4,5], and the acoustic nondestructive evaluation(NDE)[6-8].

This paper presents our efforts to determine the anisotropic properties of aged INCONEL 718. The test results include hardness, small punch test ductility, yield stress, ultimate stress, fracture toughness J_{IC}, and ultrasonic attenuation. The anisotropy parameter K_{ij} is defined to describe the extent of orientation dependence.

TEST MATERIALS AND ORIENTATION

The material used for this work was supplied by Idaho National Engineering Laboratory (INEL)[3]. Two heats(Heat 5118-EK11 and Heat 4766-EK21)of materials were tested. Both heats were given a conventional heat treatment consisting of a solution anneal at 950±14°C for 1 hour, air cooling to room temperature, aging at 718±8°C for 8 hours, furnace cooling to 621°C, and aging at 621±8°C, to give a total precipitation time of 18 hours. Heat treated pieces from each of the two heats were exposed to 649°C for times of 0, 500, and 1000 hours. The directions in which the materials were tested are shown in Fig. 1.

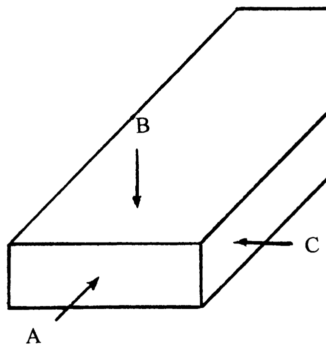


Fig.1 The diagrammatical figure showing the orientation.

HARDNESS ANISOTROPY OF INCONEL 718

The hardness measurements were taken along directions A, B, and C for every heat and aging time combination. The results are shown in Fig.2. HRC is the hardness of the tested materials on the Rockwell C-type scale.

MECHANICAL PROPERTY ANISOTROPY OF INCONEL 718

The small punch(SP) test technique was used to measure the mechanical properties of INCONEL alloy 718. The ductility is defined by the end of plastic deformation and crack initiation[4]. The fracture strain ε_f was used as the ductility which can be calculated according to the equation (3) below. The test results are shown in Fig. 3.

Semianalytical relationships among the small punch test parameters and the mechanical properties of INCONEL 718 are [9]:

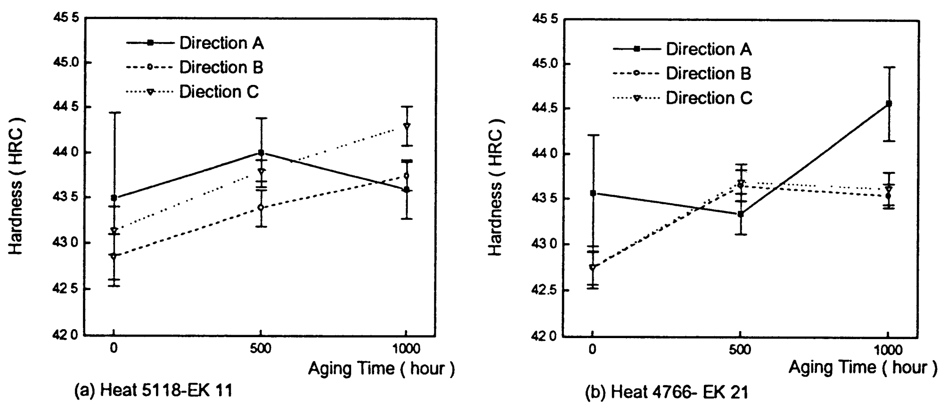


Fig. 2 Hardness anisotropy of INCONEL 718.

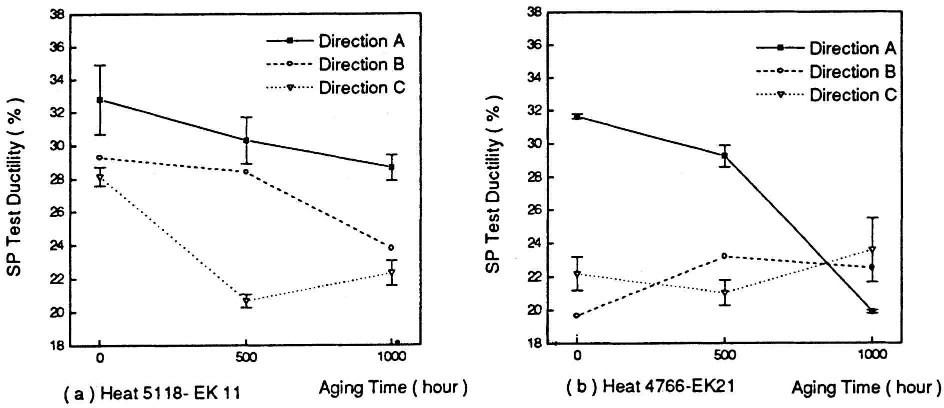


Fig. 3 Ductility anisotropy of INCONEL 718.

$$\sigma_y(\text{MPa}) = 340(P_y/t_o^2)+10 \quad (1)$$
$$\sigma_{Ult}(\text{MPa}) = 40(P_{ult}/t_o^2)+1030 \quad (2)$$
$$\varepsilon_f = 0.12(\delta_f/t_o)^{1.72} \quad (3)$$
$$J_{IC}(\text{kJ/m}^2) = 278.5\ \varepsilon_f-2.7 \quad (4)$$

where P_y, P_{ult}, t_o, δ_f and ε_f are the SP test parameters. σ_y, σ_{ult} and J_{IC} are the mechanical properties. The anisotropy of σ_y, σ_{ult} and J_{IC} are shown in Fig. 4, Fig. 5 and Fig. 6 respectively.

THE ULTRASONIC ATTENUATION ANISOTROPY OF INCONEL 718

The ultrasonic attenuation in these samples has been measured. The frequency dependence of attenuation in both heats in direction B, is shown in Fig. 7. The orientation dependence of the attenuation is shown in Fig.8, where the transducer frequency is 20 MHz and the attenuation was measured at 16 MHz.

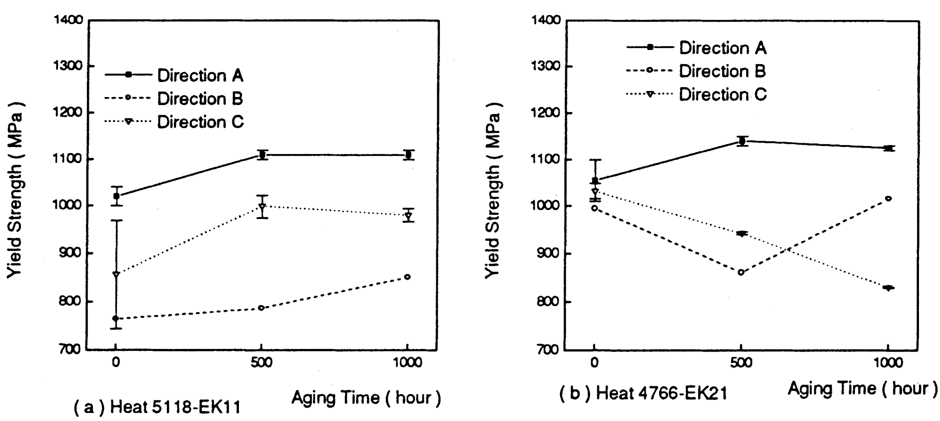


Fig. 4 Yield strength anisotropy of INCONEL 718.

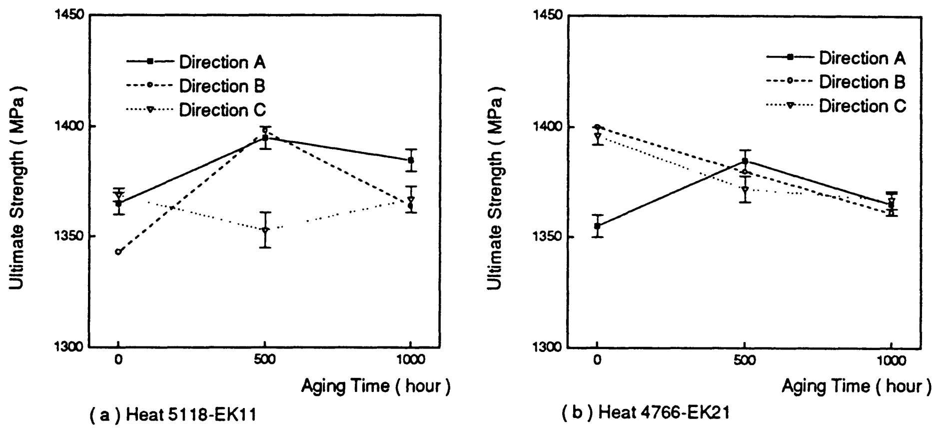


Fig. 5 Ultimate strength anisotropy of INCONEL 718.

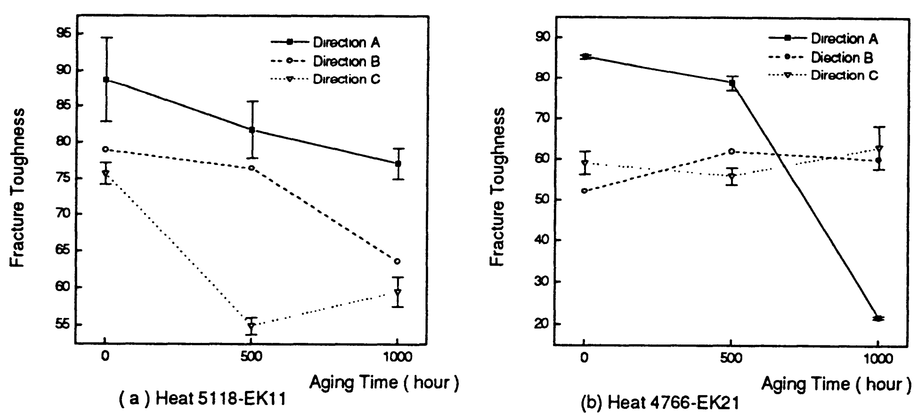
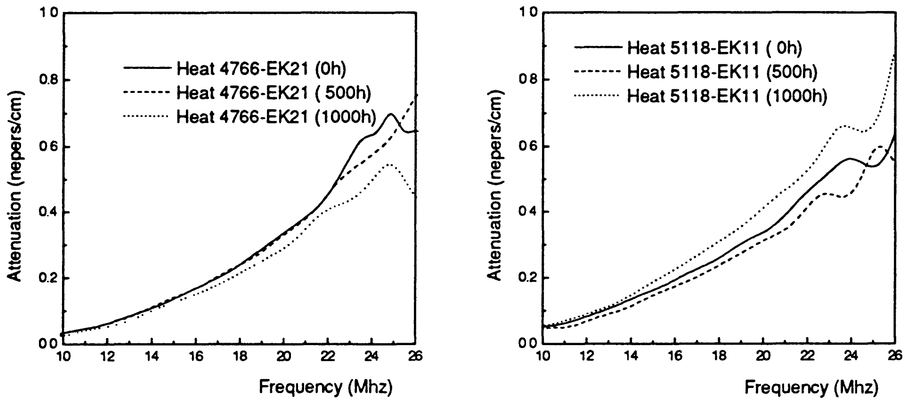


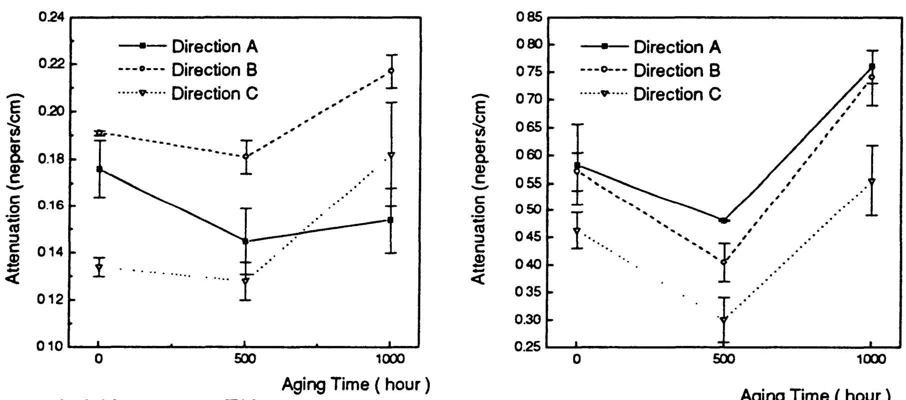
Fig.6 Fracture toughness anisotropy of INCONEL 718.



(a) Heat 5118-EK11

(b) Heat 4766-EK21

Fig. 7 Frequency dependence of attenuation.



(a) Heat 5118-EK11

(b) Heat 4766-EK21

Fig.8 Attenuation anisotropy of INCONEL 718.

DISCUSSION

From Fig. 2-6 and 8, it is obvious that there exists anisotropy of Inconel 718 in hardness, strength, fracture toughness, and ultrasonic attenuation.

We define the anisotropy parameter K_{ij} as:

$$K_{ij} = (Q_i / Q_j) \qquad (5)$$

where i is the direction in which the quantity is maximum in value and j is the direction in which the quantity is minimum in value. Then, i and j can be A, B or C, which means Direction A, E or C with notations defined in Fig.1, and Q is the quantity, such as hardness, yield stress, fracture toughness, etc. As the anisotropy was concerned, the maximum anisotropy is of interest. Then, the following Table 1 listed the results.

It can be seen that the anisotropy in ductility and fracture toughness could be as large as 1.6. During aging process, the direction with minimum properties of INCONEL 718 will change. Thus, the anisotropy should be taken into account when the component life extension was assessed.

The ultrasonic attenuation was best fitted by

$$\alpha_S = C_1/D + C_2 D f^2 \qquad (6)$$

where f is the frequency. C_1 and C_2 are constants. D is the mean grain diameter. Thus, the attenuation in INCONEL 718 is in the regions of stochastic scattering ($\lambda \doteq D$) and diffusion scattering($\lambda \ll D$). It may be pretty accurate to measure the grain size by NDE methods. And the mechanical properties of materials depend on the microstructure features[6]. However, the anisotropy in INCONEL 718 can be investigated by the acoustic measurement, but to correlate the mechanical properties and the attenuation coefficient in INCONEL 718 steel needs further work.

Table 1 Anisotropy K_{ij}

	Heat 5118-EK 11	Heat 4766-EK 21
Hardness (HRC)	K_{CA} = 1.016	K_{AB} = 1.024
Ductility (ε_f)	K_{AC} = 1.502	K_{AB} = 1.614
Yield Strength(σ_Y)	K_{CB} = 1.300	K_{AC} = 1.238
Fracture Toughness	K_{BC} = 1.392	K_{AB} = 1.636
Attenuation(16MHz)	K_{BA} = 1.465	K_{AC} = 1.376

CONCLUSIONS

The mechanical properties(Hardness, ductility, yield stress, and fracture toughness) and the ultrasonic attenuation in INCONEL 718 are anisotropic. The anisotropy parameter K_{ij} was defined as the maximum-to-minimum value ratio.

The ductility and fracture toughness anisotropy may be as large as 1.6. In different heatS of INCONEL alloy, the direction with minimum fracture toughness is dependent on the aging time.

The small punch test parameters can be used to predict the mechanical property anisotropy in materials by using the relationship of equations (1)-(4).

The ultrasonic attenuation coefficient α_f could be exploited to characterize the anisotropy in materials. However, the relation between the ultrasonic attenuation coefficient α_f and the mechanical properties is not linear and not well understood.

ACKNOWLEDGMENTS

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