Desalination and Water Treatment
www.deswater.com

15 (2010) 43–47
March

doi: 10.5004/dwt.2010.1665

Improvement of surface hardness of duplex stainless steel by laser shock hardening for the application to seawater desalination pump

Hyuntaeck Lim, Myunghwa Lee, Pilkyu Kim, Jongbok Park, Sungho Jeong*

Department of Mechatronics, Gwangju Institute of Science and Technology (GIST), Gwangju, 500-712, Korea
Tel. +82 (62) 970-2393; Fax +82 (62) 970-2384; email: shjeong@gist.ac.kr

Received 12 November 2009: Accepted in revised form 24 December 2009

ABSTRACT

A high-capacity pump for seawater desalination plant is open to highly corrosive and abrasive environment. To improve anti-corrosion and anti-abrasion properties of pump material, laser modification technology can be applied to the surface of pump material. In this work, experimental results for the laser shock hardening of 2205 duplex stainless steel (22% chromium–5% nickel) for the application to rotating pump parts are reported. The changes in surface hardness and morphology before and after laser shock hardening are investigated for varying process conditions. It is demonstrated that the hardness of duplex stainless steel can be significantly enhanced, up to 30%, by properly controlling the process parameters. The applicability of laser shock hardening for surface treatment of mechanical parts of seawater desalination pumps is discussed.

Keywords: Desalination; Pump; Laser shock hardening; Hardness; Residual stress

1. Introduction

A high-capacity pump for seawater desalination operates at an extremely high pressure in seawater environment. This extreme operation conditions are likely to cause corrosion, wear, and fatigue failure of the pump components, especially of the rotating parts such as ring, bush, or sleeve subject to high contact pressure, resulting in the increase of maintenance and operation cost (see the sample rotating part of a desalination pump in Fig. 1). To minimize corrosion by seawater, duplex stainless steel that has high chloride-corrosion resistance can be selected as the manufacturing material of a seawater desalination pump [1]. Besides high corrosion resistance, duplex stainless steel is also known to have good fatigue resistance, low thermal expansion, and high strength [2].

The abrasion resistance as well as anti-corrosion property of stainless steel are known to be enhanced by laser shock hardening (LSH), which can extend the life time of pump parts and save maintenance and operation cost. LSH is a surface treatment process in which an intense laser pulse irradiates a metal workpiece to generate a strong shock propagating through the medium and as a result, produce compressive residual stress [3,4]. During LSH, the workpiece is immersed in water in order that the laser ablation plasma can be confined and thus effectively generate a high strength shock wave propagating through the metal. Also, since the surface of a metal can be highly reflective, the metal surface is typically coated with an absorbent material to effectively absorb the incident laser energy and to produce a stronger shock wave. A laser shock hardened surface has a higher surface hardness than untreated surfaces and exhibits a better fatigue, wear, and corrosion resistances. However, to the

* Corresponding author.

Presented at SeaHERO Academic Workshop on Development and Optimization of SWRO Desalination Systems
Korea University, Seoul, Korea, November 13–14, 2009

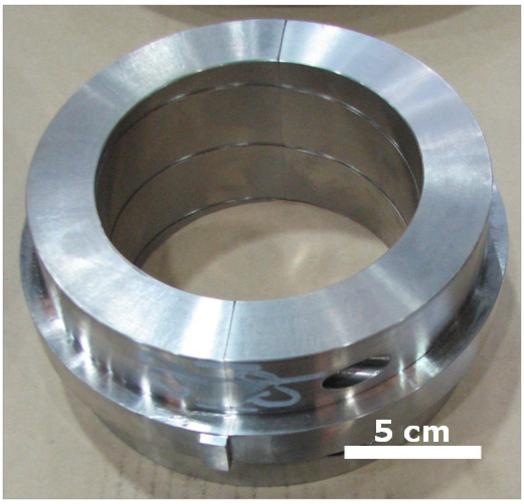


Fig. 1. Photograph of a wear ring used in desalination pump.

Table 1
Chemical composition of the 2205 duplex stainless steel used in experiments

Material	%
C	0.019
Mn	1.886
Si	0.28
P	0.025
S	0.001
Cr	22.644
Ni	5.482
Mo	3.067
N	0.158
Fe	Balance

authors' knowledge, no LSH of duplex stainless steel has been reported to date. Thus, the effectiveness of LSH on duplex stainless steel and the applicability of this process for seawater desalination pump lack reliable information.

In this work, experimental results for laser shock hardening of 2205 duplex stainless steel are reported. The changes in surface hardness and morphology before and after laser shock hardening are investigated for varying laser intensity and coating material. It is demonstrated that the hardness of duplex stainless steel can be significantly enhanced, up to 30%, by properly controlling process conditions. The applicability of laser shock hardening for surface treatment of mechanical parts of seawater desalination pumps is discussed.

2. Experiments

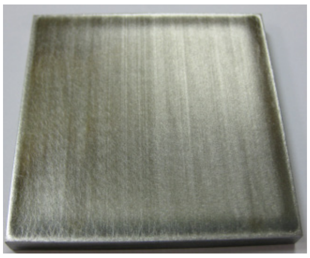
A pulsed Nd:YAG laser with a wavelength of 532 nm and pulse duration of 8 ns was used to irradiate samples. The laser beam was focused using a plano-convex lens with a focal length of 400 mm, which provides a laser beam spot size of 1–2.5 mm at the sample surface depending on the lens-sample distance. For LSH of samples, the laser beam scanned over 10 mm×10 mm area using an X–Y motorized stage. For the experimental sample, 2205 duplex stainless steel of 5 mm thickness cut into 50 mm×50 mm size by electrodischarge machining was utilized. The detailed chemical composition of the duplex stainless steel used in the present experiments is shown in Table 1. The laser intensity in experiments was varied by changing the distance between the sample surface and the focusing lens while maintaining the laser pulse energy at 1.5 J. The effects of absorbent layer was examined for three different coating materials and uncoated sample; the coating materials include aluminum foil (100 μm thick), iron foil (50 μm thick) and an organic black paint. For LSH experiments, a sample was immersed in a chamber filled with pure water and the laser beam was incident normally to the sample surface.

The surface hardness of irradiated sample was measured using a micro Vickers hardness test machine with a test weight of 200 g and loading time of 5 min. To improve measurement accuracy, six points were selected from the irradiated region for hardness measurement with 1 mm gap between points and their average was used as the hardness value of the treated area. For non-irradiated area, two points were taken for measurement. Since surface smoothness is important for rotating pump parts, average surface roughness of laser shock hardened sample was measured using a confocal surface profiler.

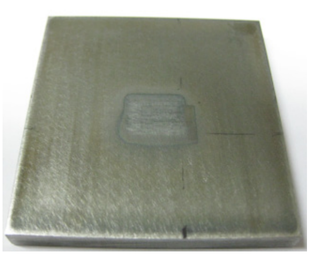
3. Results and discussion

Fig. 2 shows the results for LSH of uncoated sample. For this uncoated sample (Fig. 2a) the sample surface was maintained as machined (average surface roughness ≈1 μm,) because polishing of the surface results in a surface roughness of below 0.1 μm and high reflection loss of the incident laser beam. LSH of uncoated sample causes direct ablation of the sample surface that leaves ablation mark on the original surface as observed in Fig. 2b and results in a significant increase of surface roughness (Fig. 2c), whereas little increase of surface hardness is achieved as shown in Fig. 2d. Therefore, LSH of duplex stainless steel without absorbent coating is not useful. It should be noted, however, that other studies reported that LSH of AISI 304 stainless steel without coating produced an increase of surface hardness and mechanical properties [5]. It is unclear yet why the LSH results with no coating for duplex and AISI 304 stainless steels show different trends, requiring further investigation in consideration of their original metallurgical and mechanical properties.

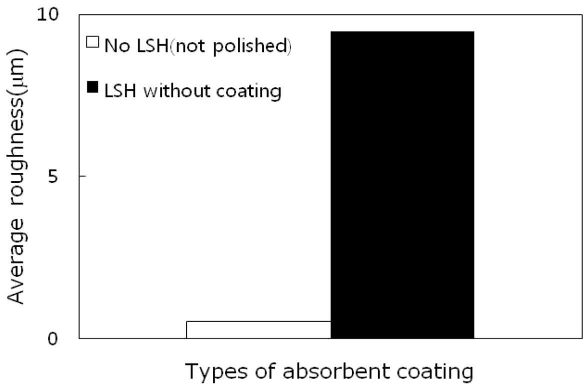
Organic black paint has been used as the absorbent



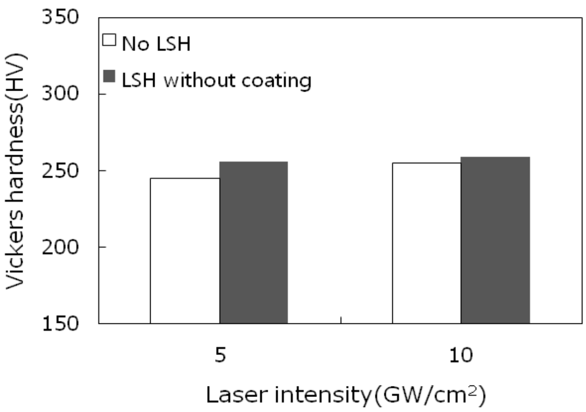
(a)



(b)



(c)



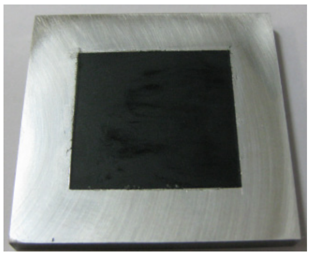
(d)

Fig. 2 Photographs of the uncoated sample (a) before and (b) after laser shock hardening and (c) surface roughness of these samples. (d) Changes in surface hardness of the samples for different laser intensity.

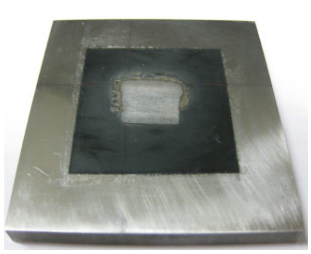
coating for LSH of certain materials [6,7]. When commercial black paint was applied to the duplex stainless steel with a thickness of 100 μm, only very slight increase of surface hardness was achieved in spite of complete ablation of the coating layer (Fig. 3). Another disadvantage of the organic black paint is that surface roughness of the sample increases substantially, about by a factor of 5, as shown in Fig. 4.

When 50 μm thick Fe foil was used as the coating material, the coating withstood laser ablation with no damage and protected the underlying sample surface (Fig. 5). For the Fe foil coating, surface roughness of the sample approximately doubled; note that the absolute value of average surface roughness is less than 0.2 μm as shown in Fig. 4. Surface hardness increased to maximum 14% when Fe foil was used as the absorbent coating.

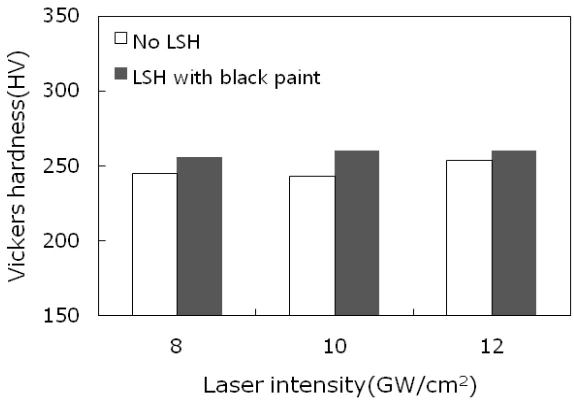
Another popularly chosen coating material is aluminum [8,9]. In our study, 50 μm thick Al foil got damaged



(a)



(b)



(c)

Fig. 3. Photographs of the sample coated with black paint (a) before and (b) after laser shock hardening and (c) measured Vickers hardness for different laser intensities.

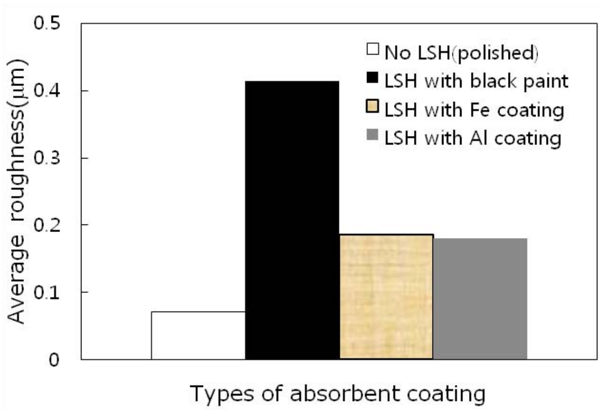


Fig. 4. Surface roughness of laser shock hardened samples with various coatings (sample surface was polished).

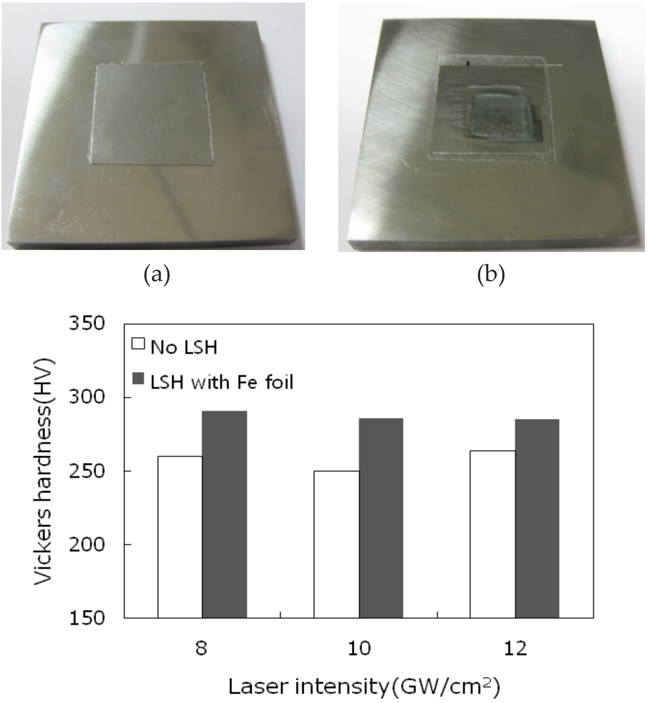


Fig. 5. Photographs of the sample coated with Fe foil (a) before and (b) after laser shock hardening and (c) measured Vickers hardness for different laser intensities.

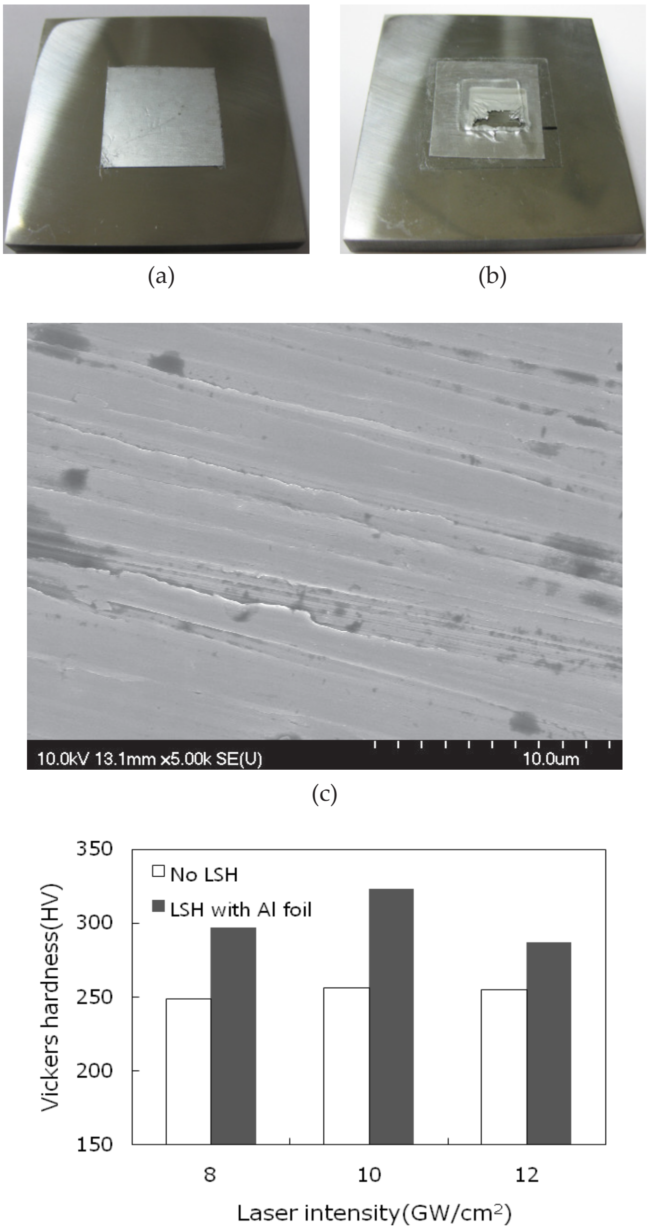


Fig. 6. Photographs of the sample coated with Al foil (a) before and (b) after laser shock hardening, (c) scanning electron microscope image of the surface of a laser shock hardened sample, and (d) measured Vickers hardness for different laser intensities.

after being irradiated with only a few laser pulses (below 10 pulse/cm^2), not properly protecting the underlying sample surface. Thus, 100 μm thick Al foil was used in the present experiments since the decrease of pulse density resulted in significantly reduction of hardness. When 100 μm thick Al foil was irradiated by laser pulses, it first withstood laser pulses directly striking the coating but as the laser scanning progresses over the adjacent area the already ablated region was torn apart as shown in Fig. 6b, possibly due to thinning and weakening of the ablated foil. However, despite the eventual break of the Al foil, the sample surface was never directly exposed to the incident laser pulses in this case, and thus the surface hardly changed from its original morphology (Fig. 6c), and remained smooth (Fig. 4). In terms of surface hardness, the use of Al foil resulted in the maximum increase of 30% as shown in Fig. 6d at the laser intensity of 10 GW/cm^2. It is considered that the enhancement of surface hardness of pump parts by 30% as demonstrated in this experiment may lead to significant decrease of wear, fatigue crack, and corrosion of the parts, saving maintenance and operation cost.

The role of absorbent coating during LSH requires further study. Among the three coating materials in this work, organic black paint has lowest reflectance whereas Al foil has highest reflectance. Nevertheless, the maximum increase of surface hardness was achieved with the Al foil, which is understood to imply that the absorbent coating contributes not only to reducing reflection loss of incident laser energy but also to generating stronger laser plasma pressure; the intensity of laser-induced shock may depend on ionization of the material as well as reflectance. Since the generation of stronger laser shock is most critical in LSH, the selection of coating material should be made on the basis of experimental observation as well as reflectance of the material. In addition, for both Fe and Al foil experiments, the maximum increase in surface hardness was achieved at the laser intensity of 10 GW/cm^2. In LSH, laser intensity is one of the key process parameters and for the duplex stainless steel of the present study 10 GW/cm^2 appears to be the optimum value.

4. Conclusion

From LSH experiments of 2205 duplex stainless steel, a material for high capacity pump for seawater desalination plant, it is demonstrated that the surface hardness of this material can be increased by maximum 30% by properly selecting absorbent coating material and process conditions. It is shown that although the reflectance of coating material is important to minimize reflection loss of incident laser energy the intensity of laser-induced shock wave is not directly proportional to the decrease of reflectance of the coating material but depends on other properties of the coating material. The application of LSH for high capacity pump is understood as a practical option to extend pump life time and reduce operation cost.

Acknowledgement

This research was supported by a grant (07sea-heroB02-04-01) from the Plant Technology Advancement Program funded by the Ministry of Land, Transport and Maritime Affairs of the Korean government.

References

[1] T. Fanjul, A. Aparicio, V. Martin, R. Segovia and J. Salas, Engineering design of Skikda Seawater Desalination Plant, Desal. Wat. Treat., 7 (2009) 206–213.

[2] J.R. Davis, ed., Stainless Steel: ASM Specialty Handbook, ASM International, 1994, p. 32.

[3] R. Fabbro, J. Fournier, P. Ballard, D. Devaux and J. Virmont, Physical study of laser-produced plasma in confined geometry, J. Appl. Phys., 68 (1990) 775–784.

[4] C.S. Montross, T. Wei, L. Ye, G. Clark and Y.W. Mai, Laser shock processing and its effects on microstructure and properties of metal alloys: a review, Int. J. Fatigue, 24 (2002) 1021–1036.

[5] Y. Sano, M. Obata, T. Kubo, N. Mukai, M. Yoda, K. Masaki and Y. Ochi, Mater. Sci. Eng. A, 417 (2006) 334–340.

[6] C.S. Montross, V. Florea and M.V. Swain, The influence of coatings on subsurface mechanical properties of laser peened 2001-T3 aluminum, J. Mater. Sci., 36 (2001) 1801–1807.

[7] X. Hong, S. Wang, D. Guo, H. Wu, J. Wang, Y. Dai, X. Xia andY. Xie, Confining medium and absorptive overlay: Their effects on a laser-induced shock wave, Opt. Lasers Eng., 29 (1998) 447–455.

[8] L. Berthe, R. Fabbro, P. Peyre, L. Toiller and E. Bartnicki, Shock waves from a water-confined laser-generated plasma, J. Appl. Phys., 82 (1997) 2826–2832.

[9] P. Peyre, L. Berthe, X. Scherpereel and R. Fabbro, Laser-shock processing of aluminium-coated 55C1 steel in water-confinement regime, characterization and application to high-cycle fatigue behavior, J. Mater. Sci., 33 (1998) 1421–1429.