INFLUENCE OF IN-SERVICE AND TECHNOLOGICAL FACTORS ON THE CYCLIC FRACTURE TOUGHNESS OF TURBOJET BLADES

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ABSTRACT

This paper presents the result of turbojet blades toughness research. Several groups of turbojet compressor blades were studied. Groups differed in alloy mark, heat treatment regimes and manufacturing technology; form and dimensions were identical. Special experimental computer-driven plant based on electromagnetic vibrator was used. Crack propagation speed and threshold stress level were defined, kinetic fatigue fracture diagrams were found.

KEYWORDS

Cyclic fracture toughness, turbojet blades, life time prediction.

INTRODUCTION

Fatigue fracture is the most frequent cause of turbojet blades failure. Fatigue crack is usually the result of service induced or technological defect (outer object impact notch, stamping crack). It is impossible to exclude such defects completely. It is important to know what material, technology, heat treatment is to be chosen in order to make a crack grow slower and what loading a crack is not dangerous at.

The solution of these problems must be based on cyclic fracture toughness characteristics analysis. The present work tasks are: to develop an experimental technique for this characteristics determination; to make up a material and technology selection recommendation; to make up a crack growth model for life time prediction.

THE EXPERIMENTAL TECHNIQUES

Particular features of turbojet blades are: a complex geometric form, specific surface layer structure, residual stress. These factors are the result of blades manufacturing method and heat treatment and that is why it is important to reproduce them in an experiment. Therefore the particular feature of experimental technique is the use of natural blades (not specimens) for determination of cyclic toughness characteristics.

Special experimental plant was fabricated. The plant basis is the electromagnetic vibrator. There is a special device for reproduction of real static loading and asymmetric loading cycle. The heating device has a window for visual fracture processes monitoring. The microscope for this monitoring is equipped with the television system. There is also the acoustic emission system for crack stopping check. The tested blade is loaded by dynamic high frequency stress in resonance vibration regime.

The plant control, information record and result calculation is produced by IBM PC type computer with CAMAC interface. This system is adaptable and allows modification of experimental procedure easily. For modification of experiment only the computer program is need to be changed. The software for computer experiment control was designed.

The plant provides the following test conditions: arbitrary time-dependent regime of vibration amplitude loading and heating; random loading; asymmetric loading cycle. The crack propagation speed and detail life time may be defined under these conditions.

Crack propagation speed was determined for different crack lengths and dynamic stress amplitudes. Stress amplitude was reduced step by step to the level of fatigue crack growth threshold.

Stress reduce step was nearly 5%. Crack length was measured at the beginning and at the end of every step by microscope with an error smaller than 0,008 mm. The crack speed was calculated by length-time curve differentiation. Crack was initiated by special sharp notch on the front edge near the blade base (Fig. 1).

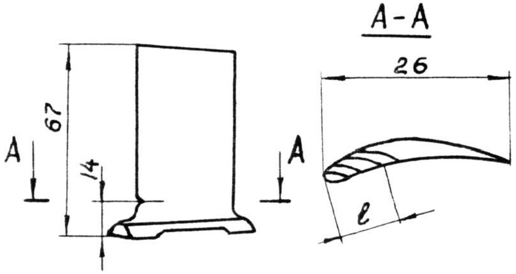

Fig.1. Turbojet blade with a crack.

Blades life time from crack initiation to complete fracture is the clearest characteristic for comparison of materials, manufacturing methods, heat treatment variants. It reflects the interaction of marked technological factors and in-service factors (static and dynamic stress, duration of regimes). Life time was studied on the base of experimental data with the help of created mathematical model and computer program.

Crack propagation speed is described by equations

$$d\ell/dN = \begin{cases} 10^{-7}(\Delta K/\Delta K^{*})^{m} & if\ \Delta K > \Delta K th \\ 0 & if\ \Delta K \leq \Delta K th \end{cases} \qquad (1)$$

$$\Delta K = \Delta \sigma Y \ell^{1/2}, \qquad (2)$$

where ℓ - crack length, N - cycle quantity, ΔK and $\Delta K th$ - stress intensity factor double amplitude and its threshold level, ΔK^{*} and m - material cycle fracture toughness characteristics, $\Delta\sigma$ - stress double amplitude, Y - form factor.

Stress in turbojet blade consists of static σ_{st} and dynamic σ_{v} components. Exploitation blade loading consists of some blocks - service loading cycle.

Every cycle consists of some regimes with constant stresses. Typical flight cycle of turbojet blade loading is represented in Fig.2 (τ - time). The ability of stress and regime time random variation is realized. Program system for blades life prediction was designed. It realizes the equations (1), (2) integration with determinate or random stress variation.

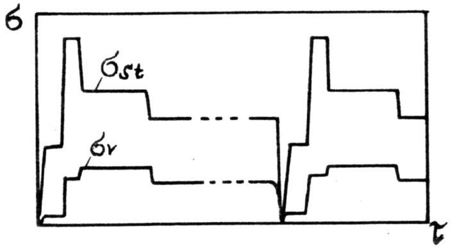

Fig.2. Typical blocks of blade loading.

STUDIED TURBOJET BLADES DESCRIPTION

Several groups of turbojet compressor blades were studied. Groups differed in alloy mark, heat treatment regimes and manufacturing technology; blades form and dimensions were identical. Marked characteristics of every group are presented in Tabl.1, blades form and dimensions - in Fig.1.

Tabl.1. Studied turbojet blades.

Group	Alloy mark	Manufacturing method	Heat treatment	Fatigue limit,MPa
1	BT3-1	mechanical treatment	double annealing (900,1h+650,2h)	465
2	BT8M	cold rolling	vacuum annealing	380
3	BT8M	mechanical treatment	double annealing (920,1h+550,2h)	517
4	BT8M	cold rolling	annealing (540, 2h)	403
5	ЭИ787	cold rolling	vacuum annealing	325

Blades of groups N 1 were made of titanium alloy BT3-1 and the others - of more plastic titanium alloy BT8M. Blades of group N 5 were made of high temperature steel. Blades of groups N 1,3 were made by swaging and mechanical treatment (templet milling, grinding, polishing). Blades of other groups were made by swaging , cold rolling and polishing of edges. This manufacturing method is more cheap and less labour-intensive, but there is no information about its technological characteristics influence on the blades cyclic fracture toughness.

There is some difference in fatigue limit for different blades groups. Blades of group N 3 have the highest fatigue limit. There is some difference in surface layer structure and residual stress for different blade groups. For example, blades of group N 4 have residual volume tension stress near the edges (nearly 50 MPa).

RESULTS

Crack propagation speed for different stress amplitude levels and different crack sizes are found in the result of the experiments. These results for blades of group N 1 are presented in Fig.3. Particular feature of all curves is the crack propagation stress threshold (left part of every curve). The longer the crack is, the threshold reduces. Crack propagation stress thresholds for different cracks length and for different blades groups are presented in Fig.4 (group numbers are marked near the curves).

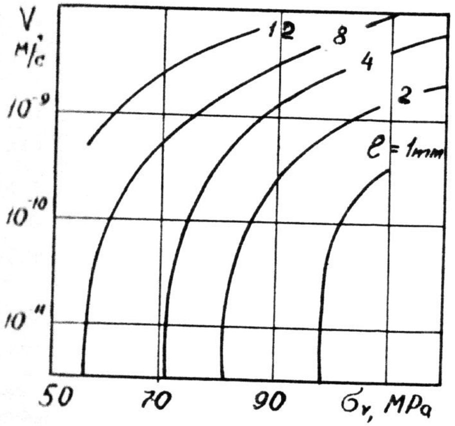

Fig.3. Fatigue crack propagation speed for one of the blades type.

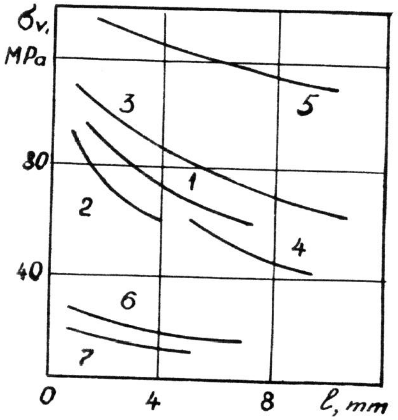

Fig.4. Threshold stress for different blade types.

It is found that there is considerable difference of cyclic fracture toughness indicators for different blades groups. This difference is considerable even in the case of identical alloy mark. This difference is the result of different technology and heat treatment. For example, crack propagation threshold stress for blades of group N 4 is reduced in the result of residual volume stress.

Cycle asymmetric (produced by static stress) influence on the fracture toughness was studied. In-service static stress in researched blades is nearly 150 MPa (cycle asymmetric ratio 0,77-0,85). This factor reduced the crack propagation threshold stress by 4-4,5 times.

This result is presented for blades of group N 3,4 in Fig.4. (curve N 6 - for group N 3; curve N 7 for group N 4). Life time analysis for different blade groups demonstrated the effect of technological and in-service factors interaction. The effect of this interaction is considerably nonlinear. It is the result of crack propagation speed difference and threshold stress for different blade groups. Definite operation stress can be dangerous for some blades and not dangerous for other. These results for the blades of group N 4 are presented in Fig.5. The crack grows from the initial length 2 mm step by step in every loading block, to complete the fracture in τ_{f1} moment (curve 1). This is life time. This result was compared with the in-service blade break, and the calculated result was found near the operation data τ_{f2} . Other materials or manufacture methods or heat treatment choice can make this initial crack not dangerous. Curve 2 in Fig.5. demonstrate behavior of blades of group N 3 τ_{f3} in the same situation.

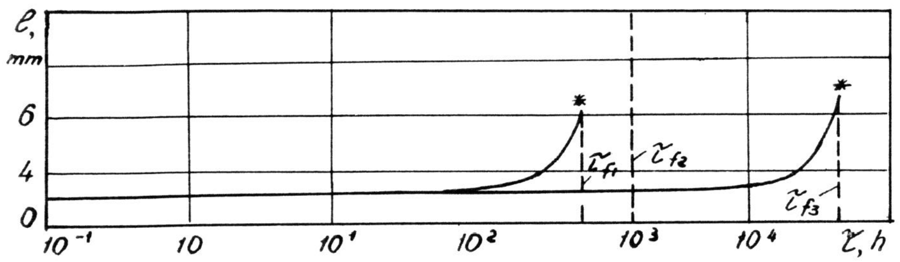

Fig.5. Crack propagation process.

CONCLUSION

Experimental data demonstrate the considerable influence of alloy mark, manufacturing method, heat treatment on the crack propagation speed and threshold stress. Threshold stress for different variants of marked factors are distinguished in 2-3 times for the identical form and dimension blades . This difference is very important for blades life time: the initial crack length may be dangerous for one type of blades and non-dangerous for other types.

Proposed in this paper experimental technique and computer programs can be useful to choice of blades material mark, manufacturing method, heat treatment regimes.