

Effect of Laser Shock Peening on Fatigue life of Austenitic stainless steels

Z Špirit^{1,2}, J Brajer³, J Kaufman³, M Chocholoušek¹, M Bohm³, J Kott¹ and J Strejcius¹

¹Centrum vyzkumu Rez s.r.o., Morseova 1245/6, Plzeň, Czech Republic, EU

²Department of Material Science and Technology, University of West Bohemia, Plzeň, Czech Republic, EU

³Hilase, Institute of Physics of the ASCR, v.v.i. Czech Republic

E-mail: zbynek.spirit@cvrez.cz

Abstract. Laser shock peening (LSP) is an innovative surface treatment technique for strengthening metallic materials. The treatment improves fatigue performance and is achieved by introducing compressive residual stresses into the material surface layer. The compressive stresses are created over a significant surface area by means of high pressure shock waves, which are generated by confining the laser-induced plasma. In the present study, the LSP effect on fatigue life of austenitic stainless steels was investigated by changing the laser parameters. The tested material was austenitic stainless steel 08CH18N10T. The influence of LSP treatment on the fatigue life was examined through the three-point bend fatigue test.

1 Introduction

The LSP is one of innovative surface treatments whose principle was firstly formulated by the American scientist Whitem in 1963 in the USA. The greatest development of LSP technology began at the end of the 90's in the military and aerospace industries [1]. LSP basically achieves similar effects as conventional shot peening (SP) treatments existing in industry for over six decades. In traditional SP process, metallic, ceramic or glass balls acting as a miniscule ball-peen hammers make a small indentation on the metal surface on impact. The advantages over LSP are that it is cheap, it uses robust process equipment and it can be applied on large or small areas as required. The disadvantages of SP are that the process is semi-quantitative and depends on a metal strip or Almen type gauge, that is used to determine the SP intensity. This method cannot guarantee uniform and accurate SP intensity across the treated area. The next limitation of SP is that the depth of compressive residual stress usually does not exceed 0.25 mm in soft metals. Moreover, the surface roughness after SP is worse when compared to LSP [1, 2]. LSP process in comparison can produce a compressive residual stress more than 1 mm in depth, which is about five times deeper than the traditional SP process. SP may also damage the surface finish of metal components and can easily cause distortion of thin section, whereas the surface of a component treated with LSP loses little dimensional accuracy [3].

The principle of LSP is based on conversion of laser energy into a shock wave that results in material plastic deformation and redistribution of residual stresses. When the high energy laser pulses of short nanosecond durations focus on a water immersed metal material, the top surface (sacrificial layer) absorbs the laser energy and evaporates instantaneously through ablative interaction, as shown in figure 1. The resulting high-density vapor is immediately ionized (multiphoton ionization and



avalanche ionization) and forms a plasma plume which absorbs the rest of the laser pulse via the inverse Bremsstrahlung mechanism, the absorption of high-intensity radiation by electrons in the field of nuclei [4, 5]. High pressure of the expanding plasma generates a shock wave, which impinges on the surface of the metal material with an intensity of several GPa, far exceeding the yield strength of the metal. The shock wave propagates into the metal interior and loses energy as it creates a permanent strain on the metal material. The permanent strain remains after the shock wave passage. The strained region is subsequently constrained with surrounded metal material as a reaction to elastic strain, thus forming a compressive residual stress on the metal surface [5].

The LSP technology is used as a substitute for SP conventional treatments where higher standard of fatigue performance is required.

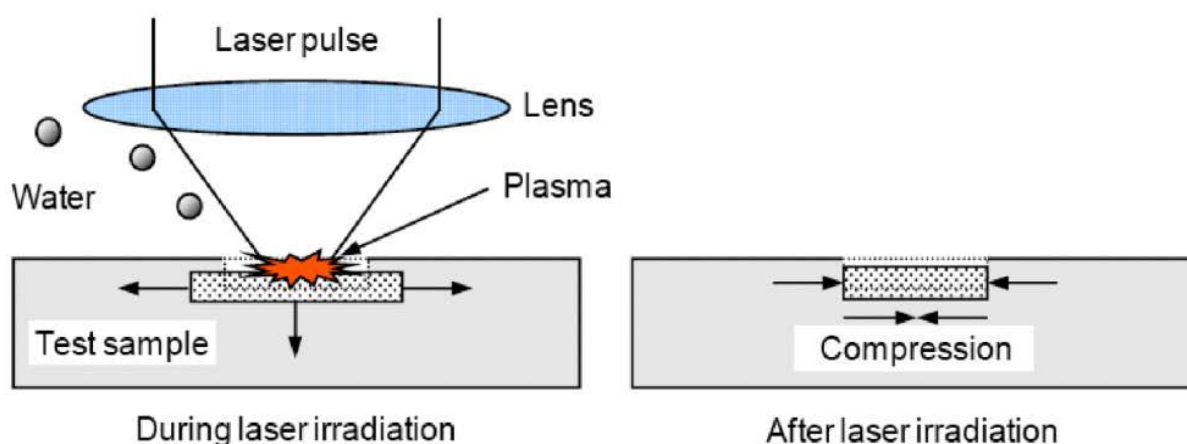


Figure 1. Principle of LSP process [5]

2 Material

Material for testing is austenitic stainless steel 08CH18N10T, which is used in nuclear industry. The material meets the required mechanical properties, microstructures and NDT inspections according to EN 10204/3.1. Microstructure after solution annealing is full austenitic with delta ferrite 3.5 wt. %, nitrides and carbonitrides. Chemical composition and basic mechanical properties are in table 1 and table 2, where YS is tensile yield strength, UTS ultimate tensile strength and HBW Brinell hardness. Specimens for High Cycle Fatigue (HCF) three-point bending (3PB) test were manufactured from the material in accordance with the drawing design in figure 2.

Table 1. Chemical composition of 08CH18N10T

Material	Fe [wt.%]	C [wt.%]	Mn [wt.%]	Si [wt.%]	P [wt.%]	S [wt.%]	Cr [wt.%]	Ni [wt.%]	Cu [wt.%]	Mo [wt.%]	Ti [wt.%]
08CH18N10T	-	0.05	1.68	0.57	0.02	0.001	17.5	9.9	0.06	0.06	0.47

Table 2. Basic mechanical properties

Material	Temperature [°C]	YS [MPa]	UTS [MPa]	Elongation [%]	Reduction [%]	HBW (2.5/62.5)
08CH18N10T	30	248	565	54,5	76	140
	350	213	425	31	69	

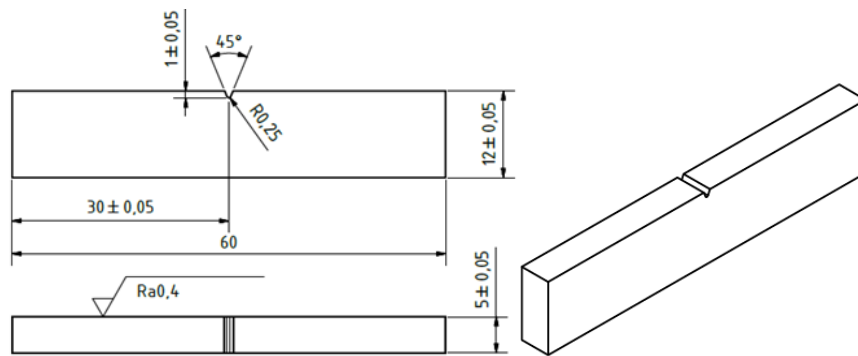


Figure 2. Specimen for HCF three-point bending test.

3 Experimental procedure

The aim of experiment is to compare the fatigue life on unpeened specimens with LSP treatment specimens. The specimens were manufactured from grinder sheet (100x120x5mm). The sheets surfaces were treated from both sides using L2 system – BIVOL (HiLASE Centrum, CZ) with a wavelength of 1030 nm, pulse duration 10 ns, maximum energy 100 J and frequency 10 Hz [6]. The laser parameters of surface treatment are shown in table 3. After the LSP surface treatment (see figure 3), the sheets were cut to specimens.

Fatigue test were performed in load control on Electromagnetic pulsator for HCF testing RUMUL. Table 4 shows the testing parameters. Post-test fractographic analyses of fracture surfaces were made.



Figure 3. Sheets 6-9 after LSP treatment

Table 3. LSP parameters

Number of sheet	Energy in puls [J]	Beam diameter [mm]	Power density [GW/cm ²]	Puls density [1/cm ²]	Overlap in line [%]	Area overlap [%]	Tape	Number of passes
8	6.2	2.65	8.8	64	52.8	77.8	Vinyl	2
6	6.2	2.65	8.8	64	52.8	77.8	No	-
9	6.2	4.15	3.6	28.5	54.9	79.6	Vinyl	1
7	6.2	2.65	8.8	28.5	29.3	50	Vinyl	1

Table 4. HCF parameters

Load	Support span [mm]	Stress ratio	Gmax - Maximum stress in 3PB [MPa]	Frequency [Hz]	Test stop at delta frequency [Hz]	Test temperature [°C]
3PB	40	0,1	320	90-92	20	22

4 Results

The results of fatigue life of laser-peened and unpeened specimen are summarized in table 5. The average value of fatigue life cycles was detected, when the value of delta frequency decreased by 20 Hz. The level of maximum stress in 3PB load was 320 MPa for all testing specimens. All peened specimens achieved higher value of fatigue life cycles than unpeened specimens.

Table 5. Fatigue life of laser-peened and unpeened specimens.

Number of sheet	Material	The average fatigue life cycles	Standard deviation
10	08CH18N10T - unpeened (G_{max} - 320 MPa)	148222	12016
8	08CH18N10T	485560	344386
6	08CH18N10T	338763	103763
9	08CH18N10T	246245	36980
7	08CH18N10T	433617	159238

Figure 4 shows achieved values of fatigue life cycles for each tested specimen. The horizontal lines show average value of fatigue life cycles of each sheet. The highest value of fatigue life cycles with highest standard deviation was measured on the samples from the sheet no. 8. The reason for such a high deviation is due to the fatigue life of specimen no. 8_3 at 1334622 received cycles.

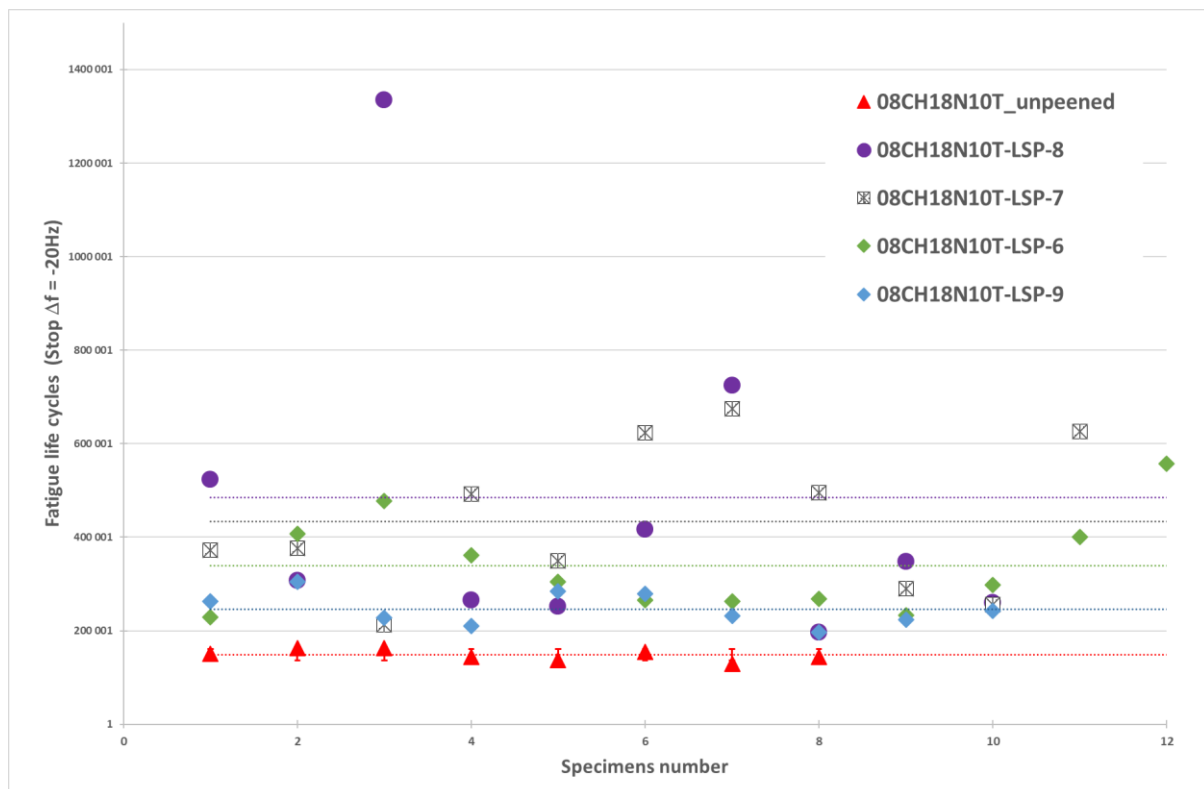


Figure 4. Fatigue life 08CH18N10T specimen at $G_{max} = 320$ MPa

Figure 5 shows crack propagation for selected specimens from each tested sheet. The number of cycles until the minimum of delta frequency corresponds to material crack resistance. The minimum of delta frequency was estimated as the start of crack initiation. Generally, the crack initiation threshold was higher for material with LSP treatment.

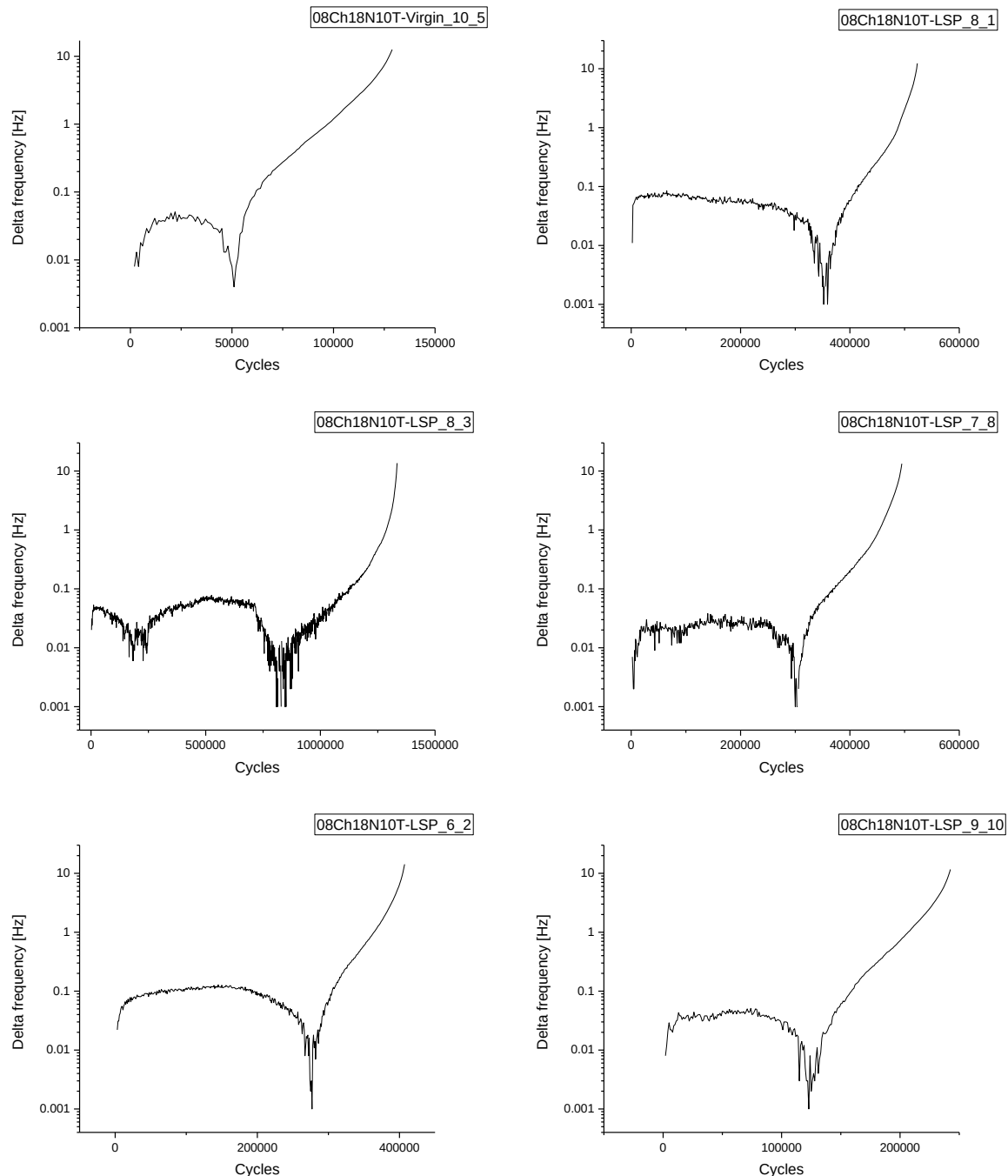


Figure 5. Crack propagation of specimens 10_5, 8_1, 8_3, 7_8, 6_2 and 9_10

Figure 6 shows fracture surface after HCF testing. The fracture surfaces of unpeened and peened specimens are transgranular and they show same cracking mechanism. The crack initiates from

notch and grows perpendicularly to the notch. Final failure is ductile with dimples. Fracture surface of peened specimens shows rougher character with little distance between striation lines; it corresponds to a slower crack propagation.



Figure 6. Fracture surface after HCF testing specimen from sheets 10, 9, 8, 7 and 6.

5 Conclusions

The presented results indicate that the HCF performance on sheets from austenitic stainless steel 08CH18N10T was more improved by applying laser shock peening. The crack initiation resistance is higher than for unpeened specimens. Problems are with higher dispersion of the fatigue life cycles values. The dispersion could be caused by inhomogeneous pulse distribution during LSP surface treatment. All peened specimens had a higher fatigue life, the specimens from sheet no. 8 had on average by about threefold increase in fatigue life compared with unpeened.

Acknowledgements

The presented work was financially supported by the Ministry of Education, Youth and Sport Czech Republic - project LQ1603 Research for SUSEN. This work has been realized within the SUSEN Project (established in the framework of the European Regional Development Fund (ERDF) in project CZ.1.05/2.1.00/03.0108 and of the European Structural and Investment Funds (ESIF) in the project CZ.02.1.01/0.0/0.0/15_008/0000293).

References

- [1] Champaigne J *History of Shot Peening Specifications*, Ninth International Conference on ShotPeening, Spring 2006
- [2] Ding K and Ye L *Laser shock peening, Performance and process simulation*, Woodhead Publishing on behalf of The Institute of Materials, Minerals and Mining, Cambridge England, Spring 2006
- [3] Claurer A.H, Gregory J.K., Rack H.J, and Eylon D(eds) *Laser shock peening for fatigue resistance. Proceedings of Surface Performance of Titanium*, TMS, Warrendale, PA. Metal Society of AIME, 217-30
- [4] Brajer J *Application of laser shock peening*, CVUT.
- [5] *Materials Reliability Program: Technical Basis for Primary Water Stress Corrosion Cracking Mitigation by Surface Stress Improvement* (MRP-267, Revision 2), EPRI Project, July 2016
- [6] Pilar J, De Vido M, Divoky M, Mason P D (eds), *Characterization of Bivoj/DiPOLE 100: HiLASE 100-J/10-Hz diode pumped solid state laser*, [online] <http://www.hilase.cz/?s=lsp> [cit.2018-09-25]