Wear Resistance Structural Aspects of Materials after Laser Processing

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Abstract. The conducted experiments show that the structures generated by laser processing are able to dissipate friction energy effectively with transformations at different structure levels. Thus, it becomes possible to manage surface strength and wear resistance of materials using the concept of “structural adaptability” of friction pairs that expands the range of normal friction and wear processes. The irradiated steel wear resistance is defined by its original hardness as well as its ability to deformation strengthening during friction. The temperature and strength load of irradiated steel surface layers through friction destabilize austenite towards $\gamma \rightarrow \alpha$ transformation. This results from alloy carbide formation which causes depleted austenite by carbon, and contributing to its transformation into martensitic deformation. It’s necessary to regulate the amount and degree of remaining austenite stability in laser-hardened steel and alloys, applied to specific load conditions, that provides that required operation features.

1. Introduction
The tribo-technical material durability is provided when the excessive internal energy accumulated during temperature and strength load manages to dissipate before reaching the critical level which causes the surface damage.

The resilient energy dissipation through loading of laser irradiated surface layers is realized in following ways: by structure dispersing; by appearance and movement of dislocations; by formation of deformation martensite; by turn of structural elements, and others [1–8].

Some ways of increasing metal properties range have been used in laser processing [9–12]:

- increase of dispersion of structure at local plastic deformation as a result of dynamic polygonization in austenitic, formation of microdomain (fragments) with high density of dislocations inherited at accelerated cooling as well as in the result of phase riveting in polymorphic transformation.
- nanoprecipitations use (formation of nanoscale precipitations) affected by plastic deformation during thermal stress.
- martensite deformation forming in the irradiated zones during external thermal and strength load in the friction process.

It should be taken into consideration that martensite transformation is a deformation hardening mechanism due to increasing amount of martensite, on the one hand, and microstress relaxation and use of martensite transformation as an extra plastic deformation mechanism, on the other hand. These two factors operate simultaneously, but they are competing.

In case the first factor is dominating, high strength is provided along with satisfactory flexibility. If the second one is dominating, the flexibility increases considerably with sufficient strength.
In the case of optimal balance of both processes, martensite transformation during loading provides the best mechanical properties range.

A heterogeneous structure is optimal for friction pairs, when the reconstruction of one structure into another, stable at a higher level, takes place through changing external thermodynamic parameters (temperature, pressure, component concentration), i.e. the phenomenon of structural-energy adaptability is realized. Formed structures after adaption dispense the most effectively the energy introduced into a tribo system, and minimize the wear of friction pairs. This structure variant is achieved through martensite optimal amount in laser processing zones in two-phase austenitic-martensitic areas of a hardened layer. At the same time, technological and structural plasticity is provided, which results from the transformation of part of austenite into martensite at loading.

There are following possible ways of choosing heat-hardening modes of the surface layers of steel to provide a given resistance of products. First of all, the alloy should experience structural transformations during friction, which ensure an increase in the density of dislocations on the working surfaces of products. Or, the selected material after surface heat treatment should retain the initial density of dislocations at external loading, that is, have a stable indifferent structure. This option is achieved in the case of obtaining martensitic structure mainly in laser treatment zones, with a little amount (less than 20%) of metastable austenite transforming into martensite through loading.

To obtain the considered variants of structural condition in the surface layers of products, laser processing was used at various radiation modes. Structures with the greatest possible stability in relation to external influence, or with the possibility of optimal restructuring and additional hardening in operation by forming secondary structures were created.

2. Research methods
Materials for research were samples of alloyed steel P6M5.

Metal tests were carried out using optical and scanning probe microscopes. The identification of the phase compounds in the laser treatment zones was carried out by the method of X-ray diffraction analysis. The study was carried out on diffractometer “DRON-0,5” in the filtered FeKα- radiation with registration of the intensity by scintillators.

Pulsed laser surface processing was carried out using technological equipment “Kvant-16” with a change of the radiation power density in the range of 80-150 MW/m².

3. Results and discussion
To confirm the considerations above on the structural aspects of the wear resistance of materials after laser treatment it’s necessary to results of experimental researches of wear resistance of alloyed steel P6M5 in dry friction conditions, as per the “disc- block” schedule on the friction machine.

Samples of steel P6M5 were made in the form of rings with a diameter of 30 mm and a width of 10 mm and were subjected to volumetric standard heat treatment. As counterbody was used samples of the liners of the bearing steel in the form of pads (HB 130-180). The cleanliness of the contact surfaces was estimated at Rz=0.63 μm. The tests were carried out at a load of 500 N and a linear slip speed of 190 m/min., with an average contact area of 100 mm². The wear was estimated by weight loss in analytical scales to 0,0001 g. Some rings were irradiated at Kvant-16 with a power density of 100 MW / m². As a result of laser hardening, a metal layer of 80-100 μm depth with an average hardness of 10.5-12 HPa was formed on the surface of the rings.

The test results, shown in Figure 1, reveal a clear advantage in the wear resistance of the laser-irradiated layers compared to standard thermal treatment. In particular, during the test period, the weight losses of irradiated rings are 13 times lower than the basic variant.

Examining the surface of the rings after the tests shows that the volumetric-hardened rings have a damaged surface of contact with the grip and drift areas of the metal. On the contrary, the rings subjected to laser treatment had a fairly clean surface after the tests. The features of structural and phase transformations in laser-hardened surface layers during friction should be considered, which lead to increased wear resistance of the material.
Figure 1. Wear curves of P6M5 steel samples after heating with 1220°C and 3 times leave (1), laser processing (2).

Figure 2, curve 1, shows that with laser hardening of alloyed steels, tetragonal martensite and some residual austenite are formed in the structure of surface layers. A different number of martensite and austenite in laser-hardened zones was reached changing radiation modes in the work, and a connection between the development of phase transformations and the properties of steels is established.

The study found that for maximum hardening (10-11.5 HPa) processing must be carried out with a radiation density of 80-100 MW / m², which ensures that a certain number of insoluble original carbides are stored in the volume of irradiated areas (30% in the case of laser hardening of tool steels). It is also important that during laser hardening the density of defects in the crystal structure of α-, γ-phases is achieved, exceeding the same for volumetric heat treatment by 10 times.

Further dissolving of carbides, by increasing the energy parameters of laser radiation and the initial stages of melting the surface, is accompanied by reducing the volume of areas with high carbon concentration and alloying elements, due to higher efficiency of diffusion processes and increasing the amount of residual austenite, which results in some reduction in the hardness of the processed metal.
Radiation specific conditions. Austenite wear measured the diffractogram load underwent deformation, which laser hardening and structural adaptability is applicable to metal-working tool on the wiping faces of which high contact stress and temperatures are developing.

Laser processing also increases the stability of the high-temperature γ-phase to martensitic transformation, thereby contributing to its partial or sufficiently complete preservation in the quenched state [13–19]. The ability of the metastable γ-phase of laser hardening to turn into martensite deformation, with the releasing of disperse carbides under the influence of external stresses and deformations, causes the hardening of the irradiated metal, as the martensite of deformation is an untempered martensite, and in its wear resistance it is not inferior to the tetragonal martensite of cooling containing the same amount of carbon. Figure 2, curves 2, 3, shows that the thermal strength load of irradiated metal leads to almost complete disappearance of the austenite reflections on x-ray diffractogram due to the flow of γ→α transformation in friction conditions.

Figure 3 shows the microstructure of irradiated steel P6M5 after friction tests and a histogram of the distribution of surface profile heights along the reference line marked in Figure 3, a, crossing the measured dispersed separated carbides. Attention has to be drawn to the disperse carbide phase separation, oriented by slip lines in the hardened layer zones after friction tests (see Figure 3, a). The consequence is texture formation of disperse precipitation of 2-10 nm (Figure 3, b). The positive result of texture formation effect in the surface layers of irradiated steels is a reduction in the friction coefficient on the wiping faces of products in operation.

![Figure 3. The structure of laser-hardened steel P6M5 after friction tests: a – optical microscopy (×500); b – profile altitude distribution histogram.](image)

It is necessary to note peculiarities of two-phase steels behavior at different types of wear. Particularly, in abrasive wear, heterogene structures have less wear resistance than completely martensitic ones. It can be explained by the intensive wear of the soft structural component. In the conditions of adhesion wear and lubricated friction, two-phase structures are characterized by high wear resistance. In this case, the martensite areas play a part of a strong frame, and the wearable austenite areas form micro-cavities on the working surface, that retain lubrication and improve friction conditions.

It can be concluded that the amount of residual austenite must be regulated depending on the specific load conditions during operation, and its stability in laser hardening structures by changing the radiation modes. This allows to control the mechanical properties of steel and to obtain a high level of those that are most important in the specific conditions of operation.

It’s important to pay peculiar attention to the role of strengthening phases in the wear resistance of laser-irradiated metal [20–21]. Inclusions, shots, are one of the factors that can increase their wear...
resistance. Due to the appearance of external stresses in the laser processing zones, dislocations are able to avoid the carbide particles by cross slip, leaving prismatic dislocation loops behind the particles. Thus, during external load, the shots are the localizers of deformation. Relaxation processes of the translatory-rotational type take place next to them and have a wave-like properties.

Therefore, from the point of view of thermodynamics, far from balance, “strengthening phase – matrix” system behavior in external load is determined by self-regulating processes of dissipative structures that control excessive energy outflow. Inclusions in steel can be considered as a set of relaxation material, which is activated when certain critical stresses are reached upon it.

The increased wear resistance of steel after laser hardening is determined by formation of austenite, quite unusual in properties, along with very hard metastable martensite. Its high original hardness and heat resistance, combined with the ability to turn into martensite of deformation, create conditions for reliable resistance to plastic deformation of metal; reduce the possibility of coalescence and micro-fracture of the surface under friction.

4. Conclusion

1. The structures obtained during laser processing are able to dissipate effectively the energy supplied by friction with transformations at various structural levels. Thus, it becomes possible to control consciously the surface strength and wear resistance of materials, using the concept of “structural adaptability” of friction pairs that extend the range of normal friction and wear processes.

2. The wear resistance of irradiated steels is determined both by their original hardness and by the ability to mechanical hardening during friction.

3. The thermal-strength load of surface irradiated layers of steel at friction destabilizes austenite to γ→α transformation. It results from the process of alloyed carbide formation, causing the austenite carbon depletion and contributing to its transformation into martensite of deformation.

4. For specific loading conditions, it’s necessary to control the quantity and stability of residual austenite in laser-hardened steels and alloys which ensures obtaining required operational properties.

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