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Particle strengthening of additively manufactured Me-Si-B (Me = Mo, V) alloys

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Introduction

Structural materials are faced with enormous requirements concerning strength, wear resistance, but also crack tolerance. In the last decade's refractory metals and their alloys were more and more considered as potential alloys for these requirements.

Besides others, Mo-rich Mo-Si-B alloys are in the focus of research on innovative turbine materials, as they provide high strength at ambient temperatures and satisfactory fracture toughness as well as high thermal resistance and improved creep resistance [1]. Simulations and comparative experimental assessments against Ni-base superalloys already demonstrated the outstanding performance of Mo-Si-B alloys [2,3]. V-Si-B alloys, following a similar alloying concept, was found to offer enormous potential as well, although at a lower temperature regime (up to 1000 °C) in comparison to Mo-Si-B alloys (up to 1300 °C) [4]. Both refractory Me-Si-B (Me = M, V) alloys show up with good ductility and fracture toughness for a microstructure consisting of hard and creep resistant silicide phases surrounded by a more ductile solid solution matrix [5,6]. Conventional processing methods, like powder metallurgy and ingot metallurgy, were already investigated for Me-Si-B alloys [1,4–6] and currently we are working on the establishment of additive manufacturing (AM) for this class of materials [7,8].

However, one limitation on the use of the above-mentioned materials is the notably decreasing creep resistance at higher temperatures. The high strength level at ambient temperatures, which is improved by grain refinement, is not stable at temperatures above $0.3*T_m$. Me-Si-B materials for the use in high temperature application suffer from creep damage, that is mainly observed in the solid solution phase, while the silicide phases provide improved creep resistance. Oxide dispersion strengthening (ODS) is known to increase the high temperature materials strength and creep response of metallic materials. The application of the ODS concept on additively manufactured alloys, like Fe- and Ti-Al-based alloys was already shown [9,10]. The feasibility of the ODS approach in structural Me-Si-B materials produced by additive manufacturing is still unexplored. In this study, a new approach of additive manufacturing of Y_2O_3-doped Me-Si-B powder is presented. This approach combines the oxide dispersed strengthening (ODS) mechanism and additive processing of innovative intermetallic materials. Homogenously distribution of Y_2O_3 particles in the pre-alloyed Me-Si-B powder material was achieved by means of a short grinding process in a planetary mill. Undoped Me-Si-B powders are used as reference material. Bulk samples were consolidated via direct energy deposition (DED) as a method for AM and examined regarding microstructure, hardness and compression tests.

Materials and Methods

Powder production: Gas atomized molybdenum and vanadium powder material with the nominal compositions Mo-13.5Si-7.5B (at %) and V-9Si-5B (at %), sized to a fraction of 45–90 µm, was produced by Nanoval GmbH & Co. KG, Germany. Y_2O_3-particles were provided by abcr GmbH, Germany, with a particle size of approx. 45 nm.

Milling procedure: The alloyed powder material was milled together with the Y_2O_3 particles in a planetary ball mill (Pulverisette 4 Classic line, Fritsch GmbH, Germany) equipped with zirconia grinding bowls and yttrium stabilized zirconia (YSZ) grinding balls with a diameter of 5 mm. The milling procedure is characterized by three milling intervals of 20 min (total milling time: 60 min) under protective argon atmosphere to avoid oxidation of the powder material. As a feedstock a manually mixed blend of 99.5 g of Mo-13.5Si-7.5B powder and 0.5 g Y_2O_3 (≙ 7.8 vol. % Y_2O_3) as well as 99.5 g V-9Si-5B powder and 0.5 g Y_2O_3 particles (≙ 5.5 vol. % Y_2O_3) was used.

Direct energy deposition: The DED process was performed in an argon purged inert gas chamber, described in detail in [7,8]. The laser beam source was a fiber coupled diode laser system (LDF2000-30, Laserline GmbH, Germany) with a maximum output of 2 kW.

Results and Discussion

Y_2O_3 reinforced Mo-13.5Si-7.5B and V-9Si-5B compacts were fabricated by means of directed energy deposition (DED). The powder material used was manufactured via a gas atomization process (Me-Si-B powder) which was followed by a short milling process to achieve a bimodal powder mixture of Me-S-B and homogenously distributed Y_2O_3 particles.

AM of ODS Mo-13.5Si-7.5B and ODS V-9Si-5B pre-alloyed powders was successfully demonstrated in a laboratory scale. The AM builds reveal crack free microstructures as well as a good interlayer bonding. A homogenously distribution of the Y_2O_3 particles within the microstructure for both alloys consolidated was observed (see Figure 1). Furthermore, first mechanical tests indicate an increasing trend in hardness and compressive strength for the Y_2O_3 reinforced alloys at room temperature. High temperature properties will be examined in ongoing investigations and will be presented at the Intermetallics conference.

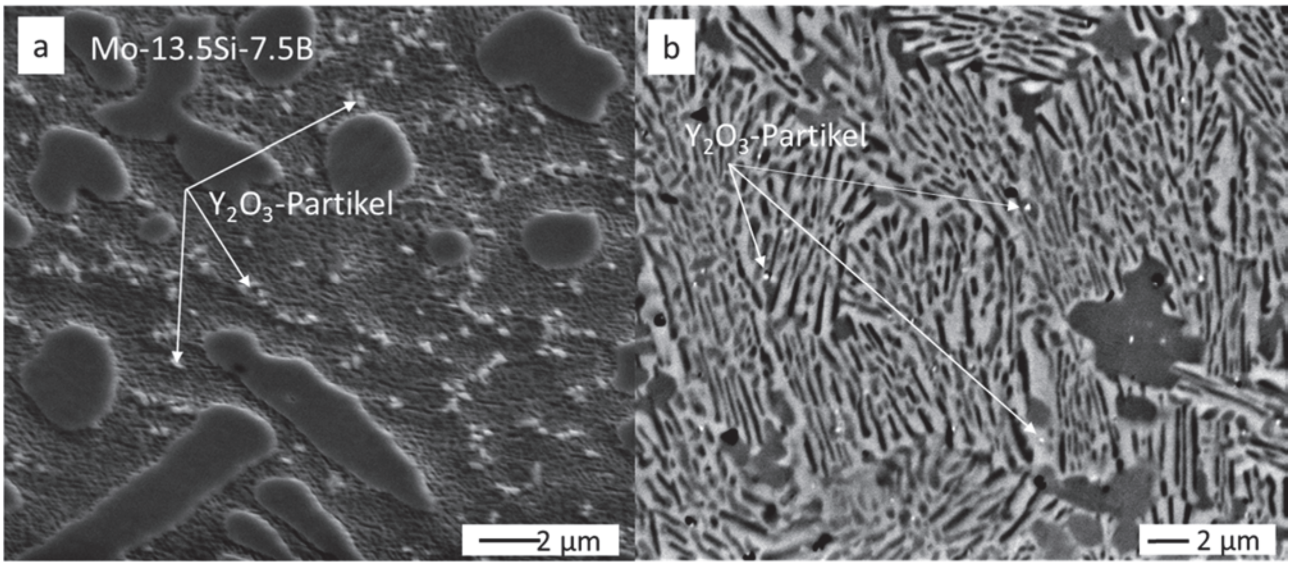

Fig. 1: Homogenously distributed Y_2O_3 particles within the AM manufactured a) Mo-13.5Si-7.5B(Y_2O_3) and b) V-9S-5B(Y_2O_3) alloys.

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