УДК

WEAR FEATURES OF BAINITIC CAST IRON USED IN AGRICULTURAL MACHINERY

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The problem. Design of material science principles of structure formation in ductile bainitic cast iron for realization of mechanisms that raise durability of products for agricultural purposes is extremely urgent problem.

It is known that high durability and high resistance to fatigue is associated with the occurrence of so-called TRIP-effect when there is a phase transformation of retained austenite to martensite under the strain.

A similar effect is known as so-called TRIP steels [1-3], which are widely used in the automotive industry. In this case the phase transformation leads to a sharp increasing of strength and value of uniform elongation. The temperature of working environment can cause the presence of phase transformations. The working conditions and chemical composition of working environment have an intense impact for the durability of material.

The new technology of obtaining articles with bainitic cast iron containing for agricultural machinery has been developed in the Institute for Problems of Material Science (IPMS).

The purpose. The aim of this work is to create material science principles of determining of maximum operating conditions and to develop technological principles of obtaining of working articles made from bainitic cast iron for soil agricultural machinery of different constructive types.

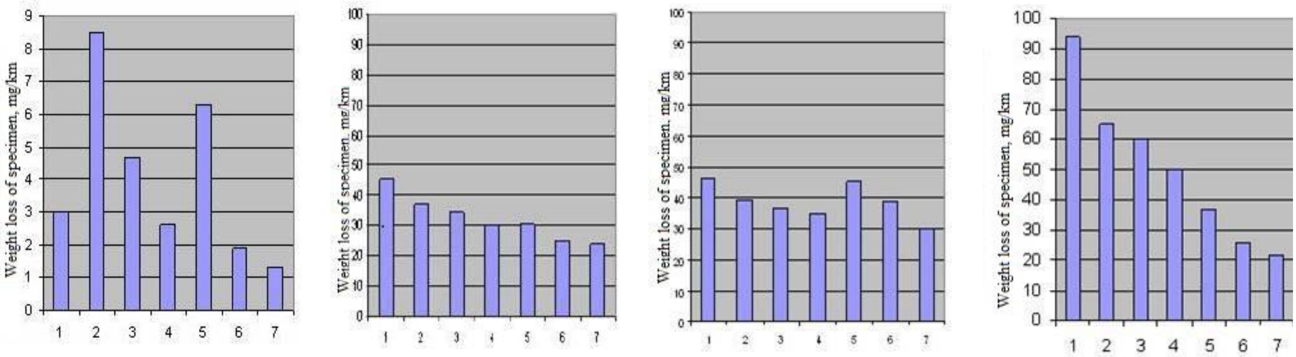
Materials and methodology. For the manufacture of plowshares and cultivators claws it is used the cast iron of following composition: 3,2 – 3,4 % C, 1,4-1,6 % Si, 0,2 – 0,3 % Mn, 0,01 – 0,02 % Cr, 0,18 % Mo, 0,3 % Cu, 0,4 % Ni, 0,02 % P, S < 0,02 % and modifiers: 7,5 % Mg, 35 % СК25, 17 % Al, 9 % SiBa (20 % Ba), 17,5 % Fe, 12 % modifier-flux «Рефтокон» and bainitic 9% REM (ФС30РЗМ30).

For obtaining bainitic cast iron structure the material was subjected to isothermal quenching in the range of temperatures from 310 to 350 °C during 1, 2 and 3 hours of exposition.

Specimens for friction have the size 10×10×20 mm. The rotation of samples was at a speed of 3 m/sec, which corresponds to the speed of the tractor 10 km/h. Specific load amounted to 8 kg/cm^2, which corresponds to 200 kg load on a plowshare. Friction happened on the edges and faces. The total length of track friction is 5 km (± 50 m). Abrasive environment had been changing after each test. Durability was determined by the weight change to within 0,0005 grams. Modifiers composition significantly affects the wear resistance.

The Results of Wear Experiment. The series of experiments show that the best wear resistances have specimens that had been subjected to isothermal quenching at 350 °C during 2 hours.

Data of the durability of materials for plowshares (fig. 1) allow to predict the dynamics of the wear process considering the formation of hardened layer. As plowshares works in different mediums with different temperatures, it was studied the impact on subsurface layers by various soils such as black soil, clay soil, wet and dry ravine sand.



Black soil | Clay soil | Wet ravine sand | Dry ravine sand

1 – heating temperature 890 ^{o} C, 30 min. Quenching in oil with tempering 320 ^{o} C, 3 hours exposition; 2 – heating temperature 890 ^{o} C, 30 min. Isothermal quenching in temperature 310 ^{o} C, 1 hour exposition; 3– the same, but 2 hour exposition; 4 – the same, but 3 hour exposition; 5 – heating temperature 890 ^{o} C, 30 min. Isothermal quenching in temperature 350 ^{o} C, 1 hou bmn r exposition; 6 – the same, but 2 hour exposition; 7 – the same, but 3 hour exposition

Figure 1. Results of tribotechnical test of bainitic cast iron specimens friction in different media

Comparison of the results shows the significant benefits of the products from bainitic cast iron. The best durability in all cases shown samples after isothermal quenching with 3 hours exposition.

According to wear resistance theory of bainitic cast iron the physical reason of such phenomenon is phase transformation of residual austenite into martensite.

Phenomenological wear resistance theory offers a semi-empirical relationship between the wear parameters and mechanical properties: hardness, fracture toughness, and Young's modulus as the Evans' formula (1981) [ ]:
V – volume reduction in friction, P – stress, K_{1c} – fracture toughness, H – hardness, E – modulus of elasticity, s – friction path length.

The results of standard mechanical tests show that in these conditions both structural characteristics differ not more than 10%, whereas the wear characteristics - more than twice. Therefore, it became necessary to investigate the physical reasons that are responsible for a sharp increase in the wear resistance of cast iron, heat-treated under the mode of the isothermal quenching at 350 ° C with 2-3 hours of exposure.

$$V=P^{1/1,25} K_{1c}^{-0/5} H^{-0/625} (E/H)^{0,8} s \ ,$$

High wear resistance of bainitic cast iron can be explained by phase transformation of residual austenite into martensite. For this purpose, it was conducted the series of experiments:

- The hardening of the subsurface layer;
- Defects formation in subsurface layers.

In the study of the friction mechanism of bainitic cast iron it should been taken into account the specific of structure formation during deformation that is not typical for others classes of materials. First of all, in the area of localized shear there is almost instantaneous rearrangement of residual austenite to cementite with a sharp hardening gradient of the material of the subsurface zone (hardness increases as we approach the surface). Moreover, there is a typical ability for such structures to withstand inhomogeneous strain (deformability) due to the preventing of some cracks formation and deceleration of destruction process in general.

The presence of hardened subsurface layer is confirmed by researching hardness change from the depth of penetration. The hardness is determined by the formula bellow:

$$H_v = H_{v1} - (H_{v1} - H_{v2})\frac{l - l_0}{l}$$

H_{v1} – the hardness of the subsurface layer, H_{v2} – the hardness of the matrix, l_0 – layer depth, l – the depth of penetration.

The values of hardness and depth of penetration at different indentation force of bainite cast iron quenched at 350 ° C is showed in table 1.

Table 1

The values of hardness and depth of penetration at different indentation force of bainitic cast iron quenched at 350 ° C

Stress, g	10	20	50	100	200
Hardness, GPa	8,7	8,5	8,0	6,5	5,5
Depth, μkm	0,7	0,9	1,67	2,8	3,8

The data in the table 1 indicate that the subsurface strain layer has a size about 2 μkm. Its hardness coincides with the hardness obtained at penetration load of 20 grams. It is 8,5 GPa, which is almost twice higher than the hardness of the matrix (5 GPa). Due to the gradient of deformation, the hardness decreases rapidly with the depth and during the loading force of 200 grams at the depth of 4 μkm, it is close to the hardness of the matrix.

The process of defects formation in the subsurface layer in structure of specimen is difficult to discover by direct studies because of the high locality of the studied phenomena. That is why to confirm the suggested hypothesis it was used a technique widely used in the analysis of TRIP-steels. A similar physical effect is the process of formation in the plastic zone at the tip of a moving crack due to the strain gradient. To do this, with the help of a scanning microscope it has been studied the plastic zone near the crack on bainitic iron specimens pots subjected to different isothermal hardening and tested to fracture.

According to the reported data, it is noticeable that for specimens subjected to isothermal hardening at 310 ^{o}C there is big amount of microcracks in the processing zone. Specimens hardened at 350 ^{o}C, destruction is localized in a narrow zone along the crack tip.

The analysis of the destruction surface shows that specimen subjected to the first mode is breaking only by ductile mechanism. On the fracture of the second specimen there are clearly visible areas of cleavage. This may indicate the formation of brittle phases during deformation – martensite, which causes the destruction by the cleavage mechanism. Despite the differences in destruction mechanisms, energy consumption for crack propagation (which can be estimated by the value of fracture toughness) is comparable. Apparently, less energy consumption in the destruction of cleavage mechanism is offset by the addition of energy to the phase change.

The results of X-Ray experiment. Research results of X-Ray experiment of bainitic cast iron, hardened at temperatures of 350 C showed that the amount of residual austenite in it reaches to 35% and decreases slightly with increasing exposure time (fig.2).

Data obtained by X-Ray method from the specimen that was subjected to heat-treatment described above; the partial decomposition of residual austenite takes place in this instance and is about 25 %. It can be explained by a well-known TRIP effect. Obviously the same effect can be realized in the surface layer of material subjected to friction.

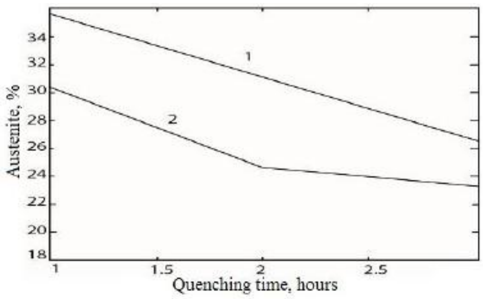


Figure 2. The changing of the amount of residual austenite according to an exposure time in an isothermal quenching: 1 – 350 °C, initial state; 2 – 350 °C, after deformation

CONCLUSIONS

Data on the wear resistance of the materials for the plowshares allow to predict the dynamics of the wear process, taking into account the formation of hardened layer. It was used the specimen with the square 1 cm^2, which is hardened at 350 ° C, excerpted 3 hours at the wet sand in the gully loses 22 mg per 1 km. Taking into account the specific weight of iron ~ 6.8 g / cm^3, it was determined that its size when wearing on the plane is reduced by 30 mm for 1 km, and a hardened 2 μkm layer will be worn out after 60 m of working. Considering the speed of movement of modern agricultural machinery, this distance can be overcome in 5 seconds. Since the martensitic transformation occurs at the sliding mechanism with a speed close to the speed of sound, during that time instead of the worn-out layer it is formed a new layer with high wear resistance.

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