Conceptual model of zonal structuring of functional areas of working elements for soil treatment

V A Motorin¹², D S Gapich¹, S D Fomin¹², V S Bocharnikov¹ and A V Gribenchenko¹

¹Volgograd State Agrarian University, 26, University Avenue, Volgograd, 400002, Russia
²All-Russian research institute of irrigated agriculture, Timiryazev Street, 9, Volgograd, 400002, Russia

E-mail: fsd_58@mail.ru

Abstract. The working elements of machines for the treatment of soils should have high rates of wear resistance and resistance to shock loads. Moreover, different parts of the working bodies have different functional purposes, and, therefore, should have different mechanical characteristics. Based on this, a conceptual model of rational structuring of functional zones of working bodies for soil treatment is proposed, providing radically different parts of the mechanical characteristics.

1. Introduction
The main details that determine the technical resource of the entire tillage unit, are their working elements. Depending on the type of soil treatment, they can be made in various versions (Figure 1), starting from the excavator bucket teeth and ending with the working elements of the tillage agricultural machines, which have a fairly complex geometric shape depending on the functional purpose. The generalizing feature of such working elements is the working conditions: variable bending loads, both in magnitude and in direction; shock loads; work in the conditions of abrasive wear.

These working conditions define the basic requirements for strength, impact and wear-resistant properties of materials for the manufacture of working elements. The criterion assessments of the latter are different: for example, the most wear-resistant materials include metal alloys, the microstructures of which correspond to the “Sharpey” principle, according to which solid inverse inclusions should be evenly distributed in a viscous solid matrix structure [1]: strength and plasticity are determined by the concentration distribution, the shape of graphite inclusions in the total volume, and the microstructure of the alloy [2, 3]. It should also be borne in mind that the various zones of the working elements have different functional purposes, due to the process being performed. Therefore, the question of local structuring of the working areas of the elements, in order to give them optimum mechanical properties, is relevant. The aim of this work is to develop a conceptual model of zonal structuring of functional zones of working elements for soil treatment.
2. Materials and methods
In the designs of any working elements of tillage implements, one can distinguish the presence of three functional zones: 1 – the working zone of the bow, its main task is to destroy the soil and introduce the elements of the working machine into its layers; 2 – the transitional zone is a part of the working elements of the soil processing process to be performed, as a rule, its geometric shape determines the quality and energy indicators of the process; 3 – zone of attachment of the working elements to the controlled link. A schematic distribution of functional zones on the example of a chisel plow bit is shown in Figure 2.

![Figure 1](image)

Figure 1. Working elements for the development of soils. (a) ECG-5A excavator bucket tooth; (b), (c) chisel plow chisel.

![Figure 2](image)

Figure 2. Conceptual model of the zonal structuring of the functional zones of a chisel plow bit (top view).

Depending on the functional purpose, the working elements of zones perceive different external loads: zone 1 perceives frontal shock loads caused by the process of soil destruction, and is actively undergoing the process of abrasive wear; zone 2 is loaded with dynamic bending moments; Zone 3 is a rigid seal that is affected by coupling reactions.

Analysis of the existing casting techniques for manufacturing working elements [4-7] showed that high-strength cast iron is widely used as the main material for the development of heavy soils. As a result of metallographic analysis of experimental samples, it was found that, due to the complex geometric shape of the working elements, a heterogeneous structure is formed during the crystallization process: ferrite-perlite in the transition zone, pearlite with cementite in the attachment zone and the working zone. Such structuring of the working elements zones significantly limits its technical resource: intense abrasive wear and chipping of the cutting edge occur (Figure 3).

3. Results
A more detailed analysis of the loads acting on the corresponding functional zones of the working elements [8] allowed proposing the concept of their rational structuring, ensuring an increase in technical resource.
The working area of the nose, actively undergoing abrasive wear should have a hardness of at least 400-450 HB. The depth of the working area, depending on the type of soil treatment can vary from 70 to 100 mm. The transition zone must have a hardness of 220-260 HB, such hardness will provide the necessary impact resistance of the working element. In the area of attachment of the working element, the hardness of the part should not exceed 140 HB [9-25]. Figure 4 shows the distribution of hardness in the functional zones of the chisel plow bit produced by the intermittently-cyclic quenching technology developed by us.

Such values of hardness of functional areas should be provided by appropriate structuring: in the working area there should be a bainite or tempered martensite, in the transitional zone a ferritic or ferritic-pearlite structure, in the attachment zone a pearlite structure (Figure 5).

4. Discussion

In the conditions of mass production of working elements, obtaining rational structuring significantly increases the price of the final product. Since the technology of manufacturing parts is introduced, additional multi-stage heat treatment, including:

— graphitizing annealing of structurally free eutectic cementite;
— normalization to eliminate ferrite and obtain a pearlite structure;

Figure 3. Premature wear (a) and cleavage of the working area (b) of the chisel-plow chisel (operating time 5 ha).

Figure 4. Scheme of the distribution of hardness in the zones of the working element.
— hardening of the working area with high tempering;
— local annealing of the attachment zone to the ferritic-pearlitic structure of the metal base.

![Microstructure images](image)

**Figure 5.** Microstructure of the metal base of the experimental chisel plow bit manufactured by cyclic quenching technology: (a) bainite in the working area, HDTV (×800); (b) perlite in the transition zone, HDTV (×500); (c) ferrite and perlite in the attachment zone, HDTV (×100).

The authors propose a new integrated technology for heat treatment of castings of working elements of tillage machines. Since the value of the heating temperature for normalization is sufficient for carrying out both quenching and annealing, it is proposed to combine all technological operations in one volumetric heating of the part.

For this purpose, the casting of the working elements is placed by the fastening zone in the holes of the steel pallets. The results of experimental studies have shown that after heating the casting pallet, the heat accumulated by the steel pallet is sufficient to carry out annealing on the ferrite-pearlitic structure of the attachment zone and protect it from overcooling during subsequent manipulations with intensive cooling of the remaining working parts.

Further combination of annealing, normalization and quenching operations, carried out for other zones of the working element, in a while, allows removing heat from the working element through the hardened zone, which accelerates cooling in the normalizing zone, but does not affect the annealing of the attachment zone.

Thus, the conditions of the technical assignment for the formation of ferrite in the attachment zone and perlite in the transition zone of the working element are realized in one heat treatment operation.

The results of cyclic quenching on experimental samples of chisel plow bits are presented in Table 1.

Analysis of the data shows that the results of hardening depend on the heating temperature, the number of cycles, the duration of exposure to water and self-heating in each cycle.

After the volumetric heating to 930 °C in the air for 15–35 sec, during the cooling of the part, only the working zone was cooled most actively, the hardness of the part in the hardened part was equalized at the required level (modes 5 and 6).

The decrease in the temperature of volumetric heating to 880 °C (with natural pressing for 10 seconds, necessary for transferring the part from the furnace to the hardening device) responded positively to the uniformity and hardness level of the hardened part (mode 11).
From the analysis of the results of the experiment, it follows that the most uniform hardness within 425 ± 25HB is achieved in modes with a large number of cooling cycles (at least 5) with short periods of immersion in water (about 1-2 sec) and short exposures at air (2-3 sec) (mode 11).

Table 1. Heat treatment modes, microstructure and hardness of hardened working zone of the bit.

| Mode Number | The temperature of kiln heating, °C | Booster time before hardening, sec | Cooling mode of the working part of the bit | Cooling time in water / air, sec |
|-------------|------------------------------------|-----------------------------------|---------------------------------------------|----------------------------------|
|             |                                    |                                   | The number of cycles | 1st cycle | 2nd cycle | 3rd cycle | 4th cycle | 5th cycle |
| 1           | 900                                 | -                                 | 2                           | 2/4       | 4/60      |           |           |           |
| 2           | 930                                 | -                                 | 2                           | 4/4       | 5/600     |           |           |           |
| 3           | 930                                 | -                                 | 3                           | 2/2       | 2/2       | 5/600     |           |           |
| 4           | 930                                 | 15                                | 3                           | 2/2       | 2/3       | 8/420     |           |           |
| 5           | 930                                 | 35                                | 3                           | 1/1       | 3/4       | 8/500     |           |           |
| 6           | 930                                 | 500                               | 1                           | 1/3       | 8/15      | 15/300    |           |           |
| 7           | 930                                 | 500                               | 1                           | 2         | 9/400     |           |           |           |
| 8           | 930                                 | 15                                | 5                           | 1/1       | 1/1       | 1/1       | 1/5       | 150/0     |
| 9           | 930                                 | 15                                | 5                           | ½         | 2/4       | 4/6       | 90/0      |           |
| 10          | 930                                 | 15                                | 3                           | 1/10      | 6/15      | 40/560    |           |           |
| 11          | 880                                 | -                                 | 5                           | 1/2       | 1/2       | 1/2       | 1/10      | 120/0     |

The cooling time in water and exposure to air can be increased, but not in the first cycle, in such modes the number of cycles can be reduced without compromising the quality of hardening (option 5, table 1).

5. Concluding remarks

1. A conceptual model for the rational structuring of functional zones of the working elements of tillage tools was proposed. As a criterion indicator in the preparation of the model, the technical resource of the part was selected.

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2. Proposed and experimentally confirmed the possibility of the formation of a given structure and properties of the functional zones of the working elements, made of high-strength cast iron, with one volumetric heating of the workpieces.

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