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Fracture of notched round-bar NiTi-specimens

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ABSTRACT

In this work fractography has been used to characterize the fracture surfaces of superelastic, notched round-bar NiTi-specimens. Several fractography studies have been performed for conventional materials, but only few studies have been conducted on NiTi-alloys. The aim of this work is to investigate the effect of semi-circular notches on the fracture behavior of NiTi. The main results indicate that the fracture process is a mixture of cleavage and micro-void coalescence, and that decreasing the notch-radius leads to a loss of ductility which manifests in a reduced fracture strain. Within the range of notches studied in this work, we can observe a transition from high scatter to low scatter in the fracture strain when reducing the notch-radius. By combining fractography studies, finite element analyses and the Rice–Tracey void-growth model, it is argued that fracture is most likely initiated close to the notch for all notch-radii studied herein, and that cleavage or quasi cleavage is the dominating fracture mechanism.

1. Introduction

Since their discovery in the 1960s, NiTi-alloys have been put to use in a number of applications [1]. It has been particularly successful in the medical industry, due to the material's bio-compatibility and special mechanical properties [2].

A lot of effort has been put into understanding the mechanisms involved during phase transformation and the superelastic behavior of NiTi-alloys [3,4], and the possibility to reproduce their mechanical behavior numerically through constitutive modeling [5–9]. However, only recently an increasing interest has arisen towards failure of shape memory alloys. The main focus in this regard is found in fatigue failure [10–12], effect of cracks on martensite transformation [13–15] and the effect of martensite transformation on fracture toughness of NiTi-alloys [16–19].

The effect of stress triaxiality is often mentioned as a contributor during fracture of shape memory alloys [11,20]. However, only few attempts have been made to quantify it's effect [21].

In this work an attempt is made to investigate the effect of triaxiality on the fracture processes in NiTi by studying notched round-bar specimens. Tensile tests until fracture of specimens with different circular notches are conducted. Subsequently SEM has been employed to investigate the fracture surfaces. Also, finite element analyses are used to quantify the effects of notches.

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Nomenclature

A_f	austenite finish temperature
A_s	austenite start temperature
d	specimen diameter
D	diameter of minimum cross-section
R	notch-radius
E_A	elasticity modulus for austenite
E_M	elasticity modulus for martenite
L	specimen length
M_f	martensite finish temperature
M_s	martensite start temperature
r	current void radius
r_0	initial void radius
R_f	R-phase start temperature
R_f	R-phase finish temperature
α	material constant
ϵ_L	transformation length
ε	total equivalent strain
ε_0^{pl}	initial equivalent plastic strain
ε_c^{pl}	equivalent plastic strain at fracture
ε_f	fracture strain
$d\varepsilon_{eq}^{pl}$	plastic strain increment
ν_A	Possion ratio for austenite
ν_M	Possion ratio for martensite
σ_{eq}	equivalent von Mises stress
σ_f^A	critical stress for austenite transformation finish
σ_m	hydrostatic stress
σ_f^M	critical stress for martensite transformation finish
σ_s^A	critical stress for austenite transformation start
σ_s^M	critical stress for martensite transformation start
0	initial value

2. Experimental set-up and procedures

In this work, a series of tests have been conducted on superelastic NiTi-alloy round-bars. The specimens have a diameter of d = 5.3 mm and a total length of L = 50 mm. Notches with three different radii were machined on the specimens by lathe-turning. Due to manufacturing limitations the smallest notch-radius was chosen to be R = 0.75 mm, while two other configurations were set to have radii of R = 1.00 mm and R = 1.25 mm, respectively. The minimum diameter at the notch-root was set to D_0 = 2 mm for all specimens. See Fig. 1 for details. The specimens were heat-treated in a furnace at 575 °C and subsequently air-cooled. The heat-treatment was conducted after machining in order to avoid surface stresses that might emerge. Three exemplars of each configuration were tested.

2.1. Tensile testing set-up

To understand the effect of the notches on the material behavior, tensile tests were conducted in a Zwick/Roell Z020 tensile testing machine with a 20 kN load capacity. Due to the relatively small size of the specimens, image acquisition and processing was chosen as the preferred tool for strain measurement. The strain was calculated from the change in diameter at

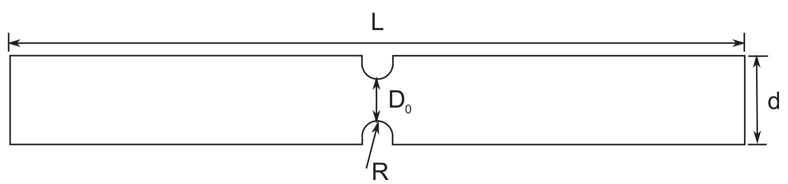

Fig. 1. Schematic drawing of specimen geometry.