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# Use of ball indentation technique to evaluate room temperature mechanical properties of a gas turbine blade

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**Abstract**

Ball indentation technique (BIT) has been used to explore its usefulness in revealing the effect of high temperature exposure on mechanical properties of a gas turbine (GT) blade of Ni base super alloy. The dependence of yield strength (YS), ultimate tensile strength (UTS), strength coefficient ($K$) and strain hardening exponent ($n$) values on different exposure time are available from the BIT results and they are validated with the standard conventional test results. It is found that while exposing at high temperature (760 °C), the room temperature mechanical properties of the virgin blade have diminished. The diminishing of mechanical properties of the exposed blade (15,000 h) is due to the average size increment of the $\gamma'$ particle. Again, the average grain size of the 15,000 h exposed blades is greater than the virgin one and it might be another cause for decreasing the YS and UTS. No further significant changes of mechanical properties were observed when the exposure time was increased to 30,000 h at the same temperature. Overall, it is found that BIT can be effectively used to determine the minute changes of mechanical properties due to microstructural variation.


*Keywords:* Gas turbine blade; Ni base alloy; Carbides; $\gamma'$ particles; Ball indentation test; Mechanical properties; Spherical indenter

## 1. Introduction

The efficiency of a gas turbine (GT) is highly dependent on the performance of the blades, thus it is important to know the degradation of the blade materials during service exposure [1,2]. Some high temperature materials become brittle at room temperature after long operating time, but they remain ductile at high temperature [1,2]. This degradation may be due to either increment of the sizes of $\gamma'$ precipitates or changes of the morphologies/compositions of the carbide precipitates, thus evaluation of room temperature mechanical properties is important.

Conventional mechanical testing needs sufficient amount of test materials. In case of GT blades, the availability of required test material may not sufficient for conventional mechanical testing. In this regard the ball indentation technique (BIT) is an ideal replacement for evaluating mechanical properties of aged components and it needs very small amount of test materials [3–9].

BIT has edge over the conventional mechanical test in use of small amount test materials [3–9]. The present authors have conducted a series of BI test on various materials (both ferrous and non-ferrous) using an in-house developed laboratory scale ball indentation (BI) set-up [10–16]. It was found that the BIT could be successfully employed to evaluate their mechanical properties [10–16].

It was Haggag and his co-workers [17,18] who developed a field indentation microscope where it has been possible either to use small amounts of test materials or as in situ on actual components. By using Haggag's set-up [17,18] many groups [19–21] have worked on various materials to evaluate their mechanical properties.

The objective of the present work is to estimate, if any, degradation of GT blades after a long time exposure at high temperature. The work also attempts to make correlation between mechanical properties and microstructure of the new and exposed blades. The BIT results were validated by conventional mechanical testing with miniature test samples.

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Table 1
Showing the elemental composition of the investigated materials (in wt.%)

| | |
|---|---|
| C | 0.12 |
| Si | 0.6 |
| Mn | 0.5 |
| Cr | 14.0 |
| Mo | 2.4 |
| V | 0.5 |
| W | 5.7 |
| Al | 2.4 |
| Fe | 5.0 |
| Ce | 0.02 |
| Ti | 2.2 |
| P | ≤0.015 |
| S | ≤0.01 |

## 2. Experimental

### 2.1. Test materials

A virgin (new) turbine blade and two other blades (all are from second stage) with different service exposure times have been considered for the present investigation. The new blade is designated as ‘A’. The others are as ‘A1’ and ‘A2’, exposed for 15,000 and 30,000 h, respectively, at 760 °C. The blades are made of nickel base superalloy. A nominal composition of this alloy is listed in the Table 1.

### 2.2. Test approach and procedure

The basic principle of the ball indentation technique is multiple indentations by a spherical indenter at the same test location on the test sample with intermediate partial unloading. Here, a spherical ball with specific rate of loading indents the test materials and multiple indentations in a single position is made through loading–unloading–reloading sequences. Spherical balls of different diameters have been used to get multiple stress–strain data points. Here, the load increases approximately linearly with penetration depth. This is due to two non-linear but opposing processes occur simultaneously, i.e. the non-linear increase in the applied load with indentation depth due to the spherical geometry of the indenter and non-linear increase of load with indentation depth due to the work hardening of the test pieces. During each subsequent loading the amount of materials experiencing plastic deformation increases, so continuous yielding and strain hardening occurs simultaneously.

In the experimentation, the multiple load–depth curves ($p$–$\delta$) constitute the raw data. For each cycle, the total ($h_t$) as well as plastic indentation depth ($h_p$) and corresponding applied load are obtained from $p$–$\delta$ curves. The computer programme determines the slope of the unloading cycle. The intersection of this line determines the value of $h_p$.

A laboratory scale BI setup [10–16] has been employed for BI testing. Standard tabletop mechanical testing machine of 10 kN capacity with a 5 kN load cell has been converted into the present

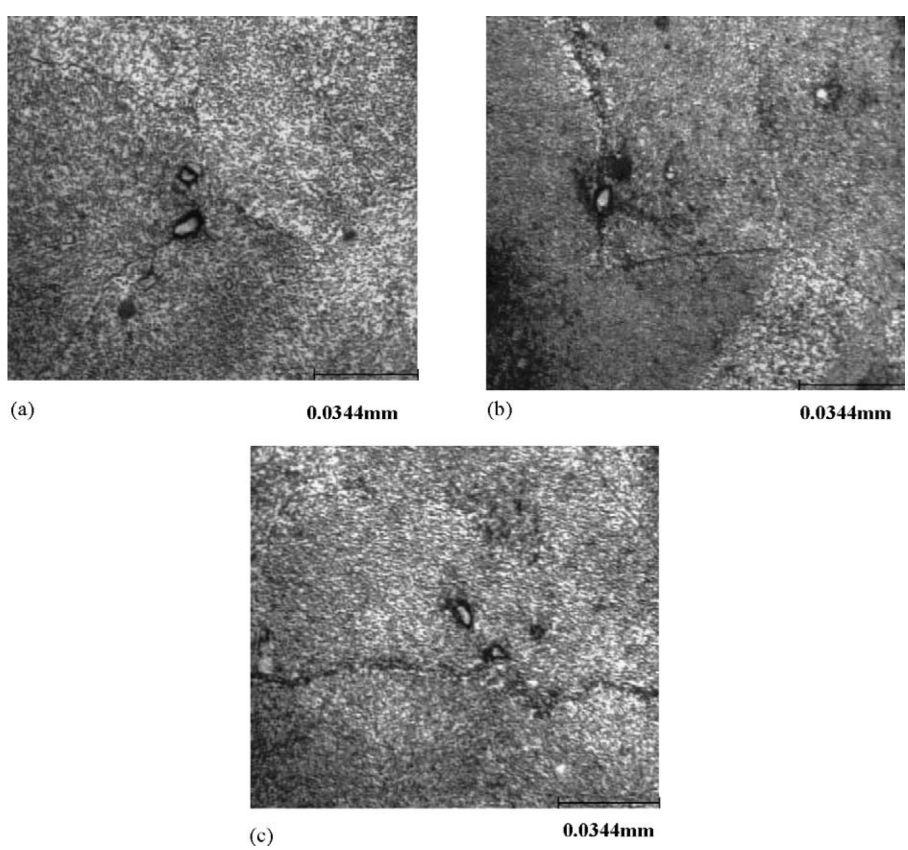


Fig. 1. Optical micrographs of the GT blades, showing carbide precipitates for (a) new blade, (b) 15,000 h exposed and (c) 30,000 h exposed at 760 °C.