DEVELOPMENT OF THE DEGRADATION INSPECTION METHOD OF INCONEL 718 SERVICED AT ELEVATED TEMPERATURES

Narihito Ohi and Hiroshi Hattori

Aero-Engine & Space Operations
Ishikawajima-Harima Heavy Industries Co., Ltd.
Mukoudai-cho, Tanashi, Tokyo, 188, Japan

Abstract

The degradation of Inconel 718 wrought alloy, occurred during service at elevated temperatures, has been evaluated by the thermal electromotive force method in this study. This method is used as one of the various non-destructive inspection methods. It was tried to determine the degree of the degradation by this quantitative measurement. The specimens cut from turbine disk forgings with different grain sizes (ASTM6 and 10) were exposed at various temperatures simulating actual turbine disk service condition. The increase of thermal electromotive force value after exposure due to the morphology changes of δ phase from γ'' phase because of containing the niobium. The increase of thermal electromotive force value with these microstructure changes corresponded to the decrease of tensile properties at 823K(550 ℃). It was confirmed that the inspection sensitivity of thermal electromotive force method was superior to other non-destructive inspection method such as hardness measurement.

In application for the actual reliable inspection, it is proposed that thermal electromotive force method is applied for using relative difference in value between the rim portion and the less heated bore portion in the actual disk. Then, it is not necessary to consider effects of the chemical compositions and grain size in the different disks on this value. Moreover, this method has a great advantage that the degree of the degradation can be estimated quantitatively without damaging the parts and easy to adopt at the shop or user.

Superalloys 718, 625, 706 and Various Derivatives
Edited by E.A. Loria
The Minerals, Metals & Materials Society, 1994

Introduction

The turbine disks are extensively used in today's aircraft engines operated under high temperature and high stress conditions. The degradation of materials for these parts, occurred during long term service, is one of the most universal problem[1-5]. The degradation evaluation systems have been investigated to estimate the residual life of the turbine disks. Destructive inspections, such as metallographic inspection by using the specimens cut from the serviced turbine disks, are available to confirm the materials quality. However, turbine disk is very costly parts and critical rotor parts in aircraft engines. It is impossible to carry out the metallographic inspection or the mechanical test for the quality certification by using the cut up specimen because of economical difficulties. Then, it has been required to establish the inspection methods of the degradation in the turbine disk serviced at elevated temperatures.

Generally, the inspection methods can be divided into two types. One is the destructive inspection method such as metallographic inspection or mechanical test by using the specimens cut from the serviced turbine disk. The other is the non-destructive inspection method such as fluorescent penetrant inspection or electrochemistry method. However, with regard to the latter method, so far, there is a few methods to evaluate the amount of the degradation of the turbine disk. Therefore, our interest is in these non-destructive inspection methods. Then, the goal of this study is to develop the alternative inspection method by using thermal electromotive force (TEF)[6].

Materials and Procedures

The solution treated and aged Inconel 718 turbine disk forging were prepared. The specimens were cut from each of them with different chemical compositions and grain sizes. The chemical compositions and grain sizes of each forging used in this study are listed in Table 1. The specimens were thermally exposed at given temperatures between 973K(700℃) and 1073K(800℃) and for given holding time between 1 hour and 100 hours so as to simulate long term service. Thermally exposed conditions are described as a function of Larson-Miller Parameter. These exposed conditions meet the service life in the high pressure turbine disk.

In this study, we used the following two destructive and two non-destructive inspection methods in order to evaluate the degradation of Inconel 718 exposed at elevated temperatures.

(A) Metallographic inspection by using SEM : Destructive inspection method
(B) Tensile test at 823K(550℃) : Destructive inspection method
(C) Hardness measurement method : Non-destructive inspection method
(D) Thermal electromotive force (TEF) method : Non-destructive inspection method

TEF method application in the non-destructive inspection technique has not been presented yet[6], however there are a few studies about TEF[7]. The equipment of TEF measurement is shown in Fig. 1. The measurement procedure is shown in Fig. 2. Two silver probes which have the difference ($T2 - T1 \fallingdotseq 80$℃) in temperature are connected each other and touched on the material surface. Then, the electric difference (TEF) between two probes was occurred.

The TEF probes was settled with 10 mm distance. We defined TEF ratio as Ee(TEF value of exposed specimen)／Ev(that of virgin specimen).

Table 1. Chemical compositions (wt%) and grain sizes of Inconel 718 tested in this study.

Heat	Ni	Cr	Mo	Nb+Ta	Al	Ti	Fe	C	Grain size
Heat A	51.9	18.5	3.0	5.1	0.5	1.0	Bal.	0.03	ASTM6
Heat B	54.5	18.3	3.0	5.3	0.4	1.0	Bal.	0.03	ASTM10

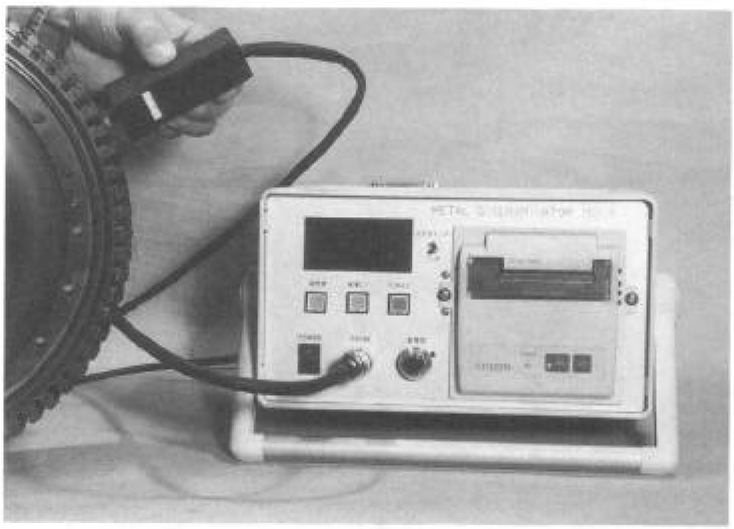
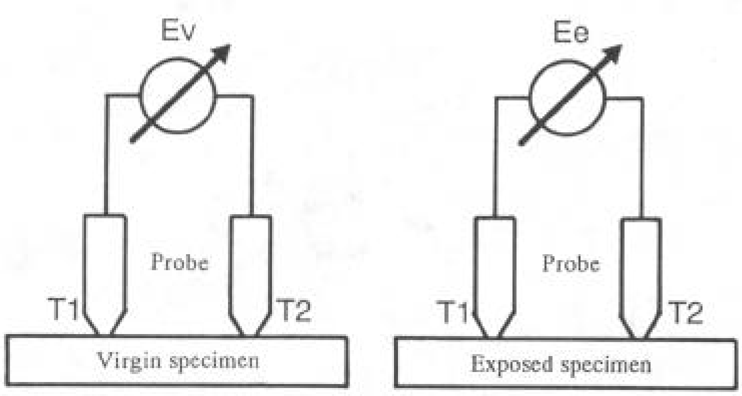


Fig. 1. Photograph of the equipment of TEF.



Ratio of TEF = Ee／Ev

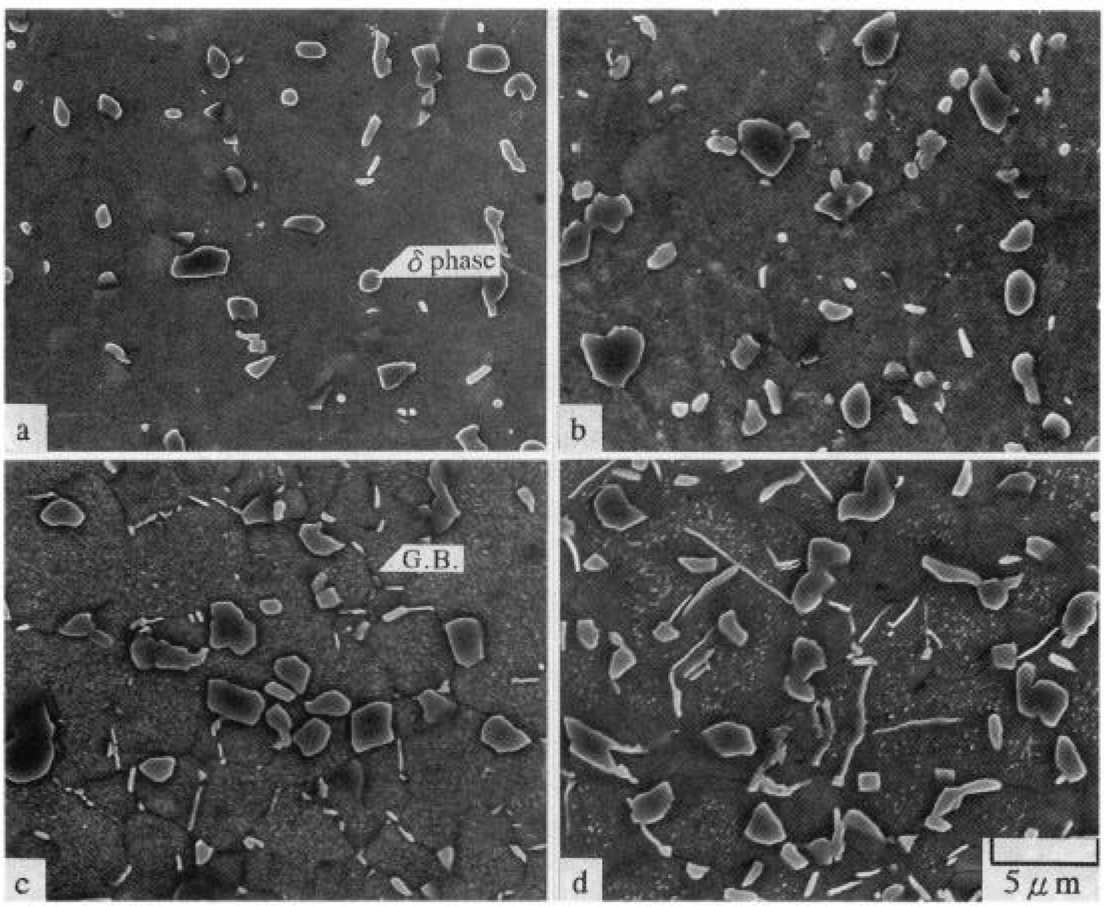
Fig. 2. Schematic diagram of TEF measurement method

Results and Discussion

1. Results of the degradation inspection

(A) Metallographic Inspection

Scanning electron micrographs of the virgin specimen with a grain size of ASTM10 and the specimens exposed at various conditions are shown in Fig. 3. In the virgin specimens, it shows that globular and large δ phase precipitates at the grain boundary. In the thermally exposed specimens, it can be observed that globular δ phase at the grain boundary enlarges and needle-like δ phase come appear within grain. Especially, secondary δ phase has a tendency to coarsen with increase of the thermal exposure. In the thermally exposed specimens with a grain size of ASTM6, it shows that same morphological changes occurred nevertheless initial morphology of δ phase seems to be affected by grain size[8]. These metallographical changes in this study are similar to the results of other studies about microstructure stability during long term service in Inconel 718[1-5]. Then, it is assumed that the thermal exposures simulate the accelerated long term service in Inconel 718. Therefore, there is a possibility that that the degradation is dependence on morphology of δ phase in Inconel 718.



(a) Virgin
(b) Exposed at 973K – 100h
(c) Exposed at 1023K – 100h
(d) Exposed at 1073K – 100h

Fig. 3. Scanning electron micrographs of virgin specimen (a) and specimens exposed for 100h at 973K (b), 1023K (c) and 1073K (d).

(B) Tensile properties at 823K(550℃)

Tensile tests were carried out at 823K(550℃). This temperature was determined from the steady state service condition in the high pressure turbine disk. Tensile and 0.2% yield strengths at 823K(550℃) in the thermally exposed specimens with different grain sizes are shown in Fig. 4. Tensile and 0.2% yield strengths decrease with increase of a value of a function of Larson-Miller Parameter (including functions of temperature and duration). Both ASTM6 and ASTM10 specimens have same mechanical tendency. Especially, the losses of 0.2% yield strengths are larger than those of tensile strengths in the thermally exposed specimens. Therefore, this results shows that degradation of mechanical properties in Inconel 718 occurs during the thermal exposures.

(C) Hardness measurement method

Relationship between Larson-Miller Parameter and hardness ratios HVe(hardness values of the thermally exposed specimens)／HVv (hat of virgin specimen) are shown in Fig.5. The parabolic losses of hardness ratio in the thermally exposed specimens with grain sizes of ASTM6 and 10 indicate the same tendency. It seems that the hardness loss is due to decrease of the precipitation hardness effects in Inconel 718 during thermal exposures. Hence, it is possible that the degradation in Inconel 718 is detected by hardness measurement.

(D) TEF method

Relationship between Larson-Miller Parameter and TEF ratios, Ee／Ev are shown in Fig.6. As increase of the thermal exposure, TEF ratios in the thermally

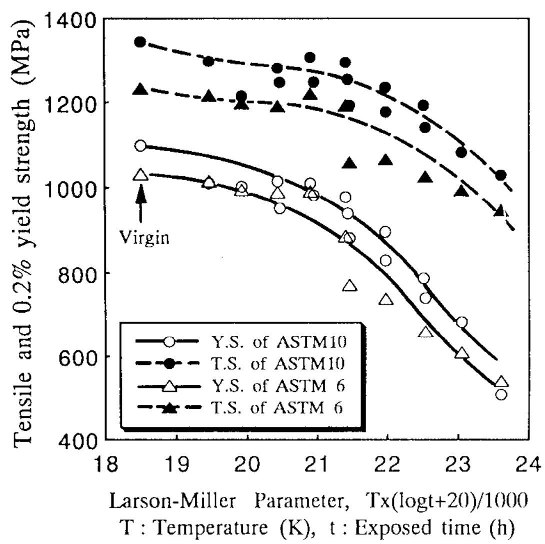


Fig. 4. Changes in tensile and 0.2% yield strength in thermally exposed specimens as a function of Larson -Miller Parameter.

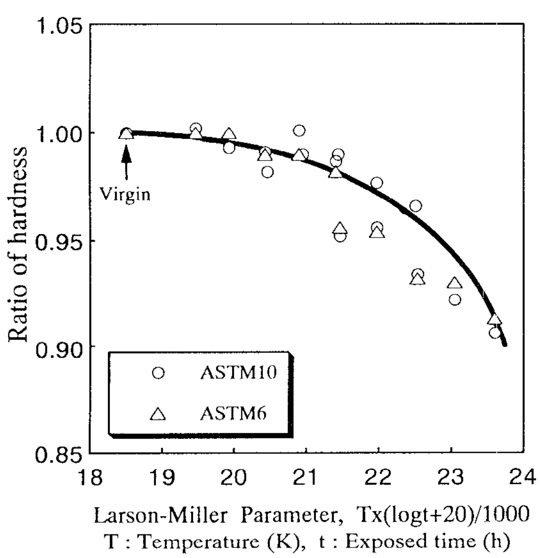


Fig. 5. Changes in ratio of hardness in thermally exposed specimens as a function of Larson -Miller Parameter.

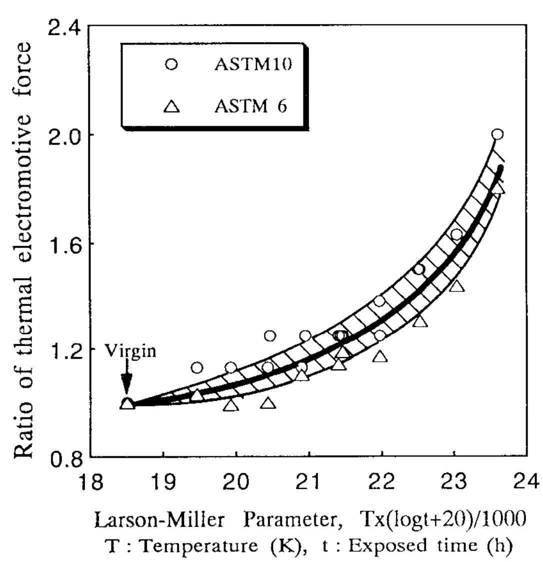


Fig. 6. Changes in ratio of TEF in thermally exposed specimens as a function of Larson -Miller Parameter.

exposed specimens with different grain sizes increase parabolically. TEF ratio in the specimen exposed at 1073K (800℃) —100h specimens indicates about twice values compared with virgin specimens. At the same exposed condition, ratio change of TEF in ASTM10 specimens is a little larger than in ASTM6 specimens. TEF value of the actual turbine disk will be estimated in the shaded portion in Fig. 6 because the range of grain size is from ASTM6 to ASTM10. From this results, it is possible to detect successfully the changes in Inconel 718 during thermal exposures by using TEF method.

2. Capability of the degradation inspection by TEF method

It was confirmed that ratios of TEF in the specimens increased parabolically with increase of the thermally exposures temperature and time. In order to evaluate the degree of the degradation by TEF inspection method, the relations between ratio of TEF and tensile properties, and between ratio of TEF and microstructure changes has been investigated.

The correlations between ratios of tensile properties at 823K(550℃) and ratios of TEF in the thermally exposed specimens with grain sizes of ASTM6 and ASTM10 are shown in Fig. 7 and 8, respectively. As increasing ratios of TEF in the thermally exposed specimens, ratios of tensile properties at 823K(550℃) decrease. Especially, there is a good correlation between 0.2% yield strengths and ratio of TEF in the thermally exposed specimens. The relation can be described as followed approximated equation;

$$\sigma e / \sigma v = a(Ee/Ev)^2 + b(Ee/Ev) + c \qquad (1)$$

a, b, c : Constant values

σ e : 0.2% yield strength in the thermally exposed specimen

σ v : 0.2% yield strength in the virgin specimen

Ee/Ev : Ratio of thermal electromotive force

Therefore, it can be possible that the degree of the degradation in Inconel 718 serviced at elevated temperatures are estimated quantitatively by using this equation.

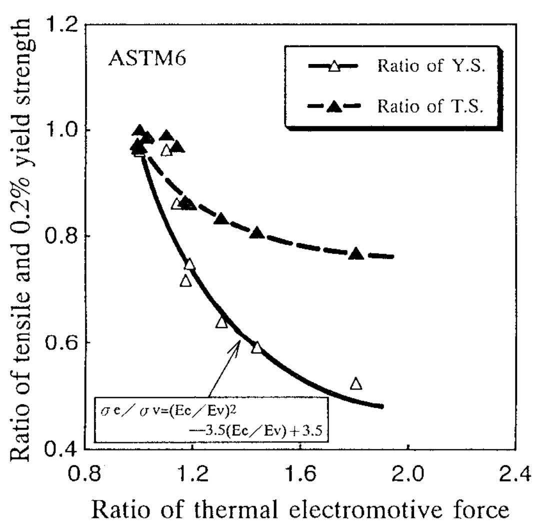


Fig. 7. Relation between ratio of TEF and ratio of tensile and 0.2% yield strength in the specimen with a grain size of ASTM6.

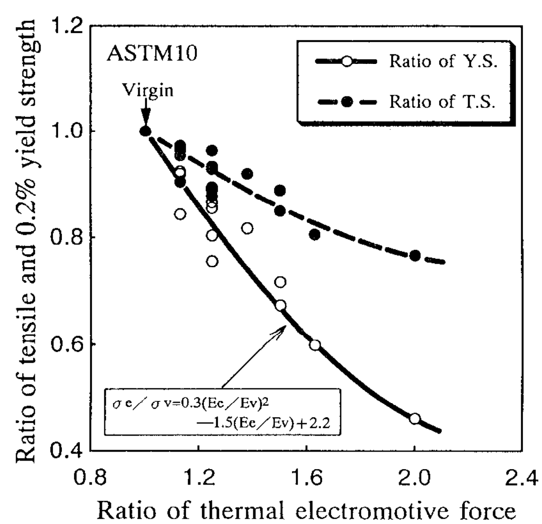


Fig. 8. Relation between ratio of TEF and ratio of tensile and 0.2% yield strength in the specimen with a grain size of ASTM10.

In order to consider the cause of TEF changes during the thermally exposures, the morphology of precipitations in Inconel 718 was investigated. It is well known that Inconel 718 has γ ', γ " and δ phase precipitations. It is necessary to determine an amount of the these phases quantitatively in order to clarify the changes in ratio of TEF in Inconel 718.

In another our study, it was confirmed that the morphology change of γ ' phase in single crystal alloy did not affect the changes in ratio of TEF.

Therefore, the area fraction of δ phase containing niobium were measured by using scanning electron micrographs. Relationship between the area fraction ratio of δ phase and ratio of TEF in the thermally exposed specimens with grain sizes of ASTM6 and 10 is shown in Fig. 9. Ratio of TEF corresponds linearly to the area fraction ratio of δ phase in the thermally exposed specimens. In virgin Inconel 718, the niobium is one of solid solution element and precipitation element of γ " and δ phases. On the other hand, γ " phase transforms to δ phase according to γ "+Nb→ δ + γ '. Thus, amount of niobium in matrix decrease and TEF value increase.

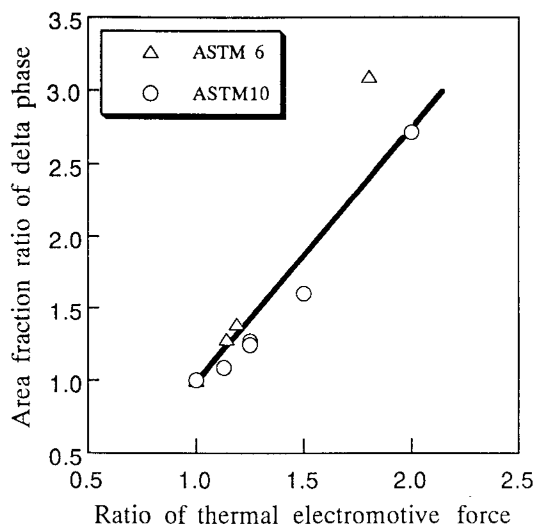


Fig. 9. Relation between TEF and area fraction of delta phase in thermally exposed specimens.

3. Application of TEF method for the degradation inspection in turbine disk

Usually, hardness changes, electrochemistry or electrical resistivity method are studied for the non-destructive inspection methods of the material degradation. In this study, hardness measurement method which is generally used for the inspection method in turbine disk and TEF inspection method which is first applied in this study have been investigated for the useful non-distractive inspection method. Then, from the point of view on the sensitivity of the degradation or easiness for application in the actual turbine disks, two methods are mentioned here.

Changes in ratios of TEF and hardness as a function of Larson-Miller Parameter with the exposed specimens in shown in Fig. 10. In the specimens at the same exposure condition, the variation of ratio of TEF is more larger than that of ratio of hardness. Since values of hardness have some deviations in the actual

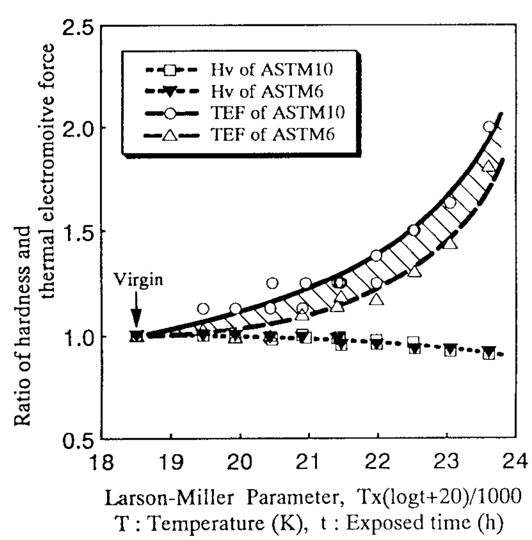


Fig. 10. Changes in ratio of hardness and ratio of TEF as a function of Larson-Miller Parameter.

inspection at shop, the degradation of turbine disk serviced during long term is hardly detected by hardness measurement method. Even though TEF value has any deviation, the degradation of turbine disk can be detected exactly because of high sensitive detector. Therefore, the sensitivity in TEF inspection method is superior to that in another non-distractive methods such as hardness measurement method. Additionally, if TEF measurement of the turbine disk is carried out, the turbine disk is not damaged. This point is completely different from another measurement such as hardness measurement.

The flow chart of TEF inspection method in serviced turbine disk is shown in Fig. 11. Reliability of TEF measurement shall be confirmed by using standard silver block. The standard value of TEF, it is very important so as to estimate an amount of the degradation, shall be measured at the turbine disk bore portion without thermal influence during service. After measurement of the standard value, TEF values at the rim portion, damaged by thermally exposure, shall be measured. Ratio of TEF can be calculated from TEF values at the bore and the rim portion by using the equation as shown in Fig. 11. TEF equipment as shown in Fig. 1, gives these mathematical value automatically. A degree of the degradation at the rim portion in serviced turbine disk can be calculated from the foregoing equation by using both ratio of TEF measured at the shop and 0.2% yield strength in the virgin specimen. In this inspection method, the manufacturing history such as chemical composition or heat treatment condition in serviced turbine disk can be neglected because measurements of TEF are carried out in the same disk. It is the considerable merit that 0.2% yield strength, it is the very important value for allowable stress for design in turbine disk, can be estimated exactly.

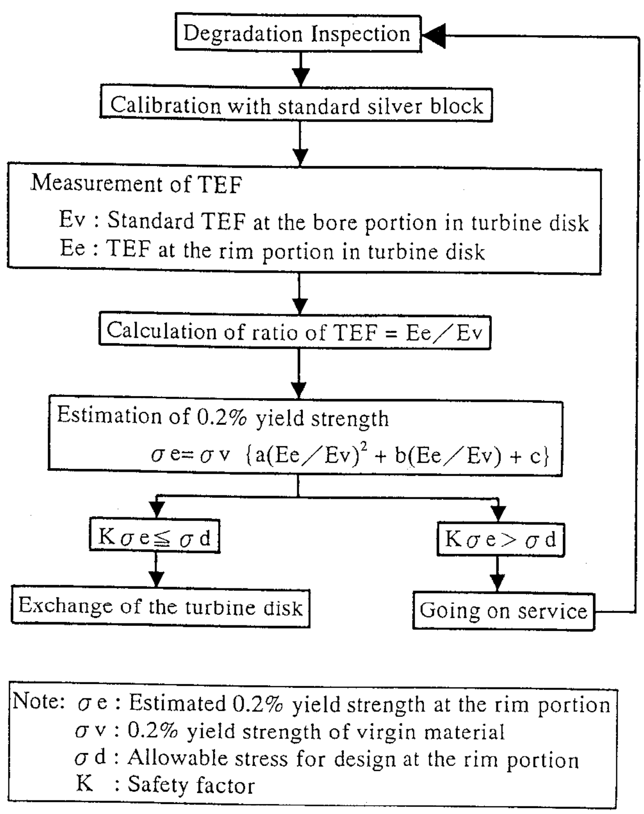


Fig. 11. Flow chart of the degradation inspection method in serviced turbine disk.

Conclusion

New non-destructive inspection method, namely TEF inspection method, is very simple and easy way in assessing the amount of the degradation in Inconel 718 exposed at elevated temperatures. We reach the following conclusions;

1. Changes of TEF ratios in thermally exposed Inconel 718 correspond to 0.2% yield strength. Therefore, there is a possibility to estimate 0.2% yield strength exactly by using TEF method.
2. Ratios of TEF in the thermally exposed specimens correspond to the area fraction of δ phase containing niobium in Inconel 718.
3. The sensitivity of the degradation in TEF inspection method is superior to that in another non-distractive inspection method such as hardness measurement method. Additionally, TEF inspection method is available for service turbine disk at the shop.

Reference

1. J.F.Radvich, Superalloy 718-Metallurgy and Applications, TMS(1988), pp229.
2. J.F.Radvich, Superalloy 718-Metallurgy and Applications, TMS(1988), pp257.
3. G.E.Korth and C. L. Trybus, Superalloy 718, 625 and Various Derivatives, TMS(1991), pp437.
4. Armida Oradei-Basile and J.F.Radvich, Superalloy 718, 625 and Various Derivatives, TMS(1991), pp325.
5. John F.Radvich and G.E.Korth, Superalloy 1992, TMS(1992), pp497.
6. N.Ohi and H.Hattori, 123rd Committee on Heat Resisting Metals and Alloys Report Japan, 34(1993), pp183.
7. W.Morgner, Material Evaluation, (1991), pp1081.
8. A.W.Dix, J.M.Hyzak and R.P.Singh, Superalloy 1992, TMS(1992), pp23.