Laser forming micro geometric structures on the surface of roller rolling mill

O S Vasilyev [1 2], J S Ruzankina [1]
[1] ITMO University, 49 Kronverksky Pr., Saint-Petersburg, Russia
[2] Laser centre Ltd, Saint-Petersburg, Russia

E-mail: tesla_90@mail.ru

Abstract. This paper presents a method of metal surface microstructuring by means of radiation of an impulse fiber laser with a scanning system, used for the displacement of the light beam. The topographic relief being presented was modeled in the graphics editor and then was manufactured on the experimental material. We also created a "parameter matrix", which allows to determine the optimal modes of operation of the laser system for treatment of a specific material. The paper describes three stages of the microstructuring process: profiling, cleaning, and polishing, and the corresponding geometrical parameters of the structures manufactured. A method for decreasing the level of relief roughness (for Ra and Rz) was developed.

1. Introduction

It is well known that the physical and chemical properties (mechanical, chemical, optical, etc.) of the surface are largely determined by its microgeometry [1]. Engineering, biomedicine, decorative and applied arts and other branches of industry require microstructuring technology; because it allows to improve certain performance characteristics of the surface (durability, friction factor, adhesiveness, corrosion resistance, electric endurance, etc.). Laser microprocessing is a relatively new method of surface microrelief formation, which is researched and used worldwide in a variety of industries [2]. However, most studies only solve the problem of optimization of a particular surface to solve a specific problem [3]. Besides the solution of each particular problem requires a full cycle of time-consuming research. It seems more promising to us to establish universal regularities of formation of various regular reliefs using laser radiation, which would greatly reduce the time, required for experimental formation of a certain microgeometry. In this paper, we focus on the formation of microstructures of regular geometric shape, with typical values of altitude and lateral settings. [4] The aim of this work is to demonstrate the possibility of creating microgeometric structures on the metal surface and to optimize laser modes, used for their formation. As a result, an interrelation between the parameters of laser treatment and geometrical characteristics of the surface structures is established.

To create surface structures we used a method of laser micro-ablation. [5] When this process is repeated many times, a system of depressions or grooves is formed on the surface, the shape and relative position of which can be changed programmatically. [6]

2. Experimental set.

The experiment was conducted using a high-precision laser marking system with impulse fiber laser and scanning light beam guidance system.

Table 1. Main specifications of the laser

Parameters	Value
Ytterbium fiber laser	
Wavelength (λ)	1064 nm
Average power (P_m)	up to 20 W
Maximum speed (V_{max})	2000 mm/s
Pulse repetition frequency (f)	20-100 KHz
Pulse length (τ)	≤ 200 ns
Beam diameter at the focus	~30 μm
Pulse energy	1 mJ
Processing field	100x100 mm

Initial and direct purpose of the selected laser system is laser marking of metal surfaces. However, its design is universal: the optical fiber supplies laser radiation to the processing area; catadioptric optical system focuses the laser beam onto any area of the processing field; additional vertical positioning system allows to process various surfaces of the item. Mentioned technical characteristics make the system in question multifunctional – the list of its technological capabilities includes marking and cutting of metal, application of oxidation coating, hole cutting and, lastly, the three-axis microstructuring, described in the present work.

3. Creation of a graphic model.

To create graphic models we used the ArtCam software. This software creates a three-dimensional image of the planned surface geometry. Laser microstructuring technology is implemented as laser ablation. In the graphics editor, we create the image in shades of gray. ArtyRay4 software breaks the image into 256 layers. Each layer is processed separately and has its own limits of the image. As a result, a darker parts of the image will be processed more times and therefore have the greatest depth [7].

4. In this paper, it is proposed to carry out the process of structuring in three stages.

The first stage - ablation - 3D-removal of surface layers. The thickness of the removed layer (H) can be up to 300 μm in one pass of the laser beam in the processing area.

The aim of the second stage is to clean the material of the products of material combustion from a metal surface after the ablation process.

The third stage - the polishing of the surface - is characterized by a decrease in surface roughness of the processed material.

Let us estimate the parameters of laser treatment, which are required to implement each of the processes above – ablation, cleaning and polishing. The problem specification satisfies the case of heating with a rapidly moving heat source, because $V_{sc}r_0/a>1$, therefore, to determine the maximum temperature of the processed surface when exposed to a series of short pulses we will use the formula [8]:

$$T = \frac{2q(1-R)\sqrt{a\tau}}{k\sqrt{\pi}} \sqrt{\frac{2ar_0}{V_{sc}}} + T_0, \qquad (1)$$

where, q is the power density of laser beam, R is the reflection coefficient, a is the thermal diffusivity of the material, τ is the pulse duration, k is the thermal conductivity of the material, r_0 is the radius of the waist spot, Vsc is the laser beam scanning speed, T is the initial temperature)

4.1 I processing step (ablation)

In this step, the laser beam heats the surface of the metal to a temperature of T_I≈3200°K. During that, a part of the material evaporates in form of vapor and other part is removed in a molten form under the influence of recoil vapors pressure $P_{rt} \approx F_{rt}/S = mW/S\tau$, where W is the pulse energy. The metal in the liquid phase is redistributed over the surface under the influence of P_{return} and the surface tension of the melt. Then it cools, forming a rough surface, and oxidizes. In addition, during the ablation process the vaporized material is accumulated on the surface of the material.

4.2 II processing step (cleaning)

At this stage, the combustion products are removed from the surface. At a temperature of T_{II}≈1600°K the metal is not evaporating yet, while the accumulated large and small particles of the material after the first processing step (contamination) are removed from the surface of the processed material. The condition of $T_{surface}$ less than $T_{evaporation}$ is facilitated by the fact that the focal plane is located above the surface of the processed area.

Cleaning mechanism is as follows: the particles accumulated on the surface are sintered together and stick to the processed surface. Consequently, a porous structure is formed. During the repeated irradiation of such a structure, the upper layers of the material are heated faster and more heavily, due to the reduced heat dissipation from the laser pulse irradiation area. Because of the temperature differences, the sintered structure becomes deformed: a porous structure collapses. Under the influence of the recoil vapor pressure, the residue of porous contamination is removed. If an additional cleaning is needed, this processing step can be repeated.

4.3 III processing step (polishing)

Since the surface temperature is significantly lower than T_I and exceeds $T_{melting}$, a recurring melting of the roughened surface of the processed sample occurs. Due to the surface tension in the liquid phase, the unevenness of the surface is smoothed. Moreover, due to the shorter pulse duration of $\tau = 4$ ns, a smaller amount of metal enters the liquid phase, than when $\tau = 100$ ns.

The greater the exposure time, the greater the volume of the liquid phase and therefore the greater the dispersion of sizes of the processed side. In addition, long time of exposure causes an increase in the depth of the heat influence zone (of the heated layer $h_\lambda=(a\tau)^{1/2}$ (3)), where the chemical and structural changes and the appearance of defects on the surface of the processed area occur. [9]

Table 2. Specific parameters of the laser system during three modes of processing and the parameters of the processed material.

	ablation	cleaning	polishing
P [W]	14	6	15
τ [ns]	100	100	4
V [m/s]	0,6	0,8	1,5
f [KHz]	30	40	100
q [W/m^2]	3,6*10^9	3*10^9	7*10^9
T [K]	3200	1200	1700
Ra [µm]	0,78	0,66	0,26
Rz [µm]	4,14	2,61	1,10
l [µm]	49,9	49,8	50

5. Results of the experiment

The total height of the structure and the density of objects on the surface is determined by the task given.

It was planned to create 3D-microstructure in the form of a cones ‘Figure 1’ [10] for cold steel rolling, where a highly developed surface is needed for its further protection by means of coating.

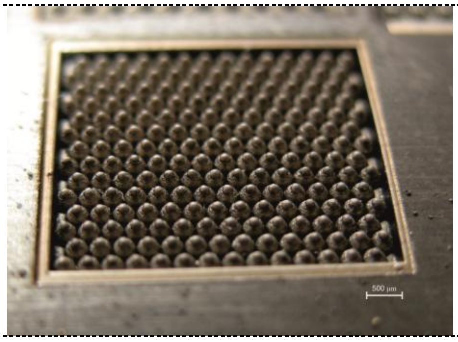

Figure 1. Images of a 3D-micro-structure on the surface of Steels 10: a series of 200 cones on the area of 0.25 cm^2

Table 3. Characteristics of microstructures in ‘Figure 1’.

	untreated surface	cones
the height of the structure, h	-	195 μm
Diameter, d	-	350 μm
Density, N	-	800 thing/cm^2
Roughness Ra, Rz	0,6 μm 2,77 μm	3,48 μm 13,33 μm
the total thickness of the removed layer, H	-	200 μm
run time, t	-	195 μm

In general, the height of the structures h equals the depth of the total removed layer H, with regard to the surface layers cleaning mode of h <H. Reduction of the roughness can be achieved at the final stage of "polishing" the surface. However, in some cases, III processing step is not required.

It is important to note again that the surface microtopography is set programmatically by imaging in a graphics editor. This makes it possible to manufacture a wide variety of structures: intended for industrial use (the surface frictional sliding wetting liquid collecting oil, etc.), as well as decorative crafts (three-dimensional image of a human face or an animal bas) [11]

6. Conclusion.

In the presented work a surface microstructuring technology was examined using a Stell 10 sample. We obtained a relief of the surface in the form of pyramid raster, cones, hemispheres, cylinders and images. It is essential that by changing the surface topography of the metal we can modify various surface properties: mechanical, optical, electrical, etc., at the same time each material, of course, requires the individual parameters of the laser processing.

It should be noted, that the accuracy and performance of this technology on the laser system, that we used, is limited by several factors: the resolving power of the focusing optics, resolution and beam-scanning field, reasonable processing time, etc.

However, in the form in which it currently exists, this technology can be used in various industrial processes: during the hot and cold embossing in the automotive industry [12], to increase the corrosion resistance of steel in metallurgical industry [13], to increase adhesiveness of the surfaces in the varnish-and-paint operations [14], in the jewelry industry for the production of stamps and seals, in microelectronics for processing of film elements [15], for the manufacture of reflective optical rasters, etc.

Journal of Physics: Conference Series **735** (2016) 012046 doi:10.1088/1742-6596/735/1/012046

The proposed method of forming the microgeometry of surface using a volume-controlled ablation can be used for development of laser-based surface engineering in various industries.

7. References

[1] Schneider J. G. Operational properties of details with regular relief. Leningrad, *"engineering"*, 1982

[2] Veiko V.P. Laser–assisted micro shaping. Proceedings of SPIE, v.4157, *Laser–assisted Microtechnology* (LAM–2000), p. **93–103**, 2001.

[3] B. Medres, Menachem Bamberger. LASER SURFACE TEXTURING. Fricso Ltd, *Technion-Israel Institute of Technology* 2008

[4] Nadeem H. Rizvi, Phil T. Rumsby. New Developments and Applications in the Production of 3D Micro-structures by Laser Micro-machining. Exitech Limited Hanborough Park, Long Hanborough, Oxford OX8 8LH, United Kingdom 2012.

[5] V. P. Veiko, A. A. Kislov, T. Y. Mutin, V. N. Smirnov. Prospects of industrial applications of optical materials. *Scientific and technical journal of information technologies, mechanics and optics,* 2012, № 3 (79), **50-54**

[6] Jin-zhong Lu, Chao-jun Yang, Lei Zhang, Ai-xin Feng, Yin-fang Jiang. Mechanical Properties and Microstructure of Bionic Non-Smooth Stainless Steel Surface by Laser Multiple Processing. *Journal of Bionic Engineering* 6 (2009) **180–185**.

[7] Ralf Knappe. Applications of picosecond lasers and pulse-bursts in precision manufacturing. *LUMERA LASER GmbH*, Opelstr. 10, 67661 Kaiserslautern, Germany 2014.

[8] Veiko VP, Shahno E. A. Collection of problems on laser technologies. SPb – *SPb NRU ITMO* 2007.

[9] V. P. Veiko, E. A. Shahno. Laser technology in problems and examples. the textbook for the course *"Physical and technical bases of laser technology".* SPb 2014

[10] S.G. Scholz, C.A. Griffiths, S.S. Dimov, E.B. Brousseau, G. Lalev, P. Petkov. Manufacturing routes for replicating micro and nano surface structures with bio-mimetic applications. *Manufacturing Engineering Centre, School of Engineering,* Cardiff University, Cardiff, UK. CIRP Journal of Manufacturing Science and Technology 4 (2011) **347–356**.

[11] Manuel Pfeiffer, Andy Engel, Steffen Weibmantel, Stefan Scholze, Guenter Reisse. Microstructuring of Steel and Hard Metal using Femtosecond Laser Pulses. *University of Applied Sciences Mittweida, Technikumplatz* 17, 09648 Mittweida, Germany. Physics Procedia 12 (2011) **60–66.**

[12] Urtsev V. N., Platov S. I., Anzupow V. P. A method of processing rolls. Patent of Russia № 2224822 2004

[13] Marshakov, I. K. Corrosion resistance and Obeschanie brass. Physicochemistry of poverhnosti and protection of materials. center of RAS *"Publishing house "Nauka"* (Moscow) ISSN: 0044-1856 2005, **PP 227-233**

[14] Won-Seock Kim , Il-HanYun , Jung-JuLee , Hee-TaeJung. Evaluation of mechanical interlock effect on adhesion strength of polymer–metal interfaces using micro-patterned surface topography. *International Journal of Adhesion & Adhesives* 30 (2010) **408–417**

[15] A. Schubert, S. Gross, J. Edelmanna, B. Schulz. Laser micro structuring of high-stressed embossing dies. **Physics Procedia** 5 (2010) **261–268**