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FORMATION OF A WEAR-RESISTANT STRUCTURE ON THE NITRIDED SURFACE OF AGRICULTURAL MACHINERY PARTS MADE OF 51CRV4 STEEL AFTER LASER TREATMENT

***Marchenko D.D.**, PhD (Engineering), Associate Professor*
***Lymar O.O.**, PhD (Physics and Mathematics), Associate Professor*
Mykolaiv National Agrarian University, Mykolaiv, Ukraine

Problem statement. The operating efficiency of the machine and tractor fleet of the agro-industrial complex (AIC) is largely determined by the durability of parts operating under conditions of abrasive wear, alternating loads and corrosive environments. Failures of wearing parts account for more than half of all failures of agricultural machines [1], and domestically produced working tools have a service life 1.2–2 times shorter than imported analogues [2]. The most critical are the parts of the cylinder-piston group of tractor and combine harvester diesel engines, for which the permissible wear of the working surfaces is tenths of a millimeters, as well as spring working tools of tillage machines (cultivator tines, harrow teeth) made of chromium-vanadium spring steels of the 51CrV4 type (EN 10089, 1.8159; equivalent to AISI/SAE 6150). Therefore, an urgent scientific and practical task is to develop combined surface hardening technologies that ensure the formation of wear-resistant structures without reducing the toughness of the part core [3].

Analysis of recent research and publications. The experience of European, Japanese and American manufacturers confirms that laser hardening and thermal spraying are effective methods for increasing the service life of engine parts [4]. Laser treatment provides heating of the metal at a rate of about 10^6 K/s in a small heating zone, which results in high cooling rates. During laser exposure, the following stages are distinguished: absorption of the light flux and energy transfer to

the crystal lattice, heating without melting, destruction of structural components, ejection of destruction products and cooling; diffusion and chemical processes and phase transformations occur simultaneously [4, 5]. Melting is not observed at a radiation flux density below 10^5 W/cm^2, whereas at a density above 10^6 W/cm^2 destruction of the surface layer occurs [5]. A promising approach is duplex treatment – a combination of nitriding with subsequent laser melting, which makes it possible to mix the brittle nitride layer with the substrate and to increase the crack resistance of the surface [6]. The contribution of Ukrainian scientists is associated with the study of the effect of pulsed laser treatment on the structure formation of the surface layer of iron-carbon alloys [7]. Mykolaiv National Agrarian University has developed technologies of surface alloying [8], restorative electric arc coatings [9] and complex laser alloying with niobium and nitrogen [10]. Thus, despite a significant number of studies, the problem of structure formation in the nitrided layer of 51CrV4 spring steel during pulsed laser melting remains relevant.

The aim of the study is to establish the regularities of formation of the structure and microhardness of the nitrided surface of 51CrV4 steel after pulsed laser treatment with micro-melting in order to increase the wear resistance of agricultural machinery parts.

Research results. Laser treatment of nitrided samples was carried out with a pulsed solid-state Nd:YAG laser (TRUMPF TruPulse, Germany). The adjustable parameters are the pump energy E_{pump} and the distance l between the lens focus and the sample surface, while the main energy characteristic of the process is the radiation power density

$$q_s = \frac{4E_p}{\pi {d_s}^2 \tau} \quad (1)$$

where E_p is the pulse energy, J; d_s is the diameter of the irradiation spot, cm; τ is the pulse duration, s.

To establish the relationship between the controlled parameters and the power density, the dependences $E_\text{p}(E_\text{pump})$ and $d_\text{s}(l)$ were investigated. The pulse energy was measured with an Ophir (Israel) thermal energy sensor.

Laser treatment leads to the formation of a complex microrelief with depressions and microcracks on the surface of 51CrV4 steel due to local melting and accelerated solidification of the metal. Under the microscope, the laser-affected areas appear white, in contrast to the base metal with a ferrite-carbide structure. The microhardness was measured using the Vickers method (load 0.49 N) along a line passing through the centre of the elliptical spot, with two additional indentations in the porous inclusion (Fig. 1, Table 1).

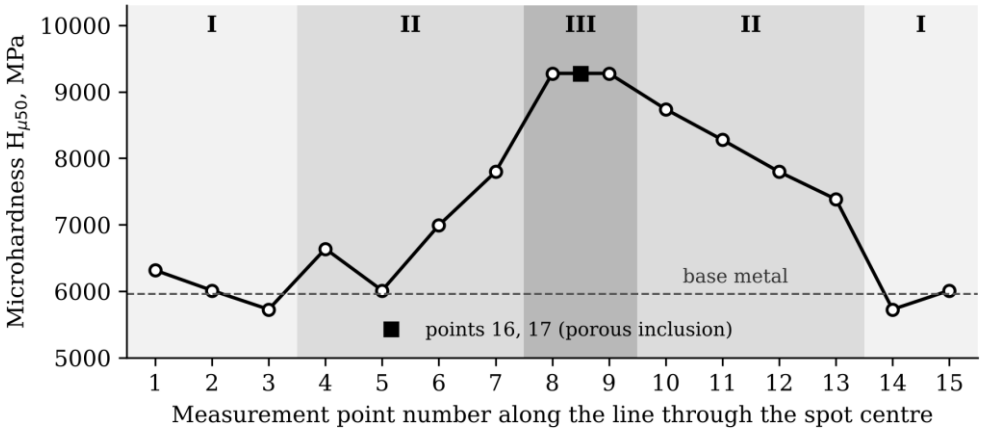


Figure 1 – Microhardness distribution on the surface of nitrided 51CrV4 steel after laser treatment: I – zone outside the intense laser action; II – adjacent zone; III – crater

The microhardness at the points of zone I is 1.47–1.62 times lower than in the center of the crater. In zone III, the maximum microhardness of 9277 MPa is achieved, which corresponds to hardenite, a type of martensite formed under non-equilibrium conditions at ultra-high heating rates

followed by accelerated cooling of the crystallized volumes [5, 7]. The hardenite layer is non-uniform in thickness (from 3…5 to 30…40 μm); individual rounded white inclusions 2…5 to 10…15 μm in size are observed in the cross section. Electron microscopy showed that the martensite crystals have a high dislocation density, a poorly pronounced plate-lath structure and microtwins on the (112) plane, which accounts for the "non-etchability" of hardenite in standard etchants.

Table 1 – Structure and microhardness of the laser-affected zones

Zone	Points	Structure	$H_{\mu 50}$, MPa	K_H
I	1–3, 14, 15	nitrided layer with metastable carbonitrides and nitrides	5727–6316	1.00
II	4–7, 10–13	α-phase (ferrite) with dispersed carbonitrides $Me_7(C,N)_3$	6012–8738	up to 1.47
III	8, 9, 16, 17	hardenite (structureless martensite)	9277	1.56

Note: K_H is the ratio of the microhardness to the average microhardness of zone I (5959 MPa).

The increased microhardness of zone II is due to the formation of a ferrite matrix with finely dispersed inclusions of the carbonitride $Me_7(C,N)_3$ with a complex orthorhombic lattice, in which some carbon sites are occupied by nitrogen atoms. The X-ray diffraction pattern revealed 13 lines of isomorphic phases of the $(Fe,Cr)_7C_3$, Mn_7C_3, Cr_7C_3 type. The strengthening effect was estimated from the ratio of the microhardness of Cr_7C_3 carbide to that of cementite [11]:

$$K_c = \frac{H_\mu(Cr_7C_3)}{H_\mu(Fe_3C)} = \frac{16 \cdot 10^8}{11 \cdot 10^8} \approx 1.45 \quad (2)$$

Hence, the dispersed carbonitrides are 1.45 times harder than cementite, which explains the high microhardness of the zone adjacent to the crater. The proposed treatment can be used to strengthen compression rings of tractor and combine harvester diesel engines, as well as spring working tools of tillage machines.

Conclusions. It has been established that pulsed laser treatment with micro-melting of nitrided 51CrV4 steel ensures the formation of hardenite with a microhardness of 9277 MPa in the center of the laser-affected zone, which is 1.56 times higher than the microhardness of the nitrided layer outside this zone. A zone of ferrite with dispersed $Me_7(C,N)_3$ carbonitrides with a microhardness of up to 8738 MPa directly adjoins the crater; the hardness of these carbonitrides is 1.45 times higher than that of cementite. The thickness of the hardened layer is 3…40 μm. The obtained results confirm the feasibility of duplex treatment "nitriding + laser melting" for increasing the wear resistance of agricultural machinery parts.

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FUNCTIONAL ALLOCATION OF SHARED AND DEDICATED EQUIPMENT IN MODULAR BANANA PROCESSING

***Mayak O.A.**, Cand. Sc. (Eng.), Associate Professor*
***Lavreniuk V.V.**, Bachelor's degree student*
State Biotechnological University, Kharkiv, Ukraine

Problem statement. Small processing plants may need to manufacture several products without maintaining a separate set of preparation machines for each one. Washing, sorting and peeling are obvious candidates for shared use, but this decision is less straightforward than it first appears. Equipment capacity, cleaning requirements and the time needed to switch products can offset the benefit of avoiding duplicate machines. The practical question is which operations can be combined without disrupting production or compromising food safety.

Analysis of recent research. Work on reconfigurable manufacturing has established approaches to changing production capacity and functions [1, 2]. Applying these ideas to food processing requires particular care because the raw material deteriorates, processing conditions vary and hygiene requirements are strict. Studies of green banana starch [3] and constituents recovered from banana peel [4] illustrate the range of operations that one fruit may require. The present work therefore focuses on equipment selection and allocation, rather than treating modularity as a new manufacturing principle.

Aim of the study. The study aims to distinguish operations suitable for common use from those that require dedicated equipment, and to set out the technical conditions for this division in a proposed banana-processing plant.

Research approach and results. Bananas provide a useful case because their pulp changes markedly during ripening, while the peel forms a sizeable secondary stream. Literature estimates place the peel at roughly 30-40% of fresh fruit mass [5]. Thus, a plant receiving one tonne of fruit might separate approximately 300-400 kg of peel. This is an indicative mass range, not a measured balance for a designed facility. Any further use of this stream would depend on its condition and the safety requirements of the intended product.

Functional layout. Two processing routes were considered. Suitable unripe pulp can be sliced, dried, milled and sieved to produce flour. Suitable ripe pulp can be reduced in size, homogenized and stabilized to produce puree. These are established processes, and the routes do not have to operate at the same time. Their initial operations-inspection, washing, sorting and peeling-could be served by a common preparation section. Subsequent operations differ in both purpose and operating conditions: dry milling and drying are needed for flour, whereas puree production requires wet processing and appropriate stabilization. These stages should therefore be