About the use of 110G13L steel as a material for the excavator bucket teeth.

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Abstract. The causes of failure of the bucket teeth of the excavator during excavations in rocks are analyzed in the article. It is shown that the most typical cause of failure of bucket teeth is wear of teeth. The wear with soft rocks (less than 1100 HV) which hardness is lower than the hardness of steel in the cold-work hardened state, a preliminary cold-work hardening can essentially (up to 10 times) increase the material wear resistance. The wear with rocks, having greater hardness with hardness of ~1250 HV, the cold-work hardening do not lead to increase of the Hadfield steel wear resistance.

1. Introduction

Currently, a considerable part of operational expenses for extraction and processing of minerals is formed by expenses for replacement and repair of fast-wearing elements of machines and equipment [1-3]. The most frequently used material of these elements is austenitic high-manganese casting steel 110G13L (0.9–1.4 C, 11.5–15.0 Mn, 0.5–1.0 Si, % wt.), known by the name of its inventor as Hadfield steel. This steel was invented in 1888 and was widely used at the beginning of the twentieth century as a material of prison gratings ("Swedish blinds"). The grating was formed by a two-layer bar, the center of which was filled with 110G13L steel that was impossible to saw due to the increase in its hardness during the cutting process to the hardness of a hacksaw and above. Such behavior of 110G13L steel is explained by the increased hardening ability of its manganese austenite at cutting with the increase of hardness from 200 to 700 HV, which is usually associated with occurrence of numerous defects in the crystal lattice of austenite or transformation of austenite into martensite. Due to complexity of the cutting process, almost all products made of this steel are produced only by casting without further machining.

Unique combination of high impact resistance and strength makes austenitic steel the basic structural material for manufacture of elements of the railway, construction and mining industries, such as excavator bucket teeth, road-building machinery tracks, hammers, lining, reflective plates of crushers and mills, etc. [4-6]. Currently, the interest of scientists from all over the world in austenitic steels does not diminish. In addition to study of Hadfield steel on wear resistance, a large number of studies aimed at regulating the properties of these steels by changing their chemical composition, heat treatment, machining, and application of special coatings is carried out [7-15].

At the same time, the practice shows that a number of specified elements made of 110G13L steel, such as excavator bucket teeth, clearly lack for wear resistance under the operating conditions. When mining granite, the set of EKG-5 excavator teeth gets worn out and requires replacement after mining of 20 thousand m³ of rock, which makes only 1.5 – 2 days of continuous operation. Operational
capacity of teeth (3 – 5 days) with copper-nickel rock does not exceed this value much [13]. The given data call into question the positive influence of the increased cold-work hardening ability of 110G13L steel on the wear resistance of the excavator bucket teeth and the expediency of their production from this steel. In particular, the author of the work [16] adheres to a similar point of view and does not see the advantages of Hadfield steel in the manufacture of teeth compared to heat-treated St. 6 steel. The studies conducted in the works [17-20] showed that the wear rate of austenitic steels is greatly influenced by the wear mechanism (micro-cutting, cracking, peeling, flaking, material transfer, etc.). Thus, the process of micro-cutting is observed at initial stages of interaction between abrasive and steel and then, as the material is hardened as a result of cutting and impact of particles, the wear intensity decreases and the mechanism turns into peeling [17].

2. Observation results
To explain the low wear resistance of the specified teeth, the results of observations obtained by the authors of this article can be useful for the analysis of appearance and hardness of different parts of excavator EKG-5 teeth made of 110G13L steel before and after their work on the granite, since this rock features the hardest rock-forming mineral - microhardness of quartz (~ 10,000 MPa) significantly exceeds the hardness of steel, including the hardness obtained after cold-work hardening.

The inspection results showed that the kinds of the upper and the lower teeth surfaces after work are different. The surface of the upper part of the teeth is smooth and shiny with some rare scratches (Figure 1, a), while the lower part is dark and rough, all covered with deep scratches, parallel to the tooth movement direction (Figure 1, b). These kinds of surfaces are typical for wear caused by impact (a) and under conditions of friction and sliding along the abrasive (b).

![Figure 1](image-url) View of the upper (a) and lower (b) surfaces of the tooth.

Application of the teeth at quarrying shows that only the lower surface of the teeth is subject to rapid wear, while the upper one does not wear out at a noticeable rate. For this reason, in order to increase the service life of the teeth, they are repositioned from time to time and rotated by 1800, so that the upper and the lower parts of the teeth replace each other.

Measurements made with the use of portable hardness measuring instrument TKM - 459 showed that the hardness of steel on the working surface of both the upper and the lower parts of the tooth has a value of ~ 50-55 HRC (HB 4810 - 5600 MPa), which significantly exceeds the hardness of the tooth material before the operation (~ 33-38 HRC (HB 3110 - 3530 MPa)). (A little different data were obtained in [21] for the working conditions of teeth in the stone-ballast quarry: the hardness of steel at the top of the tooth reaches HB 4200 MPa during the operation process and decreases with distance from the top (80 mm) to the hardness of HB 2050 MPa). This fact may indicate the material of both sides of the tooth undergoes a significant cold-work hardening during the tooth operation: on the upper side of the tooth, as one can assume, - as a result of impacts of large pieces of granite as they are rolled in the bucket at loading and unloading, on the lower side - due to plastic deformation of metal when it is scratched by the rock. The latter assumption is based on results of the study [20] showing that
abrasive wear of 110G13L steel against quartz sand microhardness of the bottom and the sides of the scratch reaches 800 HV (HB 7220 MPa).

3. Results and Discussion

Analysis of the obtained results allows one to conclude that though both sides of a tooth are exposed to intensive cold-work hardening during the operation, its influences on wear resistance of the upper and the lower tooth surfaces are different: in the conditions of impact wear, which is observed on the upper side of a tooth, the cold-work hardening essentially slows down the steel destruction rate, while in case of abrasive wear, which is observed in the operating conditions of the lower tooth side, the cold-work hardening has almost no impact on 110G13L steel destruction rate. Thus, the fact that friction of the lower tooth surface over the rock is associated with considerable loads is another one issue explaining why wear resistance of Hadfield steel does not increase in case of abrasive wear.

This conclusion is confirmed by results of the authors [22], indicating that under the conditions of impact-abrasive wear (repeated impact of a steel core on the mass of crushed apatite-nephelinic ore) preliminary cold-work hardening of the wearing core surface made of Hadfield steel is an efficient way to increase its wear resistance [23]. At the same time, the positive effect of the cold-work hardening increases proportionally to the value of the hardness achieved (Figure 2 [22]).

![Figure 2](image.png)

Figure 2. Dependence of impact-abrasive wear rate on apatite-nephelinic ore of cold-work hardened samples made of 110G13L steel on their surface hardness.

At the same time, as shown in [24, 25], in the conditions of purely abrasive wear of Hadfield steel, cold-work hardening has unambiguous influence on its wear resistance. The wear with rather soft rocks (less than 1100 HV), for example, marble which hardness is lower than the hardness of steel in the cold-work hardened state, a preliminary cold-work hardening can essentially (up to 10 times) increase the material wear resistance. While the wear with rocks having greater hardness, for example, granite and gabbro with hardness of ~1250 HV, the cold-work hardening does not lead to increase of the Hadfield steel wear resistance. In the latter case, absence of influence of the cold-work hardening on abrasion resistance of steel is explained by the general law confirmed [26] by experiments on various metals and alloys: abrasive wear resistance of materials which were subject to various degree of cold-work hardening at plastic deformation remains almost invariable, despite increase in hardness. This law is explained by the fact that when scratched by abrasive particles in the process of wear, the metal gets cold-work hardening which is greater than preliminary cold-work hardening and is the utmost high for this material [28].

When elements made of Hadfield steel are rubbed upon rocks with the grain hardness lower than that of the steel, the metal breaks down not as a result of scratching it by grains, but as a result of fatigue caused by multiple elastic strain of its surface layer. Since the process of fatigue wear destruction starts with occurrence of a fatigue crack on the surface, the surface hardening by cold-
work hardening enables to reduce the crack formation rate and, accordingly, increase fatigue resistance of the material, which was observed in the experiments [25, 26]. Such conclusion is confirmed by the view of the steel surface after wear on hard and soft rocks (Figure 3).

![Figure 3. Wear surface of Hadfield steel sample after abrasion impact of granite and gabbro (a) and marble (b)](image)

It can be seen that in the case of hard rocks (Figure 3, a), the worn out surface is covered with scratches, the direction of which matches the sample rotation, while the wear upon soft rocks (Figure 3, b) covers the surface with oblong elevations and microcraters that are typical of plastic edging at fatigue wear.

4. Conclusion

Thus, it can be concluded that the use of Hadfield steel as a material for excavator bucket teeth is reasonable if the machine works with the rocks having components the microhardness of which is less than that of the steel in the cold-work hardened state. These are, for example, gypsum, marble, limestone, calc spar, anhydrite, fluor spar, apatite, nephrite, orthoclase feldspar, olivinite, chalcedony, feldspar, flint, etc. For such rocks, cold-work hardening of the steel, occurring during the teeth operation due to significant specific forces and impacts and as a result of preliminary hardening, e.g. by explosion [21, 29], will increase their wear resistance. When working with harder rocks, the abrasive impact of their pieces and particles will lead to intensive wear of the steel teeth, regardless of intensity of the cold-work hardening that occurs. Preliminary hardening of the teeth will not bring any positive effect. In this case, the use of Hadfield steel as a tooth material is hardly justified.

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