Journal of Materials Processing Technology 225 (2015) 463–472

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Characteristics of surface layers formed on inconel 718 by laser shock peening with and without a protective coating

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ARTICLE INFO

Article history:
Received 17 August 2014
Received in revised form 12 May 2015
Accepted 20 June 2015
Available online 23 June 2015

Keywords:
Laser peening
Superalloy
Residual stress
Microstructure

ABSTRACT

Coupons of a Ni base super alloy, Inconel alloy 718 (IN718) were laser shock peened with and without an ablative layer and resulting microstructure and residual stress state were studied. Laser shock peening without a protective overlay results in both mechanical and thermal loading of the material, leading to melting and re-solidification on the surface along with deformation due to laser induced shock wave. The surface shows presence of a non-uniform recast layer which increases the roughness of the surface and also results in a tensile state of residual stresses on surface. The recast layer has areas with modified chemistry and shows presence of nano particles deposited on top of the matrix. In this study, recast layer formed in Inconel alloy 718 (IN718) as a result of laser shock peening without protective overlay was characterized and compared with surface condition of a sample peened with a protective overlay. These results are presented and discussed in relation with those of previous studies.

1. Introduction

Laser shock peening uses short duration laser pulses of nano seconds order to introduce a shock wave into material which plastically deforms the surface of the material and introduces compressive residual stresses on surface. A typical application of the process utilizes Q-switched Nd: Glass laser ($\lambda = 1.054\,\mu m$) to irradiate a target with a very short (<30 ns) and intense (Power density of several GW/cm^2) laser pulse. Such pulses can instantaneously ablate the surface layer into a high temperature (about 10,000 °C) and high pressure (several GPa) plasma (Peyre et al., 1996). This plasma is confined by the use of a transparent overlay, usually glass or water. This confining media prevents the plasma from expanding away from the surface as soon as it is generated allowing for it to absorb more energy. An overlay, opaque to the laser is applied to the surface of the component being peened. Typically black paint, vinyl tape or a variety of metallic tapes have been used. This sacrificial layer is known as protective coating or ablative material. This protective coating protects the sample surface from thermal effects (Forget et al., 1990) and helps in creating a pure mechanical effect in the material, introducing deep compressive residual stresses in the material. There are various studies in the literature providing excellent description of the LSP process and the parameters (Peyre et al., 1996) and physics behind it (Clauer and Fairand, 1979).

In absence of a protective coating, the surface of the treated zone is expanded by the thermal effects. After the laser pulse is over, the affected zone cools and tries to contract, it is resisted by the surrounding material and the sub surface. The resulting surface residual stresses are consequently tensile stresses (Masse and Barreau, 1995) although the subsurface will still have compressive residual stresses due to propagation of shock wave and consequent non-uniform plastic strain introduced by it. The resultant treatment is a combination of thermal and mechanical effects. While the ablative overlay protects the surface and helps avoid the generation of tensile stresses, it is a time consuming affair as the overlay gets damaged during peening and needs to be changed frequently, making it slow and expensive in an industrial configuration. Also, in certain applications the parts being peened might not be accessible for application of ablative overlay. Hence, a lot of attention is being given to Laser peening without protective coating (Patrice et al., 2002). This method uses a frequency doubled (second harmonic) of Q-switched Nd:YAG laser with a wavelength of 532 nm and has been applied in various applications (Sano et al., 2008). In available literature about laser shock peening without a protective overlay, the focus of studies has been on evolution of residual stress fields (Obata et al., 1999). Very few comprehensive studies have been conducted on the microstructure evolution. Hence, it is

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http://dx.doi.org/10.1016/j.jmatprotec.2015.06.026
0924-0136/

Table 1
Nominal composition of Alloy IN718.

Element	Ni	Cr	Nb	Mo	Al	Ti	C	Si	Mn	Cu	Fe
Wt.%	50–55	17–21	4.5–5.75	2.8–3.3	0.2–1	0.3–1.3	0.1	0.75	0.5	0.75	Balance

important to study the microstructural modifications introduced by laser peening done without coating.

Fairhand et al. (1977) peened the weld zone in two aluminum alloys: a wrought alloy, 5086-H32 and 6061-T6 age hardened alloy without a protective coating, with fused quartz as a confining media and studied the surface effects of peening. In both alloys, they found considerable melting and a irregularly re-solidified layer, around 10–20 μm thick consisting of numerous holes. Also, shrinkage cracks were observed in this re-solidified layer. Similar structure was noticed in case of laser peened Fe-3 wt.% Si alloy by Clauer et al. (1977), when peened with long duration pulses (200 ns). A rough estimate of the depth of thermally affected was given by: $x = 2\sqrt{kt}$, k being thermal diffusivity and t is the pulse duration. It was estimated that due to rapid cooling the thermal effects extend to only around 10 μm from the surface. Some re-solidified droplets were also observed on the surface.

Forget et al. (1990) performed direct ablation on monocrystalline CMSX-2, a Ni-based superalloy. Peening was done using a Nd:YAG laser (λ = 1.06 μm) and a very short pulse duration (600 ps). Even direct ablation in unconfined mode generated high pressures shock wave which deformed the material. TEM foils parallel to surface were extracted from 25 μm below the surface. The results showed pairs of dislocations shearing the matrix. No TEM was performed on the surface. The surface morphology of the sample showed a wavy profile with concentric circles. No melting was reported on the surface.

Bugayev et al. (2006) studied the surface morphology of IN600 coupons peened with a Nd:YAG laser using water as confinement mode. A patch was created with 80% overlap on polished IN600 coupons. Studies done using atomic force microscopy (AFM) revealed features which were tilted at an angle to the base material. They also studied the ablated material which is taken away by water during peening and found presence of nano particles of 60 nm sizes.

Some direct comparisons have been made between laser peening done with and without ablative media in a water confined regime. Peyre et al. (1996) conducted laser peening on 316 L stainless steel samples with two different kind of treatments: peening with a Nd:Glass laser with an ablative layer and peening with Nd:YAG laser to peen without ablative layer. Comparisons were made on surface topography, mechanical properties and composition changes brought about by these two treatments.

It is important to study the microstructure changes in conjunction with residual stress state, and surface morphology to develop a better understanding of treatments done with and without an ablative layer. None of the studies found in literature had TEM analysis directly from the surface region. Hence, for this study it was decided to make thin foils from the recast layer to conduct a localized study. Ni based superalloys are used in wide variety of components in a gas turbine engine. Inconel 718 (IN718) is the most widely used Ni- based superalloy with uses in compressor and turbine disks, shafts, blades, stators, seals, supports, tubes, and fasteners. Hence, this alloy was used for the present study.

2. Experimental details

2.1. Material

The nominal composition of alloy IN718 is given in Table 1. Fig. 1(a) is an optical micrograph showing the surface microstructure in the as received condition and Fig. 1(b) shows the inverse pole figure (IPF) map obtained using electron backscattered diffraction (EBSD), an orientation imaging microscopy technique. The IPF map suggests that grains are randomly oriented and there is no texture in the material. The grain size was determined to be ~25–30 μm. (ASTM 6). Before peening, IN718 coupons with dimensions 35 mm^2 × 2 mm thick were electro polished to obtain smooth surface.

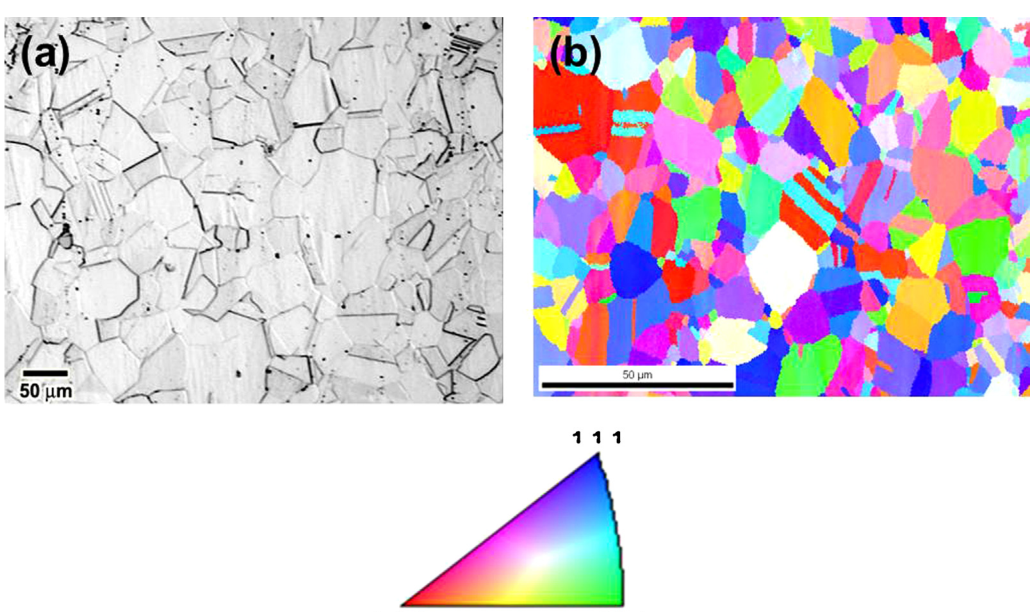

Fig. 1. (a) Optical micrograph showing microstructure and (b) inverse pole figure map from the surface of as received IN718.