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HIGH-ENERGY LASER TREATMENT OF PLASMA COATINGS FROM MATERIALS BASED ON OXIDE CERAMICS

The article studied and optimized the technological parameters of hardening by pulses of laser radiation of sprayed coatings from materials based on oxide ceramics using additives of refractory metals. According to the methodological approach, when varying the technological parameters, the radiation power density and the total number of laser beam pulses in the treatment spot were changed. The optimization criterion is the maximum degree of local melting and densification of the sprayed compositions in the absence of signs of coating destruction under the influence of radiation. The microstructure of coatings obtained under optimized processing conditions is considered . During reflow, chemical interaction at the boundaries of the main phases of the applied compositions is activated. The products of chemical interaction can be finely dispersed (including nanoscale) formations that strengthen the boundaries of the main phases and the coating as a whole.

Keywords: ceramic coating, plasma spraying, laser radiation, parameter optimization, refractory metals.

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ВЫСОКОЭНЕРГЕТИЧЕСКАЯ ОБРАБОТКА ЛАЗЕРОМ ПЛАЗМЕННЫХ ПОКРЫТИЙ ИЗ МАТЕРИАЛОВ НА ОСНОВЕ ОКСИДНОЙ КЕРАМИКИ

В статье изучены и оптимизированы технологические параметры упрочнения импульсами лазерного излучения напыленных покрытий из материалов на основе оксидной керамики с использованием добавок тугоплавких металлов. Согласно методического подхода, при варьировании технологических параметров изменяли плотность мощности излучения и суммарное количество импульсов лазерного луча в пятне обработки Критерием оптимизации режимов является максимальная степень локального плавления и уплотнения напыляемых композиций при отсутствии признаков разрушения покрытия под излучения. Рассмотрена микроструктура покрытий, полученных на оптимизированных режимах обработки.

При оплавлении активизируется химическое взаимодействие на границах основных фаз нанесенных композиций. Продуктами химического взаимодействия могут быть тонкодисперсные (в том числе наноразмерные) образования, которые упрочняют границы основных фаз и покрытие в целом.

***Ключевые слова:** керамическое покрытие, плазменное напыление, лазерное излучение, оптимизация параметров, тугоплавкие металлы.*

1. Introduction.

The technique for optimizing the laser processing process is based on the need to obtain hardened amorphous or nanocrystalline coating structures that are the object of research. For this, severe operating modes are most applicable, the optimization of which is based on the maximum possible degree of local melting of the sprayed powder compositions with no signs of thermal destruction on their surface. The number of crystallization (amorphization) centers of the material from which hardened structures develop during ultrafast cooling directly depends on the degree of short-term melting of the composition containing various phases (including refractory ones) [1]. As technological equipment, we used a solid-state quasi-stationary laser emitter, which makes it possible to process coatings with pulses up to 4 ms in duration, obtained in the free-running mode. An important component of this technology is the processing environment. It is most expedient to use nitrogen for protection against oxidation, while heat removal from the processed material becomes difficult, which is important in the formation of hardened nanostructured and amorphous phases [2-4]. For the process of optimizing hard modes of laser processing according to the mentioned criterion, it is desirable to investigate the effect of the power density of the laser radiation pulse on the degree of fusion of the deposited compositions. When varying the power density, it was also taken into account that the shape of the radiation pulses from solid-state lasers in the free-running mode is determined by the shape of the pump current pulses [5]. Together with the power density, the total number of pulses in the treatment spot was also optimized. This technological parameter affects the thickness of the treated layers of the coating [9]. For wear-resistant coatings, it is necessary to obtain increased cohesive and adhesive strength during spraying. Consequently, the total number of pulses must ensure the melting and densification of the obtained coatings over the entire thickness, which will contribute to the production of hardened nanocrystalline or amorphous structures due to the factors mentioned above. Evaluation of the degree of fusion and compaction was carried out by examining thin sections of the cross-section of the treated coatings on a MeF-3 metallographic microscope (Reichert, Austria) and on an AutoScan image analyzer. When studying the properties of the obtained compositions during processing at optimal conditions, the creation of hardened nanocrystalline and amorphous structures corresponded to an increase in the average microhardness of composite materials in comparison with untreated plasma coatings [10].

2. Optimization of processing of plasma coatings made of materials based on oxide ceramics.

According to the applied methodological approach, when changing the technological parameters, the radiation power density and the total number of pulses in the processing spot were changed. Table 1 shows the results of optimizing the power density. The optimal radiation power densities (W) for processing Al_2O_3-TiO_2-12%(MoS_2-Ni) compositions obtained by agglomeration of a fine charge followed by high-temperature sintering are in the range of (4.0 -6.5) x 105 W / cm2, and for Al_2O_3-TiO_2-12% (MoS_2-Ni) obtained by the SHS method are in the range of (3.5 -6.0) x 105 W/cm2. This is confirmed by the dynamics of increasing the degree of melting of the treated compositions and changes in porosity, the desired reduction of which (according to the optimization criterion) does not occur at W greater than 6.0 and 6.5 x 105 W/cm2. The decrease in the efficiency of heat transfer can be explained by the significant content of the refractory oxide phase in the obtained coatings (more than 80%), which accordingly prevents an increase in the degree of melting and compaction of the coatings. With a further increase in W, undesirable thermal destruction of the surfaces of the processed materials is observed. In addition to the power density of pulsed radiation, the total number of laser beam pulses in the treatment spot was optimized for the formation of completely fused coatings over the entire thickness (0.5 – 0.6 mm). Metallographic analysis of non-etched grinds revealed that the required number of pulses for coatings obtained from Al_2O_3-TiO_2-12%(MoS_2-Ni) powders obtained by the SHS method is 4-5 impacts, and for coatings made from Al_2O_3-TiO_2-12%(MoS_2-Ni) powders obtained by agglomeration of fine charge followed by high-temperature sintering-3-4. Additional pulses do not give an additional effect, since their repeated repetition only worsens the geometry of the resulting coating surface due to thermal destruction. This complicates the final mechanical processing of the formed materials, since the allowance increases, which should be minimal due to the significant cost of the coating materials used and the problematic nature of their processing due to hardness and wear resistance. The total number of laser radiation pulses according to the results obtained is significantly less in comparison with the pulses of the compression plasma jet (11-14) when exposed to the same coatings. This can be explained by the duration of the impacts, which is 4ms and 400 microseconds, respectively.

Table 1. – Results of power density optimization studies

Coating	**The power density of the laser beam pulse, x 10^5 W / sm^2**	**The porosity index on the sections of the treated coating, %**
Al_2O_3-TiO_2-12%(MoS_2-Ni) (SHS)	3,5	3,3 – 4,1
	4,5	3,0 – 3,7
	5,5	2,8 – 3,4
	6,0	2,5 - 3,0
	6,5	2,7 – 3,2
Al_2O_3-TiO_2-12%(MoS_2-Ni) (agglomerations)	4,0	4,0 – 4,7
	5,0	3,4 – 3,8
	6,0	3,2 – 3,6
	6,5	3,1 – 3,4
	7,0	3,3 – 3,5

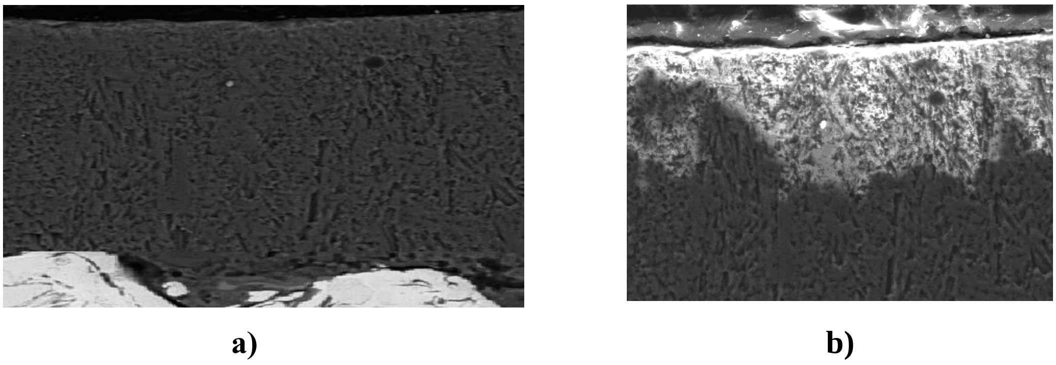
Table 2. – Optimized technological parameters of pulsed laser processing

Coating	**Modes of coating treatment with a pulsed laser beam**	
	The power density of the laser beam pulse, x 10^5 W / sm^2	**The porosity index on the sections of the treated coating, %**
Al_2O_3-TiO_2-12%(MoS_2-Ni) (SHS)	5,5-6,0	4-5
Al_2O_3-TiO_2-12%(MoS_2-Ni) (agglom.)	6,0-6,5	3-4

With a significantly longer duration of exposure, the zone of concentration of the supplied energy and the thickness of the layer increases when treated with a single pulse of laser radiation, while the total number of impacts for melting coatings over the entire thickness decreases. The results of research on the optimization of technological parameters are presented in Table 2 (the diameter of the treatment spot is 8.0 mm).

3. Study of coatings with a modified structure obtained using optimized laser radiation pulse processing modes

Figure 1 shows the microstructure of coatings formed under optimized processing modes. As in the case of the technology of compression plasma effects, the layers of the obtained coatings are fused metal-ceramic material. During the melting process, the chemical interaction is activated at the boundaries of the main phases of the formed compositions. The resulting products during chemical interaction can be finely dispersed formations that significantly strengthen the boundaries of the main phases and the entire coating as a whole. A fairly uniform distribution of structural elements is obtained. This helps to increase the wear resistance of the obtained compositions. The geometry of the surface of the obtained coatings in comparison with the sprayed material (without subsequent laser treatment) is characterized by a decrease in the height of the micro-dimensions. Due to the optimization of the technological characteristics of laser radiation, there are no "craters" of thermal destruction of the formed surface. As with compression plasma effects, the etching of its elements becomes more complicated. A significant increase in the number of non-etched areas indicates the presence of hardened amorphous structures in the coatings with high corrosion resistance, which are difficult to dissolve in acid etchants. In accordance with the method, when studying the properties of the obtained coatings, their average microhardness (H) was estimated. The change in the parameter H for various compositions is illustrated in Figure 2. Compared with compression plasma treatment, there is a noticeable decrease in microhardness, this is explained by a decrease in the degree of locality of melting of the material from exposure to a laser radiation pulse. The melt cooling rate is also reduced due to the heat removal into the sample substrate. The degree of grinding of its grain structure and the value of the parameter H , the number of amorphous phases of the coating are reduced. The results obtained indicate that, along with compression plasma treatment, the laser technology under consideration allows improving the properties of coatings made of Al_2O_3-TiO_2-12%(MoS_2-Ni) powders obtained by the SHS method and the method of agglomeration of fine charge with subsequent high-temperature sintering.



a) **b)**

Figure 1. The microstructure of the Al_2O_3-TiO_2-12%(MoS_2-Ni) (x 500) coating after treatment with laser radiation pulses: a-the SHS method; b - the method of agglomeration of a fine charge followed by high-temperature sintering.

4. Conclusion.

1. The technological parameters of high-energy processing of sprayed plasma coatings made of materials based on oxide ceramics with the use of additives of refractory metals obtained by self-propagating high-temperature synthesis and agglomeration of a fine charge with subsequent high-temperature sintering are investigated and optimized. The optimization was carried out in the study of the processes of structure formation during melting, compaction and high-speed cooling of coatings. The main optimization criterion was the maximum degree of local melting, compaction of the formed compositions in the absence of signs of destruction from the effects of laser radiation pulses. The impact energy was generated using a solid-state quasi-stationary laser emitter.

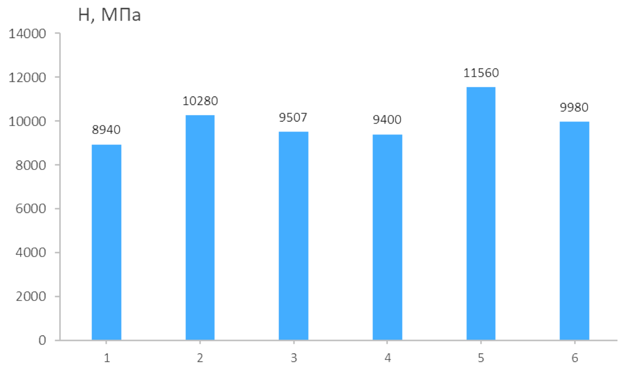


Figure 2. Microhardness of Al_2O_3-TiO_2-12%(MoS_2-Ni) coatings (1, 2, 3 - agglomeration; 4, 5, 6 - SHS): 1, 4-after plasma spraying; 2, 5-after compression plasma treatment of sprayed materials; 3, 6-after treatment with a pulsed laser beam.

2. Based on the metallographic analysis of non-etched grinds, it was revealed that the required number of laser radiation pulses for coatings made of Al_2O_3-TiO_2-12%(MoS_2-Ni) powders obtained by agglomeration of a fine charge followed by high-temperature sintering is 3-4, and for coatings made of Al_2O_3-TiO_2-12%(MoS_2-Ni) powders obtained by the SHS method is 4 - 5 effects. The optimal radiation power densities (W) for processing Al_2O_3-TiO_2-12%(MoS_2-Ni) compositions obtained by agglomeration of a fine charge followed by high-temperature sintering are in the range of (4.0 -6.5) x 105 W/cm2, and for Al_2O_3-TiO_2-12% (MoS_2-Ni) obtained by the SHS method are in the range of (3.5 -6.0) x 105 W/cm2. The total number of laser radiation pulses is significantly less in comparison with the pulses of the compression plasma jet (11-14) when exposed to the same coatings. This is explained by the duration of the impacts, which is 4ms and 400 microseconds, respectively. With a longer duration, the total number of impacts for melting coatings over the entire thickness decreases.

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