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NON-ALLOYED Ni3Al BASED ALLOYS – PREPARATION AND EVALUATION OF MECHANICAL PROPERTIES

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The paper reports on the fabrication and mechanical properties of Ni_3Al based alloy, which represents the most frequently used basic composition of nickel based intermetallic alloys for high temperature applications. The structure of the alloy was controlled through directional solidification. The samples had a multi-phase microstructure. The directionally solidified specimens were subjected to tensile tests with concurrent measurement of acoustic emission (AE). The specimens exhibited considerable room temperature ductility before fracture. During tensile testing an intensive AE was observed.

Key words: Ni3Al based alloys, directional solidification, tensile test, acoustic emission, fracture

INTRODUCTION

Favourable properties of inter-metallic compounds enable their use in demanding environments, especially at elevated and high temperatures in oxidizing atmosphere. Nickel or Ni_3Al based alloys can be used for mechanical joining of high temperature parts, such as insert bolts in the combustion chamber of the gas turbine [1, 2]. Practical applications of these materials are so far severely limited by their considerable brittleness. Structure of these alloys may be favourably influenced by addition of suitable alloying elements, by heat treatment and directional solidification [3]. Mechanical properties of these materials depend on the volume fraction, distribution, size and morphology of the γ'-precipitates [4, 5]. Their microstructure consists of a high volume fraction of γ'–strengthening precipitates (70 %) coherently merged in a γ (Ni-based solid solution) matrix [6]. For steam power plants that operate at temperatures of 700 °C and higher, nickel-base alloys have been developed. In order to achieve desirable creep properties of these alloys further strengthening through solid solution or precipitation strengthening is needed.

Solid solution strengthening is achieved by addition of Mo, Fe, W, Ta, Cr and Co [7, 8]. The additions of Ti and Al are necessary to improve the yield and creep strength of Ni_3Al based alloys through precipitation strengthening by the γ' particles.

FABRICATION OF MATERIAL

Binary Ni_3Al based alloy with 22 at.% of Al, were used for determination of mechanical characteristics and characterisation of fracture behaviour. The alloy was melted in corundum crucible in a vacuum induction furnace and cast into graphite moulds. Chemical composition of the samples was checked by the optical emission spectroscopy method. The samples were subjected to directional solidification in a two-zone furnace. The samples were melted in a corundum tube with specific apex angle. Temperature of the melt was optimised on the basis of numerous preliminary measurements and temperature gradient in liquid at the solid-liquid interface was within the interval of 70 - 90 °C·cm^{-1}. Two solidification rates (r_{DS}) were applied, i.e. 50 and 20 mm·hod^{-1} (Table 1). After directional solidification the samples had a multi-phase microstructure formed mainly by Ni_3Al (γ‘) phase and two phase regions composed of the γ‘ precipitates embed in the γ matrix. The precipitation of very fine γ‘ particles was observed in the γ channels separating the γ‘ particles.

EXPERIMENTAL

Short tensile specimens with a length of 55 mm and gauge diameter of 5 mm were prepared by lathe-turning from directionally solidified samples. The strain rate was approximately 1,33x10^{-3} s^{-1} for all tested specimens. Table 1 gives the measured values of offset 0,2 % tensile yield stress ($R_{p0.2}$), ultimate tensile strength (R_m) and tensile strain until the fracture.

Figure 1 shows stress-strain curves of the samples No. 1 and No. 2. Acoustic emission (AE) was measured by the four-channel commercial facility instrument

Table 1 **Obtained mechanical characteristics**

Specimen No.	r_{DS} / mm/h	$R_{p0.2}$ / MPa	R_m / MPa	Tensile strain / -
1	20	164	451	1,42
2	50	172	487	1,41

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DAKEL IPL. This device enables a continuous data acquisition and subsequent analysis of signals. Two-threshold detection was used in accordance with the ASTM standard, which enables a simple amplitude discrimination of signals. For all tested specimens the total amplification of 40 dB was used. Dynamic range of the A/D converter was 0-2 400 mV. The first threshold level was set to 15 % of this range and the result was the count rate dN_{C1}/dt. The second threshold level was set to 30 % of the full range for registration of the AE signals with high amplitude. The result was the count rate dN_{C2}/dt. The AE signal was measured by a miniaturized piezoceramic AE transducer MICRO 2006 working in the frequency range from 100 to 600 kHz. An intensive AE was observed with characteristic dependence on time and correlation with individual stages of deformation (Figures 2 and 3).

EVALUATION OF MEASUREMENT RESULTS

Deformation curves of the specimens 1 and 2 are very similar. The deformation curves are smooth with considerable deformation strengthening. The shape of the curves resembles the strengthening curve of single crystals. The AE response in the specimen 1 up to strain of about 0,4 corresponds to prevailing plastic deformation. Afterwards the material gets damaged. A distinct AE response of discontinuous character can be seen in Fig. 2, when formation of cracks occurs. AE disappears at strain of approx. 0,7 and it reappears only close to the rupture. As a result of failure processes immediately after plastic deformation a drop on the deformation curve is observed at the strain of about 0,8 (Figure 2). The specimen 2 has also high ductility. We assume that plastic deformation dominates up to the strain of 0,5, but the deformation may be of a non-homogeneous character.

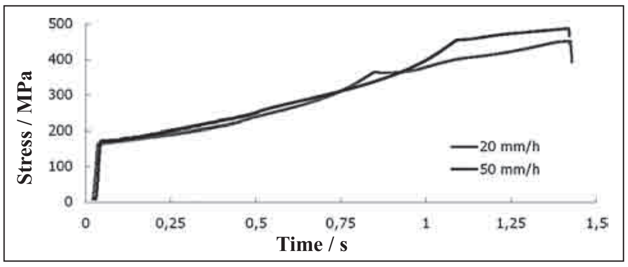

Figure 1 Stress-strain curves of the specimen Nos. 1 and 2

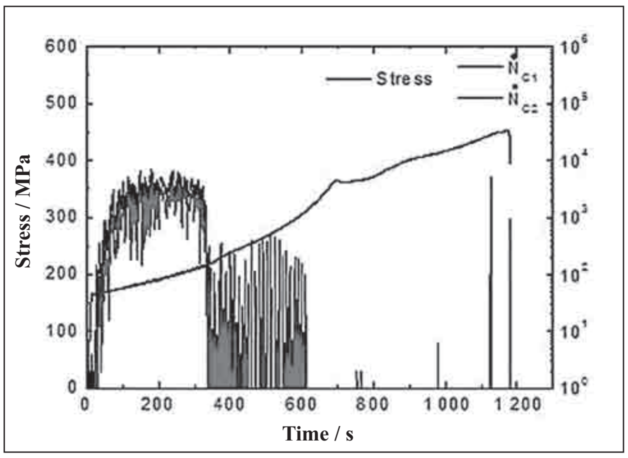

Figure 2 AE record - specimen No. 1

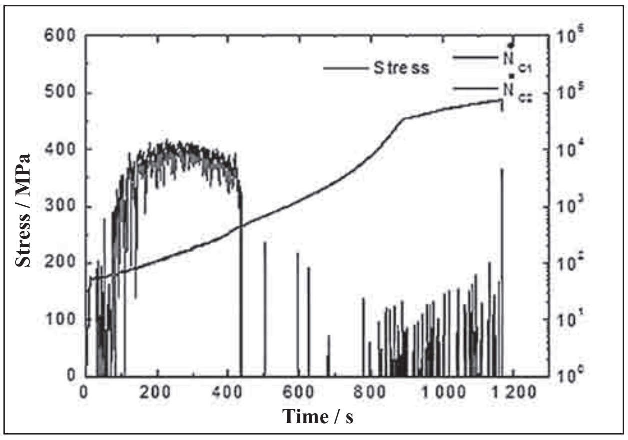

Figure 3 AE record - specimen No. 2

As soon as the failure processes appear, the character of the curve corresponds to crack formation. In the speciment 2 a drop was also observed on the deformation curve at the strain of about 1,1. This drop appeared later than in the specimen 1 and failure processes take place mainly at the final stage of deformation (Fig. 3). TRIP steels show also similar type of failure, where additional strengthening of material takes place. In this case, however, material shows significantly higher values of $R_{p0.2}$ at room temperature [9].

Figures 4-7 show fracture surfaces. Fracture surface of the specimen 1 has elliptic shape (Figure 4). It is formed by several plane areas, which are mutually inclined in such a manner that the fracture surface is concave above the sample cross-section. The entire fracture surface exhibits transcrystalline plastic fracture with dimple-like morphology (Figure 5). For comparison, the wrought alloy Nimonic 80A shows mainly brittle fracture with ductile areas at the edges of the specimen [1]. The fracture surface of the specimen 2 has mostly planar character. This planarity is disrupted at two places at the edge by a distinct step. Cross-section of the specimen is also elliptic (Figure 6). Also by this sample, the entire fracture surface exhibits again character of transcrystalline plastic fracture of dimple-like type (Figure 7). This type of fracture corresponds to multiphase structure with high proportion of regions with two phase γ /γ‘ microstructure.

CONCLUSIONS

Mechanical characteristics and fracture behaviour of directionally solidified Ni_3Al based alloy with 22 at.% of Al were determined. The samples exhibited a multiphase microstructure formed mainly by single Ni_3Al (γ‘) phase and two phase regions containing γ‘ particles embed in the γ matrix. During tensile testing an intensive AE was observed, exhibiting direct correlation to various stages of deformation (plasticity and failure). Tensile curves were smooth with significant deforma-

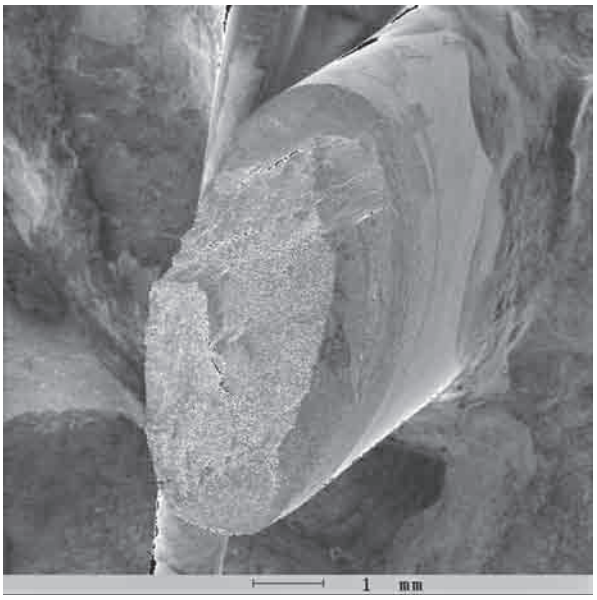

Figure 4 Fracture surface - specimen No. 1

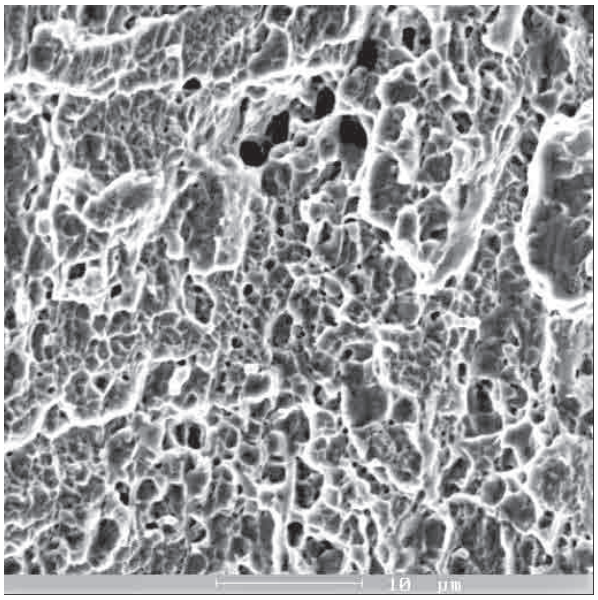

Figure 5 Fracture surface - specimen No. 1

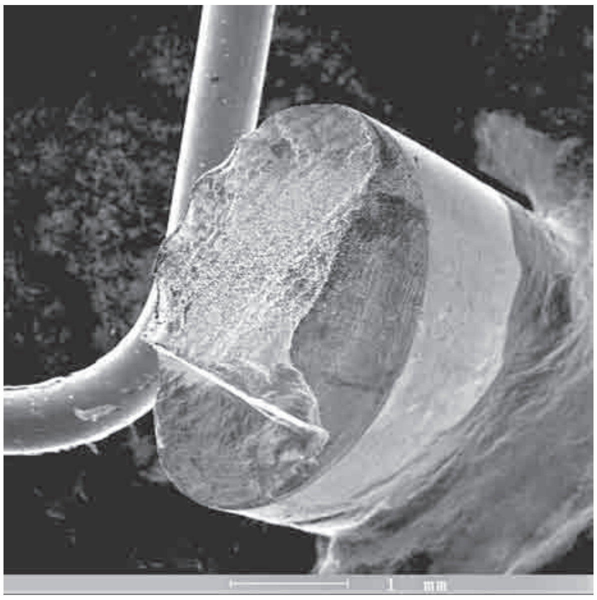

Figure 6 Fracture surface - specimen No. 2

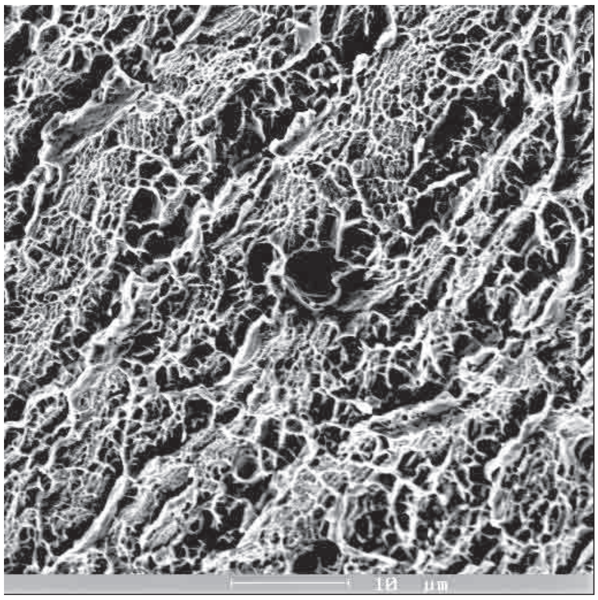

Figure 7 Fracture surface - specimen No. 2

tion strengthening. The specimens showed unusually high room temperature ductility. Only transcrystalline plastic fracture with dimple-like morphology was observed on fracture surfaces. Dimple-like fracture corresponds approximately to the proportion of the γ/γ' network in microstructure.

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Note: The responsible translator for English language is B. Škandera, Informetal, Dobrá, Czech Republic