Nanosecond laser texturing of aluminium for control of wettability

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ABSTRACT

There is increasing interest in the use of lasers to modify the wettability of surfaces. Here we report on the use of a 20W nS pulsed IR fibre laser to create strong hydrophobicity on the surface of aluminium sheets. This is unexpected, hydrophobicity is usually associated solely with femto- or pico- second laser processing. At a 20W average power level the area coverage rate is too small for many industrial applications. Further trials using a 800W DPSS laser are described and the ability of this system to change surface wettability at a much higher production rate are indicated. There is little reported literature on surface texturing at higher average power levels. Indications of the productivity, or surface coverage rate, are given.

Keywords: Fibre lasers, DPSS lasers, Surface Engineering, texturing, wettability, aluminium

1. INTRODUCTION

The control and modification of the wettability of surfaces has been a process of increasing interest. It is one of the key applications of the field that has now become known as Surface Functionalisation. The wettability of a surface depends on two principal factors – the surface energy of the material that forms the surface in contact with the liquid, and the topography, or geometrical structure, of the surface [1,2].

The control of wettability is useful for several engineering applications. Examples of these applications include: The control of flow in microfluidic channels, e.g. to determine the dispersion of different liquid phases on the walls of microfluidic channels[3]. The modification of the surfaces of metals and Carbon Fibre Reinforced Polymers (CFRP), principally to enhance the performance of adhesive joining. This includes the preparation of titanium surfaces for adhesive joining to CFRP[4], and the treatment of CFRP components for adhesive bonding[5,6].

The control of wettability is also a crucial element in the process of lithographic printing. In lithographic printing the ink is carried in a fount solution of ink and water. Traditional lithographic plates are polymer coated pure aluminium sheets[7]. The imaging process, using high speed laser diode based "Computer to Plate" platesetters, create regions of hydrophilicity and hydrophobicity corresponding to the image. The water component moves to the hydrophilic areas leaving the ink component on the hydrophobic, allowing the image to be printed.

A new development in the field of lithographic printing is the introduction of the so-called "Miracle Plate" process-less reusable lithographic plate based solely on anodised aluminium sheet, without polymer coatings[8]. The miracle plate is in fact simply the anodised aluminium plate without polymer coatings. It was found that this plate could be imaged using ultrashort pulse (pico- and femto-) lasers to image them and print from them. The imaging operation created hydrophilic areas. These could be reverted to hydrophobic hence erasing the image, allowing a different image to be made and printed from[9,10].

The development of hydrophobicity is of particular interest. Superhydrophobic surfaces can be self-cleaning as well as water repellent and efficient light collecting surfaces[11]. Such surfaces have generally been achieved by exposure to ultrashort laser processing[11-14]. The generation of hydrophobicity is generally ascribed to the presence of sub-micron features in the topography of the surface, often related to the generation of laser induced periodic structures or "plasmon structuring".

In this paper, the development of hydrophobic surfaces on aluminium using nanosecond pulsed fibre and DPSS lasers operating in the region of 1064nm is described. Results from a low power (20W) fibre laser are described, together with initial findings from the used of an 800W laser, both demonstrating the ability to achieve significant hydrophobicity.

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2. EXPERIMENTAL SETUP

The low power trials were conducted using a 20W fibre laser. A SPI Lasers G3 nS pulsed fibre laser (20W average power, 1060nm wavelength, 9-200nS pulse length, 5kHz to 250kHz) was delivered via a Linos variable beam expanding telescope into a GSI Lightning galvanometer scanning head, figure 1. The beam was expanded and collimated to fill the 10mm diameter entry aperture for the scanning head. A Linos 100mm focal length f-theta lens is used to focus the beam. Samples were mounted on a Thorlabs motorised lab jack. Focal position was found as the centre point between the two extremes of z travel for which plasma generation was witnessed. Various methods have been employed to measure the focal spot size and a value of 23µm is accepted. Patches of approximately 10mm x 10mm were textured, using a parallel unidirectional hatch, with the hatch spacing being a process variable.

Figure 1: SPI Laser processing experimental set – SPI laser in background, GSI Scanning head in foreground.

Higher power trials were conducted using a Powerlase Photonics Rigel i800, an 800W average power Q-switched 1064nm laser producing 60nS pulses at repetition rates starting at 5kHz, figure 2. The beam from the laser is collimated using a 1000mm focal length plano-convex then directed by plane mirrors to a 40mm focal length meniscus lens. The beam diameter at the lens is 21mm and the estimated focal spot size is 60µm. Samples were mounted onto an Aerotech ALS linear motor driven table capable of achieving 1m/s traverse speed.

Samples of pure aluminium sheet were processed on these systems. Thickness of these samples was 0.3mm. The water contact angle of the samples was measured using a KSV CAM101 contact angle goniometer..

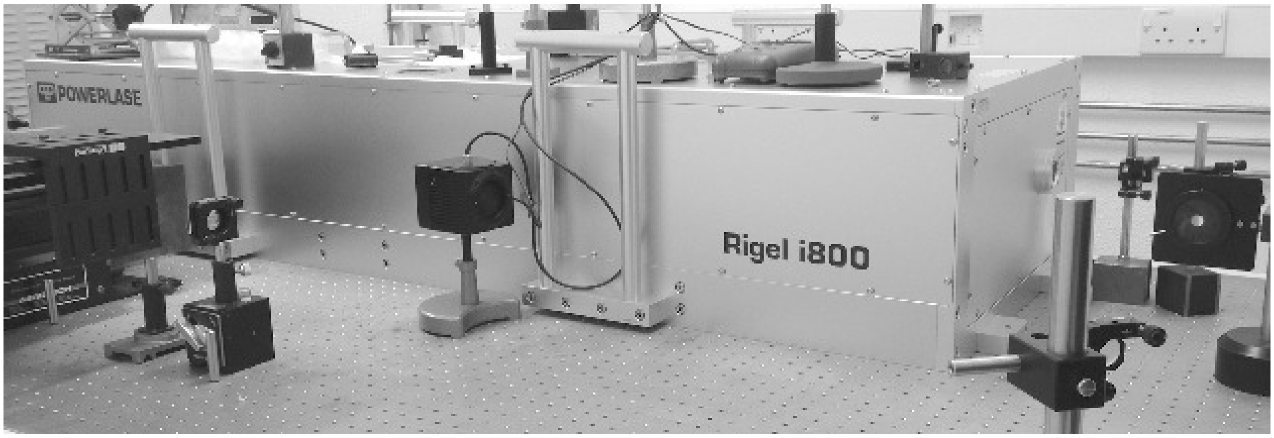

Figure 2 Powerlase Photonics Rigel i800 laser (background). The beam is directed via mirrors to a 40mm focal length lens (foreground left) and samples mounted on a linear motor driven Aerotech stage.

3. DATA AND RESULTS

A large number of samples, 208 in total, were produced using the SPI laser set up described. The range of the key parameters employed are given in table 1. These parameters produced surfaces with contact angles ranging from 0° to 162° i.e. hydrophilic surfaces to superhydrophilic surfaces. Where 2 passes were used, the hatch line direction were perpendicular to each other. The parameters were varied around values ascertained in previous studies to give hydrophobic surfaces. The individual trials were arranged as 19 small series in which a single parameter was varied.

Table 1. Ranges of the key laser process parameters employed in the SPI studies.

Parameter:	**Average Power**	**Frequency**	**Traverse Speed**	**Pulse length**	**Hatch Spacing**	**No of passes**
	(W)	(kHz)	(mm/sec)	(nS)	(µm)	
Max. value	20	500	5400	200	75	2
Min. value	8	50	800	9	5	1

No clear trends could be identified in the relationships of the parameters to the resulting contact angle data. Examples of the individual parameter variation trials are shown in figures 3-6 below:

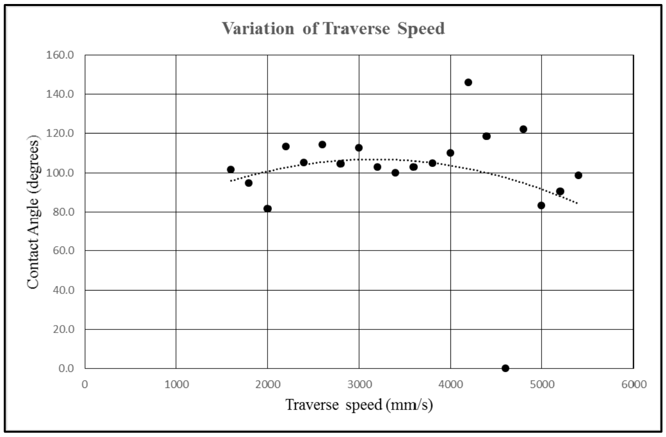

Figure 3 Variation of Contact Angle with traverse speed. Laser Power 20W, Frequency 500kHz, Pulse Length 9nS, Double hatch at 25μm

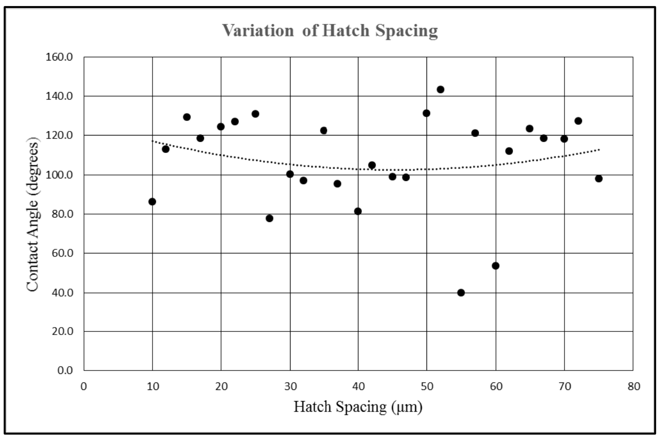

Figure 4 Variation of Contact Angle with hatch spacing. Laser power 20W, Frequency 500kHz, Pulse length 9nS, Traverse speed 3200mm/s, single pass hatch.

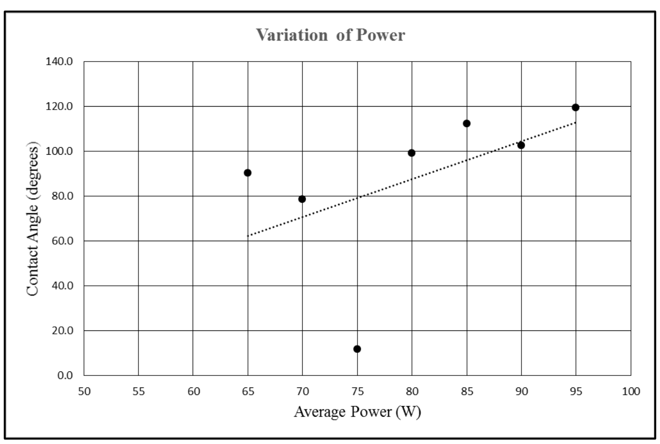

Figure 5. Variation of Contact Angle with laser power. Frequency 500kHz, Pulse length 9nS, Traverse speed 3200mm/s, double hatch spacing 25μm.

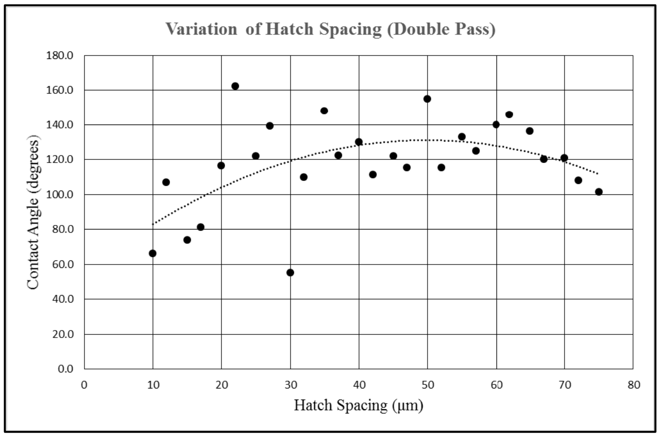

Figure 6 Variation of Contact Angle with hatch spacing (double hatch): Laser power 20W, Frequency 500kHz, Pulse length 9nS, Traverse speed 3200mm/s, double pass.

Single variable correlation analysis fails to provide any significant correlations between contact angle and any single process variables. A number of derived variables are also tested, these include pulse peak power, pulse intensity (pulse peak power / area of focal spot), pulse fluence (pulse energy / area of focal spot), inline incubation (determined by overlap of pulses along travel path), hatch incubation (given by spot diameter / hatch spacing), area incubation (inline incubation multiplied by hatch incubation), total fluence (individual pulse fluence multiplied by area incubation), specific energy (average power divided by the focal spot diameter and traverse speed multiplied together), and area coverage rate. The data was further analysed using bubble plots against two derived process variables. No clear correlations could be identified, although there were areas indicated where high contact angles were most likely to occur, figure 7.

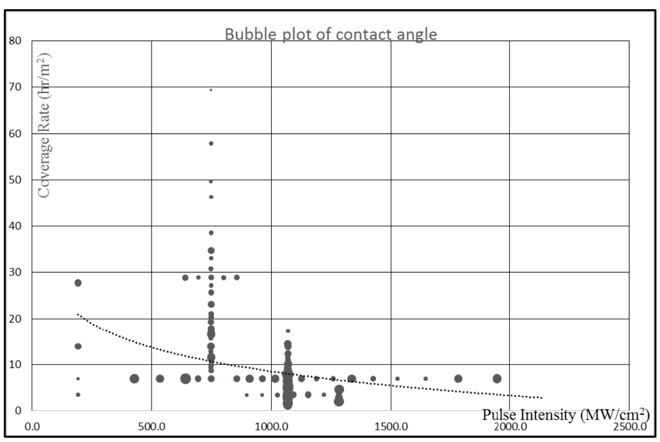

Figure 7 Bubble plot for SPI Contact Angle trials against the pulse intensity and the coverage rate.

Initial trials have been carried out using the Powerlase Photonics Laser. The aim of these trials is to demonstrate that hydro- and Superhydrophobic surfaces can be achieved at higher average powers and hence higher coverage rates. Hydrophobic surfaces with contact angles have been obtained, with the highest contact angles reaching 134° at average laser powers up to 220W. Experiments at higher powers are underway at higher powers at the time of writing, and the figure of 220W is not presented as a limit to the average power at which hydrophobicity can be achieved. Figure 8 gives some representative data obtained.

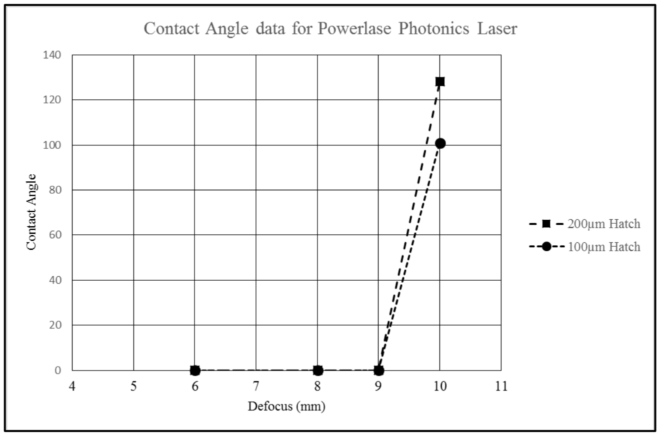

Figure 8 Contact angle results for Powerlase Photonics Laser, Average Power 220W, Speed 800mm/s.

4. CONCLUSIONS

Texturing trials conducted on Aluminium sheets using nanosecond pulsed 1064nm wavelength lasers have produced hydrophilic and superhydrophilic surfaces. Superhydrophobic surfaces with contact angles up to 160° have been produced using a fibre laser at average powers up to 20W, and hydrophobic surfaces with contact angles up to 134° with a DPSS laser running at average powers up to 220W.

There is some inconsistency in the data obtained, particularly in the laser parameters used and the resulting contact angles, and it has not been possible to identify significant trends to help understand the mechanisms in play that create the hydrophobicity. This work continues. However the direct production of hydrophobic surfaces using nanosecond lasers is not reported elsewhere in the literature reviewed.

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