Experimental report

26/09/2024

Proposal: **1-02-369**

Council: 4/2023

Title: Quantification of residual stresses via selective pre-sintering in laser powder bed fusion of Ti-6Al-4V

Research area: Engineering

This proposal is a new proposal

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Samples: Ti64

Instrument	Requested days	Allocated days	From	To
SALSA	5	4	25/09/2023	29/09/2023

Abstract:

Large residual stresses as a result of rapid, highly localised melting and solidification are a common feature of Ti-6Al-4V components manufactured by laser powder bed fusion (LPBF), which may cause irreversible damage to components during manufacturing or in end-use applications. To overcome this, heat treatments are often used post-processing to release residual stress accumulated during processing. More recently, heat treatment methods have been successfully implemented in situ for the reduction of residual stress through reduced thermal gradients, thereby improving the mechanical properties of as-built components. In this proposal, we plan to investigate the influence on residual stress of a novel multi-laser process, called laser pre-sintering (LPS). LPS has promising benefits from a manufacturing perspective, but its influence on residual stress has never been studied, and therefore its true impact is not yet understood.

SALSA Experimental Report for Proposal 1-02-369

Influence of Laser Preheating on Residual Stress in Ti-6Al-4V Laser Powder Bed Fusion (LPBF)

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Introduction

Preheating in LPBF is commonly employed as a way of reducing residual stresses in as-built metallic components. Preheating has successfully been applied to reduce residual stress both for LPBF [1] and electron beam melting (EBM) [2] via baseplate heating with the addition of selective preheating in EBM. Both preheats were able to reduce the thermal gradients inside the melt pool, thereby reducing residual stress [3]. In powder EBM, selective preheating is often employed to lightly sinter powder particles prior to the processing step, avoiding a detrimental phenomenon known as “smoking” [4]. With multiple lasers now in LPBF machines, it is also possible to employ a similar tactic for LPBF. Recently it was proven that laser preheating (or laser pre-sintering) was able to reduce spatter in LPBF [5], which could result in improved mechanical properties and productivity. It is reasonable to hypothesize that a laser preheating step could also reduce thermal gradients, thereby improving the residual stress state, but this has not yet been explored. In this study, we will examine the effects laser preheating in LPBF on the as-built residual stress state via bulk residual strain mapping of industrial scale Ti-6Al-4V components with neutron diffraction.

Methods

Sample Development. Ti-6Al-4V cantilevers (Fig. 1a) were developed at Renishaw plc. with their commercially available RenAM 500Q LPBF machine. This machine is equipped with four 500 W fiber lasers, a 250 mm x 250 mm powder bed, and an inert processing atmosphere. Four cantilevers over two process conditions were developed in total, where the first condition was standard, single laser process and the second implemented laser preheating. Laser preheating was realised by a leading + trailing laser format. The leading laser applied 20% of the single laser melting power and the trailing laser 80%, trailing the leading laser by 350 µs. The single laser melting power was 320 W and all lasers used a scan speed of 1500 mm/s.

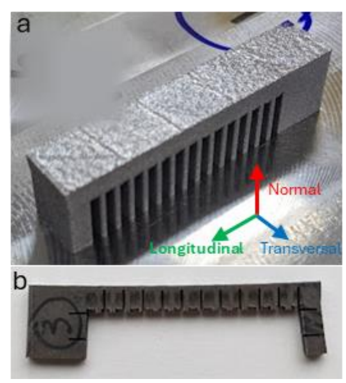

Fig. 1 a) Cantilever sample 50 mm (length) x 12 mm (height) x 5 mm (width). b) d0 reference comb cut from sample identical to a).

Neutron Diffraction. Bulk residual strain measurements were carried out during SALSA experiment 1-02-369. A wavelength of 1.9 Å was chosen to measure the Ti-101 peak of the α/α' phase. The gauge volume was a rhomboid of 2 mm in height with a 1.55 mm diagonal at 2θ=50°. A “stress-free” reference for each process condition was also measured to obtain d_0, as in Fig. 1b. For 13 datapoints inside each cantilever, the Ti-101 peak was measured for three principle strain components, indicated in Fig. 1a. A triaxial stress tensor was obtained using generalised Hooke’s law [6], assuming isotropy. The Ti-101 diffraction elastic constant and poisson ratio of 107 GPa and 0.39, respectively, were taken from [7].

Results and Discussion

The measured strains and calculated residual stresses along each component in Fig. 1a are plotted in Fig. 2. For the single laser process condition (2a), the normal component shows the most asymmetry and variation from the longitudinal and transverse components, where the 101 plane shows compression in the wide leg, shifting towards balanced in the bridge and towards tension in the narrow leg. The longitudinal and transversal components show tensile strains throughout, with a gradual reduction in magnitude towards the narrow leg. All three components show similar tensile strain in the narrow leg. The laser preheating strain components (2b) are more varied between one another, with the longitudinal strain displaying the most tensile strain, followed by the transversal component mostly in balance, and the normal component mostly in compression. Unlike the narrow leg of the single laser process, the narrow leg of the laser preheat shows high divergence between the three components.

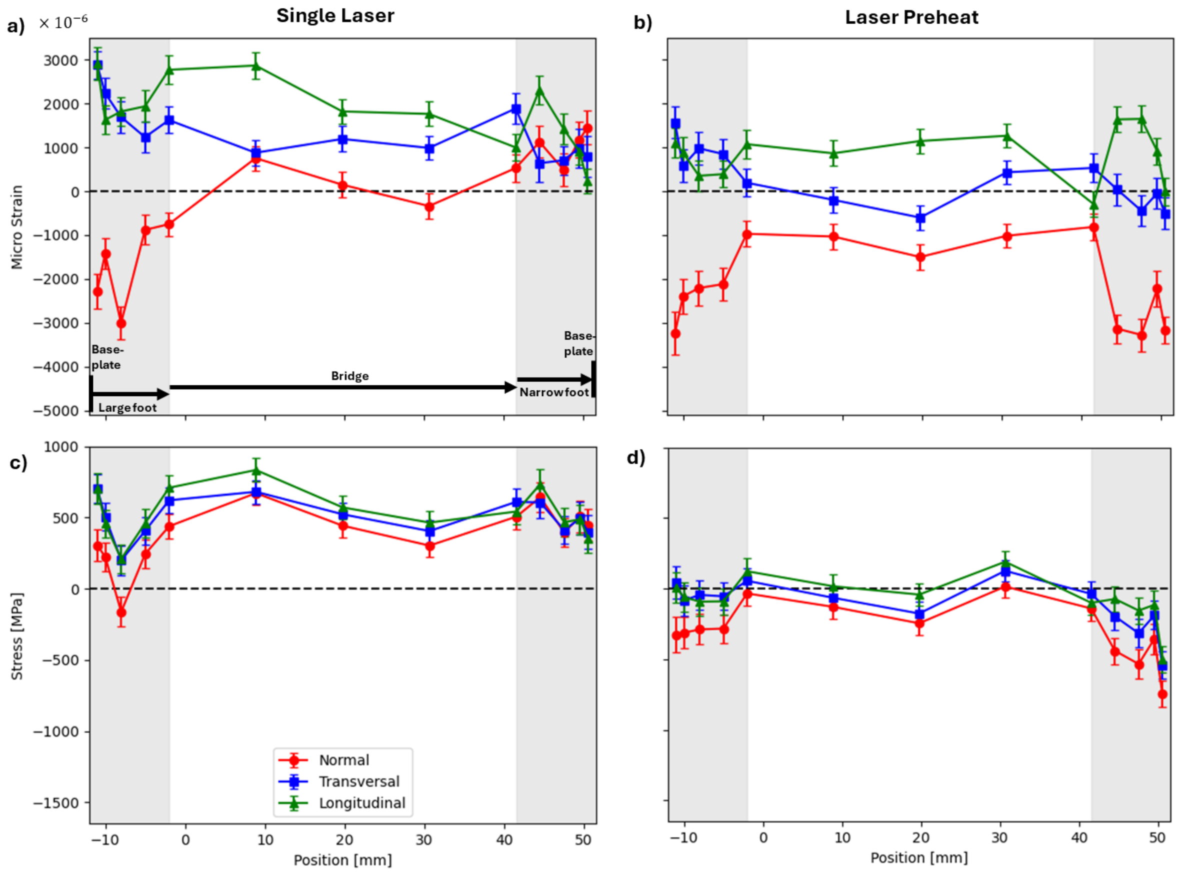

Fig. 2 The measured strains (**a** and **b**) and calculated stresses (**c** and **d**) for single laser process (**a** and **c**) compared to the laser pre-heating process (**b** and **d**).

The residual stress of the single laser process is tensile for all components and more balanced for laser preheating. The three components are quite hydrostatic, with the same trend of longitudinal being the most tensile and normal being the most compressive for both samples. This is a potential validation of our hypothesis, where the expected reduction in thermal gradient corresponds with a shift towards balanced and compressive residual stress.

Conclusion and Outlook

The results presented in Fig. 2 indicate that laser preheating affects the residual stress state, specifically reducing the magnitude of tensile stresses compared to the single laser (traditional) process condition for a Ti-6Al-4V cantilever. In a future experiment, we hope to continue this work to also examine the effect of baseplate preheating for comparison.

References

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