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

Schmelzer, J.[1]; Krüger, M.[1]; Michael, O.[1]; Rittinghaus, S.-K.[2]; Wilms, M.B.[2]
[1]Otto-von-Guericke University Magdeburg, Institute of Materials and Joining Technology
[2]University of Wuppertal, Materials Science and Additive Manufacturing

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*Tm. 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 Y2O3-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 Y2O3 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.

References

[1] J.H. Perepezko, The hotter the engine, the better, Science. 326 (2009) 1068–1069.
[2] K.A. Brindley, M.W. Priddy, R.W. Neu, Integrative Materials Design of Three-Phase Mo-Si-B Alloys, Integrating Materials and Manufacturing Innovation. 8 (2019) 1–16.
[3] O. Kauss, H. Tsybenko, K. Naumenko, S. Hütter, M. Krüger, Structural analysis of gas turbine blades made of Mo-Si-B under transient thermo-mechanical loadings, Computational Materials Science. 165 (2019) 129–136.
[4] M. Krüger, High temperature compression strength and oxidation of a V-9Si-13B alloy, Scripta Materialia. 121 (2016) 75–78.
[5] J.J. Kruzic, J.H. Schneibel, R.O. Ritchie, Ambient- to elevated-temperature fracture and fatigue properties of Mo-Si-B alloys: Role of microstructure, Metallurgical and Materials Transactions A. 36 (2005) 2393–2402.
[6] G. Hasemann, C. Müller, D. Grüner, E. Wessel, M. Krüger, Room temperature plastic deformability in V-rich V–Si–B alloys, Acta Materialia. 175 (2019).
[7] J. Schmelzer, S.-K. Rittinghaus, A. Weisheit, M. Stobik, J. Paulus, K. Gruber, E. Wessel, C. Heinze, M. Krüger, Printability of gas atomized Mo-Si-B powders by laser metal deposition, International Journal of Refractory Metals and Hard Materials. 78 (2019) 123–126.
[8] J. Schmelzer, S.-K. Rittinghaus, K. Gruber, P. Veit, A. Weisheit, M. Krüger, Printability and microstructural evolution of a near-eutectic three-phase V-based alloy, Additive Manufacturing. 34 (2020) 101208.
[9] T. Boegelein, S.N. Dryepondt, A. Pandey, K. Dawson, G.J. Tatlock, Mechanical response and deformation mechanisms of ferritic oxide dispersion strengthened steel structures produced by selective laser melting, Acta Materialia. 87 (2015) 201–215.
[10] S.-K. Rittinghaus, M.B. Wilms, Oxide dispersion strengthening of gamma -TiAl by laser additive manufacturing, Journal of Alloys and Compounds. 804 (2019) 457–460.