Application of Laser Shock Peening on Nitrided Steel for Power Transmission Components

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Abstract
Laser Shock Peening (LSP) has been performed on 32CrMoV13 nitrided steel. Surface properties, residual stresses (RS) and hardness had been investigated to study the effect of LSP on these kinds of materials. High level of compressive RS had been measured after LSP through the depth. No changes had been noticed in terms of hardness and microstructure. Degradation of roughness had been observed after treatment. This paper presents the first results about LSP on nitrided steel.

Keywords
Laser shock peening, Deep nitrided steel, Compressive residual stresses, Roughness, Gear tooth root.

Introduction
Gear teeth root load-carrying capacity is one of the key factors in gear design for transmission components. For fatigue life enhancement, thermochemical treatments on such material are a promising method. In order to improve the performances even more, the shot peening can be performed afterwards. Because of the high surface hardness (700HV to 800Hv) of nitrided parts, introducing additional compressive residual stresses with conventional shot peening requests specific conditions and shots. In addition, the perfect control and repeatability of the peening operation is very difficult. In the opposite, Laser Shock Peening (LSP) technology involves a better control and therefore repeatable loading. It generates very high pressure on material surface and so introduce higher and deeper compressive residual stress than conventional shot peening. Today, most of the study about laser peening are performed on aluminum or titanium alloys. In this study, LSP is applied on samples made of 32-CrMoV-13 deep nitrided steel. The present study aims to identify material response for laser peening parameters. Its main goal consists of finding a set of LSP parameters which allows the surface and sub-surface compression residual stress enhancement with a minimum impact on surface morphology and roughness. Moreover, no change in nitrided material's metallurgic features (hardness, microstructure in particular) is desired. This study is performed as part of IRT-M2P TRANSFUGE project, which aims to study innovative material and treatment for gear parts. In the following, process parameters and experimental measurements have been normalized by reference values to compare the results obtained without LSP and with LSP while guaranteeing the confidentiality of the values obtained.

Experimental Methods

1. 32-CrMoV-13 deep nitrided steel characteristics

The 32-CrMoV-13 deep nitrided steel studied has high surface hardness (~800HV), and compressive residual stresses deep into the treated material.

2. Mechanical behavior of the 32-CrMoV-13 under high pressure (give a range of pressure) laser induced shock wave.

Thin specimens of nitrided 32-CrMoV-13 steel were shocked with a high-intensity laser and water confinement configuration. Specific foils of 400 µm, 600 µm and 800µm thickness had been prepared to conduct these experiments. Two sets of targets had been prepared: a nitrided set (representative of the surface composition) and a raw set (representative of the bulk).
The laser irradiation produces a high-pressure shock wave at the metal surface which propagates through the thickness of the foil. This propagation results in a displacement of the rear free surface of the target. The velocity of this displacement is measured using VISAR (Velocity Interferometer System for Any Reflector) diagnostic. The velocity associated with the elastic precursor provides the Hugoniot limit value and thus the minimal pressure of the shock wave required to produce plastic deformation within the material at a strain rate representative of LSP conditions (around 10^6 s^{-1}). Seddik et al's paper give details about this method [1].

3. Laser shock peening process (LSP)

A flashlamp-pumped Nd:YAG with a Gaussian temporal profile has been used for all the LSP treatments presented here. This laser can provide up to 14 J of energy with 7 ns pulse, at 2 Hz of repetition rate.
LSP treatments had been performed on $35x35x20mm^3$ specimens, using the pattern introduced on Figure 1.

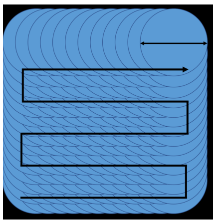

Figure 1: Pattern used for LSP treatment

Pulse energy had been chosen according to the VISAR results to provide a high enough power density to plastify the material. Only one pulse density is used in this paper and is defined by PD1. Two overlappings conditions have been tested and their defined by %OVA and %OVA x2 in this paper. A higher overlapping, %OVA x4, has been also used to assess the material's response under high intensity LSP treatment.

4. Residual stresses measurement

Residual stress (RS) measurements have been carried out on X-Raybot (Chromium detector, λ = 2.2909 Å, beam diameter 2 mm) at the PIMM Lab. Displacement of the 211 peak had been studied. Electropolishing using salt-saturated solution has been used to perform in depth RS measurement. Correction due to the several polishing has been applied on the RS value measured [2].

5. Profilometry and micro-hardness measurement

The profilometry of the surface has been determined using contact Dektak 150 Surface Profiler. Step and Average Roughness (Ra) values have been measured with this tool.

Hardness measurements have been carried out using 200g load for 12 seconds on a Clemex CMT micro hardness tester.

Experimental Results

1. Profilometry

Figure 2: Step and roughness variation caused by LSP shows the variation of roughness and the step caused by LSP at power density PD1 for % OVA and % OVA x2 overlapping.

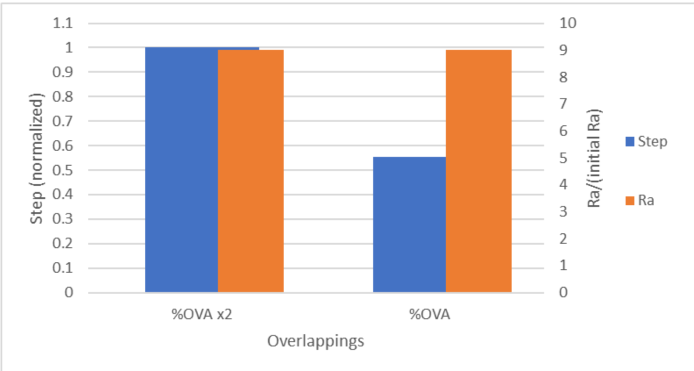

Figure 2: Step and roughness variation caused by LSP

The step measured after LSP varies from 0.55 step unit to 1 step unit while the overlapping goes from % OVA to % OVA x2.

In terms of roughness, it appears that Ra after LSP is 9 times higher than the initial one. Switching from % OVA to % OVA x2 does not make any difference in terms of roughness.

2. Micro hardness

Figure 3 presents the micro hardness profile observed on 3 different positions of an LSP treated sample (PD1 and % OVA x4).

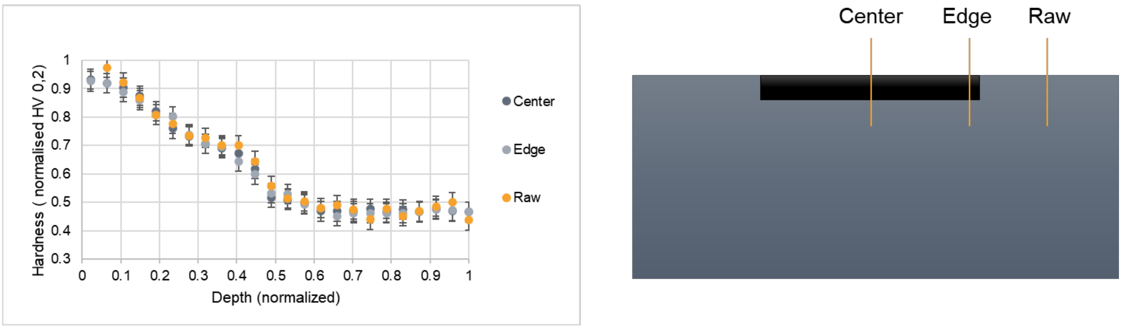

Figure 3 : Micro hardness profile measured on 3 positions (center edge and outside a LSP patch)

The 3 curves follow the same trend. The maximum hardness is reached on the surface and remains constant for 0.1 depth unit. This value of hardness decreases from 0.1 depth unit to 0.6 depth unit where it remains constant at 50% of the maximum hardness.

3. Residual stresses:

Figure 4 shows the typical RS profiles obtained after LSP and compare them to the initial RS profile.

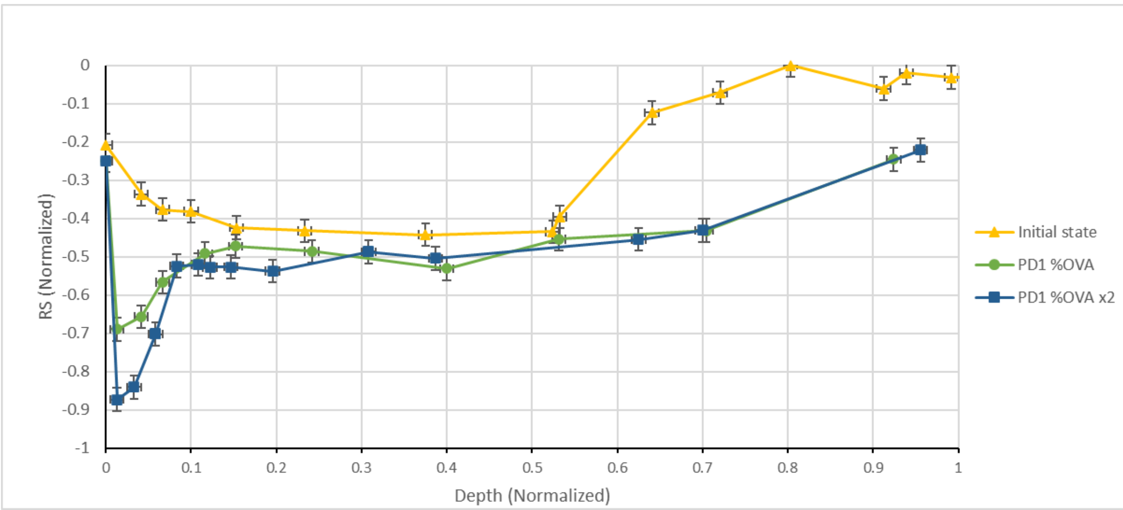

Figure 4 : RS profiles obtained for % OVA and % OVA x2 overlapping values at PD1 GW/cm²

Those RS profiles have been obtained for a power density PD1. Overlapping % OVA and % OVA x2 have been investigated. The initial RS profile start on the surface with a -0.2 RS unit, reach -0.43 RS unit from 0.15 depth unit to 0.52 depth unit. From 0.52 depth unit to 0.8 depth unit, the compression level decrease to reach 0 RS unit, and then remain at zero.

RS profiles post LSP shows some additional compression in comparison with the initial state profile. Compression peaks are observed at 0.02 Depth unit. The maximum of compressive stresses reaches -0.9 RS unit for the % OVA x2 sample versus -0.7 RS unit for the % OVA sample. From 0.1 depth unit to 0.52 depth unit, the stress level remains constant for LSP profiles, at -0.5 RS unit.

After 0.52 depth unit, the stress level decreases until it reaches 0 RS unit at 1.2 depth unit. At 0.8 depth unit, the RS level is still at -0.35 RS unit for the LSP treated samples, while it was 0 RS unit for the initial state.

Discussion and Conclusions

Results presented above gives an overview of the effect of LSP on 32CrMoV13 nitriding steel. Profilometry and roughness measurements show a 9 times higher roughness than the initial state, regardless of the overlapping. However, doubling the overlapping induces a two times higher step. These results allow us to conclude that the surface roughness does not follow the variation of overlapping for these overlapping rates, while the step variation tends to follow the overlapping variations. These results also call into question the position of LSP step in a full manufacturing process. The consequences of finishing processes on such surfaces should be investigated, even though Petan and al shows that the negative effect on roughness can be overcomed by the amount of RS introduced by LSP [3].

It appears that the initial hardness profile is not affected by the LSP treatment at PD1 and %OVA x 4 overlapping. These results are in adequation with the preservation of the microstructure observed after EBSD observation that is not shown in this paper.

Variations of overlapping influences compressive residual stresses level. The intensity of the RS peak of the % OVA x2 overlapping is nearly 30% higher than the % OVA peak. The RS peak width is not affected by the variation of overlapping. It has been showed by Halilovič and al. that the width of the RS profile increases with the pulse duration [4]. It is also interesting to notice that LSP provides compressive RS up to 1 depth unit. Increasing the compression depth should provide a benefic effect on fatigue life.

All these results show the ability of LSP to introduce high level of compressive RS in 32CrMoV13 nitriding steel without impacting the hardness and the microstructure. The roughness degradation may have some negative impact on fatigue. However, this effect is competing with the positive impact of RS level and depth

References

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