Localization of antifriction alloys on the metal materials surface

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Abstract. The main goal of the work was the localization of color alloys on the surface of a copper-foamed glass-textolite by laser radiation of a microsecond pulse duration. Researches of processes of change of physicomechanical properties, and also the structures created in near-surface layers of a copper foil were conducted. During the work, images of the sample surface, data from the diffractometer, and structural and phase analysis of the surface state of the samples were obtained.

1. Introduction
Currently, in many industries there is a problem of increasing reliability and increasing the durability of tools, as well as a reduction in the staging of the final product. One of the important tasks is also the production of new materials with a given set of properties. The use of laser energy for surface modification of the structure of materials can significantly improve the performance of products. The change in the local properties of the surface of the treated material, depending on the type of treatment, allows changing the thermal characteristics, improving the mechanical properties and increasing the resistance to various physical effects. Many papers [1-3] were devoted to laser surface modification of various metals and alloys. Thus, in work [4], an experiment was conducted to determine the effect of laser modification modes on the structure, properties, and wear resistance of a small-sized tool of high-speed steel P6M5. During the work it was found that the use of highly concentrated energy sources can increase the microhardness of the surface layer of high-speed steel P6M5 1.5-2 times.

The advantage of laser radiation over traditional methods, in order to improve the physical and mechanical properties of the product, is the local high radiation intensity, the possibility of processing in hard-to-reach places, reducing the processing time, the possibility of creating a layer of material with specified properties. To perform this task, it is necessary to choose the correct treatment mode for laser radiation. In general, for the selection of the mode, such parameters as the radiation power and scanning speed are changed. Depending on the scanning speed of the laser beam, the energy contribution to the selected area changes. At low scanning speeds, the energy contribution to the target area increases. As the scanning speed increases, less radiation energy enters the area due to the faster passage of the beam through the area. The choice of this parameter depends on the tasks. Thus, by adjusting these parameters, it is possible to select the optimal processing mode to achieve various physical and mechanical properties of the metal surface.
2. Equipment and samples
In experiments ytterbium fiber laser system LS-02-T was used. A continuous ytterbium fiber laser is shown in Figure 1.

![Ytterbium fiber laser LS-02-T.](image)

The maximum output power of this laser system reaches 200 watts with the possibility of adjustment. The system generates radiation at a wavelength of 1.06 µm. Type of pumping - semiconductor laser diodes; The beam quality parameter M2 is not worse than 1.2; Power consumption - no more than 1 kW; Cooling - with a water-to-air chiller. The system is designed for research and industrial applications. The applications of this series of lasers are different: cutting, annealing, drilling, hard soldering, welding, heat treatment and plating.

The laser system is used in conjunction with various systems for positioning laser radiation (galvanoscanners, portal system for moving the laser head). It allows laser cutting of materials, laser surfacing, laser welding, local laser thermal hardening.

As sample double-sided copper-foiled glass-textolite стеклотекстолит was used. As applied to the surface of the metal sample, various solders were used. One of the solders was applied by hot-tinning on the company OOO "RUSALOX". The composition of the factory solder is shown in table 1.

| Chemical element | Sn  | Pb   | Fe  | Ta  | Se  | Cu  |
|------------------|-----|------|-----|-----|-----|-----|
| The percentage of the total number (%) | 52,3 | 46,8 | 0,3 | 0,3 | 0,2 | 0,2 |

As the second applied material solder POS-61 was used. The composition is presented in table 2, which corresponds to GOST 21930-76.

| Mass fraction of impurity %, (no more indicated value) |
|------------------------------------------------------|
| Sn Pb Sb Cu Bi As Fe Ni S Zn Al |
| 59-61 Etc. 0,1 0,05 0,2 0,02 0,02 0,02 0,002 0,002 |

1* – Mass fraction of main components %

The third solder a sample of tin was used, the chemical composition of which: Sn = 99.7% Fe = 0.3%.

Figure 2 shows an installation on which laser radiation was processed.
3. **Conducting an experiment and discussing the results**

The soldering process was carried out by the laser annealing method. With this method was applied solder POS-61, as well as solder tin. Figure 3 shows the scheme of the experiment.

![Figure 3](image)

**Figure 3.** Scheme of the experiment: 1 - laser installation, 2 - focusing lens, 3 - laser radiation, 4 - deposited solder, 5 - sample.

The processing was performed by different modes. An x-ray analysis was performed. The result is a diffractogram, a curve of the dependence of the intensity of the scattered beam on the scattering angle. Figure 4 shows the diffractogram of a polycrystalline sample.

![Figure 4](image)

**Figure 4.** Diffractogram of polycrystalline sample [5].

The diffractogram of a crystalline object is a set of diffraction peaks, each of which has an angular position, relative intensity and width. By the positions of the peaks one can obtain a set of interplanar
distances $d$, inherent in the crystals of the object. Together with the intensities of the peaks, they allow us to determine the crystalline phases present in the sample, their percentage and the parameters of their crystal lattices. The intensities of the peaks make it possible to determine the positions and types of ions in the unit cell of the crystal. In the case of coarse material, knowing the relative intensities of the peaks, it is possible to determine the dimensions of regions with an ordered structure (grain). Measurement of the width of the peaks makes it possible to calculate the sizes of crystallites in finely dispersed materials and the density of microstresses.

Like any physical method of investigation, X-ray diffraction analysis has limitations in accuracy and sensitivity. The accuracy of the results depends mainly on the experimental conditions, as well as on the exposure time. The lattice period of the crystal can be measured to within 0.001 angstroms. The sensitivity limit largely depends on the type of object [6].

After processing the sample with laser radiation, 15 rectangles with an area of 4 cm$^2$, differing in the power of the radiation, were obtained. Each rectangle consists of 4 squares, an area of 1 cm$^2$, differing in the parameters of the scanning speed ($\nu$) and the density of pouring ($\rho$). On the studied samples it is visually possible to observe the change of the surface color towards the yellow range (Figure 5) with the acquisition of a bronze shade. In some cases, there was peeling of copper foil and burning of glass, which indicates a local overheating of the surface of the samples under laser exposure. In samples with a predominance of yellow shade, structural thermochemical transformations in the near-surface layers of copper foil are most likely to occur.

![Figure 5. The resulting samples after laser treatment.](image)

In an optical microscope with a resolution of up to 40 $\mu$m, surface images of some samples were obtained, where the largest change in the structure of the material occurred.

The topography of the surface of sample N is shown in Figure 6. Solder POS-61 on this sample was applied.

![Figure 6. Photo from the optical microscope sample with a solder POS-61: a - the second square, b - the third square, c - the fourth square.](image)
Table 3 shows the processing parameters of sample N at a radiation power $P = 120$ W.

**Table 3. Sample N.**

| № square | $v$ (mm/s) | $\rho$ (l/mm) |
|----------|------------|---------------|
| 1        | 560        | 20            |
| 2        | 580        | 20            |
| 3        | 600        | 40            |
| 4        | 620        | 40            |

The surface image of sample O, with factory solder, is shown in Figure 7.

**Figure 7.** Photo from the optical microscope sample with tin solder: a - the second square, b - the third square, c - the fourth square.

Table 4 presents the parameters of processing by laser radiation at $P = 100$ W.

**Table 4. Processing parameters - sample O.**

| № square | $v$ (mm/s) | $\rho$ (l/mm) |
|----------|------------|---------------|
| 1        | 400        | 10            |
| 2        | 400        | 30            |
| 3        | 400        | 20            |
| 4        | 400        | 40            |

As a result of the analysis of these images, it can be concluded that the interaction of laser radiation with the tinned foil surface results in the formation of linear recesses (depressions) along the trajectory of the focal spot and the transfer of copper atoms and ions from the cavities to the flat tops of adjacent projections.

In samples C, I, N, a change in the color of the surface with a "bronze" shade is also recorded.

Using a diffractometer, the phase composition of these samples was studied and X-ray diffraction analysis was performed.

On the diffractogram of sample C (Figure 8), after applying the solder POS-61, a markedly high content of copper (red peaks $Cu \approx 93\%$). Peaks of green color show the intermetallide $Cu_6Sn_5 \approx 34\%$ (thick layer adjacent to tin); peaks of violet color indicate content $Cu_3Sn \approx 11\%$ (thin layer adjacent to the copper). Table 5 shows a comparison of the intensity of $Cu$ x-ray peaks (by 5 peaks of 100%).
Table 5. The intensity of X-ray peaks of sample C.

|     | 111 | 200 | 220 | 311 | 222 |
|-----|-----|-----|-----|-----|-----|
| 1*  | 100%| 46% | 20% | 17% | 5%  |
| 2*  | 100%| 50% | 26,7%| 28,5%| 13,4%|

1*) – tabular value;
2*) – the treated surface after exposure to a short radiation pulse, where (111), (200), (220), (311), (222) - Miller’s indexes.

Figure 8. Diffractogram of sample C.

On the diffractogram of sample I (Figure 9), with tin solder, we can see peaks of red, indicating a content of Cu ≈ 78%. Peaks of green color show the content of Cu₆Sn₅ ≈ 19%; peaks of violet color Cu₃Sn ≈ 3%. Table 6 shows a comparison of the intensities of the X-ray peaks of Cu.

Table 6. The intensity of X-ray peaks of sample I.

|     | 111 | 200 | 220 | 311 | 222 |
|-----|-----|-----|-----|-----|-----|
| 1*  | 100%| 46% | 20% | 17% | 5%  |
| 2*  | 100%| 48,7%| 25% | 26,9%| 11,5%|

Figure 9. Diffractogram of sample I.
On the diffractogram of sample N, with solder POC-61, (Figure 10), red peaks show a content of Cu₆ ≈ 98%. Peaks of green color Cu₆Sn₅ ≈ 24%; peaks of violet color Cu₃Sn ≈ 3%. Table 7 also shows a comparison of the intensity of X-ray peaks of Cu.

|     | 111 | 200 | 220 | 311 | 222 |
|-----|----|----|----|----|----|
| 1*) | 100% | 46% | 20% | 17% | 5% |
| 2*) | 100% | 50,8% | 27% | 28,8% | 13,5% |

Figure 10. Diffractogram of sample N.

These data shows the formation in the alloy structure of a tightly packed hexagonal lattice. Type of the formed communication – metal. Besides, unregulated solid solution was formed, including, with impurity.

The intensity of copper in samples C, I, N differs slightly from the table values due to the presence of impurities and the recrystallization process.

The revealed features confirm the changes connected with the sizes of crystallites, as well as with elastic microdistortions of the crystal lattice and crystallographic textures. As a result of interaction between clusters, stresses arise. Excess energy and pressure at the boundaries of Cu clusters decrease when an impurity appears on its surface. Copper foil is recrystallized to a lesser extent when impurity metals are added.

4. Conclusion

Thus, as a result of the experiments, the processes of changes in the chemical composition in the near-surface layer of copper-foiled glass fiber using laser annealing were identified. In laser surface treatment double-sided copper-foiled glass-textolite is the growth of the grains of intermetallic compounds: Cu₆Sn₅ и Cu₃Sn. The proportion of the intermetallic Cu₆Sn₅ in all samples is much greater than the proportion of the intermetallic compound Cu₃Sn. As a result of evaporation of atoms in the near-surface layer of Cu crystals, vacancies are formed, which diffuse deep into the crystal Sn. Is the introduction of Cu atoms in the interstices of Sn (atomic radius of Cu = 1,57 Å, Sn = 1.72 Å), as well as the formation of solutions of substitution. By varying the laser radiation parameters (in order to adjust the processing temperature) and the thickness of the applied tin layer, the formation of intermetallic compounds is achieved in the absence of the process of peeling the copper foil from the surface of the glass fiber. The obtained results can be used for surface treatment of various parts in order to improve their physico-mechanical properties.
Acknowledgements
This work was performed as a part of Vladimir State University’s State Task 3.5531.2017 / 8.9 GB-1106/17. It was supported by the Russian Foundation for Basic Research, project № 16-48-330031, № 16-08-01226.

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