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Compositionally graded magnetic-nonmagnetic bimetallic structure using laser engineered net shaping

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Fabrication of compositionally-graded magnetic-nonmagnetic bimetallic structures was successfully completed using a laser engineered net shaping (LENS™) system. A graded magnetic functionality was implemented by directly transitioning from non-magnetic austenitic stainless steel 316 (SS316) to magnetic ferritic stainless steel 430 (SS430) in a single structure. LENS™ additive manufacturing utilizes a high-powered laser to continuously melt and bond metallic powder in successive layers to create the 3D structure. Microstructures revealed a preferred grain growth direction at the interfaces of the deposited layers. Micro-hardness values across the part's cross-section exhibited a smooth transition from the highest value of 266 ± 4 HV in the SS430 region to the lowest value at the SS316 substrate of 174 ± 3 HV. Magnetic functionality was observed on the SS430 side of the bimetallic structure, showing how LENS™ can additively combine materials of varying compositions for location-specific functionality.

1. Introduction

Processing compositionally-graded materials (CGM) using additive manufacturing techniques is becoming attractive as size, shape and functionality can be varied through design. As shown in previous works, a stainless steel 304 (SS304) part was printed with the addition of niobium carbide that increased surface hardness and reduced wear rates by over 75% [1], while a calcium-phosphate/titanium CGM was additively fabricated to increase wear resistance [2]. With this designed functionality, increased mechanical properties can be influenced in user-definable locations to best improve the system's performance. This idea of adding functionality to specific regions was the foundation for additively manufacturing magnetic SS430 to non-magnetic SS316 structures. Magnetic functionality has been implemented from environmental sustainability efforts by contaminant adsorption [3] to NASA's ion propulsion engine "Deep Space 1" for space travel [4]. Additive manufacturing of some single magnetic materials has already been reported [5–7] for increased part functionality. By creating a unique magnetic CGM with two different stainless steel alloys in one processing operation through LENS™, the functional capability of direct energy deposition techniques for multiple material systems can be demonstrated while creating a useful, single component without using any traditional joining process limitations.

2. Materials and methods

A 3 mm SS316 plate was used as a substrate for sample fabrication in the LENS™ (LENS™ 750, Optomec Inc. Albuquerque, NM). SS316 powder (Höganäs Belgium SA, Belgium, particle size: 45–150 μm) was first deposited onto the substrate by argon carrier gas converging the powder to the focal point of a continuous wave Nd:YAG laser. SS430 powder (Sandvik Osprey Ltd., Wales, particle size: 45–150 μm) was then directly deposited on top of the SS316 deposit to create the final structure. Various parameters were tried before structurally-sound parts could be successfully made. Final parameters used a 46 cm/min deposition for hatch and contour paths at a 34A current for the Nd:YAG laser. Oxygen levels ranged from 30 to 170 ppm during the builds, and all samples directly transitioned from one material to the next in a continuous process.

Samples were cut along the cross section to observe microstructural variations and test hardness values. Once cut, samples were hot-mounted and placed through standard metallographic wet-grinding preparation techniques from 220 to 1000 grit sandpaper. Samples were then polished from 1 μm to 0.05 μm alumina-DI water polishing suspension until a mirror finish was obtained. Finally, samples were etched with Carpenter 300 series stainless steel etchant to expose microstructures.

3. Results and discussions

After several rounds of process optimization, the austenitic-ferritic stainless steel parts were built with minimum porosity

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and strong interfacial bonding. Final functional pieces can be seen throughout Fig. 1, where the bottom of the structure is SS316 and an obvious direct transition to the SS430 can be observed, particularly on the CNC-machined surface. Taller parts were CNC-machined to reduce the inherent surface roughness of LENS™ processing and provide a macroscopic viewpoint of porosity and interfacial bonding, as seen in Fig. 1b–d. The enhanced surface finish revealed a strong, coherent bimetallic structure across the entire component with no observable cracking or defects. Magnetic functionality is also presented, as shown in Fig. 1d where magnetic particles were sprinkled around the tube lying down and particle accumulation only occurred on the magnetic SS430 side along the magnetic field lines.

To test the hardness of the structure, a Micro Vickers Hardness Tester (Phase 2 Plus, New Jersey, USA) was used. Hardness indents started at the top of the cross section in the SS430 region, indicated by the 0 mm depth in Fig. 2. A 100 g load was applied for 15 s. Indents were taken across every 1 mm gap in the cross section and effectively displayed how the property transitioned from SS430 deposit to SS316 deposit to the SS316 substrate. Hardness values began at a maximum of 266 ± 4 HV at the 0 mm depth and steadily declined down the cross section. There were slight shifts in hardness across both interfaces, which is natural even for the shift from the SS316 deposit to the SS316 substrate. The rapid solidification processes of LENS™ causes the material to have a refined grain structure in a preferred growth direction toward the

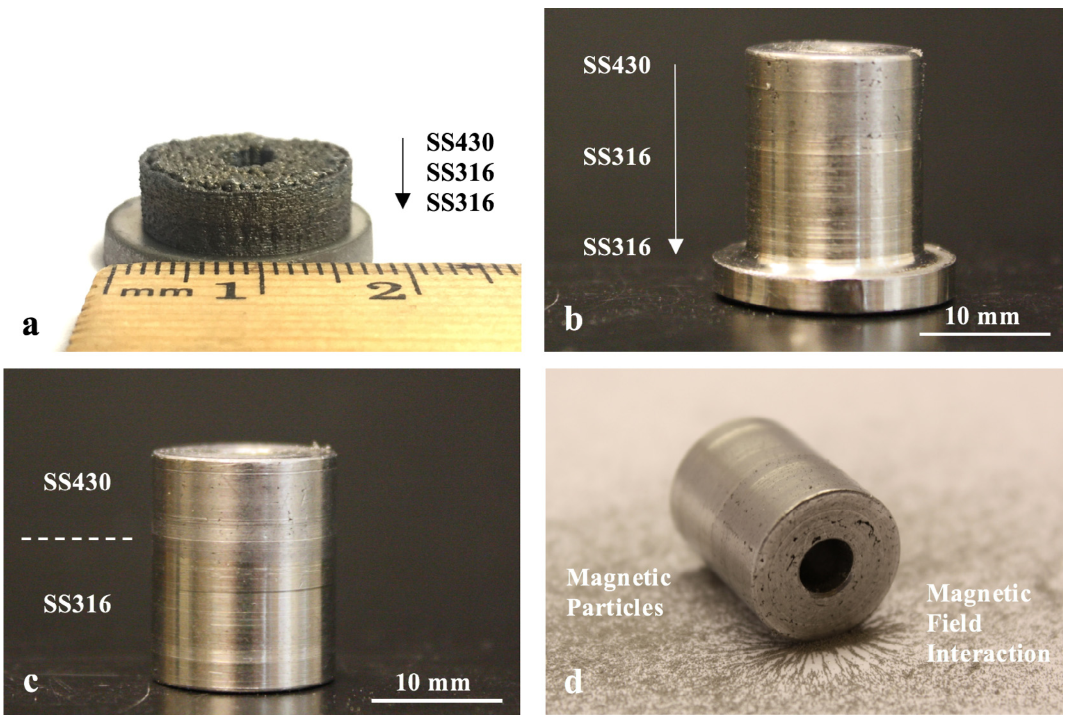

Fig. 1. a) As-deposited structure, b) a final CNC machined sample with substrate, and c) a final CNC machined sample used to d) demonstrate magnetic functionality.

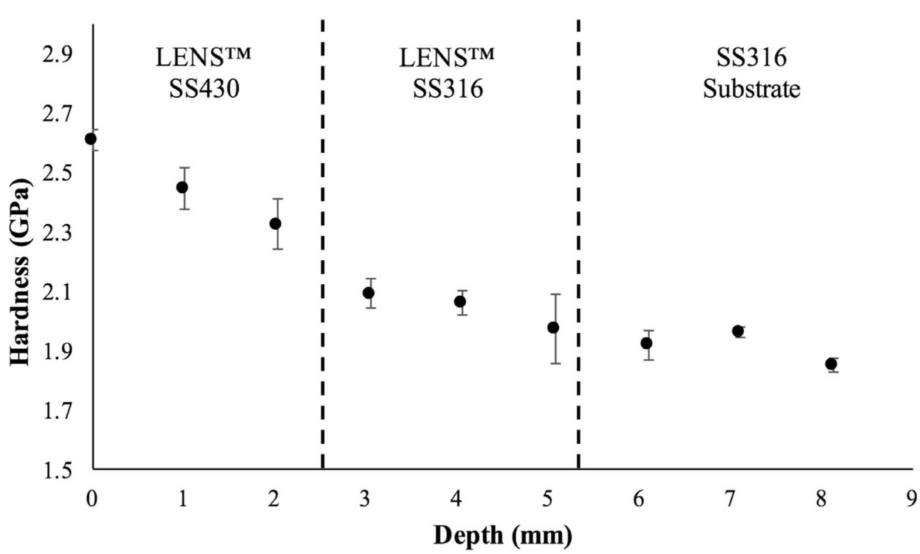

Fig. 2. Hardness vs. cross-sectional depth profile showing a smooth hardness transition across deposited regions to the substrate.