Femtosecond Laser Production of Nanoparticles and Their Subsequent Layered Aggregate Growth Using a Line Focused Beam

Craig Zhulke, and John Bruce III, and Dennis R. Alexander

Department of Electrical Engineering, University of Nebraska-Lincoln, Lincoln, Nebraska, 68588-0511

Introduction

Femtosecond laser processing of materials is usually performed using spherical lenses to focus the laser to the highest irradiance. In this paper, we present work where a femtosecond laser beam is focused to a tight line source. A line focus produces a lower irradiance over the illuminated area. When this line source irradiance is above the threshold for material removal, nanoparticles are ejected during rastering of the sample and nanoparticles can agglomerate to form small aggregate structures that grow with each laser pass to form shelled composite structures. In this work, 2024 T3 Aluminum alloy samples were processed using the line source method. The nanomaterial deposited on each pass has the properties of the original 2024 T3 material. The 2024 T3 alloy machined surface is black in color. SEM analysis shows that the surface is composed of a large number of domed shaped micron sized structures.

Experimental

A Spectra Physics Spitfire laser system was used as the laser light source. The system is an amplified Ti:sapphire femtosecond laser producing a maximum of 1 mJ of energy in 50 fs pulses at a 1 kHz repetition rate, centered around 800 nm. A 150 mm focal length plano-convex fused silica cylindrical lens was used to focus the output of the femtosecond laser into a line focus onto the surface of the samples.

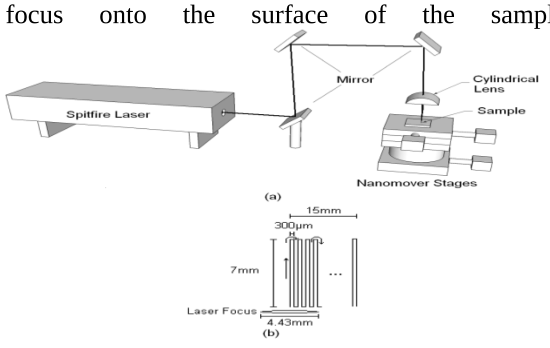

Fig. 1. (a). Experimental setup used in growing layered shelled nanocomposites and the blackening of the 2024 T3 aluminum alloy (b) rastering pattern and step size.

Results and Discussion

Fig. 2a is an SEM image of aggregates grown on a 2024 T3 aluminum sample. Aggregates preferentially grow on surface defects, but also grow in locations where defects are not visible on the micron scale. When a sample covered in these aggregates is placed in an ultrasonic bath filled with 20˚C distilled water for about 1 minute, the aggregates break off. The ultrasonic bath used is a model PC3 by L&R, dissipating 40 Watts at 50 kHz. Fig. 2b is an SEM image of aggregates that have broken off, have settled back onto the sample surface, and have been subsequently viewed using a SEM. When a large number of these loose aggregates are collected into a small pile they appear black. Also, individual aggregates look like black dots on a white background surface. Notice the ring structure on the bottom of the center aggregate (Fig 2b). There is also a ring structure that remains on the sample surface and extends beyond the physical boundary of the aggregate after it is removed (Fig. 2c).

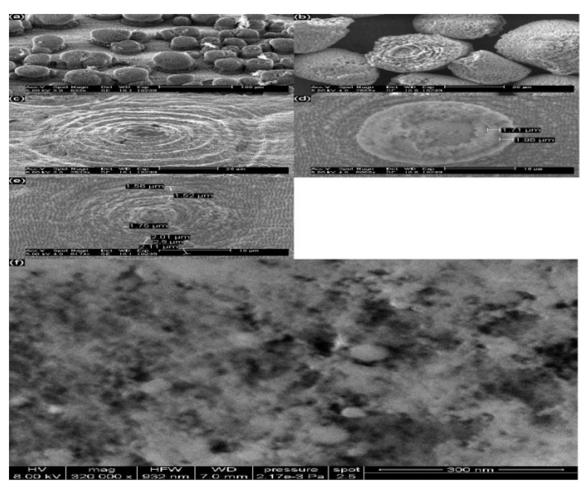

Fig. 2 (a) Spherical aggregates on 2024 T3 aluminum surface. (b) Aggregates that have been removed in an ultrasonic cleaner. (c) Ring structure that has developed under an aggregate. (d) An aggregate with several shells broken open. (e) Image of the ring structure left behind from the aggregate in (d). (f) A high magnification view of the inside of one of the aggregates.

Fig. 3 is a progressive set of SEM images showing growth of aggregates per pass over a single location. From these images it can be seen that with each pass the aggregates increase in size. This stepped growth is a result of ablated nanoparticles redepositing on the aggregate surface from each individual pass.

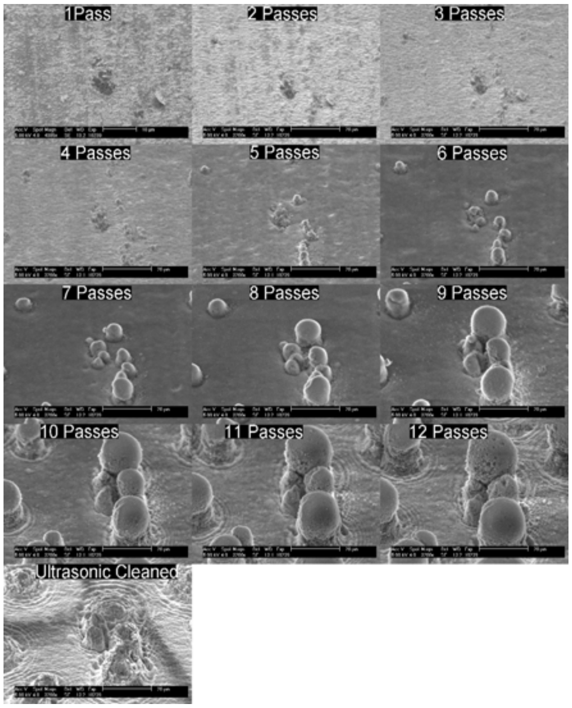

Fig. 3 Progressive set of SEM images showing the growth of each shell of the composite.

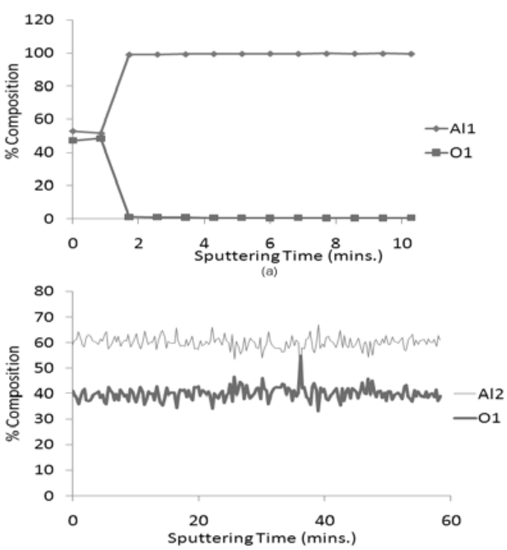

Fig. 4. Auger plots of elemental composition for (a) an unablated sample (b) a sample covered in aggregates.

Conclusion

We have demonstrated how a cylindrical lens can be used to produce nanostructured micron size aggregates with a 5-60 μm diameter on 2024 T3 aluminum sample. Aggregates increase in size each time the laser passes over them as ablated plume nanoparticles self assemble on their surface. As a result, permanent ring structures develop inside the aggregates' bodies. The processed surfaces are black in color with both the surfaces and the aggregates consisting of the same oxide material. Since these micron size aggregates are made up of nanoparticles, they are very porous and have a high surface area. These unique ring structured aggregates could prove to be useful in a number of applications including high surface area electrodes for ultracapacitors, optical stealth surfaces, and increased thermal emissivity. A focused line source optimizes the formation of aggregate growth and the blackening of a surface. This increased rate of blackening has important applications for large area surface modifications of metals and semiconductor materials.

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