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Oxide dispersion strengthened steel manufactured by laser powder bed fusion and directed energy deposition

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Abstract

Additive manufacturing technologies are ideally suited for the generation of custom geometries and parts. In the context of specific applications such as high-temperature industrial processes like gas turbines or furnaces, the development of parts with enhanced high-temperature strength and oxidation resistance is highly desired. Oxide dispersion strengthened (ODS) steels are considered as suitable materials for such high temperature applications. To assess the effect of the processing technique on the manufacturing of ODS steels and its properties, an Fe-Cr based steel powder coated with 0.08 wt% of laser generated Y_2O_3 nanoparticles is processed by laser powder bed fusion (LPBF) and directed energy deposition (DED). We show that the produced specimens show superior mechanical properties at 600^{o} C compared to the reference part built without nanoparticle-addition. The enhanced mechanical properties are explained by the microstructure and nanoparticle dispersion in the generated ODS steels.

Keywords: Laser powder bed fusion; Laser ablation in liquids; Selective laser melting; Directed energy deposition; Laser metal deposition

1. Introduction

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Laser additive manufacturing (LAM) technologies that are based on the processing of powders by high power lasers are often used to develop steel parts with complex geometries and specific properties.[1] The two main powder-based LAM technologies are directed energy deposition (DED) and laser powder bed fusion (LPBF). Their basic principle relies on the melting of steel powders by a laser source, however the deposition method differs. Both techniques can be used to process oxide nanoparticle strengthened steels (ODS) with a characteristic fast solidification rate. The addition of well dispersed Yttrium based nanoparticles to steel powders have been shown to enhance the mechanical properties at high temperatures of conventionally generated ODS steel due to their effect as dispersoids, hindering dislocation propagation.[2] Typically, the powders employed in ODS steel fabrication are produced by mall milling, however the pH controlled dielectrophoretic deposition of laser generated nanoparticles on the steel powder has been shown to improve the dispersion of the nanoparticles and enhance the control over the process.[3,4] In the current contribution, the effect of the LAM processing technique over the nanoparticle dispersion and mechanical properties of laser generated ODS steels is evaluated by micro- and nano-structural analysis of the DED and LPBF fabricated parts.

2. Results

Yttrium oxide nanoparticles are generated by irradiation with a 10 ps, 355 nm laser of commercial Yttrium nanoparticles dispersed in water. A ferritic micropowder (PM2000) is added to the colloid and the pH controlled to achieve dielectrophoretic deposition and a 0.08 wt% Y_2O_3 nanoadditivated PM2000 powder. The obtained powder is used for DED and LPBF. The generated parts are analyzed by electron back scattering diffraction (EBSD), atom probe tomography (APT) and mechanical testing. The microstructural analysis by EBSD reveals that the LPBF produced parts exhibit the biggest grain refinement effect up to a 20 % factor (Fig 1a, b). The inclusions can be already observed by EBSD and further confirmed by SEM-EDX, finding that they are Y-based.

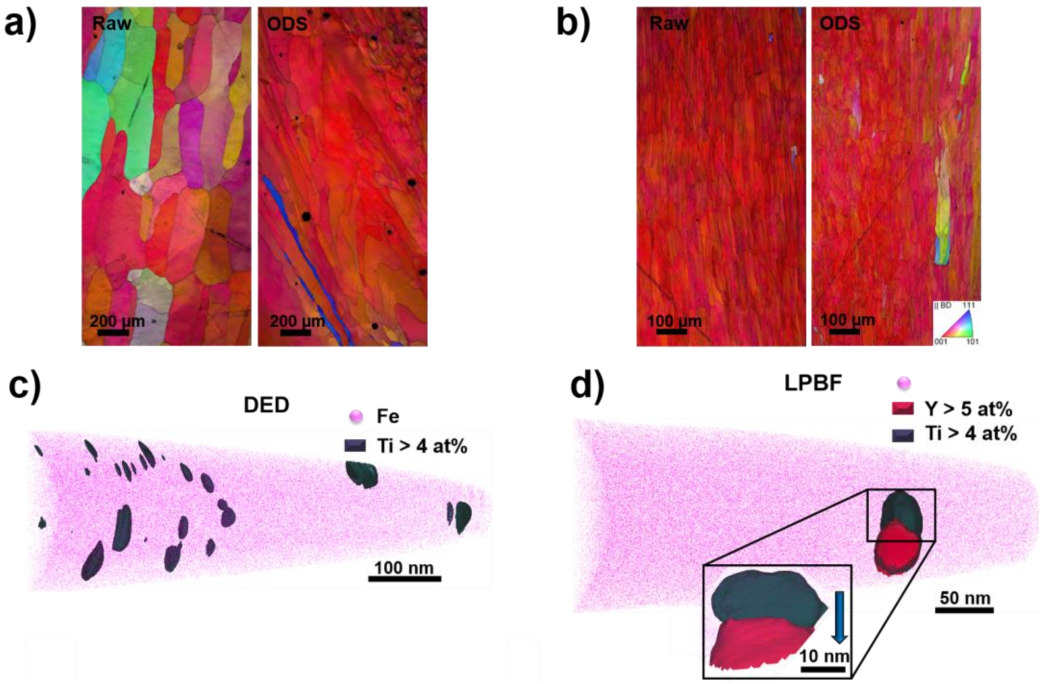

Fig. 1. EBSD inverse pole figure maps with superimposed image quality (band contrast) of LAM steel samples in cross-section (viewing direction parallel to the building direction) for: a) DED raw and ODS steel, and b) LPBF raw and ODS steel SEM backscatter electron micrograph and the corresponding EDS maps of the elements Y, O, Al and Si for a) the DED ODS steel sample, and b) LPBF ODS steel sample. The circles highlight selected particles found in the microstructure. APT results from c) DED produced ODS steel and d) LPBF produced ODS steel. Panel d) further indicates the occurring Orowan mechanism. Figures adapted from ref [5].

To further resolve the nanoinclusions, APT measurements were performed (Fig 1 c,d) that also confirmed the presence of Y-based nanonclusions. The APT and SEM-EDX joint analysis allows to observe a reduced agglomeration of the initially added nanoparticles in the LPBF processed samples while DED leads to larger Y.based inclusions sizes. Mechanical tests at 600°C further showed that LPBF samples have a 29% enhancement of the compressive strength.[5]

3. Conclusions

The dielectrophoretic additivation of a PM2000 powder with laser generated nanoparticles was shown to be a convenient methodology for the generation of nanoparticle-additivated steel powders. The processing technique employed was shown to influence the nanoparticle dispersion in the final ODS steel parts, obtaining a better dispersion and smaller nanoinclusion size for LPBF processed parts. This is confirmed by EBSD measurements in which the highest grain refinement effect is found in the LPBF sample and APT where individual nanoinclusions size and composition are confirmed. Finally, all these differences affect the mechanical properties of the ODS steel, finding a 29% enhancement of the mechanical strength at 600°C for the LPBF ODS steel compare to the non nanoadditivated (raw) LPBF steel.

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References

[1] D. Herzog, V. Seyda, E. Wycisk, C. Emmelmann, Additive manufacturing of metals, Acta Mater. 117 (2016) 371–392. https://doi.org/10.1016/j.actamat.2016.07.019.

[2] A. Wasilkowska, M. Bartsch, U. Messerschmidt, R. Herzog, A. Czyrska-Filemonowicz, Creep mechanisms of ferritic oxide dispersion strengthened alloys, J. Mater. Process. Technol. 133 (2003) 218–224. https://doi.org/10.1016/S0924-0136(02)00237-6.

[3] R. Streubel, M.B. Wilms, C. Doñate-Buendía, A. Weisheit, S. Barcikowski, J.H. Schleifenbaum, B. Gökce, Depositing laser-generated nanoparticles on powders for additive manufacturing of oxide dispersed strengthened alloy parts via laser metal deposition, Jpn. J. Appl. Phys. 57 (2018) 040310. https://doi.org/10.7567/JJAP.57.040310.

[4] C. Doñate-Buendía, F. Frömel, M.B. Wilms, R. Streubel, J. Tenkamp, T. Hupfeld, M. Nachev, E. Gökce, A. Weisheit, S. Barcikowski, F. Walther, J.H. Schleifenbaum, B. Gökce, Oxide dispersion-strengthened alloys generated by laser metal deposition of laser-generated nanoparticle-metal powder composites, Mater. Des. (2018). https://doi.org/10.1016/j.matdes.2018.05.044.

[5] C. Doñate-Buendia, P. Kürnsteiner, F. Stern, M.B. Wilms, R. Streubel, I.M. Kusoglu, J. Tenkamp, E. Bruder, N. Pirch, S. Barcikowski, K. Durst, J.H. Schleifenbaum, F. Walther, B. Gault, B. Gökce, Microstructure formation and mechanical properties of ODS steels built by laser additive manufacturing of nanoparticle coated iron-chromium powders, Acta Mater. 206 (2021) 116566. https://doi.org/10.1016/j.actamat.2020.116566.