# High-temperature fatigue testing of turbine blades

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**Abstract.** The effectiveness of the patented grip for high-temperature fatigue testing was assessed through the determination of the S-N curve for the full-scale nickel-based turbine blades operating under their environmentally simulated conditions. Before fatigue investigations, a bending test was performed to reflect the stress-displacement characteristics of the component examined. Subsequently, a series of fatigue tests were carried out at 950°C under a cyclic bending for selected values of force amplitude (5.2 kN – 6.6 kN) and frequency equal to 10 Hz. The proposed setup involving a grip fixed to the conventional testing machine was effectively used during high-temperature tests since the service life of the full-scale components was successfully determined.

**Keywords**: fatigue, high temperature, turbine blade, full-scale fatigue test

## Introduction

The performance and efficiency of aircraft engines largely depend on the inlet gas temperature. Increasing the flue gas temperature to the combustion point of aviation fuel (~2300°C) is desirable, but limited by the strength of materials used in turbine blades. Nickel-based superalloys, with excellent corrosion and creep resistance, are typically used in these conditions. Applying thermal barrier coatings (TBC) extends the effective service temperature to 1300°C, while keeping blade attachment temperatures below 300°C. The harsh operating environment, with factors like oxidation, hot corrosion, erosion, and foreign object damage, accelerates turbine blade degradation. High-temperature fatigue testing is critical for assessing material durability, but standard tests on simplified specimens often fail to capture the complex behaviour of full-scale components. Recent methods aim to bridge this gap. However, research on blade behaviour under high-temperature fatigue remains limited. Damage typically results from a combination of fatigue, creep, oxidation, coating degradation, and surface wear. To address these challenges, this paper presents a new grip design for high-temperature fatigue testing and determines the S-N characteristics of full-scale nickel-based turbine blades under simulated environmental conditions.

## Results

High-temperature fatigue tests were conducted using the MTS 810 and a patented testing stand (Kopec et al., 2023) placed in conventional servo-hydraulic machine grips (Fig. 1a). After mounting the turbine blade (Fig. 1b), an induction heater raised the temperature to 950°C (Fig. 1c). Force control mode applied loads to the blade via an Inconel round-ended bar, with load amplitudes ranging from 5.2 kN to 6.6 kN at a 10 Hz frequency. Temperature stability was monitored with a bicolor infrared pyrometer (Fig. 3c). Fatigue tests began 1 hour after reaching the target temperature, allowing thermal expansion effects to stabilize. The tests continued until blade fracture (Fig. 1d), with results presented as hysteresis loops for selected cycles. The heat-resistant Inconel testing stand provided high rigidity and minimized bending effects, ensuring accurate high-temperature fatigue testing.

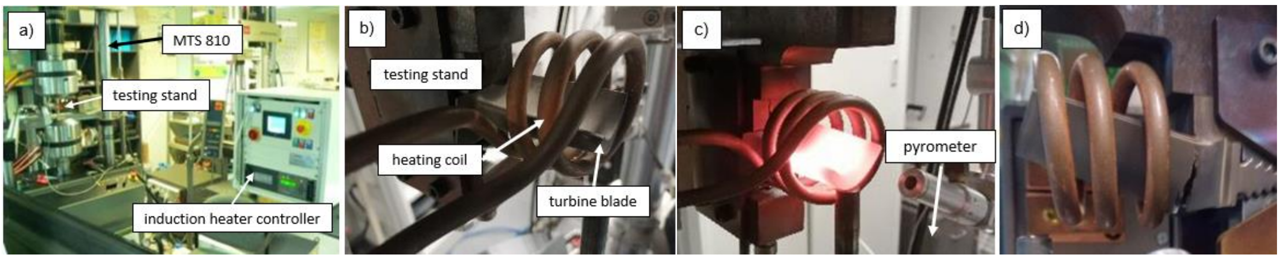


**Fig. 1.** Overview of the experimental setup (a); turbine blade mounted in the grip within the heating coil (b); high-temperature fatigue testing at 950°C (c); fractured turbine blade post-testing (d).

Initially, a uniaxial bending test was conducted to determine the fracture force for the turbine blade in the testing grip (Fig. 2a). A reference force of 6.8 kN at 4 mm displacement was established, defining the bending force amplitude range for fatigue tests. Six fatigue tests were carried out with force amplitudes between 5.2 kN and 6.6 kN, leading to the creation of the S-N curve (Fig. 2b). High-frequency data recording enabled the analysis of hysteresis loops (Fig. 2c-d). Blade behaviour varied with applied force amplitude: a nearly elastic response at 5.8 kN (Fig. 2c) and noticeable loop distortion at 6.2 kN (Fig. 2d). The loop deformation likely resulted from plastic deformation caused by higher forces during repeated loading cycles. Notably, the turbine blade's behaviour was consistently tracked through the force-displacement relationship, regardless of the applied force amplitude. Furthermore, the heating system adopted to the testing stand enabled to maintain the high temperature during the experiment within the reasonable scatter range of ±3°C (Fig.2e).

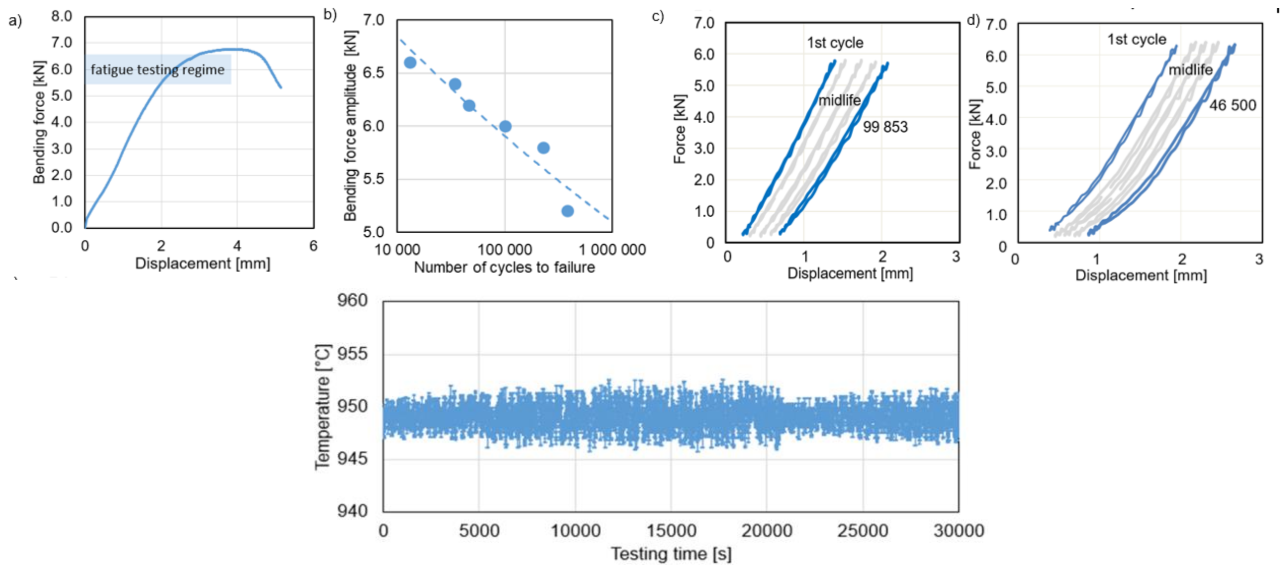


**Fig. 2.** Bending characteristic of the exemplary turbine blade at 950°C (a); S-N curve for turbine blades subjected to fatigue at 950°C (b); selected hysteresis loops obtained for the force equal to 5.8 kN (c) and 6.2 kN (d); temperature recordings during testing (e).

## Conclusions

Effectiveness of the proposed experimental setup for high-temperature testing of full-scale turbine blades subjected to cyclic loading was successfully assessed during fatigue tests executed at 950°C. It was confirmed, that the design of the new testing stand enabled precise determination of both, the S-N characteristic and the hysteresis loop evolution recorded throughout the experimental programme. Furthermore, the fatigue damage development of the turbine blades was effectively monitored based on the data recorded during tests.

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