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Laser shock peening of steam turbine blade for enhanced service life

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Abstract. Fretting-fatigue is an important factor influencing service life of turbine blades. The present paper describes laser shock peening of potential crack nucleation site in the root region of steam turbine blade for its enhanced service life. The experimental study, performed with an in-house developed 2.5 J/7 ns Nd:YAG laser demonstrated that laser peening introduced a residual surface compressive stress of −260 to −390 MPa. Case depth of laser peened surface layer was found to be more than 900 μm.

Keywords. Laser peening; turbine blade; residual stress; martensitic stainless steel.

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1. Introduction

Fretting-fatigue is a major life-limiting factor for turbine blades. Grooves in the 'fir-tree shaped' root region of turbine blades, due to associated notch effect, act as stress raisers and form potential crack nucleation sites. Introduction of residual compressive stresses (RCS) into the substrate is known to inhibit initiation and propagation of fatigue cracks [1, 2]. In 2008, Curtis-Wright Corp., Roseland, NJ, reported that Siemens Power Generation used laser shock peening (LSP) technology to enhance fatigue strength of titanium blades of some of their advanced steam turbines [3]. Present study, an integral part of a larger study to develop indigenous LSP process for enhanced service life of turbine components, involves standardizing LSP process on the root part of a steam turbine blade (made of DIN X10CrNiMoV1222 martensitic stainless steel) with respect to surface residual stress.

Laser shock peening (LSP) is an effective surface treatment for introducing residual compressive stress (RCS) on the surface of the substrate. In contrast to conventional shot

Table 1. Nominal chemical composition (in wt%) of turbine blade used for laser shock peening experiments.

Substrate	C	Cr	Ni	Si	Mo	Mn	V	Fe
DIN X10Cr-NiMoV1222	0.08–0.13	11.5–12.5	2.2–2.8	0.1–0.5	1.6–1.8	0.6–0.9	0.25–0.4	Balance

peening, laser-peened surfaces are characterized by good surface finish (original surface roughness is retained) with the absence of process-generated defects [4]. Laser peening employs high energy short laser pulses to generate shock waves to generate RCS into the substrate. Irradiation of the substrate with laser pulses causes instantaneous vapouriza-tion of the surface layer into high-temperature high-pressure plasma. Rapid expansion of laser-generated plasma from the surface results in a high-pressure shock wave, which propagates into the substrate. When peak pressure of the shock wave exceeds dynamic yield stress (Huguniot elastic limit) of the substrate, the metal is plastically deformed to generate RCS on the surface of the substrate. Confinement of laser-generated plasma with a suitable laser-transparent medium (usually water) results in significant increase in peak pressure and duration of the resultant shock wave [5–8]. The surface of the substrate should be exposed to nearly pure mechanical stresses for efficient utilization of the energy of laser-generated shock wave to introduce compressive surface stresses [9]. Any undue heating of the surface of the substrate during laser irradiation causes development of unde-sirable tensile residual stresses [10]. Hence, surface is coated with a suitable sacrificial thermo-absorptive layer to avoid thermal exposure to substrate's surface.

2. Experimental

Laser shock peening experiments were performed with an indigenously developed 2.5 J flash lamp pumped electro-optically (E-O) Q-switched Nd:YAG laser system [4]. The experimental LSP set-up comprised of (i) Nd:YAG laser system, (ii) beam delivery sys-tem comprising of a 45° plane mirror and a focussing lens of 400 mm focal length, (iii) a 2-axis CNC workstation and (iv) a water recirculation system. The raw laser beam emanating from the laser system is folded with a 45° plane mirror and focussed with the help of a convex lens of 400 mm focal length. LSP experiments were carried out on 'fir tree'-shaped root part of one of the last stage LP blades of a 500 MW steam turbine. Laser treatment was performed in the groove region of the turbine root, which by virtue of being a stress concentration site, forms a potential fatigue crack nucleation site. Table 1 presents nominal chemical composition (in wt%) of the material of construction of turbine

Table 2. Experimental parameters for laser shock peening.

Pulse energy	Pulse width	Repetition rate	Spot diameter	Scan speed	Track-to-track displacement
1.5 J	7 ns	2 Hz	1.8 mm	1.7 mm/s	700 μm

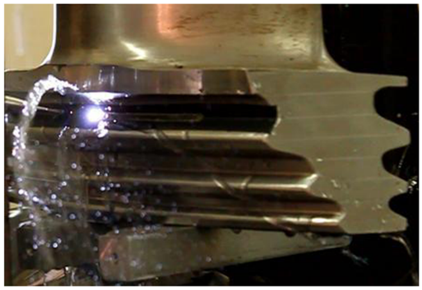

Figure 1. LSP of the root of the turbine blade in progress.

blade root used for LSP experiments. For LSP, a 125 μm thick commercial PVC-based black insulation tape was used as the sacrificial coating. Black PVC insulation tape has been found to be a suitable choice for laser peening of ground metallic surfaces [11]. LSP is done by scanning the taped surface of the work piece with a pulsed laser beam, while maintaining a layer of flowing water on the surface. The details of the laser and experimental laser peening set-up have been provided elsewhere [4]. Table 2 summarizes experimental parameters used for LSP. Figure 1 presents the photograph of turbine blade root during laser shock peening. It should be noted that besides peening groove region, LSP was also performed on a flatter part of the turbine root, as shown in figure 2.

3. Results and discussion

Laser-peened specimens were characterized by residual stress measurements, performed with an X-ray diffraction-based stress analysis system using CrK_α radiation (λ =2.29 Å). Standard d vs. $\sin^2\psi$ method was adopted for the determination of surface residual stresses. Depth profiling of residual stresses was performed on larger rectangular laser-peened region, shown in figure 2. It involved sequential electropolishing and stress measurement at regular intervals of about 50 μm.

Figure 2 shows photograph of the laser-peened root part of the turbine blade, with duly marked laser-peened regions. Visual examination of the laser-treated work piece did not bring out any difference in the visual appearance of laser-peened and untreated

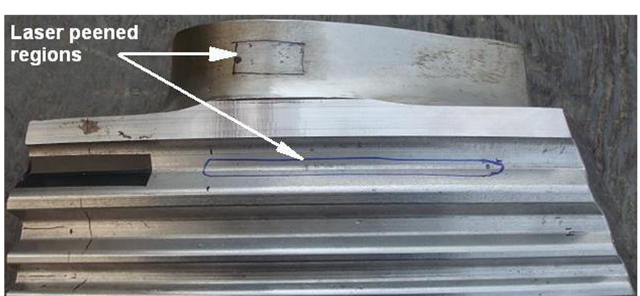

Figure 2. Laser-peened regions on the root of the turbine blade.

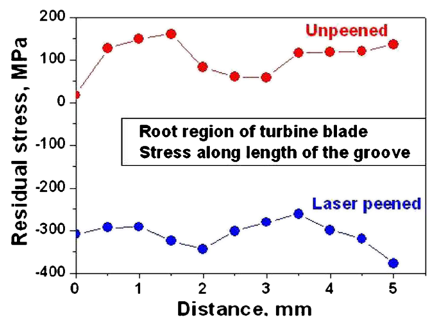

Figure 3. Surface profiles of the residual stress on laser-peened and unpeeed regions of the root region of the turbine blade.

surface. Residual stress analysis of the groove region of the work piece revealed that laser shock peening introduced surface compressive stresses (along the length of the groove) of −260 to −390 MPa. Figure 3 compares surface profiles of residual stress in unpeened and laser-peened regions. It should be noted that due to the shadowing effect of the walls of the groove, stress measurements could be performed only in one direction, i.e. along the length of the groove. Moreover, due to very limited space available for *in-situ* electropolishing, depth profiling of residual stress could not be performed in the grove region. Instead, residual stress measurements for depth profiling were conducted on flatter laser-peened region (figure 2). For this purpose, residual stresses were measured in two orthogonal directions, along and across the length of grooves. Figure 4 presents depth profiles of residual stresses in flat laser-peened region. The figure shows that laser shock peening introduced a compressively stressed surface layer of more than 900 μm thickness. The difference in the magnitude of surface compressive stresses in the two laser-peened regions, viz. groove and flat regions, is attributed to the difference in the magnitude of surface stresses in initial condition, introduced by processing history of the turbine blade.

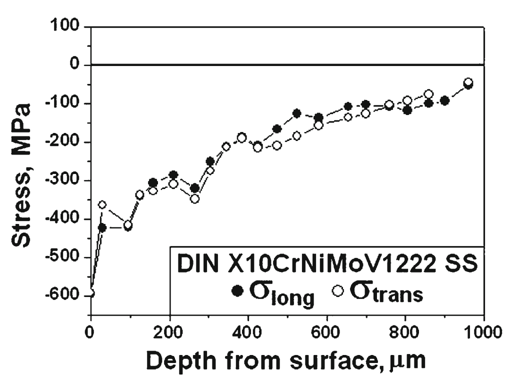

Figure 4. Depth profile of residual stresses in laser-peened flat region on the root part of the turbine blade.

4. Conclusions

The results of the present investigation demonstrated that laser shock peening, under the experimental parameters, was successful in introducing a compressively stressed surface layer, without causing noticeable change in surface topography. Laser-peened groove region exhibited a surface compressive stress of −260 to −390 MPa. The depth of the peened layer was found to be more than 900 μm.

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