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Improving surface finish of 3D-printed metals by ultrasonic nanocrystal surface modification

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Abstract

Poor surface finish of 3D-printed metals significantly deteriorates their corrosion, wear and fatigue resistance. Ultrasonic nano-crystal surface modification (UNSM) is an innovative surface processing technique that utilizes low amplitude ultrasonic frequency vibrations superimposed on a static load to generate plastic deformation on a metal surface to its improve properties and performance. In this study, we investigate the effect of UNSM on the surface finish of 3D-printed metals. An aluminum AlSi10Mg alloy fabricated by direct metal laser sintering (DMLS) was used as an example. It has been demonstrated that UNSM can significantly improve surface finish of 3D-printed aluminum alloy. For example, the surface roughness of the AlSi10Mg alloy was decreased from 18 to 3.5 μm . With a better surface finish, UNSM is expected to improve the properties and performance of 3D-printed metals.

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1. Introduction

Metals fabricated by additive manufacturing hold many potential applications in the biomedical, aerospace and defense industries [1]. The poor surface finish of additive manufactured metals, however, significantly deteriorates their corrosion, wear and fatigue resistance and thus hampering their wide applications [2].

Ultrasonic nanocrystal surface modification (UNSM) [3,4] is an innovative technique that utilizes low amplitude ultrasonic frequency vibrations superimposed on a static load to induce high strain rate plastic deformation on a metal surface to improve its properties and performance [5]. In a UNSM process, a tungsten carbide ball attached to an ultrasonic device scans over material surface while striking it at high frequency (20 kHz). The overlap of the mechanical impacts generates plastic strain at the material surface and leads to surface plastic deformation. The process parameters in UNSM include the static load, the dynamic load, the interval between neighbouring scans and the scanning speed. These parameters can be precisely controlled and the system

can be easily integrated into a modern manufacturing system.

It has been reported that UNSM can improve the fatigue [6], wear [7] and corrosion [8] resistance of metallic materials. In a recent study [9], the effect of UNSM on the tribological behavior of a sintered Cu-based alloy has been investigated and it was reported that the surface roughness has been significantly reduced.

In this study, a 3D-printed aluminium AlSi10Mg alloy was processed by UNSM. The effect of the UNSM parameters on the surface finish of 3D-print material was investigated.

2. Materials and Experiment Method

2.1. Materials

An AlSi10Mg alloy was fabricated by the direct metal laser sintering (DMLS) method using an EOS M280 system. The composition of the alloy is shown in Table 1. A stress relieving cycle of 2 hours at 300°C was used to relieve the

thermal stress generated during DMLS. The relative density is approximately 99.85% and the density is 2.67 g/cm³.

Table 1. Composition of the AlSi10Mg alloy

Element	Weight Percentage
Si	9.96
Fe	0.15
Cu	< 0.005
Mn	< 0.005
Mg	0.35
Zn	< 0.005
Pb	< 0.05
Ti	< 0.004

2.2. UNSM processing

Fig. 1a shows a side view of the UNSM tip and the sample fixture; Fig. 1b shows a schematic of the UNSM process. In a UNSM process, a tungsten carbide ball attached to an ultrasonic device scans over the metal surface while striking it at high frequency. At the same time, a static load is applied to the ball against the material surface. The repeated, high frequency strikes cause severe surface plastic deformation on metal surfaces. Generally, tool wear is observed after extended operation time. It is recommended to replace the tungsten carbide tip after 20 to 50 hours of processing.

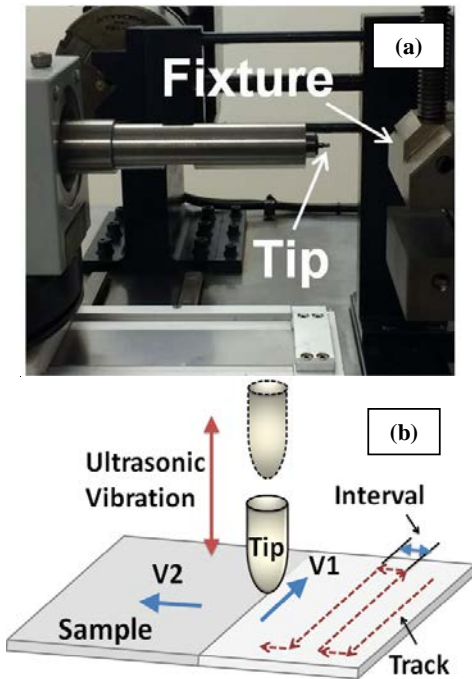


Fig. 1. (a) Lateral view of the UNSM unit; (b) Schematic of the UNSM process

The UNSM parameters used in this study are shown in Table 2. With a vibration frequency of 20 kHz and a feed rate of 2400 mm/min, the spacing between impacts is 2 μm. To investigate the effects of interval and vibration amplitude on surface finish, different intervals and vibration amplitudes were used.

Table 2. UNSM parameters

Parameter	Value
Frequency	20 kHz
Interval	10 to 70 μm
Static load	10 N
Scanning speed	2400 mm/minute
Tip diameter	4 mm
Vibration amplitude	8 to 20 μm

2.3. Surface morphology characterization

A Zygo NewView 7300 surface profiler was used to measure the surface roughness of untreated and treated samples. The dimension of the measured area is 2.83 mm by 2.12 mm. In this study, the surface roughness Ra numbers were reported.

3. Results and Discussion

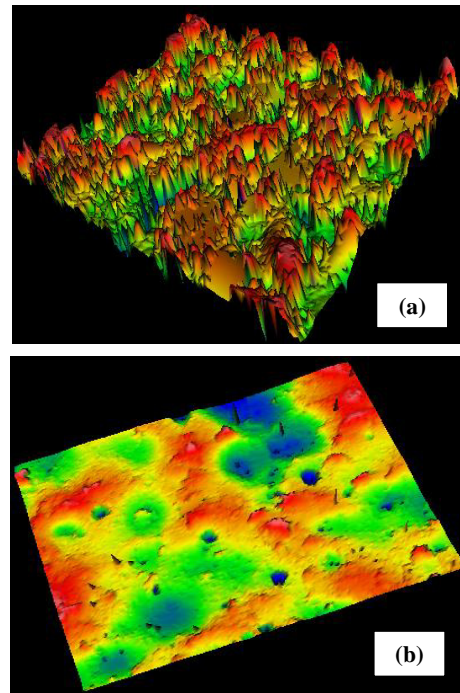


Fig. 2. 3D surface morphology of the untreated sample (a) with a Ra of 18.0 μm and the UNSM-treated sample (b) with a Ra of 3.5 μm, (UNSM parameters, static load 10 N, interval 10 μm, vibration amplitude 12 μm), the measured area is 2.83 mm by 2.12 mm

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