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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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Keywords: additive manufacturing, direct metal laser sintering, ultrasonic nanocrystal surface modification, surface roughness

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 300ºC was used to relieve the

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thermal stress generated during DMLS. The relative density is approximately 99.85% and the density is 2.67 g/cm^3.

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.

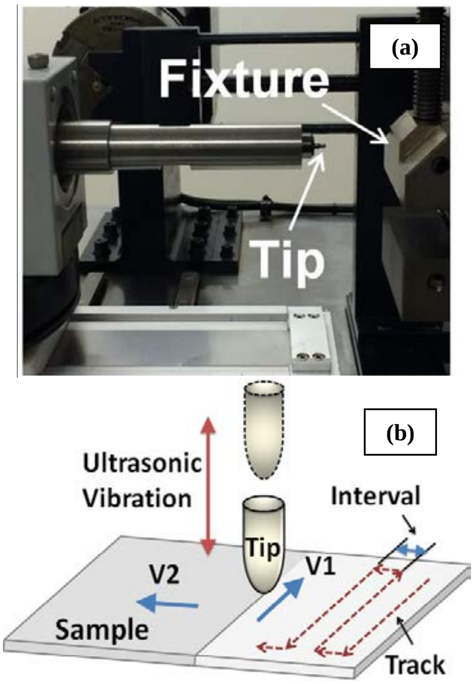

Fig. 1. (a) Lateral view of the UNSM unit; (b) Schematic of the UNSM process

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

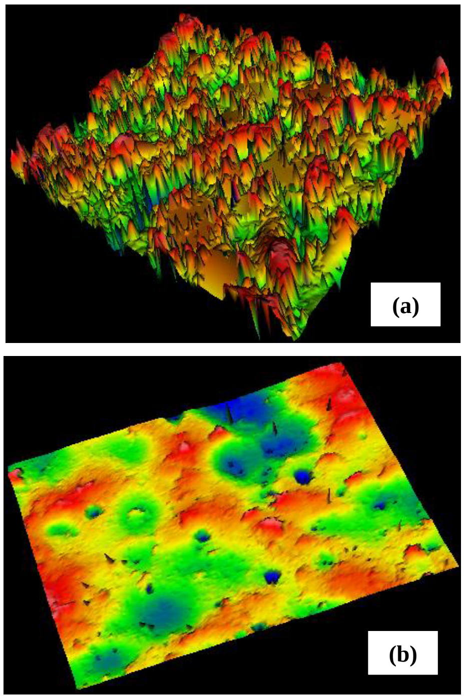

Fig. 2. 3D surface morphology of the untreated sample (a) with a Ra of 18.0 µm and the UNSM-treated sample (b) with a Ra of 3.5 µm, (UNSM parameters, static load 10 N, interval 10 µm, vibration amplitude 12 µm), the measured area is 2.83 mm by 2.12 mm

Fig. 2 compares the surface morphology of the samples before and after UNSM processing. The sample in Fig. 2a has a surface roughness (Ra) of 18.0 µm. A rough surface with peaks and valleys can be observed. This is a typical surface morphology of samples prepared by powder-bed-based additive manufacturing. Fig. 2b shows the surface morphology of UNSM-processed sample. We can observe that majority of the peaks were removed by UNSM. The UNSM-processed sample assumes a much smoother surface morphology with a surface roughness of 3.5 µm. Through UNSM processing, a significant surface roughness reduction has been achieved.

Fig. 3 compares the 1D surface profiles of the untreated sample and the UNSM-treated sample. We can clearly observe (Fig. 3a) that the untreated sample has many peaks and valleys. The height difference between the peak and the valley can be as great as 100 µm. For the UNSM-processed sample (Fig. 3b), however, the sample is smooth with a height difference between peaks and valleys around 15 µm.

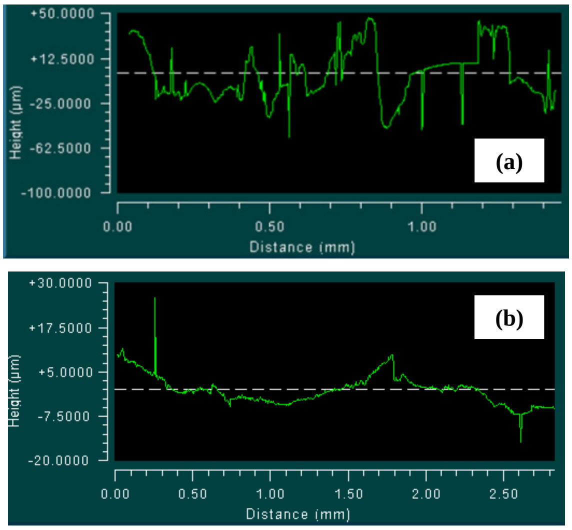

Fig. 3. 1D surface profile of the untreated sample (a) with a Ra of 18.0 µm and the UNSM-treated sample (b) with a Ra of 3.5 µm (UNSM parameters: static load 10 N, interval 10 µm, vibration amplitude 12 µm)

The effects of UNSM interval and amplitude on the surface roughness were investigated. Fig. 4a shows the surface roughness (Ra) of the untreated and UNSM-treated samples with different UNSM intervals while other parameters were the same. We can observe that as the interval decreases, the surface roughness decreases, indicating better surface finish at lower UNSM intervals. While the interval represents the distance between neighboring UNSM scans, the lower interval means higher overlap of the UNSM scans, i.e., more UNSM scans over a given area. This means at smaller interval, more UNSM scans were imposed on the sample surface, leading to better surface finish.

The UNSM amplitude also affects the surface roughness. In UNSM, higher amplitude represents higher impact energy. We can observe from Fig. 4b that while all amplitudes lead to much better surface finish compared with the untreated samples, lower amplitude has the best surface finish with an Ra of 3.0 µm. This means a low amplitude of 8 µm is sufficient to effectively process the AlSi10Mg alloy to improve its surface finish. It should be noted that higher amplitude with higher impact energy would produce a deeper compaction and thus overall better surface/subsurface microstructure. This will be investigated in a future study.

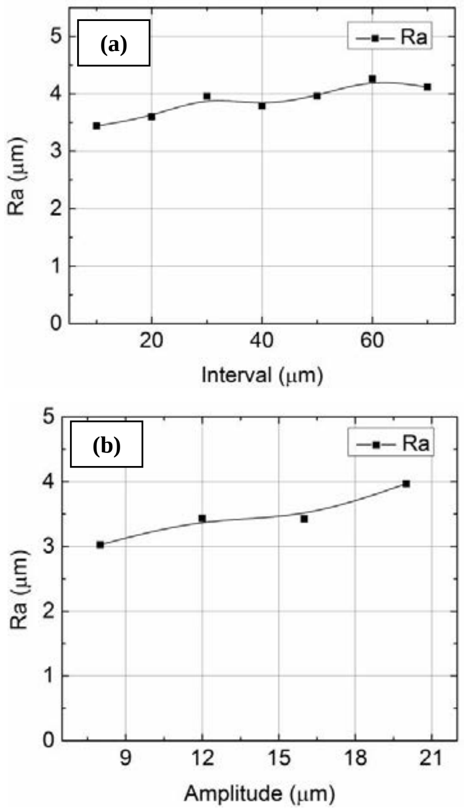

Fig. 4. (a) Surface Ra as a function of interval (static load 10 N, vibration amplitude 12 µm) and (b) Surface Ra as a function of vibration amplitude (static load 10 N, interval 10 µm)

4. Conclusion

In summary, a 3D-printed AlSi10Mg alloy was processed by a novel technique called UNSM with the goal of improved surface finish. After UNSM, the surface roughness (Ra) of the AlSi10Mg alloy was decreased from 18 to 3.5 µm. While better surface finish is beneficial for material corrosion, wear and fatigue resistance, UNSM has high potential in processing 3D-printed metals. Further investigation is underway.

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