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Characterization of the Fracture Morphology of Commercially Pure (cp)-Titanium Micro Specimens Tested by Tension-Compression Fatigue Tests

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Abstract

Surface modification could improve functional or mechanical properties of components, which are used for example in biotechnological or automotive applications. Thereby, small structures produced by micro milling or laser structuring processes are in the same order as the grain size. They act as geometrical notches and could reduce the mechanical properties.
In this work we will show detailed investigations of the fracture morphology of tension-compression tested micro notched specimens. The fracture surfaces were analyzed with a Scanning Electron Microscope (SEM) to determine the location of the failure. Furthermore metallographic microsections of some specimens were prepared to analyze the crack growth in detail: the aim is to investigate whether the crack propagation is affected by metallurgical features, such as the crystallographic orientation of the grains or microstructural barriers like grain boundaries. With these analyses we expect to be able to correlate the different stages of crack growth.
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Keywords: cp-titanium; fracture analysis; crack growth; micro notches

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1. Introduction

To achieve high performance components the surface of engineering parts is coming more and more into the focus of research. To reach good functionality and suitable mechanical properties different manufacturing processes for the surface modification are possible, for instance micro milling [1] or laser structuring [2]. These processes introduce very small notches, whose in dimensions which vary from smaller than the grain size up to a depth of a few grains, into the component surfaces. Normally, notches reduce the fatigue limit of components due to stress concentrations.

The question is whether these small notches influence the mechanical properties and in particular the endurance limit. In a previous work tension-compression fatigue tests were done with laser structured, micro milled and unstructured cp-titanium specimens [3]. The results do show an influence of the micro notches on the endurance limit, depending on the dimension of the notches in relation to the grain size. The laser structured specimens with deeper notches failed directly at the notch root and showed typical cleavage planes at the crack initiation area. The crack initiation of the other specimens occurred by slipping processes. The reason for the different fracture morphologies is not completely understood yet. One reason could be a strengthening at the melted zone of the laser structured notch. Another reason could be the existence of a local stress concentration at the notch, which increased the susceptibility of cp-titanium for cleavage fracture [4].

The notches in our investigated specimens act similarly as microstructural small cracks. The initiation of the crack is controlled by the stress concentration at the notch root. Furthermore, the crack propagation depends on local microstructural features like grain size, structure of the grain boundaries, and the crystallographic orientation of the neighboring grains [5-7]. The question is whether a crack can be initiated and then grows and cause failure of the specimen, or whether the cracks will be constrained by the microstructural barriers, e.g. grain boundaries. The present work investigates this problem by analyzing the fracture surfaces of micro structured specimens with a SEM and by light microscope analyzes of metallographic microsections.

2. Material and Methods

2.1. Material and chemical composition

The tested material is a commercially pure (cp)-titanium (grade 2) with the chemical composition as shown in Table 1. The average grain size is approximately 30 µm.

Table 1. Chemical composition of cp-titanium (grade 2)

wt-%	N	C	H	Fe	O	Ti
analysis	0.004	0.042	0.003	0.037	0.127	balance
max. ASTM B265	0.05	0.60	0.013	0.20	0.18	balance

2.2. Specimen geometry and surface states

The geometry of the microspecimens, which were analyzed by tension-compression fatigue tests, is shown in Fig. 1. The specimens were cut out of sheets. The thickness of the specimens depends on the machining process and lies between 0.5 and 0.6 mm. Four different surface states were produced and tested: two of them were laser structured at only one side, and the other two were faced milled and micro milled at both sides. Fig. 2 shows the longitudinal metallographic microsections with the notch geometry after the different machining processes. For comparison an untreated technical surface state and a both-side faced milled surface state were tested, too.