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Insights into the secondary laser processing of LPBF IN718 alloys

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Abstract
Laser powder bed fusion (LPBF) based additive manufacturing (AM) technology has been widely adopted for manufacturing complex-shaped engineering components. However, in order to satisfactorily use such AM components and assess their admissibility as useful engineering components, the response to secondary processing methods must be investigated. In one such attempt, we present the response of LPBF IN718 parts to laser texturing and compare it with that of conventional IN718 alloys. The study explores the laser texturing track and depth formation behavior and its response to the patterning features (width, depth, the formation of resolidified layers, damaged zones, etc.). The influence of different laser scanning speeds and the number of pulses has been studied to correlate the pattern features with the properties of the base materials. Larger centreline depth of AM IN718 has been found compared to the cast counterpart.

Keywords: Laser powder bed fusion, Laser texturing, Inconel 718, Additive Manufacturing

1. Introduction

Laser surface processing methods (texturing, polishing, shock peening, etc.) have been utilized for patterning and scribing on conventional metallic and alloy surfaces to impart additional functionality (adhesion, wettability, roughness features, hardening, tribological advantages, etc.) [1]. Laser surface processing of materials has offered great precision and control at a fairly low cost, short operating time, and heating/ablation at a micron scale [2]. Since its invention, researchers have been utilizing lasers' potential for various manufacturing applications. Recent applications of lasers in additive manufacturing (AM) [3–5] have opened limitless opportunities for the manufacturing of complex-shaped components. 3D printing methods such as laser powder bed fusion (LPBF) and laser metal deposition (LMD) have been instrumental in the growth of metal AM [3,6].

Printed metallic components have different material properties than conventional cast or vacuum arc-remelted alloys [7]. Owing to their distinct solidification behavior, grain growth, and consequent anisotropy, completely different thermo-mechanical properties are obtained for printed alloys. Different secondary processes, e.g., laser peening [8], laser remelting [9], and laser polishing [10] have been tested for AM alloys. A myriad of events (thermal heating, ablation, erosion, asperities formation, microcracking, voids, bulges, recast and redeposition layers, etc.) appear during the laser processing of an alloy. Such phenomena necessitate proper selection, optimization and control of laser parameters. The influence of laser surface texturing on Inconel 718 alloy processed by different methods (cast and AM) has not yet been studied. Differences in the original alloy processing (cast or AM) must significantly influence the laser texturing and surface processing. For cast IN718, optimization of the process parameters has been studied by Marque et al. [11]. The low-range laser power ($1-16\%$) and medium scan speeds ($500-2000\ mm/s$) promote ablation and generate well-defined textures. Line, grid, and spot patterns have been textured on conventional IN718 [12], which generated variable morphology and roughness by changing chemical compositions. But no report is available on surface patterning of AM Inconel 718 alloy developed by LPBF route. The present study is an initial attempt to explore the influence of laser texturing AM IN718 and its comparison with cast alloy.

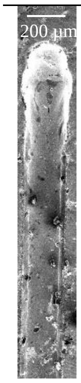
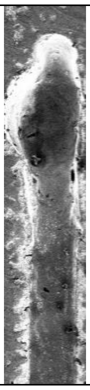
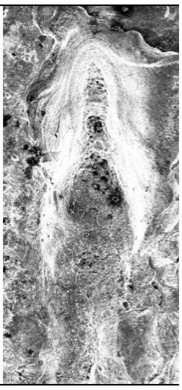
2. Materials and methods

IN718 metallic substrates have been printed using a Renishaw AM400 powder bed fusion metal printer. Gas atomized powder of IN718 was used for printing at 200 W laser power, 1 m/s scan speed, 0.09 µm hatch speed, and 60 µm layer thickness. The laser spot diameter was fixed to 70 µm, and parts were printed using the stripe strategy. The printed parts have been heat treated following AMS 5663 standards. After printing and heat treatment, the skin was finished under flood cooling to remove the oxidized layer. Laser texturing has been performed on conventional and AM IN718 alloy using SPI-SP200C fiber laser having wavelength 1064 nm and maximum power 200 W. TEM_{00} mode has been used to focus the laser on the substrate surface using a convex lens (focal length 50 mm). Texturing on the substrates has been conducted at scan speeds $50-400\ mm/s$ (with 50 mm/s increment) and $15-90$ (15 pulse increments). The centerline depth of the textures, the mechanism of material expulsion and related features have been deduced from the FESEM micrographs (FEI Quanta 200).

3. Results and discussion

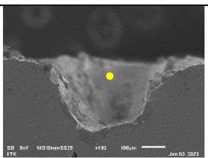
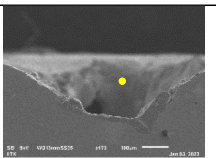
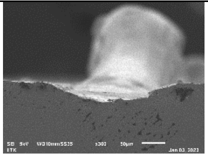
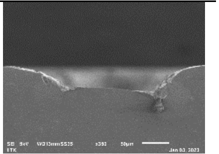
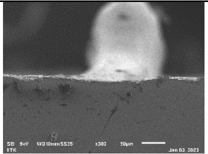
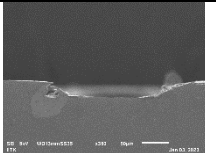
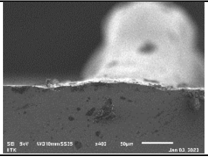
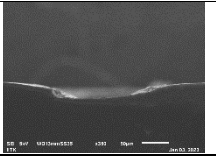
Higher width of the tracks has been obtained for AM Inconel surfaces with the heavily damaged track at low scan speeds. Damage and spatter of the ablated material were evident for AM alloy at low scan speed. The centreline depth of the microtextures under different scan rates is plotted in Fig. 1. Table 1 shows laser tracks on the cast (C) and printed (P) Inconel surfaces. At 400 mm/s, negative depth corresponds to the bulge formation at the cast surface. At higher scan speeds, the surface is heated, remained in the conduction mode of laser-matter interaction, and expanded to relieve the thermal stresses.

Table 1. Laser tracks on the cast and printed IN718 after 90 pulses

400 mm/s		200 mm/s		50 mm/s	
					
C	P	C	P	C	P

Appreciable texture depth at cast IN718 is obtained at 50-250 mm/s and the texture depth has always been less than the corresponding printed IN718 surface (except 50 mm/s). A drastic increase in texture depth has been obtained for cast IN718 at 50 mm/s. High melting and evaporation might have appeared at low scan speed, causing higher texture depth with no visible redeposition around the texture edge. The cross-section micrographs in Table 2 show the distinct behavior of the cast and the printed surface under the influence of laser.

Table 2. Cross-section of the textured zone after 90 pulses

		As cast	Printed
Scan Rate (mm/s)	50		
	200		
	300		
	400		

In most cases, a lump of the redeposited material could be seen in cast IN718 at the end of the track (Fig. 2). The ablated material has moved along the laser scan direction and solidified at the edge with the decelerating laser beam. The decelerating laser leaves a heavy deposit of molten material at the end of the track, whereas such features are not present in the case of printed alloy. Higher scan rates control and modify the cooling rate by self-annealing effect as thermal diffusion from previous interaction impacts the next laser-matter interaction, thus increasing the depth of textures [13]. Micrographs at the boundary wall of textures (located by a yellow dot) reveal the differences in the solidification behavior of the two alloys. High cooling rates at lower scanning rate result in high thermal stresses and form cracks and large-size cavities.

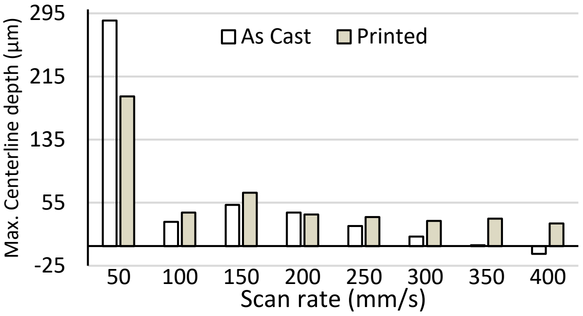


Fig. 1 Maximum centerline depth on cast and printed IN718

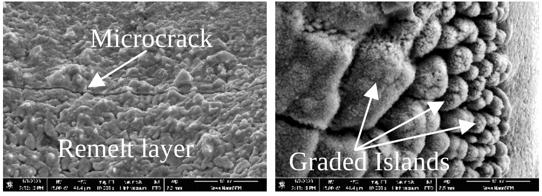


Fig. 2 Microscopic features on the side wall of the textured microhole at marked locations for (a) cast and (b) printed alloy.

4. Conclusions

Different processing methods have yielded distinct texturing behavior of the Inconel alloy. Higher texture depths have been obtained for additively manufactured IN718 than the cast alloy. High scan rates control the cooling rates and offer lower damages by self-annealing process irrespective of the processing method. The anisotropic behavior of AM alloy causes the graded solidification along the wall of the textured microfeature, whereas high tensile residual stresses generate transverse microcracks for cast alloy.

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