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PROGRESSIVE FATIGUE TESTING METHODS OF AIRCRAFT TURBINE ENGINE BLADE MATERIALS

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Abstract: *Safety is the most important value in aviation. However, an aircraft incident may occur. Sometimes, during operation or maintenance, new, previously unknown degradation effects can be observed and need to be tested or analysed in the shortest possible time. This article describes the advanced laboratory mechanical testing of turbine blades, combined with a data classification process, offering a way to find the root cause of some specific fatigue damage and thus contribute to increased operational safety.*

Keywords: Nickel superalloy, Fatigue crack growth, Small specimen testing, Aircraft turbine blades

1. Introduction

Turbine blades are critical components of aircraft engines and the failure of one can cause a catastrophic scenario. Engine certification specifications are defined in the CS-E standard of the European Aviation Safety Agency (EASA) or in the Part 33 standard of the Federal Aviation Administration (FAA). These standards cannot cover the entire set of all specific operations, such as rescue or firefighting missions due to the limitations of conventional ground, flight and laboratory tests. However, at present, the necessary durability and damage tolerance (DADT) assessment can be based on available models. This approach requires service relevant mechanical and fracture properties that are often not available. Progressive testing methods available at CTU such as blade testing at elevated temperature or small specimen resonance testing can be efficiently utilized. These methods are presented and set in the landscape of material testing for DADT with focus on turbine blade testing.

2. Current state of aircraft power unit certification testing

Each aircraft engine must be complied with associated certification program including design process and subsequent laboratory, ground, and flight tests. After this process one of aviation authorities (e.g., EASA or FAA) confirms airworthiness and issue a type certification. Then standard operation can start under the conditions of the operational manual. Service and maintenance procedures must be performed between the general overhauls (Kocáb and Adamec, 2020). These processes include tests such as boroscope or Non-destructive Testing (NDT) procedures. After final assembly, the engine is subjected to performance testing on a ground test rig and flight tests.

3. Air accident investigation procedures

If any serious accident happens, the competent aviation authority starts the air incident investigation process. The authority can restrict the operation of a given type until the causes are clarified. Sometimes this period can be long and additional testing (e.g., SEM, NDT, etc.) may be required during this investigation. Operators can be under extreme pressure when they don't know the root cause of a crash and face operating restrictions. Unfortunately, sometimes it is not possible to define the right cause of the failure. One reason can be the complexity of degradation effects.

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4. Progressive testing methods

This chapter submits information about methods that can be used when some material data are missing and obtaining them is very difficult.

One example of advanced testing procedures was performed by Bartošák, et al. (2024). The Inconel 718 Nickel superalloy specimen was subjected to high-temperature low-cycle fatigue and fatigue-creep analyses. Scanning Electron Microscopy (SEM) was used to investigate damage mechanisms and Transmission Electron Microscopy (TEM) was used to analyse deformation mechanisms. This procedure help understand the effect of prescribed loading conditions on damage and deformation mechanisms, fatigue lifetime and cyclic stress–strain response. This method can also be used for turbine blades.

Another innovative approach to identifying fatigue crack growth rate (FCGR) for life prediction was developed by Kovářík et al. (2017). This bending based small specimen testing method enables to test small amounts of materials with specific service history. At the same time, the method provides FCGR data fully comparable with established FCGR curves for classical aerospace materials such as 7075 Aluminium alloy and 4043 high strength steel. This method is relevant for superalloys testing, so far Inconel 718, Inconel 738 and Inconel 625 alloys were tested. The small specimen size allows to determine the crack growth rate curve of a miniature specimen cut from small parts such as a turbine blade.

Progressive challenges in the field of material degradation during operation or maintenance can be applied by using these two mentioned methods with standard borescope procedure combined with automated microscopic image analysis and subsequent machine learning algorithms.

Three examples of the possible use of the mentioned methods above are presented. As a demonstrator a turbine blade of a helicopter turboshaft engine was chosen (Fig. 1).

Fig. 1: The turbine blade after the service life

The first example shows the surface of the non-homogeneous protective layer (Fig 2), (Rohlová, 2017) after the general overhaul. The blade with the allowed interval of the protective layer thickness is determined by the type certificate holder, but usually only visual inspection and measurement of SEM results are performed. This type of image can be subjected to data classification procedures and after the overhaul procedure can be automatically defined as suitable or not suitable according to the allowed interval. Methods performed by Bartošák (2024) can bring more precise information about the mechanical degradation of overhauled blade and define whether the blade is airworthy or not.

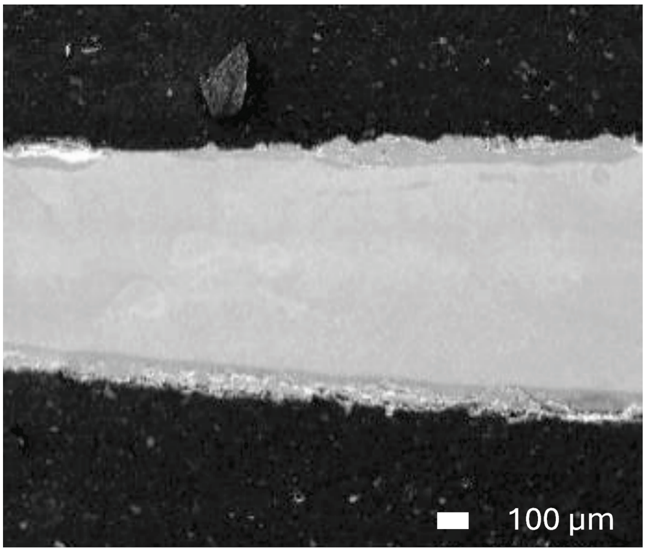

Fig. 2: The turbine blade surface after the general overhaul

The second example shows the same type of the blade after the service life. Fig. 3 shows the surface degradation in deeper detail. The blade surface is full of specific non-homogeneous craters. Maximal observed diameter of these craters is 20µm with maximal depth 10µm.

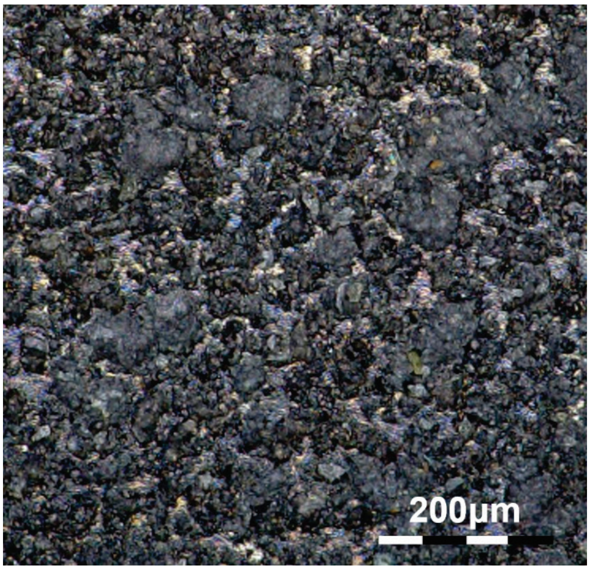

Fig. 3: The turbine blade after the service life in detail

These craters were also observed in the blades during the operation. Knowledge of fatigue prediction defined by the first two methods, combined with data classification analysis, can determine whether turbine blade with specific degradation is still suitable or unsuitable for further operation.

Another example of the possible using of automated microscope image analysis is show in Fig 4. The initial short fatigue cracks can growth from the protective layer to the basic material. Human factors significantly influence the NDT results, machine learning and data classification are applied to decrease the human errors such a false positive or false negative finding. Fatigue crack growth rate data can then help to define residual fatigue life and crack prediction.

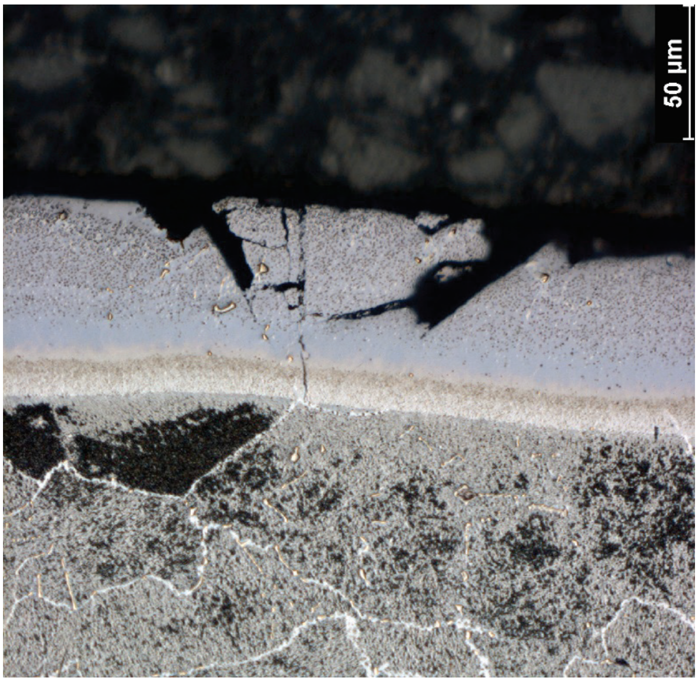

Fig. 4: The protective layer of the turbine blade in detail after the service life

5. Conclusions

Using methods performed by Bartošák, et al. (2024) and Kovářík, et. al (2017) in combination with automated image analyses and data classification algorithm can be applied throughout the entire life cycle of the blade and can divide the blades into airworthy and non-airworthy according to predefined criteria. Ideally, after this classification, it should be defined how many cycles the airworthy blade can be operated. Once optimized and standardized, these methods can significantly increase operational safety.

Using these procedures in real operation can provide:

- Faster acquisition of new material data
- Clarification of some specific degradation effects

Using these procedures in maintenance procedures can provide:

- More reliable NDT results
- More reliable visual inspection results

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