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Surface modifications induced by pulsed-laser texturing—Influence of laser impact on the surface properties

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ABSTRACT

Laser cleaning technology provides a safe, environmentally friendly and very cost effective way to improve cleaning and surface preparation of metallic materials. Compared with efficient cleaning processes, it can avoid the disadvantages of ductile materials prepared by conventional technologies (cracks induced by sand-blasting for example) and treat only some selected areas (due to the optical fibers). By this way, laser technology could have several advantages and expand the range of thermal spraying. Moreover, new generations of lasers (fiber laser, disc laser) allow the development of new methods. Besides a significant bulk reduction, no maintenance, low operating cost, laser fibers can introduce alternative treatments. Combining a short-pulse laser with a scanner allows new applications in terms of surface preparation. By multiplying impacts using scanning laser, it is possible to shape the substrate surface to improve the coating adhesion as well as the mechanical behaviour.

In addition, during the interactions of the laser beam with metallic surfaces, several modifications can be induced and particularly thermal effects. Indeed, under ambient conditions, a limited oxidation of the clean surface can occur. This phenomenon has been investigated in detail for silicon but few works have been reported concerning metallic materials. This paper aims at studying the surface modifications induced on aluminium alloy substrates after laser texturing. After morphological observations (SEM), a deeper surface analysis will be performed using XPS (X-ray photoelectron spectroscopy) measures and microhardness testing.

1. Introduction

In recent years, short-pulse lasers have been shown to be suitable tools for cleaning applications due to their ability to deliver high power per unit area to the localised part surface [1]. Generally, oxides, carbon and oils have to be removed from a metallic surface before its final use. In an ideal case study, the laser energy necessary to remove contaminants should be below a threshold value to prevent substrate modifications and damage. Conversion of absorbed energy via collisional processes into heat is one of the most important effects that occur during the laser interaction. The process can be athermal for the substrate when the layer to be removed is an oxide film (rapid expansion and explosion of gases close to the oxide-metal interface). Another possibility is the vaporisation of micrometric layers through ablation phenomenon corresponding to the fast transition from the overheated liquid to a mixture of vapour and drops. Part of the incident heat can then be absorbed by the material causing microstructure modifications. For reactive metallic substrates treated under ambient atmosphere, a limited oxidation is sometimes considered to explain the modifications of surface properties (adhesion, corrosion resistance). In other cases, localised melting (texturing) promoting a small surface roughness can be developed to improve the interface behaviour. These phenomena have been investigated in detail for silicon [2] and tend to develop for metals [3,4] or ceramics especially for the fluence range considered in this work (thermoelastic range of interaction for metallic surfaces).

But without new laser technologies (fiber laser, disc laser) which open up new perspectives (significant bulk reduction, no maintenance, low costs), it would have reached its limits. By multiplying laser impacts using a scanner, it is possible to shape the substrate surface to improve applications such as adhesion of coatings as well as surface lubrication against wear, etc. [5].

There is a wide range of texturing techniques commercially available based on different processes such as chemical etching, electro-erosion, sand blasting and laser texturing (Table 1) [6].

Among them, laser technology presents competitive advantages as easy automation, localised treated area, three dimensional treatments and great flexibility. Using laser, topology modifications may occur for all types of materials like glass, ceramic, polymer and

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Table 1
Texturing processes [6].

Mechanical texturing	Litography	Thermal texturing	Surface coating
Grinding	Chemical	Electro erosion	PVD
Sand-blasting	Electrochemical	Electron beam	CVD
Printing	Ion beam	Laser	Electro deposition

Table 2
Characteristics of Al2017.

Chemical composition	Properties	Value
Alloy elements (wt %)	Density (g cm^{-3})	2.79
Cu/Mn/Fe/Mg/Si/Al	Thermal conductivity (W m^{-1} K^{-1})	134
4/0.7/0.7/0.6/0.5/balance	Mass heat capacity (J kg^{-1} K^{-1})	920
	Melting temperature (°C)	587
	Absorption @ $\lambda = 1.06$ μm, 25 °C (%)	∼5

metals. Selecting a specific laser tool adapted to the material to be treated (in terms of wavelength, pulse duration, spot size and pulse frequency), scanner characteristics such as scanning velocity, pulse numbers and structure can influence strongly the surface modifications. Of course, the material behaviours and more precisely their optical and thermal properties as well as surface state induce different responses against laser impact. On top of a surface alteration, material modification can be involved according to the heat flux absorbed during the treatment. In spite of short pulse duration (∼100 ns), the high energy implemented can be effectively absorbed by the material causing local alterations. When considering applications implementing laser texturation, it is necessary to know whether these modifications are beneficial or not.

The objective of this work was to investigate the modifications of an aluminium alloy after laser texturation treatment. After surface evaluations including SEM observations and XPS analysis, the material was deeply analysed to consider all the transformations from a mechanical (microhardness) as well as microstructure point of view.

2. Experimental procedure

2.1. Materials

The material used for texturing experiments consisted of 10 mm thick cylindrical discs of 25 mm diameter blank machining aluminium alloy Al2017. The chemical composition and some of the properties of the Al2017 are detailed in Table 2.

2.2. Laser treatments

The experiments were carried out using a pulsed fiber Nd-Yag laser (Ylia M20, Quantel, France) operating at 1064 nm and generating 100 ns pulses at various frequencies (<250 kHz) with 20 W of power output.

The laser beam is circular with 8 mm in diameter and a Gaussian energy distribution. The texturing technique consisted of series of equidistant lines covered with a number of holes as illustrated in Fig. 1. For this, the scanner stop the laser beam at positions and a certain number of pulses is applied to build holes. The resolution (R) sets the number of lines to be textured per millimetre ($y = 1/R$). In order to obtain a symmetric texture, the distance between holes (x) is equivalent to y. Then, various parameters can be selected like the number of shots per drilled hole, the laser power and the frequency to achieve the surface texturation. In all conditions, experiments were carried out at the focal point of the laser (60 μm in diameter).

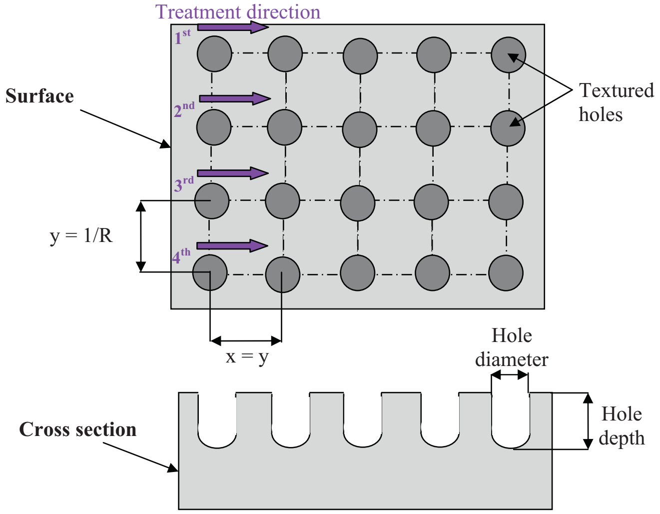

Fig. 1. Scheme of the texturing treatment.

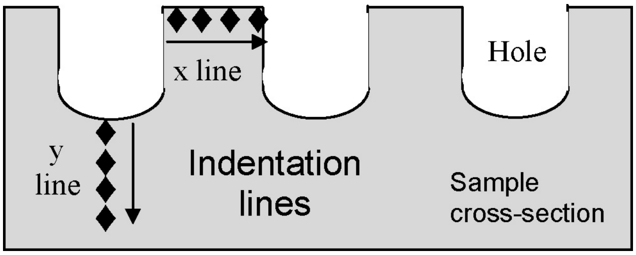

Fig. 2. Profiles of the indentation lines carried out on the sample cross-sections.

2.3. Surface analyses

Several levels of characterizations were implemented during this work. The morphology and the microstructure of aluminium samples were investigated by Scanning Electron Microscopy (SEM) using a JEOL JSM-5800 LV.

To investigate the surface composition and more precisely the oxide layer potentially developed through the laser treatment, X-ray Photoelectron Spectroscopy (XPS) analyses were carried out. XPS measurements were performed using a PHI Versaprobe 5000 system with 200 μm diameter beam. A Al K_α X-ray source with a power of 50 W and a spectrometer, MAC 2 Riber, with an energy resolution (width of Ag 3d$^{5/2}$) of 2.3 eV for spectra and of 0.8 eV for window were used. All the data were analysed using the software Multipak.

In order to estimate the modifications induced inside the aluminium alloy after laser impact, microhardness and microstructure observations were carried out. The Vickers microhardness was measured with a standard device (Miniload-2, Leitz) at 300 g load. Eight measures were carried out to evaluate the mean value with the standard deviation. To estimate the variations after laser treatments, two strategies were developed around the holes. A first indentation line was performed just under the surface between two holes and a second was implemented vertically from the end of the hole to the material bulk (Fig. 2). For measuring the microhardness, samples were cut and polished on the cross section. SEM observations were carried out on cross-sections after mirror polishing and chemical etching. For this, Kellers reagent (2 mL HF, 3 mL HCL, 5 ml HNO_3, 190 mL water) was elaborated and applied on material during 15 s at 9 V of voltage.