JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
**56**, 3, pp. 893-896, Warsaw 2018
DOI: 10.15632/jtam-pl.56.3.893

SHORT RESEARCH COMMUNICATION

# DAMAGE DEVELOPMENT OF INCONEL 718 DUE TO LABORATORY SIMULATED CREEP

Katarzyna Makowska, Adam Brodecki
*Motor Transport Institute, Warsaw, Poland*
*e-mail: katarzyna.makowska@its.waw.pl; adam.brodecki@its.waw.pl*

Sławomir Mackiewicz, Zbigniew L. Kowalewski
*Institute of Fundamental Technological Research Polish Academy of Sciences, Warsaw, Poland, and*
*Motor Transport Institute, Warsaw, Poland*
*e-mail: smackiew@ippt.pan.pl; zkowalew@ippt.pan.pl; zbigniew.kowalewski@its.waw.pl*

The paper presents an attempt of application of the acoustic birefringence coefficient for early stage degradation assessment of Inconel 718 nickel superalloy after short-term creep. It is shown that it can serve as a good damage sensitive parameter and, moreover, it can be well correlated with hardness variation.

*Keywords:* creep, nickel superalloy, microstructure, pre-deformation, hardness, acoustic birefringence

## 1. Introduction

Inconel 718 is extensively used in aerospace applications, particularly in aircraft engines (Pollock and Tin, 2006). This is because of the combination of high strength, toughness, resistance to degradation in oxidizing and corrosive environments as well its excellent weldability (Pollock and Tin, 2006). Due to large stress levels and high temperatures taking place during operation of jet engine parts, special materials guarantying adequate creep resistance are required. Such properties exhibits Inconel 718 (Reed and Tao, 2009). Typical conventional non-destructive techniques (based on measurement of ultrasonic wave velocities for example) are sensitive to material damage mainly in the advanced stage of material life. Previous attempts of application of the acoustic birefringence coefficient to damage evaluation provided some encouraging results well reflecting material degradation, sometimes even better than the replica technique and destructive tests.

The acoustic birefringence is based on the velocity difference between two shear waves polarized in mutually perpendicular directions (Szelążek *et al.*, 2009). Measurements are usually carried out using the same ultrasonic probes, rotated by 90°. The ultrasonic beam goes through the same thickness of the material and reflects from the same area of the opposite surface (Mackiewicz, 2005). In this way, errors coming from structure and heterogeneity of the material can be eliminated (Mackiewicz, 2005).

## 2. Materials and methods

The material used in all tests has been wrought Inconel 718 nickel superalloy. Chemical analysis was carried out on SpectroMAXx AMETEK. Solution annealing at 968°C was applied following cooling in the air. Subsequently, precipitation hardening at 718°C for 8 hours plus furnace cooling (56°C for 1 hour) to 621°C, held at 621°C for 8 hours, followed by air cooling was performed. The microstructure of the non-deformed material after heat treatment was investigated. Scanning-

-transmission electron microscope STEM Titan 80-300 was used. In order to control the result of heat treatment, the standard tensile test at room temperature was carried out. Also, Vickers hardness tests were performed. In the next step of experimental programme, short-term creep tests under stress of 70 MPa at temperature 850°C were executed on specimens of 40 mm gauge length and 5 mm×7 mm cross-section dimensions. Each creep test was interrupted in the range of selected time periods in order to achieve specimens with the increasing level of pre-strain: 0.5%, 1%, 2.5%, 5%. After each interrupted creep test, ultrasonic inspection was performed to find values of the acoustic birefringence $B$.

It was calculated according to the following relationship

$$B = 2\frac{t_{Tl} - t_{Tp}}{t_{Tl} + t_{Tp}} \tag{2.1}$$

where: $t_{Tl}$ – time of propagation of the shear wave polarized in the longitudinal direction of the specimen, $t_{Tp}$ – time of propagation of the shear wave polarized in the perpendicular direction of the specimen.

Ultrasonic measurements were performed in five spots on each specimen along their gauge length and in two reference spots on the gripping parts, aside from the creep stresses. In that way, the maximum value of the acoustic birefringence increase along the gauge length $\Delta B_{max}$ could be determined. The measurements were taken by means of a 5 MHz shear wave piezoelectric transducer coupled to the specimen surface by a viscous epoxy couplant (Makowska *et al.*, 2017). The distribution of ultrasonic measurement points on the specimen is schematically presented in Fig. 1.

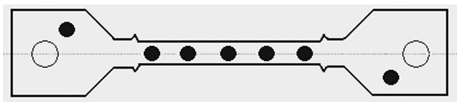

Fig. 1. Spots of ultrasonic measurements

Afterwards, the specimens were subjected to hardness measurements HV0.1. Having had all experimental data, a relationship between the creep strain and the acoustic birefringence coefficient was elaborated. It was shown that HV hardness also exhibited a functional relationship with the variation of the acoustic birefringence coefficient.

## 3. Results and discussion

The chemical composition of the material tested is shown in Table 1.

**Table 1.** Chemical composition of Inconel 718 alloy [wt %]

| C | Si | Mn | Cr | Ni | Mo | Nb | Ti | Al | Fe |
|---|---|---|---|---|---|---|---|---|---|
| 0.082 | 0.12 | 0.25 | 18.24 | 52.7 | 3.09 | 4.68 | 1.10 | 0.55 | 18.59 |

The representative microstructure of heat-treated Inconel 718 is shown in Fig. 1a,b. Figure 1a shows the structure of the material in a single grain. The area in the square is enlarged and presented in Fig. 1b. According to the diffraction pattern (Fig. 1c,d), the microstructure of Inconel 718 contains a dispersion of $\gamma'$ and $\gamma''$ precipitates in $\gamma$ matrix, see Fig. 1b. Similar results of microstructural investigations were presented in (Xiao *et al.*, 2004) and (Azadian, 2004). HV hardness of the material reaches 450HV10 after heat treatment, whereas the parameters coming from a static tensile test at the room temperature are as follows: yield point $\sigma_{0.2} = 1114$ MPa, ultimate tensile strength $\sigma_m = 1376$ MPa, elongation $A \approx 25\%$.

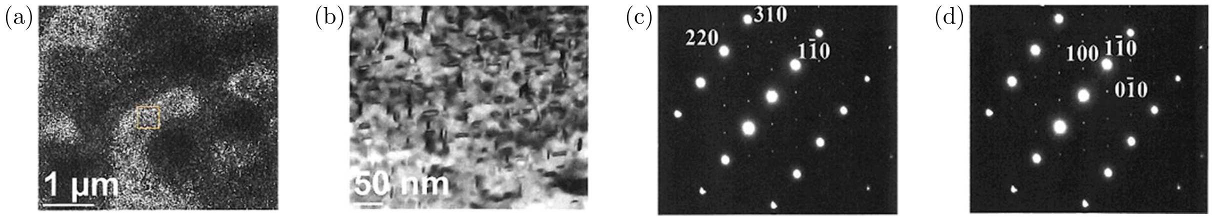


Fig. 2. Microstructure of heat-treated Inconel 718

The results of mechanical tests are shown in Figs. 3 and 4. The creep curve of the alloy is illustrated in Fig. 3a, whereas the mutual relationship between hardness and predeformation of Inconel 718 due to creep in Fig. 3b. The acoustic birefringence coefficient $\Delta B_{max}$ representing the maximum increase of the acoustic birefringence on the gauge length due to creep (measured in relation to the gripping section) is shown in Fig. 4a. The values of the parameter are presented as a function of the creep strain. According to the results (Fig. 4a), the $\Delta B_{max}$ increases with growth of deformation due to creep. The mutual relationship between the hardness and ultrasonic parameter $\Delta B_{max}$ can be well described by an exponential function, see Fig. 4b.

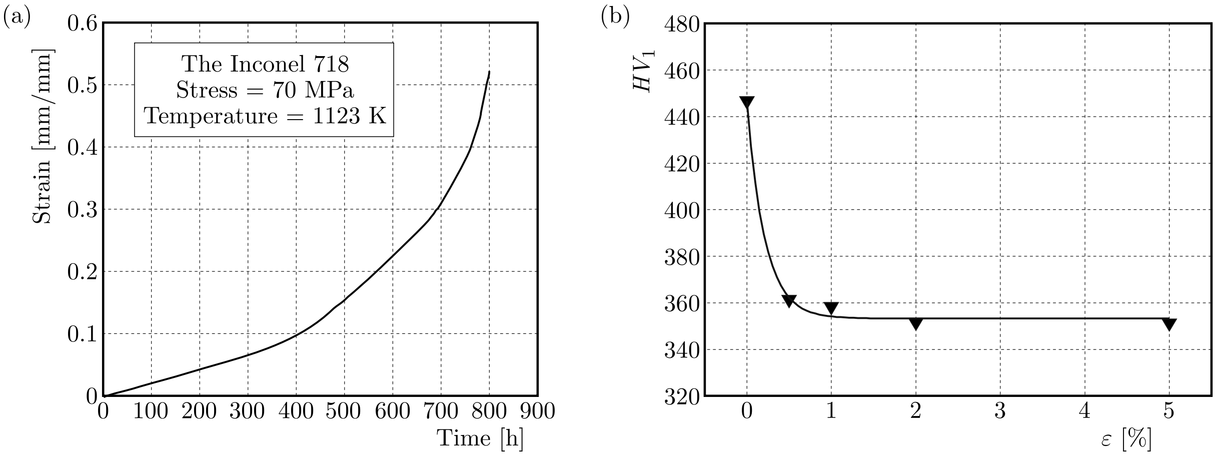


Fig. 3. (a) Creep curve of Inconel 718. (b) Relationship between the hardness and creep strain

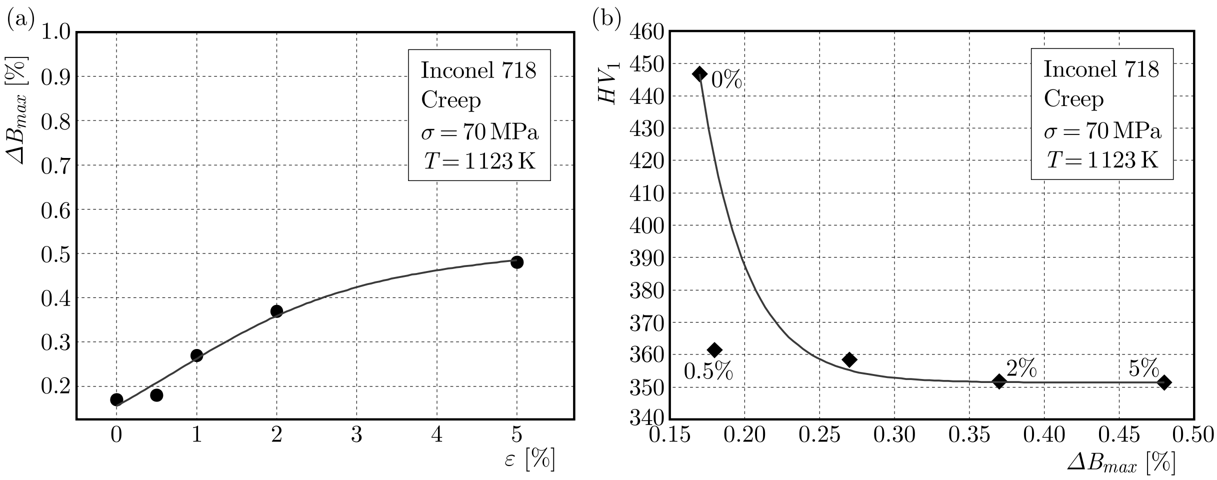


Fig. 4. (a) Variation of the acoustic birefringence coefficient $\Delta B_{max}$ versus creep strain. (b) Variation of the HV hardness versus the acoustic birefringence coefficient $\Delta B_{max}$; the numbers 0%-5% denote the level of creep strain

## 4. Conclusion

The acoustic birefringence coefficient might be useful in assessment of the state of degradation Inconel 718 nickel superalloy in the relatively wide range of material exploitation. The correlation discovered between selected parameters derived from non-destructive and destructive tests may serve as the starting point enabling evaluation of mechanical properties of the materials using only nondestructive investigations.

*Acknowledgments*

The research was performed within the financial support of the National Science Centre (2013/09/N/ST8/02084).

## References

1. Azadian S., 2004, Aspects of Precipitation in the Alloy Inconel 718, Doctoral Thesis, Luleå University of Technology, Sweden
2. Mackiewicz S., 2005, Possibilities of ultrasonic evaluation of energetic steels as a result long-term exploitation (in Polish), *Conference Book, VII Information and Training Seminar: Diagnostic and Renovations Energetic Devices. New Diagnostic Problems on the Old Power Units*, Ustroń, Poland, 2005
3. Makowska K., Piotrowski L., Kowalewski Z.L., 2017, Prediction of the mechanical properties of P91 steel by means of magneto-acoustic emission and acoustic birefringence, *Journal of Nondestructive Evaluation*, **35**, 1-10
4. Pollock T.M., Tin S., 2006, Nickel-based superalloys for advanced turbine engines: chemistry, microstructure and properties, *Journal of Propulsion and Power*, **22**, 361-374
5. Reed R.C., Tao T., 2009, Alloys-by-design: application to nickel-based single crystal superalloys, *Acta Materialia*, **57**, 5898-5913
6. Szelążek J., Mackiewicz S., Kowalewski Z.L., 2009, New samples with artificial voids for ultrasonic investigations of material damage due to creep, *NDT&E International*, **42**, 150-156
7. Xiao L., Chen D.L., Chaturvedi M.C., 2004, Shearing of $\gamma''$ precipitates and formation of planar slip bands in Inconel 718 during cyclic deformation, *Scripta Materiala*, **52**, 603-607

*Manuscript received May 9, 2018; accepted for print May 21, 2018*