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Damage evolution in nickel-base alloy torsion specimens and its influence on subsequent tensile deformability

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Abstract

The massive forming process can consist of consecutive deformation steps. Voids, initiated in preceding forming steps or present from the material production process, can reduce the deformability in the subsequent forming processes.

Therefore, this work evaluates the influence of initiated voids on the deformability in a two step forming process. In the first step voids were initiated in a nickel-base alloy by torsion deformation of a rod. Tension specimens were machined from this predamaged rod and deformed until failure at a test temperature of 1000 °C. The tensile elongation leads to failure as a result of the growth and coalescence of the inherent voids. A constant void volume fraction at fracture was obtained for the specific material and test conditions, whereas the reduction in area – or fracture strain – varies significantly.

Keywords: Nickel-base alloys; Ductile fracture; Void volume fraction; Damage; Void growth; Void coalescence

1. Introduction

The massive forming process can consist of consecutive deformation steps. It has to be considered that voids, initiated in preceding forming steps or present from the material production process, can reduce the materials deformability. The growth and coalescence of the inherent voids by further plastic deformation usually lead to failure, whereas plastic deformation at negative stress states can also cause shrinkage and closure of the inherent voids, for example this is intended in the hot isostatic pressing process [1]. However, heat treatments alone such as annealing, which are used between deformation steps in order to increase the deformability, cannot change the void content. Therefore, it is important to know how the existing voids – or predamage – influence the deformability in subsequent forming processes.

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Nomenclature

C_v	void volume fraction
C_{vi}	initial void volume fraction
C_{vc}	critical void volume fraction at fracture
ε_p	equivalent plastic strain
γ	shear strain
Θ	stress triaxiality ratio (defined as the hydrostatic pressure divided by the von Mises equivalent stress)
S_0	initial cross sectional area of the tensile specimens
S_f	cross sectional area at fracture
Z	reduction in area

In order to analyse the influence of predamage on the deformability at hot forming conditions, voids were induced in a nickel-base alloy by torsion deformation. In a second step this material was tested by tensile experiments. The investigated deformation paths are drawn schematically in Fig. 1. The influence of the primary voids, initiated by torsion deformation after non-ideal heat treatment, on the fracture behaviour of the tensile specimens and the obtained flow curves is described in this work.

Various fracture criteria are already used to predict the materials deformability in different forming processes. The review articles of Clift et al. [2], Wifi et al. [3], Venugopal Rao et al. [4] and Ragab and Saleh [5] present the most commonly used criteria. Some of them describe the physical processes of void initiation, void growth and void coalescence; however, most of them are based on empirical considerations. The obtained results will be used to evaluate the different criteria and their ability to describe failure in hot forming processes.

2. Experimental data

2.1. Predamage creation

All experiments were carried out with the nickel-base alloy NiCr20TiAl (Böhler L306 VMR). Two different fracture processes were found for torsion specimens deformed at 1000 °C with a shear strain rate at the edge of

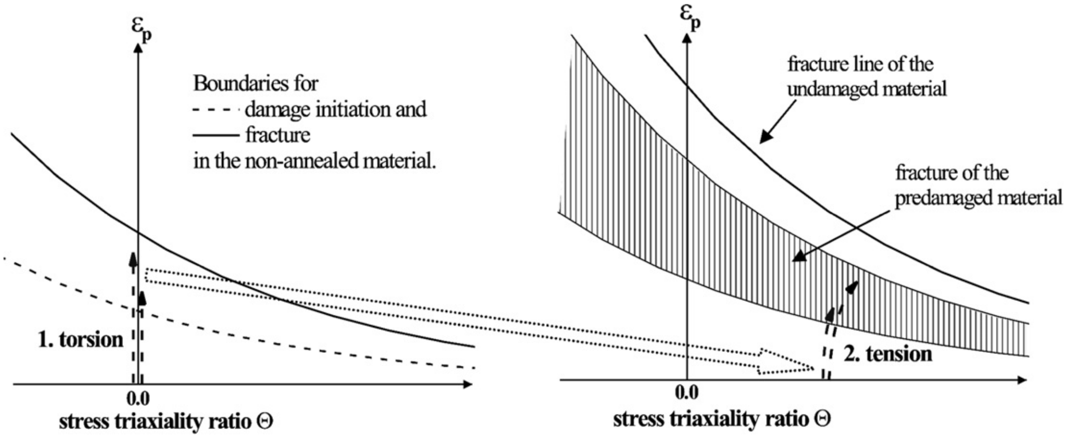

Fig. 1. Schematical deformation paths of the predamaged tension specimens. (*1. torsion*) Voids are induced by torsion deformation in the non-annealed material at 1000 °C. (*2. tension*) Afterwards tension specimens are machined from this damaged material and tested until failure at 1000 °C, after annealing at 1100 °C. The obtainable fracture strain (dashed area) depends on the predamage level. The two deformation steps are drawn in separate drawings, in order to point out the different microstructure before deformation. This is important, since the boundaries for fracture and damage initiation are strongly affected by the initial microstructure, which depends on the heat treatment.