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Effect of Laser Peening without Coating on 316L austenitic stainless steel

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Abstract. Laser Peening without Coating (LPwC) is an innovative surface modification technique used for the in-suit preventive maintenance of nuclear reactor components using frequency doubled (green) laser. The advantage of LPwC is that the laser required for this technique is in milli joule range and the processes can perform in aqueous environment. This paper discussed the effect of LPwC on 316L austenitic stainless steel using low energy Nd: YAG laser with various laser pulse density. The base specimen and laser peened specimen were subjected to surface residual stress, surface morphology, micro hardness and potentiodynamic polarization studies. The laser peened surface exhibit significant improvement in surface compressive residual stress. The depth profile of micro hardness revealed higher strain hardening on laser peened specimens. Though corrosion potential reported an anodic shift,current density is found to be increased after LPwC for the specimen peened with higher pulse density.

1. Introduction

Enhancement of surface properties of metals and alloys is an important methodology used to improve the durability, fatigue strength, wear resistance and corrosion resistance of structural components. Laser shot peening is one of such surface enhancement technique which is found to be effective in preventing foreign object damage of aircraft engine fan blades, preventing crack initiation of turbine blades and recently used as a preventive maintenance technique against stress corrosion cracking of nuclear plants[1,2,3]. Thae last two decade experience an intense research in the versatility of laser shot peening under various application sectors and the results are promising compare to conventional shot peening technique[2] .The laser peening technique was evolved as a fully mechanical treatment technique using high power pulsed laser[2]. But after the discovery of new alternative technique by Mukai etal ,low power lasers also become a choice for laser shot peening[3].This alternative method was termed, Laser Peening Without Coating(LPwC).This note worthy advancement in laser shot peening increase the scope of laser peening technology and the method was successfully implemented as a preventive maintenance strategy against stress corrosion cracking in Japanese nuclear power plant[4].

Laser peening without coating encouraged the feasibility of using low energy laser for laser peening application. The authors already reported the successfulness of using low energy laser for laser peening application [5,6,7]. This present work focused on the effect of laser peening without coating on 316L SS using low energy Nd:YAG laser. The usage of IR radiation has advantages and disadvantages with respect to frequency doubles (Green) laser. The transparency of green light in water is higher compare to IR, however dielectric breakdown threshold will reduce with respect to the decrease of wave length, this in effect cause decrease of peak power pressure [2].

2. Experimental

Low carbon stainless steel 316L was selected for present investigation which has wide application as valve pump, jet engine parts, digesters parts, power plant components due to its weldability and high corrosion resistance strength. The specimen was placed on an XY computer controllable translation stage consists of two perpendicularly fixed translation stages. The movement on each axis was controlled using RS485 daisy chain of two servo motors. Laser source was Nd:YAG laser operating at pulse width 10 ns,5 Hz repetition rate and 1064 nm fundamental wavelength. The experimental parameters are tabulated in table.1.

Table1. Experimental parameters

Specimen	Beam diameter (mm)	Laser Fluence (GW/cm^2)	Pulse density ($pulses/mm^2$)
LP-1	1	2.5	9
LP-2	1	2.5	22
LP-3	1	2.5	32

After laser peening the surface roughness of the specimens were measured using Mitutoyo profilometer of resolution 0.01 µm. Surface residual stress was evaluated based on X-ray diffraction $\sin^2\psi$ method [8,9,10]. Mn –Kα line was used as X-ray source (20 kV, 4 mA), diffraction angle was 151.2° with 2 mm beam diameter. Microstructure analysis was conducted by taking cross section of the laser peened specimen across the direction of laser peening. The sample was electrochemically etched using 10% oxalic acid solution with 5.6 V potential and etching time 1.3 minute. Vickers micro hardness studies were conducted to evaluate the work hardening after laser peening. Depth profiles of the specimens were made with 50 g load and 10 s hold time. Potentiodynamic polarization study was performed to investigate the corrosion behaviour in 3.5% NaCl solution using a potentiostat (Gill A.C, ACM make).

3. Result and Discussion

3.1 Surface Roughness and Surface Residual stress. The surface roughness values of laser peened and unpeened specimens are represented in table 2. The direct laser ablation lead to an increase of surface roughness compare to untreated surface. The average roughness value (Ra) indicates an increase with increase of laser pulse density. However in respect to conventional shot peening increase in roughness was appeared to be less [2].

Table 2. Surface Roughness

Specimen	Ra (µm)	Ry (µm)	Rq (µm)
Base material	0.41	3.61	0.55
LP-1	0.69	6.71	1
LP-2	1.04	7.6	1.34
LP-3	1.42	10.18	1.78

Ra: Average roughness
Ry: Maximum Height of the Profile
Rq: Root mean square roughness

Table 3. Surface residual stress

Specimen	σ_x (MPa)
Base material	-12.6
LP-1	-273.1
LP-2	-180.8
LP-3	-165.4

The surface residual stress of unpeened and laser peened specimens are tabulated in table 3. From the residual stress result it can be confirmed that laser peening without coating induces higher compressive residual stress whilst the increase of laser pulse density reduces the magnitude of surface compressive stress. Increase of thermal influence with increase of pulse density will be the reason for decrease of magnitude of stress.

3.2 Microstructure analysis. The microstructure of unpeened and laser peened specimens are presented in figure 1. There is no significant difference identified before and after laser peening. No near surface solidification or dendrites formation observed after LPwC. So it can be confirmed that the surface melting was limited to small micro meter range on top surface.

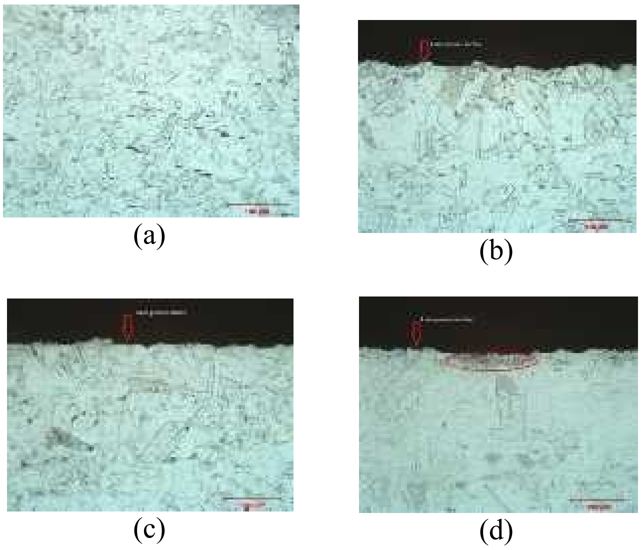

Figure 1. Micro structure of laser peened specimens (a)Un peened (b)LP-1 (c)LP-2 (d)LP-3

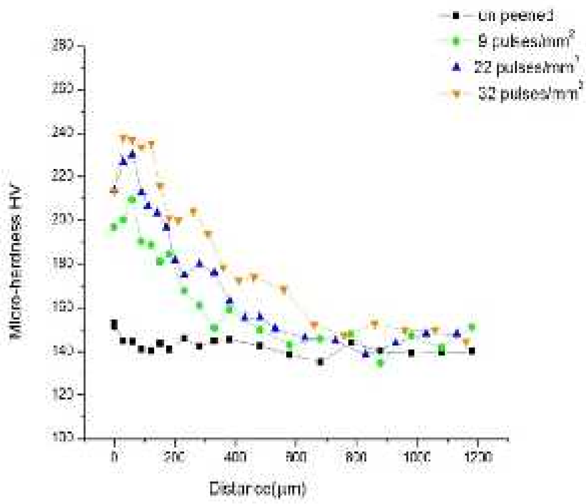

Figure 2. Depth profile of micro hardness

3.3 Micro Hardness. The work hardening impact of LPwC can be identified from the depth profile of micro hardness. The micro hardness profile is presented in figure 2. The unpeened material near surface hardness value is151 Hv, whereas for LPwC specimens the near surface hardness improved to 196 Hv (9pulses/mm^2) and 213 Hv (22 and 32 pulses/mm^2)

It can be observed from the plot that on Laser peened samples the fall of harness from improved value to the range of untreated base material varies according to the pulse density. The specimen peened with lower pulse density indicates the drop of hardness with in 300 µm. But when the pulse density increases it extended to 0.76 mm. This is clearly an indication that when number of impact increases the depth of hardened layer also increases

3.4 Corrosion. Tafel extrapolation method is used to determine the corrosion potential (E_{corr}) and corrosion current density (I_{corr}) from potentiodynamic polarization plot by Tafel extrapolation method. The polarization plot and results are presented in figure 3 and table 4 respectively.

After LPwC the corrosion potential enhanced to more anodic region. However the current density of the laser peened specimens LP-2 and LP-3 is slightly higher than that of the unpeened sample. It can be observed that I_{corr} values increases with increase of laser pulse density. The higher surface roughness resulted due to increased pulse density will be the reason for that. As the roughness increases practically the area exposed to corrosion per unit area will automatically increases [13]. Previous study conducted by Peyer etals on thermo mechanically peened 316L steel also exhibit an increase of current density after laser peening without coating . The surface topographical changes like higher surface roughness, formation of critical zones in the near inclusion region due to direct ablation suggested as the primary reason for deterioration of corrosion resistance of thermo mechanically laser peened alloys [12]

The anodic plot of specimens Lp-2 and LP-3 exhibits a reduction of current density and re-passivation trend at -32.27 mV and -93.35 mV respectively. This part of the curve is clearly distinguished as it shifts towards the left part of the graph compare to other samples curves. Specimen peened with higher pulse density exhibit a maximum decrease in current density at this point compare to other ones. Further, when the potential reaches at 269 mV current density of these samples overlapped to that of the base material.

Table 4 Corrosion potential and corrosion current density

Specimen	I_{corr}(mA/cm^2)	E_{corr}(mV)
Untreated	2.3793	-406.71
LP-1	2.3035	-369.42
LP-2	2.4827	-384.78
LP-3	2.6339	-351.87

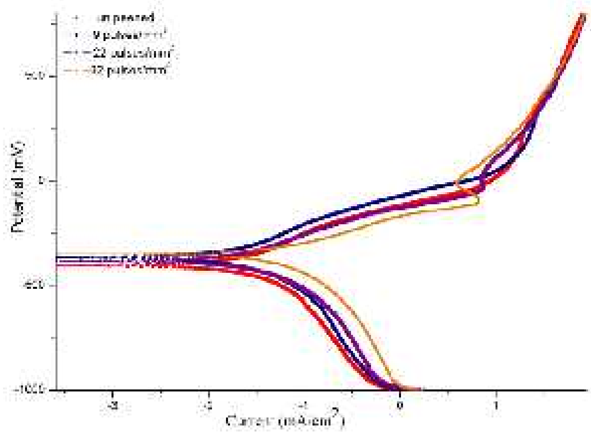

Figure 3.Potentiodynamic polarization plot

4. Conclusion

Laser Peening without Coating has been successfully performed on 316L austenitic stainless steel with three various pulse densities. The surface residual stress study indicates that when the pulse density increases the magnitude of compressive residual stress induced is decreasing. However the increase of pulse density increases the micro hardness and depth of work hardened layer. The direct laser surface ablation leads to an increase of surface. The potentiodynamic polarization study indicate that there is no significant improvement in corrosion resistance but due to higher surface roughness the specimen laser peened with higher pulse density reported an increase of current density.

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