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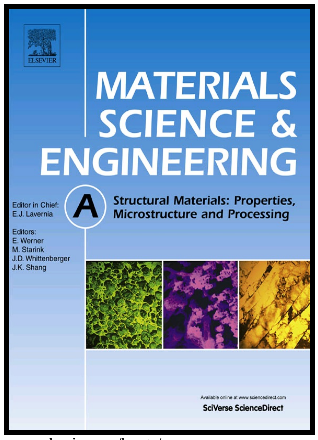

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Mechanical properties of thermally-stable, nanocrystalline bainitic steels

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Abstract

Two novel, thermally stable bulk nanocrystalline bainitic steels were subjected to a range of mechanical tests. One alloy, containing 0.72 wt% carbon exhibited an ambient-temperature 0.2% proof strength of 1500 MPa and a fracture toughness of 64.6 MPa m$^{1/2}$ after the bainite transformation. The other, containing 0.45 wt% carbon and 13.2 wt% nickel, had a 0.2% proof stress of 1000 MPa and a fracture toughness of 103.8 MPa m$^{1/2}$. Both steels showed excellent creep resistance, with a rupture life at 450 ℃ and 700 MPa of 114 h and 94.8 h, respectively. Both displayed fatigue lives consistent with other steels of similar structure in the literature. After thermal exposure at 480 ℃ for 8 d, both steels increased in strength to 1800 MPa, and 1600 MPa, respectively. The latter steel reduced in fracture toughness to 19.6 MPa m$^{1/2}$. These alloys are suitable for a range of engineering applications and remain so after thermal exposure. Combined with impressive high-temperature performance, this makes the current alloys candidates for use in some elevated temperature applications.

1. Introduction

Building on earlier work, two novel bulk nanocrystalline bainitic steels (table 1) have been developed to resist thermal decomposition [1, 4]. Bulk nanocrystalline steels are well-known to possess an impressive combination of strength and toughness [2, 3] and, in combination with enhanced thermal stability, this class of alloys are particularly suited to use in applications where with high demands on mechanical performance with prolonged exposure to elevated temperature, for example in gas turbine engines and power generation. The current alloys are subjected to a barrage of mechanical tests (tensile, fracture toughness, impact toughness, fatigue and creep tests) to prove their suitability for such applications.

2. Experimental Methods

All mechanical tests were performed by Westmoreland Mechanical Testing and Research Ltd. of Banbury, U. K. and were in accordance to industry standards. All testpiece geometries are illustrated in supplementary figures S1–S4 and S6. In order to assess the performance of the alloys under conditions that may be expected in service, mechanical test were performed at both ambient temperature and at the elevated temperature of 450 ℃. Due to equipment constraints, elevated temperature toughness experiments were performed at 150 ℃. To derive the effect of heating, mechanical properties of the alloys were measured both in the as-transformed condition and after prolonged thermal exposure (table 2). According to the well-known Larson-Miller parameter, the tempering condition is equivalent to 60 y of exposure at 400 ℃, typical of the requirements of a component in a gas turbine engine. The temperature is chosen to minimise the time of heat treatment while avoiding phase changes.

2.1. Tensile properties

Tensile tests were performed in accordance with ASTM E21-09 and using industry-standard testpieces (supplementary figure S1). A constant strain rate of 0.002 min^{-1} was used for all tests, which were run to failure.

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