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Laser polishing of steel surface for microfluidic applications

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Abstract. The paper examines various modes of laser polishing of stainless steel surface to decrease a surface roughness for creating model micro-grooves corresponding to the elements of the microfluidic topology. The effect of the formation of an oxide film and its effect on the roughness of the treated area is considered as well. The data obtained is confirmed by measurements using a profilometer.

Keywords: microfluidics, laser processing, laser polishing, steel

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Лазерная полировка стальной поверхности для микрофлюидных применений

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Аннотация. В статье рассмотрены различные режимы лазерной полировки поверхности нержавеющей стали с целью снижения шероховатости поверхности для создания модельных микроканавок, соответствующих элементам микрофлюидной топологии. Рассмотрен эффект образования оксидной пленки и ее влияние на шероховатость обработанной области. Полученные данные подтверждены измерениями с помощью профилометра.

Ключевые слова: микрофлюидика, лазерная обработка, лазерная полировка, сталь

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Introduction

Microfluidics is one of the fastest growing fields in the modern world. Microfluidic technologies are used in such areas as medicine, pharmacology, microelectronics, mechanical engineering and the aerospace industry [1]. Therefore, the search for new materials and methods of their processing determines the economic, environmental and technological needs of microfluidic chip production.

The main difficulty is to create microchannels with low roughness and surface morphology without microcracks and nanopoils. Previously, in our work [2], using multi-stage laser processing of a stainless steel plate, where parameters such as repetition rate, power and pulse duration were changed between iterations, model microchannels were obtained on its surface (Fig. 1), which are elements of a microfluidic system.

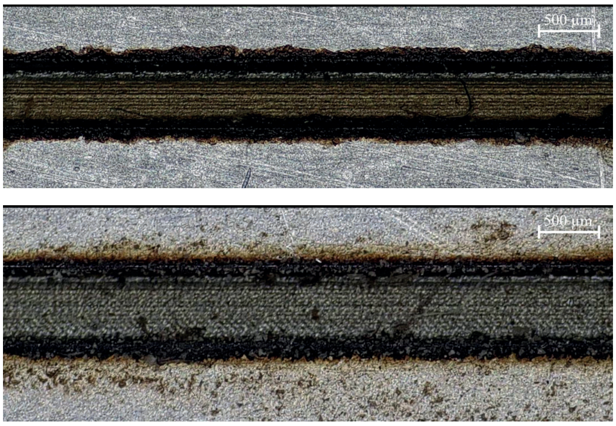

Fig. 1. Photos of experimental grooves

Obtained results showed that the stripes corresponding to the scanning paths of the laser beam are clearly visible on the walls of the obtained topologies, which indicate the high roughness of this surface of the microchannels. In particular, these parameters are important for controlling the technological process, since a high roughness value can noticeably change the properties of fluid movement due to the transformation of the influence of capillary and gravitational forces inside the microfluidic chip, up to the impossibility of stable functioning of the entire system [3, 4]. Therefore, the development and improvement of the polishing process when creating a microfluidic topology is very important. Moreover, AFM research indicated micro cracks on the surface after laser treatment with such energy parameters, which meant that laser processing iterations must be transform and include some steps, which allow decreasing the surface roughness. To reduce this surface parameter, it was decided to develop softer, polishing laser treatment modes.

There are 3 main processes of laser polishing: ablation of large areas of the surface, ablation of local (small) areas of the surface and polishing by remelting the surface layer of the material [5]. When polishing large areas by ablation, the material evaporates over the entire surface, while local areas ablation leads to removing the material from the peaks of the surface (a complex and expensive measurement system is needed to find the peak positions). When polishing by remelting, a thin surface layer melts and the surface tension leads to the alignment of the material [6, 7]. In this paper, the results of the development of laser treatment modes based on the 3rd method of polishing metal surfaces described above are presented.

Materials and Methods

The studies were carried out on a 2 mm thick stainless steel plate. The percentage of chemical elements of metal is shown in Table 1 (the data were obtained by X-ray fluorescence analysis). The sample was processed with a precision laser marker “MiniMarker2” (Laser Center LLC, Russia) based on ytterbium fiber laser with a wavelength of 1.064 microns.

Table 1

Percentage content of chemical Elements

Elements	Content, %	Elements	Content, %
Iron (Fe)	71.738 ± 0.348	Silicon (Si)	0.424 ± 0.115
Chromium (Cr)	18.233 ± 0.147	Cobalt (Co)	0.259 ± 0.020
Nickel (Ni)	8.076 ± 0.138	Vanadium (V)	0.077 ± 0.011
Manganese (Mn)	1.165 ± 0.040	Titanium (Ti)	0.021 ± 0.006

The roughness of the treated surface was assessed using an Industrial NSRT-100 profilometer (NORGAU, Russia). Before evaluating the roughness parameter of the treated zones, the profilometer was calibrated on a reference sample with known roughness. The measurement error of the parameter R_a was about 5%. Measurements of 1 sample occurred 5 times, after which the average roughness was calculated.

Results and Discussion

During a multi-stage exposure to a metal plate with an IR laser, it was possible to identify processing modes to create a polished surface. The initial roughness of the plate (R_a) is 0.754 microns. Such parameters as power, frequency, pulse duration, and fill angle were changed between the stages of exposure. Examples of some modes are shown in Figure 2.

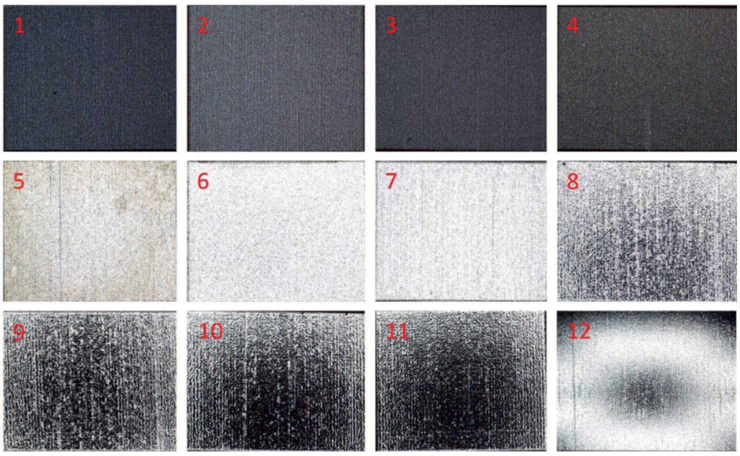

Fig. 2. Photos of polishing treatment modes

In the first 4 treatment modes, one can notice a change in the color of the treated area as a result of the appearance of an oxide film. This effect is observed due to the fact that heated ambient gases react with the heated plate material, forming iron oxides and other impurities on its surface.

Table 2

Roughness parameters of polishing modes

№	R_a, µm	№	R_a, µm
1	0.775	7	0.447
2	0.690	8	0.270
3	0.615	9	0.232
4	0.704	10	0.188
5	0.420	11	0.180
6	0.370	12	0.173

According to our previous study [2] the effect of oxide film formation is negative, as it increases the roughness of a larger area, as can be seen from the table above. It proves our previous measurements and conclusions.

At the same time, the presence of a metallic sheen indicates a lower surface roughness value. In this case, the most effective laser treatment modes are from 10 to 12 from the table above. These modes were obtained by a laser beam with a diameter of 50 microns and a pulse duration of 350 ns with four-stage processing, between which the power (from 5.4 to 2.1 W), pulse repetition rate (from 40 to 60 kHz), scanning speed (from 500 to 1000 mm per second), as well as the fill density varied (from 100 to 200 lines per mm) and the fill angle (from 45 to 315 degrees).

However, it is necessary to take into account the corrosion resistance of the material both with and without the presence of an oxide film to the effects of chemical liquids, therefore, one of the next stages of the work will be experiments to identify the corrosion resistance of the metal under different polishing conditions.

Conclusion

Using laser treatment with IR radiation, it was possible to reduce the roughness from 0.754 microns to 0.173 microns, that is, this parameter improved by 77.1%. The most effective laser polishing modes demonstrated in this work will be used in further studies as part of iterations in obtaining model grooves with subsequent AFM examination for the presence of microcracks.

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