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Featured Letter

Strength-ductility paradox in a directionally solidified nickel base superalloy

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ABSTRACT

In contrast to other structural alloys, yield strength of nickel base superalloys either remains constant or increases with temperature up to 700–800 °C making them more suitable for high temperature structural applications. However, the increase in yield strength is usually accompanied by a decrease in ductility. The results of the present investigation describe the substurural evolution in a directionally solidified nickel base superalloy CM 247 DS LC during tensile deformation, where ductility is not impaired even when yield strength is highest (at 750 °C). Extensive TEM studies offer plausible dislocation based mechanisms for retention of high ductility at 750 °C. The highest yield strength is attributed to the presence of intersecting faults along with partials bounded by anti-phase boundary. However, high ductility is due to the formation of SISF inside γ' precipitates. These mechanisms provide necessary impetus for further alloy development.

1. Introduction

Nickel base superalloys are microstructurally designed for use in high temperature structural applications such as in the hot sections of aircraft gas turbine engines [1,2]. The main feature of their microstructure is the dispersion of precipitates that have ordered $L1_2$ crystal structure and are coherently embedded in a solid solution strengthened γ matrix [2]. Due to presence of these ordered precipitates, γ', nickel base superalloys exhibit typical tensile behaviour known as yield strength anomaly (YSA), which consists of an increasing or constant value of yield strength (YS) over a range of temperatures [3–4]. It is usually observed that increase in yield strength owing to YSA is accompanied by decrease in ductility of the superalloys, and the reasons for reduced ductility are different for different alloys [3–6].

However, in the present study it is observed that the alloy CM 247 DS LC exhibits enhanced ductility at 750 °C, where the yield strength of the alloy is highest. Such type of strange behaviour, where both high yield strength and high ductility occurs together is termed as strength-ductility paradox. CM 247 DS LC is a directionally solidified (DS) nickel base superalloy used for manufacturing of turbine blades and vanes. This alloy has multiphase microstructure consisting of γ' precipitates embedded in γ matrix, carbides, and γ-γ' eutectics [7]. In the present investigation, the micromechanism of tensile deformation of alloy CM 247 DS LC at 750 °C is studied and an attempt has been made to understand the strength-ductility paradox behaviour based on the sub structural evolution. This study will be beneficial for future alloy development and improving the mechanical behaviour of alloy at elevated temperatures.

2. Material and methods

The nominal composition of the alloy is listed in Table 1. The development and processing of the superalloy CM 247 DS LC is reported in [8]. The alloy was received in the form of rods of 14 mm diameter and 135 mm length with rod length parallel to the DS direction. The rods were heat-treated in the following sequence: 1221 °C/2h/1232 °C/2h/1243 °C/2h/1250 °C/2h/ gas fan quenching (GFQ), followed by aging at 1080 °C for 4 h (GFQ) and 870 °C for 20 h (GFQ).

Tensile tests were conducted in the temperature range 25–955 °C employing a strain rate of $1x10^{-3}$ s^{-1} on round shaped threaded specimens fabricated in accordance with ASTM E 8 M in INSTRON 8862 series servo electric testing machine of load capacity 100 KN and equipped with resistance furnace. The temperature during test was controlled by a 3-zone Eurotherm PID temperature controller. During test, constant temperature within ± 2 °C was maintained in all the 3 zones. The temperature on the test piece was measured with two Pt-13%Rh thermocouples tied to the gauge length portion. Strain measurements were made using a high temperature

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Table 1
Chemical composition (wt %) of the as-received CM 247 DS LC alloy.

Ni	Cr	Co	Mo	Ti	Al	Ta	W	B	Zr	Hf	C
62	8	9.3	0.49	0.74	5.58	3.21	9.49	0.018	0.009	1.41	0.07

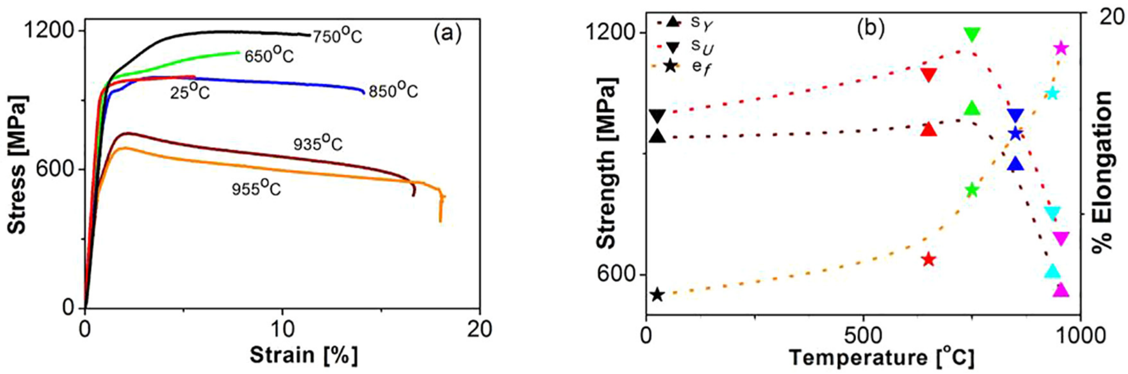

Fig. 1. (a) Typical engineering stress-strain curves and (b) Variation of S_Y, S_U and e_f of alloy CM 247 DS LC at different tensile test temperatures.

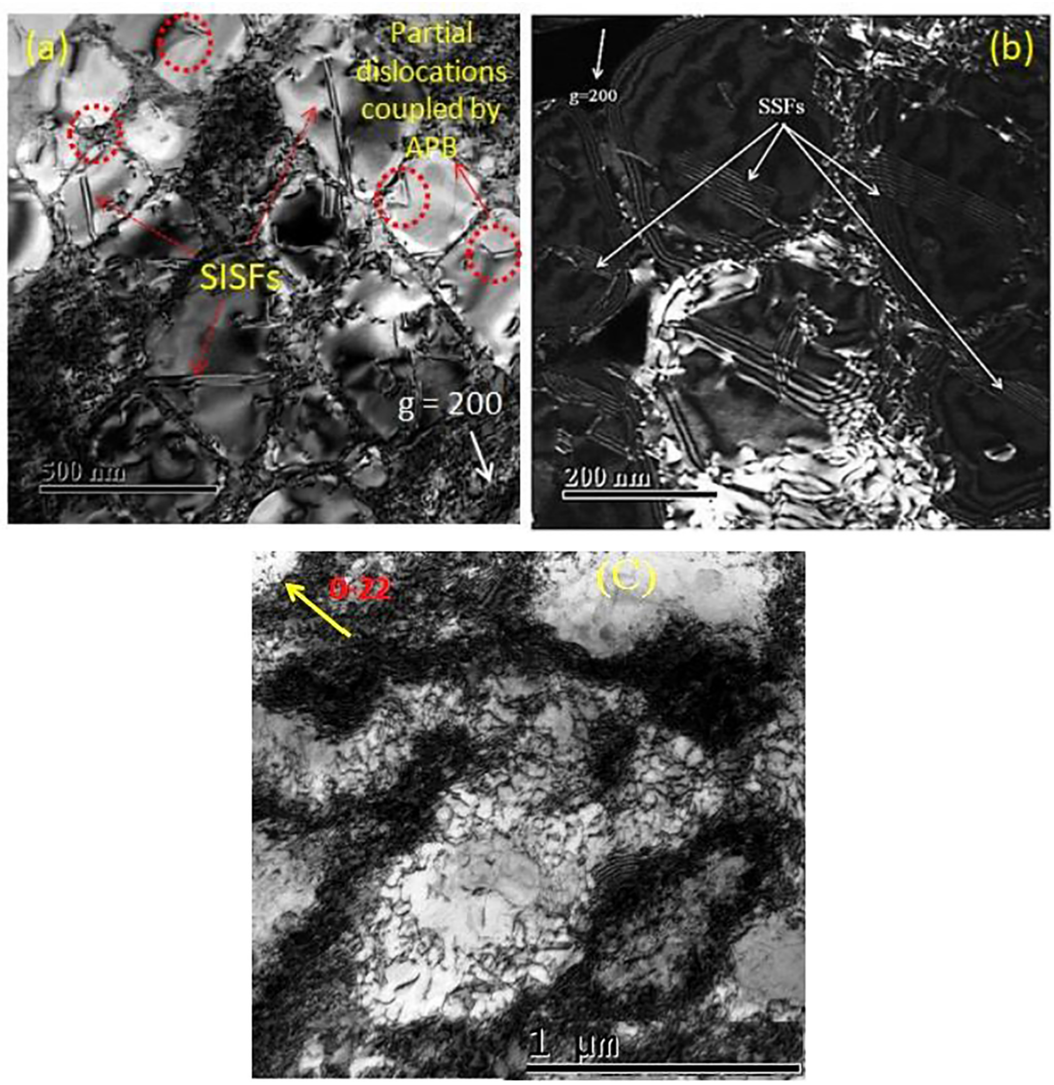

Fig. 2. (a) TEM bight field image showing intense dislocation activities inside γ'-precipitates, superlattice intrinsic stacking faults (SISFs) and superpartial dislocations bounded by APB in the specimen and (b) TEM dark field image showing various superlattice stacking faults (SSFs) intersecting each other inside γ'-precipitate in the specimen tensile tested at 750 °C, and (c) TEM image of the specimen tensile tested at 850 °C.