APPLICATION OF SHIFTED LASER SURFACE TEXTURING

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Abstract

Laser surface texturing (LST) is an emerging effective method for forming surfaces with specific parameters: optical, electrical, tribological, hydrophobic or hydrophilic and so on. The LST is laser parameters and overlap sensitive process. The new shifted LST is introduced, where heat load by laser picosecond pulses is decreased by specific schedule of scanning. Moreover, the shifted LST gives possibility to increase scanning repetition rate without heat accumulation effect. In this paper we have compared results of application classical methods of LST with shifted LST on stainless steel AISI 304L, 2017 aluminum alloy and nickel-based superalloy AM1.

Keywords: Shifted LST, laser processing, laser high speed texturing, overcoming heat accumulation effect

1. INTRODUCTION

Laser surface texturing (LST) is widely using technologies for decreasing of low friction bearings [1], formation hydrophobic or hydrophilic surfaces [2], anticorrosion processing [3], preparing substrates for thermal spray coating [4] and other. Complex of short pulse laser scanning parameters gives possibility to activate several processes of modification of material: ablation, melting, recrystallization, thermal stress involving and so on [5]. One important parameter it is time of laser beam influence, which depends not only from laser pulse duration, but from scanning speed and repetition rate too. It is because laser beam scanning speed and repetition rate provide overlapping of laser spots and as result thermal regime of laser processing. Correlation of overlap value gives possibility to approach smaller roughness of processed surface [6], but on the over hand the bigger overlap involves bigger heat accumulation effect [7]. Heat accumulation effect is undesirable for biggest applications, especially for high rate repetition processes [8]. One of possibilities for avoiding of the heat accumulation effect is to use low-repetitions rate regimes and higher speeds [5]. But at the same time need to keep in mind that smaller overlapping products higher roughness, especially of firm materials. The alternative way for decreasing the heat accumulation effect it is using shorter, or concrete femtosecond laser pulses. But need to consider nonlinear effects of femtosecond laser pulses processing [9]. The best solution will be a LST process, where nonlinear effects have not high influence, but overlapping and scanning speed is independent values. From this point of view lasers with picosecond pulse delay is more attractive tool for microprocessing of materials [10]. Of course, such aspects of laser micromachining still require further studies [5]. The next possibility for overcoming heat accumulation effect is shifted LST, when surface laser scanning has not sequentially ordering between next lines. In this case the time intervals and distance between overlapped lines will be enough for cooling surface, but scanning process is not stop between next scanning.

The goal of this this work is comparative studies of application of classical LST vs. shifted LST with multiple-shot laser ablation of surfaces with different thermal-mechanical properties. For both types of LST the picosecond laser pulses at frequency rates from 303 kHz till 20 MHz was applied. The basic parameters for shifted LST processing were analyzed by studies of structure changes of aluminum alloy surface. For stainless steel and super alloy the structure analyses and chemical components analyses are presented. The influence of the shifted LST with different number of repetition rate N on structure changes is analyzed. It is shown, that high speed shifted LST makes the heat accumulation effect neglected for polycrystalline materials.

2. EXPERIMENT

Classical and shifted LST experiments were performed using slab laser PX25-2-G from EdgeWave GmbH based on the contact cooled crystal and a Pockel cell [11], delivering with a beam quality M2, pulse width 10 ps, the maximum pulse energy is limited 600 µJ at lower repetition rates, while above 303 kHz, the maximum available average power is 10 W. An external Q-switcher allows the generation of bursts of any desired number of pulses. LST processing was controlled by Scanlab software in connection with scanhead intelliSCAN® III 14 [12]. There are two F-Theta objective, with 255 mm and 100 focal length. **Fig. 1** shows the schematic layout of the experimental setup.

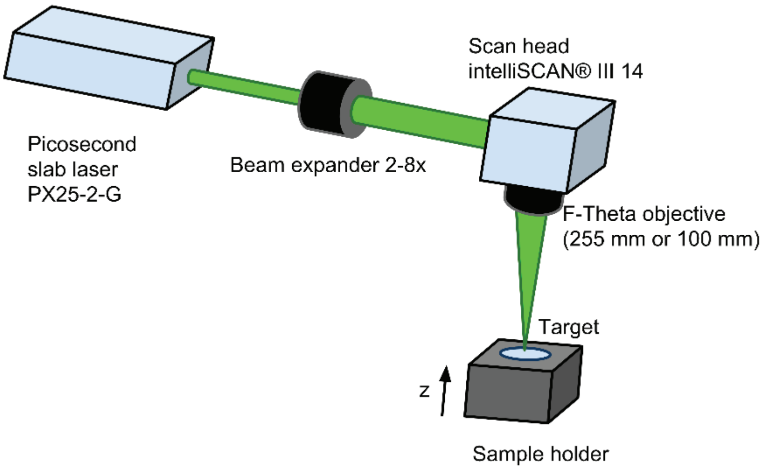

Fig. 1 Experimental layout of the experimental setup

Three types of microobjects were applied for laser engraving. The first one is a keyhole with cylindrical form and flat depth, and the second one is a keyhole with toroid form (**Fig. 2a and b**). For aluminum alloy was applied the third type of texturing - one pass multi line sharp texturing (**Fig. 2c**). Variable parameters of processing were: speed of laser beam scanning, frequency, Q-switcher timing and geometry of microobjects, like diameter or line width. Resulting structure of laser processed materials was studied by 3D optical microscope KH-7700. Microstructure analyses in the bottom of key holes and chemical components analyses of LST processed surfaces were provided by SEM with EDX.

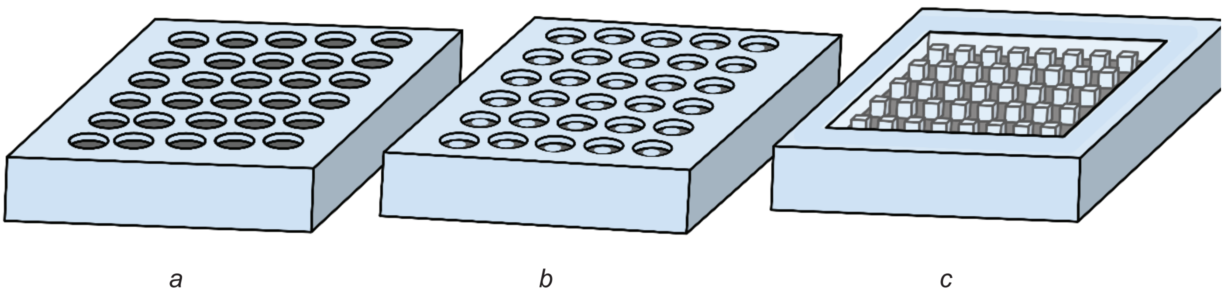

Fig. 2 Keyholes and stones graved by shifted LST

The targets were 2-mm-thick stainless steel 304l AISI plates, 3-mm-thick aluminum alloy 2017 plates and 1.5÷2 mm thickness nickel-based superalloy AM1. The sample surfaces were placed in the focal plane of the F-Theta objective and then irradiated with predefined repetition rate of LST. The different frequencies of laser pulses from 303 kHz to 20 MHz with Q-switcher were in use. Ablation experiments were carried out in ambient air without any gas shielding for constant pulse duration 10 ps. The spot diameter was assigned by set F-Theta objective. It is 20 µm or 10 µm for 255 mm or 100 mm accordingly. The number of shots of LST processing was in rage N from 1 to 350. On the **Table 1** is whole range of experimental operating parameters.

Table 1 Experimental operating parameters range

Speed (m/s)	0.1-1-1.2-1.5-2-3-4-5-6-7-8
Frequency (kHz)	303-606-800-1000-1660-2000-2500-5000-10000-20000
Repetition rate	1-10-40-100-350
Q-switcher (kHz)	10-20-30-40-50-60-70-80-100
Overlap value (µm)	1-2-3-4-5-6-7-8-9-10-15-20

Before shifted LST processing the laser spot diameter was controlled by high speed scanning of aluminum surface by laser sequence dotted by Q-switcher. Obtained in this way data are important for overlapping setting in LST sequences and heat accumulation effect diminishes. After LST processing the part of samples were cleaned by laser plan ablation with removing away thing destructed surface layer (~1 µm).

3. RESULTS AND DISCUSSION

3.1. APPLication OF Classical LST

At processing surface of stainless steel by classical LST methods there were two problems need to be solved - the precision of texturing and the heat accumulation effect. These both problems are in strong interrelation. For high precision better to use slow speed of laser scanning, but on the over hand low speed of scanning decreasing overlapping at high frequency laser pulse generation and as result increasing of heat accumulation effect. Where are two classical possibilities of LST - line by line hatching or by scaling. The first one is more attractive, because it is possible to scan surface through several texturing objects in one line. But in this case it is impossible to use specific texturing inside of microobjects, for example if it is need to apply more laser pulses in the regional area (like on **Fig. 2b** or **Fig. 2c**). Moreover, the precision and heat accumulation effect stay to be unsolved, because a lot of laser pulses in short line segment are applied and as result processes oxidation are activated already after N = 10 repetitions (**Fig. 3a**).

The second one type of LST has independently processing for every microobject and it is give possibility to use specific texturing parameters inside of each of them. But, for microobjects, when the diameter is about 100 µm, it is become really problematical. In this case it is difficult to keep precision shape with high speed of processing. On **Fig. 3,** ***b*** is shown round microobject produced by one laser beam with scan speed 8 m/s. It is visible, that out line has gaps and internal rounds are not correctly processed. In the case, than speed smaller, the microobject geometrically processed correct, but the heat accumulation effect is too high (**Fig. 3c**). As result the oxidation process are appearing inside of textured microobject (**Fig. 4**).

a *b* *c*

Fig. 3 Classical LST processing of microobjects with diameter 50, 100 and 100 µm respectively: *a* - high speed line by line hatching, *b* - high speed processing with scaling hatch, *c* - low speed scaling hatch

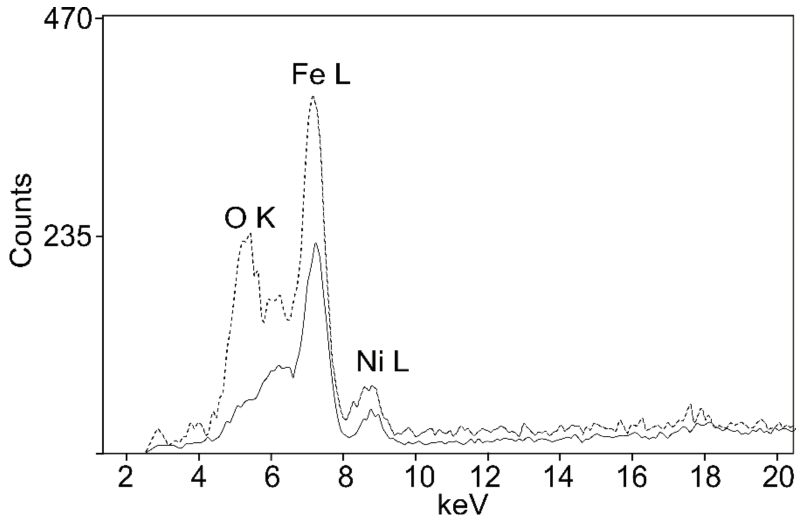

Fig. 4 EDX spectrum for clear and laser processed surfaces 304l AISI. The solid line is a spectrum of clear surface and the dotted line it is spectrum from central area of textured object processed by classical LST method

3.2. Application of shifted LST

Whole mentioned problems it is possible to overcome by shifted LST method, when whole scans makes in disordered time sequence lines in hatched objects. Hatch, power distribution and timing become more independent parameters. The first important phase for shifted LST it is defining laser system parameters for processing surface by distant hatch lines. It means that need to define scanning speed, frequency of laser pulse generation and Q-switcher gate parameters when on surface will be forming non-overlapped lines. As model material was used 2017 aluminum alloy, because it has minimal thermal limit for laser ablation. On **Fig. 5** it is shown surface 2017 aluminum alloy with one laser scan contains smallest destined objects.

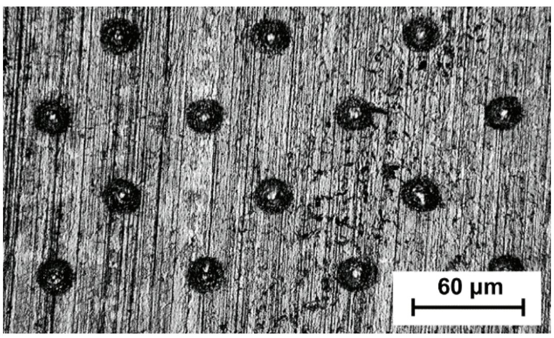

Fig. 5 Smallest objects on the surface of 2017 aluminum alloy processed by shifted LST (optical microscopy)

It is possible to apply the same process for every planar geometry of microobjects by shifted LST. Selected planar geometry has no heat accumulation effect in the case of application shifted LST. Moreover, there is hybrid shifted LST processing of material. It means, that shifted LST gives possibility to combine parameters of classic laser scanning of surface with techniques involved by shifted LST. For example there are some parameters of laser scanning, for cleaning up material surface by short laser pulses [13]. For 304l AISI it is combination of high speed scanning and frequency, than thin layer of material is removed and as result only clear polycrystal surface is remained. In the shifted LST it is possible to include the same scanning speed parameters for softly drilling of this material. In this case the bottom of keyholes and surface of textured material have similar structure. There are no visible heat accumulation effect, in despite of high repetition value of scanning equal to 350 times (**Fig. 6**). This structure has the same EDX spectrum without oxidation peak, as on start surface (**Fig. 4**, solid line).

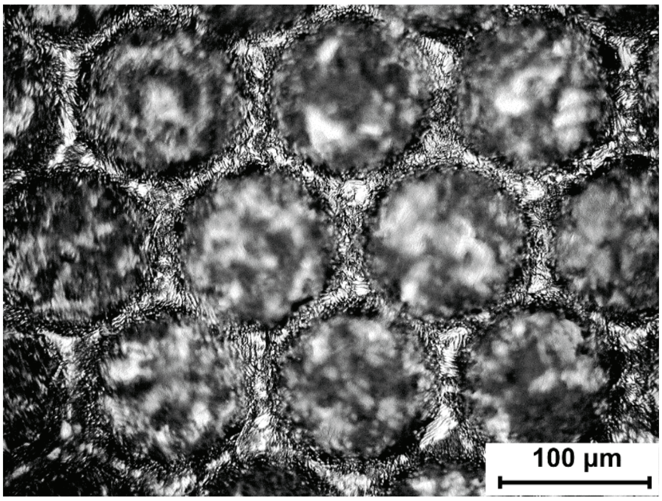

Fig. 6 Soft-cleaned surface of 304l AISI. Surface, obtained by shifted LST processing, with the same parameters of keyholes drilling as for laser cleaning, but with 350 times repetition

The shifted LST was applied for processing of superalloy surface. It is a specific material, which has stable mechanical parameters in the wide temperature range [14]. In our experiments we have defined, that this material is more sensitive for heat accumulation effect. This feature imposes a restriction on the choice of parameters of laser processing and classical methods of LST become inapplicable. The shifted LST processing gives possibility to use soft processing of material, but superalloy surface become more and more sensitive for laser scans, when depth of the microobjects becomes bigger from 30 µm.

Of course, there are many factors which are influenced on application of shifted LST, like full field processing area size, Q-switcher power limitation and synchronization with main frequency. But shifted LST becomes an essential method for laser processing of surfaces, when heat influence of overlapping is extremely undesirable.

4. CONCLUSION

Comparative analysis of LST processing is presented. There are three types of classical LST processing applied for microobjects - line by line hatching, scaling and low speed scaling. It is shown, that the best classical LST method with line by line hatching has basic limitation in control of processing inside of keyholes and repetition rate. In the case of application of high precision low speed scaling hatch involved oxidation by heat accumulation effect.

It is shown, that repeated application of shifted LST method on surface of AISI alloy is not involved heat accumulation effect. This difference between classical LST methods and shifted LST method makes the last one the most attractive alternative for high speed scanning technologies, where laser processing should to have high precision and low thermal influence.

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REFERENCES

[1] SCARAGGI M., MEZZAPESA F. P., CARBONE G., ANCONA A., SORGENTE D. and LUGARÀ P. M. Minimize Friction of Lubricated laser-Microtextured-Surfaces by Tuning Microholes Depth. Tribology International, 2014, pp. 123 - 127.

[2] TANG M., SHIM V., PAN Z. Y., CHOO Y. S. and HONG M. H.. Laser Ablation of Metal Substrates for Super-hydrophobic Effect. JLMN-Journal of Laser Micro/Nanoengineering Vol. 6, No. 1, 2011, pp. 6 - 9.

[3] VILAR R. 1 - Laser Surface Modification of Steel and Cast Iron for Corrosion Resistance. Laser Surface Modification of Alloys for Corrosion and Erosion Resistance, University of Macau, China, 2012, pp. 3 - 40.

[4] COSTIL S., LAMRAOUI A., LANGLADE C., HEINTZ O., OLTRA R. Surface Modifications Induced by Pulsed-laser Texturing-Influence of Laser Impact on the Surface Properties. Applied Surface Science, Volume 288, 2014, pp. 542 - 549.

[5] CHENG J., PERRIE W., EDWARDSON S.P., FEARON E., DEARDEN G., WATKINS K.G.. Effects of Laser Operating Parameters on Metals Micromachining with Ultrafast lasers. Applied Surface Science 256, 2009, pp. 1514 - 1520.

[6] KIBRIA G., DOLOI B., BHATTACHARYYA B. Investigation into the effect of overlap factors and process parameters on surface roughness and machined depth during micro-turning process with Nd:YAG laser. Optics & Laser Technology. 60, 2014, pp. 90 - 98.

[7] BAUER F, MICHALOWSKI A, KIEDROWSKI T, NOLTE S. Heat accumulation in ultra-short pulsed scanning laser ablation of metals. Opt Express. Jan 26; Vol. 23, No. 2, pp.1035 - 1043. doi: 10.1364/OE.23.001035.

[8] DI NISOA F., GAUDIUSOA C., SIBILLANOA T., MEZZAPESA F.P., ANCONA A., LUGARÀ P.M. Influence of the Repetition Rate and Pulse Duration on the Incubation Effect in Multiple-shots Ultrafast Laser Ablation of Steel. Physics Procedia, Vol. 41, 2013, pp. 698 - 707.

[9] ANCONA, A.; DÖRING, S.; HÄDRICH, S.; LIMPERT, J.; NOLTE, S.; TÜNNERMANN, A.QUELLE, LIU, X. Critical Performance Aspects of Ultrashort Pulse Laser Materials Processing at High Repetition rates and average powers. 29th International Congress on Applications of Lasers & Electro-Optics (ICALEO), Anaheim, CA, USA (2010). pp. 716-722.

[10] CORBARI C., CHAMPION A., GECEVIČIUS M., BERESNA M., BELLOUARD Y. AND KAZANSKY P. G. Femtosecond versus picosecond laser machining of nano-gratings and micro-channels in silica glass", Opt. Express, Vol. 21, Feb, 2013, pp. 3946-3958.

[11] http://www.edge-wave.de/web/en/technologie/innoslab/ (accessed 30 April 2015)

[12] http://www.scanlab.de/link/en/6521296 (accessed 30 April 2015)

[13] APOSTOL I., APOSTOL D., DAMIAN V., IORDACHE I.; GAROI F. et al. Laser removal of thin layers for surface cleaning. Proc. SPIE 7007, INDLAS 2007: Industrial Laser Applications, 70070I, 2008, pp. 70070I-1 - 70070I-5. doi:10.1117/12.801968

[14] POLLOCK T. M., TIN S. Nickel-based superalloys for advanced turbine engines: chemistry, microstructure and properties. J. Propul. Power 22, 2006, pp. 361-374.