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Full Length Article

Laser polishing of 3D printed mesoscale components

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ABSTRACT

Laser polishing of various engineered materials such as glass, silica, steel, nickel and titanium alloys, has attracted considerable interest in the last 20 years due to its superior flexibility, operating speed and capability for localised surface treatment compared to conventional mechanical based methods. The paper initially reports results from process optimisation experiments aimed at investigating the influence of laser fluence and pulse overlap parameters on resulting workpiece surface roughness following laser polishing of planar 3D printed stainless steel (SS316L) specimens. A maximum reduction in roughness of over 94% (from ~3.8 to ~0.2 μm S_a) was achieved at the optimised settings (fluence of 9 J/cm^2 and overlap factors of 95% and 88–91% along beam scanning and step-over directions respectively). Subsequent analysis using both X-ray photoelectron spectroscopy (XPS) and glow discharge optical emission spectroscopy (GDOES) confirmed the presence of surface oxide layers (predominantly consisting of Fe and Cr phases) up to a depth of ~0.5 μm when laser polishing was performed under normal atmospheric conditions. Conversely, formation of oxide layers was negligible when operating in an inert argon gas environment. The microhardness of the polished specimens was primarily influenced by the input thermal energy, with greater sub-surface hardness (up to ~60%) recorded in the samples processed with higher energy density. Additionally, all of the polished surfaces were free of the scratch marks, pits, holes, lumps and irregularities that were prevalent on the as-received stainless steel samples. The optimised laser polishing technology was consequently implemented for serial finishing of structured 3D printed mesoscale SS316L components. This led to substantial reductions in areal S_a and S_t parameters by 75% (0.489–0.126 μm) and 90% (17.71–1.21 μm) respectively, without compromising the geometrical accuracy of the native 3D printed samples.

1. Introduction

Additive manufacturing (AM) or 3D printing is rapidly developing as a viable technology for producing complex components as it offers many advantages over conventional processing. This includes greater design freedom as well as the capability to efficiently produce complex parts with intricate internal and external structures. While there is evidence of growing interest and initial utilisation of AM processes in several industries such as the automotive, aerospace, opto-electronic and biomedical sectors [1], uptake of this technology on a larger production scale remains limited. This is primarily due to shortcomings of current AM processes relating to achievable workpiece geometrical accuracy and surface integrity, with parts generally suffering from poor surface roughness (typically ranging from ~5 to 15 μm R_a), stair-step effects on surfaces, balling, adverse residual stresses and low dimensional precision [2]. Therefore, post-process operations such as sand blasting, machining, etching, electro-polishing or plasma spraying is often employed for AM components to meet functional tolerances and surface integrity requirements. Some of these methods however are time consuming and not viable particularly for products with complex geometries. A potential alternative is laser polishing (LP), which is a flexible, contactless method that can be fully automated without the need for dedicated equipment. The technology has been continuously developed over the past two decades and successfully employed for improving the surface morphologies of components made from various materials such as diamond, glass, silica and metals including steel, nickel/titanium alloys and to a somewhat lesser extent, aluminium alloys [3]. The present paper

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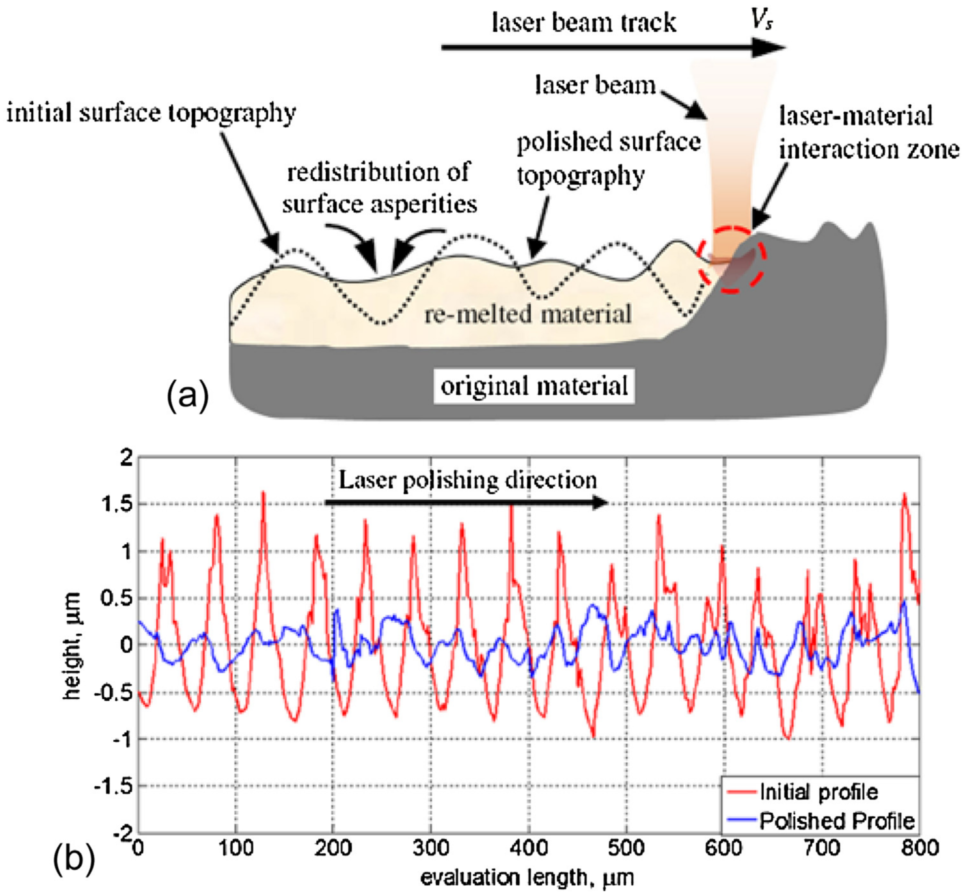

Fig. 1. (a) Schematic view of the re-melting mechanism, and (b) effect of laser irradiation on surface asperities [3].

details results from experimental trials to evaluate the performance of laser polishing for finishing additively manufactured stainless steel surfaces. The effects of varying laser fluence and pulse overlap factors on workpiece surface roughness were assessed, followed by an analysis of oxide layer formation, microstructure and microhardness after polishing at different fluence levels under atmospheric and argon environments.

2. Literature review and research motivation

2.1. Review of laser polishing research

Polishing using laser irradiation can be achieved through three different process mechanisms, which are large area ablation, localised ablation and re-melting at macro (over depths of 20–200 µm) or micro (over depths of 0.5–5 µm) polishing regimes [4]. The majority of research on LP however has focussed primarily on the re-melting mechanism due to several advantages compared to the ablation based methods, such as greater scope for automated operation, shorter machining times, reduced environmental impact, better user control of surface roughness and localised processing capability [4].

Re-melting is initiated when material from surface asperities is redistributed into adjacent troughs/valleys to form a molten pool due to surface tension as a laser beam passes over the workpiece. This leads to a decrease in peak-to-valley heights of the initial surface asperities [3]. A schematic illustrating the re-melting mechanism in LP is given in Fig. 1(a) while its effect on surface topography is shown in Fig. 1(b).

2.1.1. *Laser polishing of non-metallic materials*

Surface treatment of thick (>100 µm) and thin (<100 µm) diamond films (deposited by chemical vapour deposition) using LP was introduced in the mid-1990s, with the process demonstrating remarkable reduction in polishing times compared to mechanical methods [5,6]. It was reported that mechanical polishing techniques typically required 12–28 h in order to achieve optical quality surface finish for 150–400 µm thick diamond films over an area of 8 × 10 mm^2, while LP processing time was less than 1 h for a 5 × 5 mm^2 area [6]. However, the average surface roughness (R_a) following LP was of the order of micrometres whereas the mechanical based treatment was capable of producing roughnesses in the nanometre range. Thus, LP is usually recommended as an initial “rough” polishing operation in order to reduce the overall processing time for generating optical quality surfaces.

Apart from thick/thin diamond films, LP has also been employed for the finishing of fused silica/glass parts [7–11]. Bol’shepaev and Katomin [7] reported that workpiece surface cracking following LP of fused silica was due to thermal stresses induced by the laser beam and consequently recommended pre-heating the workpiece to near annealing temperatures (500–600 °C) prior to polishing. In order to achieve an acceptable surface finish Wang et al. [8] showed that an optimum range of laser energy density (800–1100 J/cm^2) was required for LP of silica, below which no obvious surface modifications occurred whilst higher energy densities led to vaporisation and breakdown of SiO_2 to SiO. However, in another study by Hildebrand et al. [10], it was observed that the final surface roughness was largely influenced by the initial roughness and waviness of the as-received workpieces. Heidrich et al. [11] proposed a three-step manufacturing route for producing optical components, starting with high speed laser ablation followed by LP and finally high