Available online at www.sciencedirect.com

ScienceDirect

Acta Materialia 87 (2015) 201–215

Acta MATERIALIA

www.elsevier.com/locate/actamat

Mechanical response and deformation mechanisms of ferritic oxide dispersion strengthened steel structures produced by selective laser melting

Thomas Boegelein,[a,b,*] Sebastien N. Dryepondt,[b] Amit Pandey,[b,1] Karl Dawson[a] and Gordon J. Tatlock[a]

[a]*Centre for Materials and Structures, School of Engineering, University of Liverpool, Liverpool, L69 3GH, UK*
[b]*Materials Science and Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA*

Received 15 October 2014; revised 17 December 2014; accepted 22 December 2014
Available online 28 January 2015

Abstract—Oxide dispersion strengthened (ODS) ferritic steels typically contain a fine dispersion of nanoscopic Y(Al, Ti) oxides, leading to an improvement in mechanical and physical properties. A rapid prototyping technique, selective laser melting (SLM), was successfully applied to consolidate as-mechanically alloyed ODS-PM2000 (Fe–19Cr–5.5Al–0.5Ti–0.5Y_2O_3; all wt.%) powder to fabricate solid and thin-walled builds of different thickness. This work is intended to act as a first study to investigate the tensile response of such configurations at room temperature, using miniaturized test specimens along and perpendicular to the growth direction. The 0.2% offset yield strength of as-grown wall builds was inferior to conventional PM2000 alloy (recrystallized), but could be significantly increased by conducting post-build heat treatments. Young's modulus and yield strength showed anisotropy and were enhanced when testing perpendicular to the build growth direction. Electron backscatter diffraction revealed a strong [0 0 1] fibre texture along the growth direction, which explains the anisotropic behaviour. Additionally, studies on the morphology of the individual fracture surfaces, the grain structure of the cross-section near this region and the size distribution of ODS particles in such builds were conducted. A fine dispersion of precipitates was retained in all SLM builds, and findings suggest that a certain amount of Y is probably still in atomic solution in the as-grown condition and forms new small nanoscopic dispersoids during annealing, which lead to enhanced strengthening.
© 2015 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

Keywords: Oxide dispersion strengthened alloys; Rapid prototyping; Tensile testing; Anisotropy; Transmission electron microscopy

1. Introduction

Oxide dispersion strengthened (ODS) ferritic steels typically contain a fine homogeneous dispersion of thermally stable nanoscopic Y(Al, Ti) oxides. These ceramic particles lead to an improvement in mechanical and physical properties, hence significantly increase the permitted operating temperature of components made of ODS materials compared to dispersoid-free alloys [1]. Al-containing ODS steels form a slow-growing adherent alumina scale at high temperatures and thus offer extreme tolerance to oxidation [2], and the presence of a coarse microstructure after recrystallization is beneficial to creep strength [3]. Those excellent properties make Al-containing ODS steels candidates for applications in future conventional power plants [4,5], biomass combustion [6] and other high temperature applications [7]. Small ODS dispersoids also act as sink sites for detrimental transmutation He formed in the material under neutron irradiation [8,9]. However, Al forms unwanted long-lasting isotopes when exposed to nuclear radiation, thus Al-free ODS steels are considered for future fusion/fission applications [10,11]. This type of ODS steel is being used with a significantly smaller grain size than Al-containing variants, which increases tensile strength and ductility but lowers creep strength at high temperature [12]. The major strengthening mechanisms of ODS steels at low (<∼700 °C) temperatures were identified as solution strengthening, dispersoid (Orowan) strengthening and grain boundary strengthening; the individual contributions may vary significantly, depending on the alloy composition, the micro- and nanostructure, and temperature [13,14]. At elevated temperatures (>∼700 °C), thermally activated processes become more distinct, leading, for instance, to a significant drop in grain boundary strengthening, solution strengthening and changes in particle/dislocation interactions, and also the occurrence of creep effects [14]. Conventionally, ODS steels are fabricated through complex and inflexible powder metallurgical processes. This starts with mechanical alloying (MA), where powder raw materials are subject to repeated cold welding and fracture, leading to dissolution of the alloying elements [15,16]. MA is followed by degassing, hot extrusion or hot isostatic pressing to consolidate the product, and sometimes hot and cold rolling steps followed by heat treatments. A recent study

* Corresponding author at: Centre for Materials and Structures, School of Engineering, University of Liverpool, Liverpool L69 3GH, UK. Tel.: +44 (0) 151 795 2273; fax: +44 (0) 151 794 4675; e-mail addresses: t.boegelein@liv.ac.uk; thomas.boegelein@web.de

[1] Present address: Reliability Division, Rolls Royce LG Fuel Cell Systems Inc., North Canton, OH 44224, USA.

http://dx.doi.org/10.1016/j.actamat.2014.12.047
1359-6462/© 2015 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

on the formation and evolution of oxide particles in Fe–14Cr–2W–0.3Ti alloys mechanically alloyed with Y_2O_3 or Fe_2Y has shown that Y, Ti and O are present in the matrix after ball milling, and that the nanoclusters of Ti–Cr–O initially formed increase in size and become enriched in Y during the various consolidation steps as Y diffuses very slowly in the α-Fe matrix [16]. Once ODS materials are molten, as is evident from the study of fusion welds [17], dispersoids agglomerate and slag off because of density differences between the dispersoids and the matrix. This leads to a loss in mechanical performance in the weld zone due to reduced particle strengthening. Thus, current research interest in this field has concentrated on the evaluation and the development of alternative fabrication and solid-state joining techniques for ODS materials, as this would significantly increase their widespread use. Several joining processes have recently demonstrated potential feasibility in the ODS alloy environment, including friction-stir welding [18,19], diffusion bonding [20], transient liquid-phase bonding [21] or pulsed plasma-assisted diffusion bonding [22]. Other alternatives are beam-based techniques, e.g. electron beam welding [23] or laser beam welding. This latter technique in particular has shown promising results, as ODS particles could be retained in the bond zone [24,17,25]. These findings motivated Walker et al. to use an additive manufacturing technique, selective laser melting (SLM), to consolidate as mechanically alloyed ODS steel powder [26].

SLM is a recent additive rapid prototyping development. The machine layout used to manufacture the builds for this study is illustrated in Fig. 1. Metal powder is used as the build material and is delivered in a thin layer onto a substrate. This deposit slice is successively scanned with a finely focused laser beam leading to molten material fusing to an underlying substrate or to previously deposited material. For the present builds, the layer thickness of consolidated material was ~50 μm. After these steps, the substrate lowers and the process repeats until the desired build is achieved. The thermal conditions near the fusion zone are obviously similar to conventional laser welding (conduction based). Due to localized heat input, there are strong cooling rates in the heat affected zone, which depend on several parameters, such as scanning velocity, laser spot size and thermal conductivity of the material [27]. Due to Marangoni-type forces, caused by a strong thermal gradient in the melt pool and different coefficients of surface tension, constant stirring occurs under such conditions [28]. Using an Al alloy, Thijs et al. [29] demonstrated that submicron-sized grains grow in an [100] orientation perpendicular to the liquidus/solidus interface. Favoured by successive remelting of previously deposit material, grains become elongated in the same orientation, growing through several deposited slices along the SLM build direction if the scanning directions remain unchanged. Similar to other recent rapid prototyping technologies, SLM fabrication uses computer-aided design, which allows a great level of design freedom and flexibility [30]. A number of build configurations can be produced with SLM, including complex thin-walled structures, coatings, solid builds, meshes and porous structures. Due to small melt pools and high cooling rates, SLM is a candidate technique for processing ODS alloys.

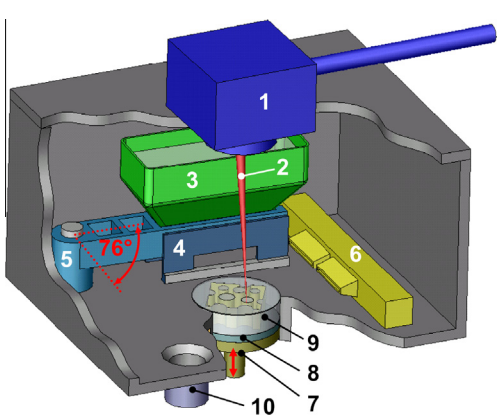

Fig. 1. The SLM operating principle. The image shows the scanner system (1) with a focused laser beam (2), the powder container (3), the wiper & powder deposition mechanism (4), a moveable arm (5), the gas nozzle system (6), the moveable piston (7), the substrate plate (8), the powder bed with a consolidated part (9) and a powder overflow (10).

Walker et al. [26] demonstrated that a fine dispersion of ODS precipitates can be retained under certain processing parameters by manufacturing thin walls using as mechanically alloyed powder of PM2000, a FeCrAl ODS alloy. The developed settings were recently successfully applied on the same material to fabricate a complex thin-walled honeycomb structure. The build was subject to major investigations [31,32], and only the key results are summarized here. In the as-grown condition, there was a fine homogeneous dispersion of globular shaped precipitates, composed of different phases and probably amorphous regions, which had varying concentrations of elements, such as O, Al, Ti, Cr, Fe and Y. A post-build heat treatment at 1200 °C for 1 h resulted in a change of such particulates into Al–Y oxides, typically of a single phase. During annealing, Y, which diffuses slowly in α-Fe matrix, becomes more mobile and can replace other elements included in the multi-phased precipitates, which simply diffuse into the surrounding matrix. The resulting particle size distribution changed during this annealing step. In the as-grown condition, the size distribution was similar to conventionally processed recrystallized PM2000, but after the heat treatment pre-existing precipitates coarsened and a dispersion of new fine oxides was observed. During this annealing step, precipitates present in the as-grown condition probably coarsen due to Ostwald ripening, during which the free energy of the system decreases, while larger particles grow at the expense of smaller species by diffusion-based interparticle migration processes [33–35]. Simultaneously, other fine particles nucleate and grow, probably due to a supersaturation of Y in the matrix prior to annealing.

In order to address some of the detrimental issues observed in previous builds, the SLM processing parameters were optimized for the walls and solid builds. The mechanical tensile response and deformation mechanisms of these improved builds are the subject of this article.

However, in this study, the emphasis is placed on the mechanical tensile response and deformation mechanisms of these build configurations at room temperature, before conducting further studies and testing at elevated temperatures.

Download English Version:

https://daneshyari.com/en/article/7880615

Download Persian Version:

https://daneshyari.com/article/7880615

Daneshyari.com