



## Original Article

# Comparative study of mechanical properties using standard and micro-specimens of base materials Inconel 625, Inconel 718 and Ti-6Al-4V

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### ABSTRACT

To improve innovative joining and deposition technologies for the construction of dissimilar joints, precise knowledge of the local mechanical properties of materials must be obtained. In the present article a comparative study of the tensile properties and fatigue behaviour in case of flat standard and micro-specimens of base materials Inconel 625, Inconel 718 and Ti-6Al-4V was accomplished. The aim of the study was to develop an efficient method for the investigation of the local mechanical properties by the use of micro-specimens subjected to electro discharge machining treatment and to obtain reliable tensile and fatigue test results. By the miniaturization of specimens a significant effect of roughness on mechanical properties was obtained. By considering a correction for the effective load-bearing cross-section the data obtained from micro-specimens are within 3% error with respect to standard specimen results. The results showed that the proposed technique can be successfully used to determine the tensile and fatigue properties of a small material volume.

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## 1. Introduction

The miniaturisation of tensile specimens for obtaining reliable mechanical characteristics of small volumes is limited by the micro-structural properties of the material [1,2]. A large variety of micro-tensile specimens were developed for different materials [3-8]; however, scientific publications on small-scale fatigue tests are relatively rare [3,5,7]. The miniaturisation of specimens causes scaling effects, which lead to different

mechanical behaviour with respect to standard macro-tensile tests [5,7,8]. Nevertheless, studies that compare the mechanical characteristics of micro-specimens and standard specimens are scarce [4]. In the current study, the tensile and fatigue properties of base materials Inconel 625, Inconel 718 and Ti-6Al-4V are compared, and the transferability of mechanical characteristics from standard flat to micro-flat tensile and fatigue specimens at ambient temperature is investigated.

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## 2. Experimental procedure

In the present study, nickel-base super-alloys Inconel 625 and Inconel 718 as well as the titanium alloy Ti-6Al-4V were investigated. All specimens were fabricated from sheet material parallel to the rolling direction. Standard tensile specimens (3 specimens for each material) were fabricated according to the recommendations of ASTM E8-04, DIN EN 2002-001:2006-11 and DIN EN ISO 6892-1:2009-12 (load-bearing cross-section = 12.5 mm × 3.1 mm, total length of 165 mm). Standard fatigue specimens (9 for Inconel 625, 8 for Inconel 718 and 10 specimens for Ti-6Al-4V) were fabricated according to the recommendations of ASTM E-466, ASTM E-468 and DIN 50100 (load-bearing cross-section = 10 mm × 3.1 mm, total length of 150 mm). All micro-specimens (3 micro-tensile specimens for each material, 15 micro-fatigue specimens for Inconel 625, 18 micro-fatigue specimens for Inconel 718 and 27 micro-fatigue specimens for Ti-6Al-4V) with a thickness of 0.5 mm were extracted via electro discharge machining (EDM), and the geometry of micro-specimens was designed on the basis of standards DIN EN 2002-001:2006-11, DIN EN ISO 6892-1:2009-12 and DIN 50100 (Fig. 1). To investigate the influence of the surface roughness on the obtained mechanical values for all of the materials, the surfaces of micro-fatigue specimens (4 specimens for each material) were polished. The average maximum height of the profile,  $R_z$ , was measured by the use of a *Veeco Dektak 6M Stylus Profilometer* according to the DIN 4768/1 standard.

All of the mechanical tests were performed at ambient temperature. The tensile and fatigue tests were performed using standard techniques. For micro-tensile specimens, a 5 kN electro-mechanic universal testing machine with a constant transverse main displacement was used. The load was introduced using a special specimen adaptor. The displacement was measured with a laser extensometer. For the micro-fatigue specimens, a 5 kN high-frequency resonance

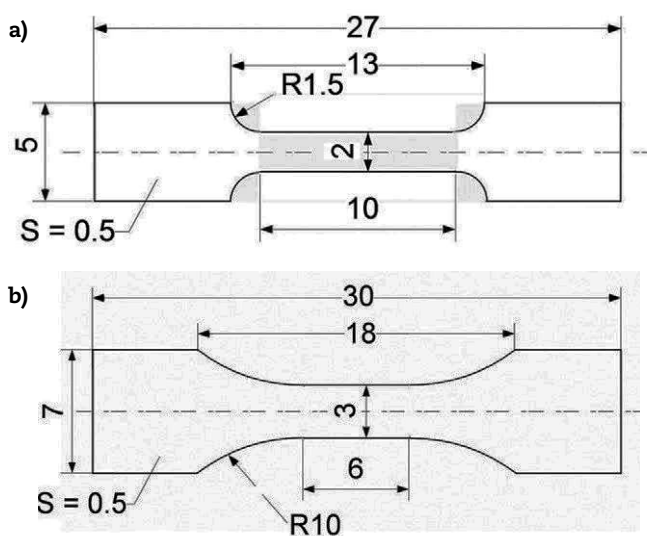


Fig. 1 – Dimensions of micro-specimens used in (a) tensile tests and (b) fatigue tests (all of the dimensions are in mm).

testing machine was used. The tests were conducted with force control using a sinusoidal wave-form with a frequency between 123 Hz and 130 Hz. The stress ratios ( $R$ ) were equal to 0.1. The maximal stress of an undamaged fatigue-tested specimen after  $N \geq 10^7$  was identified as the endurance strength at high-cycle fatigue. To obtain stress-number (SN)-curves, only specimens with damage within the gauge length were used.

## 3. Results and discussion

The micro-hardness, grain size and roughness results for the different surface preparations of the specimen are presented in Table 1. The aim of the current study was to develop an efficient method for the investigation of the local mechanical properties of micro-specimens subjected to EDM treatment and to obtain reliable tensile and fatigue test results. A correction factor for the measured stress values was based on micro-specimens with high  $R_z$  values according to their effective load-bearing cross-section,  $A_{eff}$ , calculated from

$$A_{eff} = (S - 2R_z) \cdot (W - 2R_z) \quad (1)$$

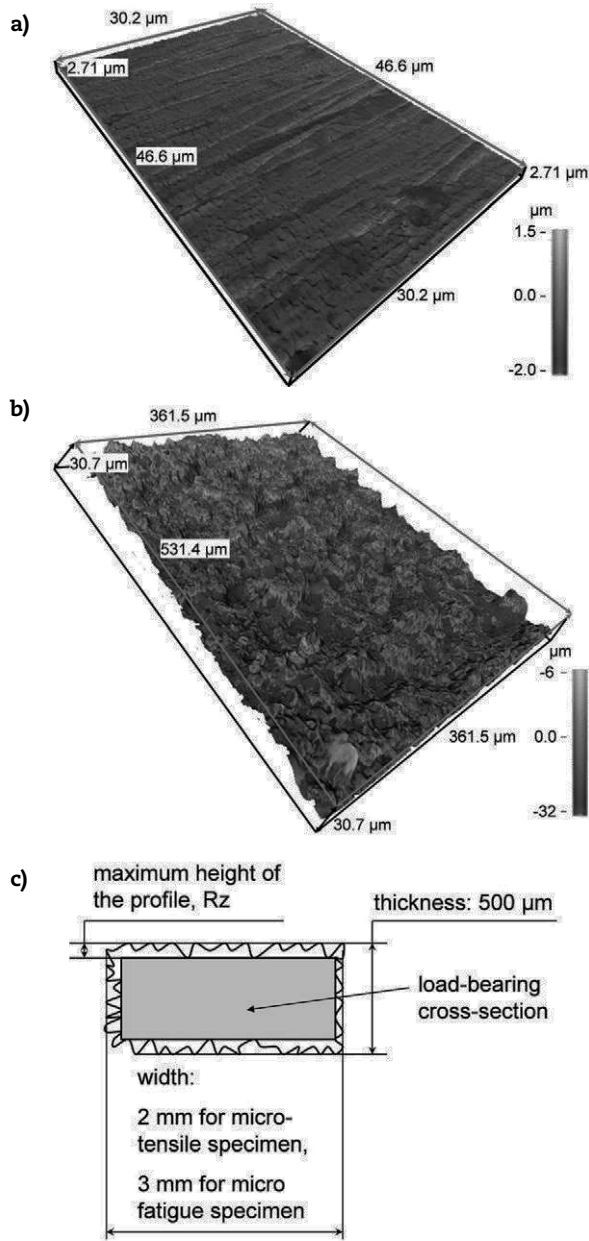
where  $S$  is the thickness and  $W$  is the width of the micro-specimen (Fig. 2). The results of the tensile tests are summarised in Table 2, and the stress-strain curves obtained for standard and micro-specimens are compared in Fig. 3. If the actual load-bearing cross-section is corrected according to Eq. (1) only minor differences between the strain-stress curves and the yield and tensile strengths are detected. The observed differences between the obtained elongations are attributed to size effects.

The results of the fatigue tests are presented in Fig. 4, which displays the stress-number (SN) curves. In case of Inconel 625 and Inconel 718 an increasing difference in the number of cycles until fatigue failure between standard and micro-specimens can be observed with increasing stress amplitude (Figs. 4a and 4b). However, in case of Ti-6Al-4V, there are a nearly constant difference in the number of cycles until fatigue failure between standard and micro-specimens within the entire stress region (Fig. 4c). Also the results of the

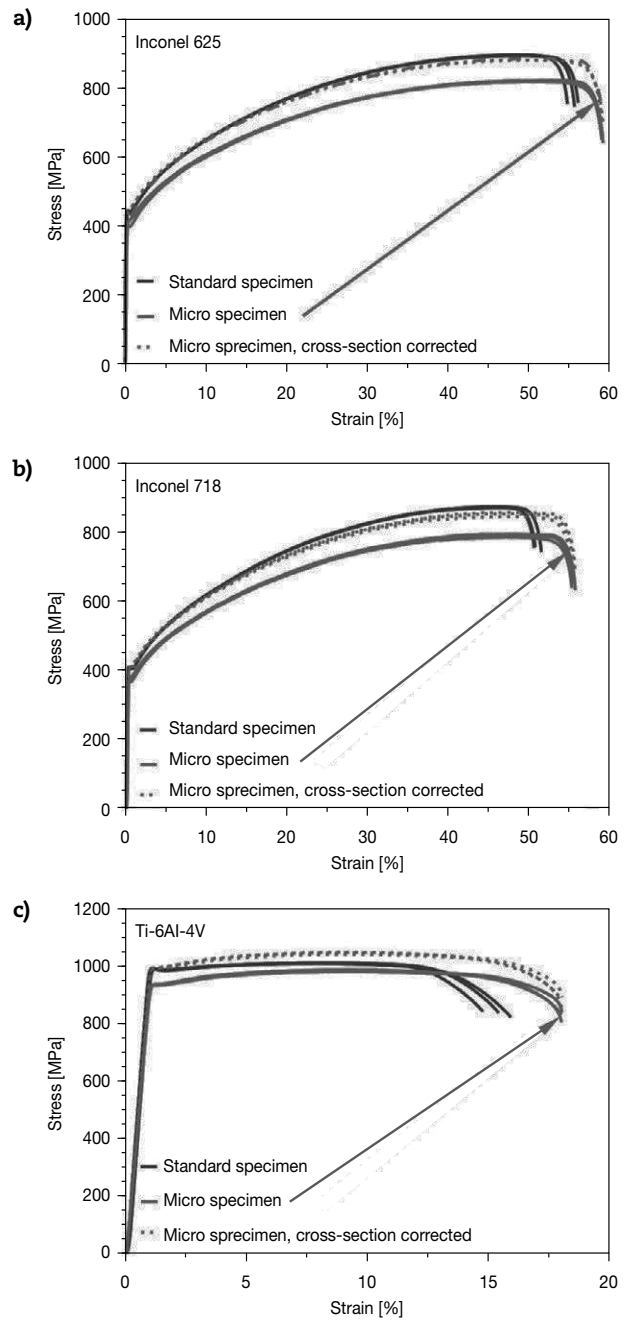
Table 1 – Micro-hardness, grain size and roughness results.

Material	Micro-hardness [HV 0.5]	Grain size [ $\mu\text{m}$ ]	Max. height of the profile, $R_z$ [ $\mu\text{m}$ ]		
			SS	MS	MSP
Inconel 625	220	11	2.71	30.7	3.56
Inconel 718	210	12	3.67	24.1	1.74
Ti-6Al-4V	339	5.5	5.60	20.7	1.83

MS: obtained from micro-tensile and micro-fatigue specimens subjected to electro discharge machining treatment; MSP: obtained from micro-tensile and micro-fatigue specimens subjected to electro discharge machining and polishing treatment; SS: obtained from standard specimens.



**Fig. 2 – (a) SEM-image of the standard specimen surface subjected to polishing treatment (Inconel 625); (b) SEM-image of the micro-specimen surface subjected to EDM (Inconel 625); and (c) schematic representation of the actual load-bearing cross-section of a micro-specimen.**



**Fig. 3 – Stress-strain curves of base materials obtained by testing standard and micro-specimens.**

**Table 2 – Summarized results of tensile tests, average values with standard deviations of three test specimens.**

Material	Tensile strength, $R_m$ [MPa]				Yield strength, $R_{p0.2}$ [MPa]				Elongation, $A_5$ [%]		
	S	SS	MS	MSC	S	SS	MS	MSC	S	SS	MS
Inconel 625	890	896 ± 1	821 ± 2	884 ± 2	450	442 ± 2	409 ± 9	436 ± 7	50.7	55.4 ± 0.7	58.9 ± 0.1
Inconel 718	865	891 ± 2	808 ± 5	871 ± 6	390	417 ± 1	386 ± 6	420 ± 4	50.3	50.8 ± 1.4	56.0 ± 0.2
Ti-6Al-4V	930	1,019 ± 2	992 ± 3	1,052 ± 3	865	998 ± 3	943 ± 2	1,000 ± 2	14.0	15.1 ± 0.5	17.9 ± 0.01

MS: obtained from micro-tensile specimens; MSC: obtained from micro-tensile specimens, the cross-section was corrected for roughness; S: according to the manufacturer's specification; SS: obtained from standard specimens.

micro-fatigue specimens polished after EDM treatment were within the scatter band of the fatigue life for standard-fatigue specimens. Analogous to the tensile tests results, minor differences are observed between the SN-curves when the actual load-bearing cross-section is corrected using Eq. (1).

Then the fatigue life is similar for standard and micro-fatigue specimens.

#### 4. Conclusions

Micro-tensile and micro-fatigue test techniques were established and validated. The results of the present study showed that the proposed technique can be used to determine the tensile and fatigue properties of a small material volume. This technique is needed for small components, such as turbine blades, or for investigating the property distribution in welds. The findings of the current investigation can be summarised as follows:

- A significant decrease of the load-bearing cross-section due to roughness reduces the tensile strength and yield strength of micro-specimens. Independent of the specimen size and surface preparation this effect can be corrected by roughness measurement and calculation of the effective cross-section area. For Inconel 625, Inconel 718 and Ti-6Al-4V, the remaining differences in the yield strength and tensile strength are within 3% when the correction for the real load-bearing cross-section is considered.
- The values of elongation to failure obtained with micro-tensile specimens are higher than those from standard specimens. Despite the significant reduction in the specimen size the difference is still within about 10% of the correct value.
- The suggested approach for correcting the actual load-bearing cross-section is also applicable to micro-fatigue specimens. After correction the data obtained from micro-fatigue specimens are within 3% error with respect to standard specimen results.

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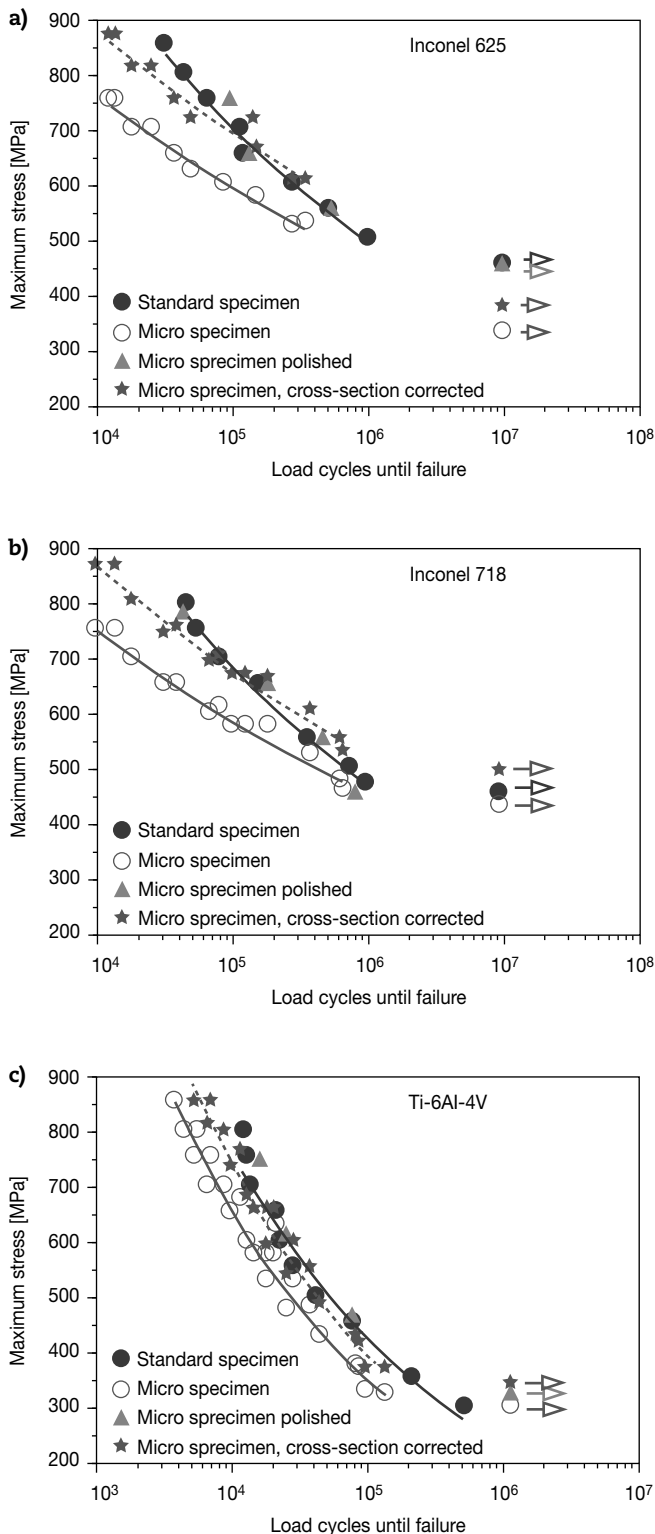


Fig. 4 – Results of the fatigue tests.

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