HARDENING OF STEEL Kh12F1 DURING ABRASIVE WEAR

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During pressing of refractory materials containing chamotte with a microhardness up to H 1300 in large presses developing pressures of 1000 kg/cm^2 the wear of the facing plates (steel Kh12F1) of the press molds is observed to vary with the heat treatment (Fig. 1).

The percentage of martensite is highest (80%) after quenching from 1050°C, resulting in the highest hardness (HRC 63). However, the wear resistance, determined from the reduction in the thickness of the press mold plates during pressing of refractory material, is not the highest in this case. As the quenching temperature is raised the ratio of martensite to retained austenite and the hardness of the steel decrease continuously, and the resistance to abrasive wear increases. On quenching from 1170°C the wear resistance is maximum, and three times that of the steel with the highest percentage of martensite and highest hardness (quenched from 1050°C).

An x-ray structural analysis of the working surface of plates with 80% retained austenite in the original structure, which was made in the URS-50IM apparatus, showed that the amount of martensite after a full working cycle increased from 20 to 40%. The transformation of such a quantity of austenite into martensite cannot be explained by the increase in the resistance of the steel to abrasive wear [1], since the wear resistance in this case is above that of the steel with 80% martensite. The increase in the abrasive wear resistance of the steel with a large amount of retained austenite points to internal changes in the austenite.

The microhardness (under a load of 50 g) of the retained austenite and martensite in the original structure is about H 300 and H 950 respectively. The microhardness of the working surface of the plates after wear reaches H 1230.

The interaction of abrasive particles with the working surface of the plates consists of two stages, which depend on the structure of the metal. Whatever the mechanism of abrasive wear (except for seizing), it begins with the abrasive particle pressing into the surface of the metal.

The resistance of the metal to the abrasive particle in this stage of wear is analogous to the resistance to the indentor in hardness tests, and is therefore of the same value. The pressing of the abrasive particle into the surface of the steel does not constitute wear in itself, but is of great importance in later damage.

During the impression of a groove or the removal of a microshaving from the surface of the metal by the abrasive particle the resistance of the steel depends on the plastic deformation of the metal, i.e., it capacity for generation and movement of dislocations.

Thus, the resistance to abrasive wear depends on the ability to resist the intrusion of the abrasive into the surface and the capacity for blocking dislocations during cutting of a microshaving or a groove as well as the bonding strength of the grains.

Steel Kh12F1 is not wear resistant after quenching from 1050°C, which can be explained by its good resistance to only the first stage of wear, i.e., the pressing of the abrasive particle into its surface. In the following stage of wear the low bonding strength of martensite [2], the large internal stresses, the substantial degree of incoherence at the martensite-retained austenite interface, and the presence of numerous microcracks in the martensite platelets and at their junctions as well as the austenite — martensite interface [3, 4] weaken the ability of the metal to resist the damaging effect of the abrasive particle.

It has been found that the coherence of the martensite-retained austenite boundary that is obligatory in the martensitic transformation can disappear after plastic deformation of one or both phases [5]. Since

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abrasive wear can be regarded as microplastic deformation of the structural component, the slight disruption of coherence at the interphase boundary by the abrasive is the source of crack nucleation. It was found in [6] that quenched steels have a low resistance to deformation. Distortion of the martensite crystal lattice can be summed up as deformation due to external loads leading to breaking of the interatomic bonds.

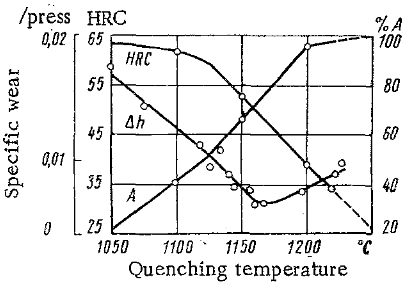

Fig. 1. Wear resistance of press mold plates of steel Kh12F1 in relation to structure.

As the result, the wear resistance of the steel with a martensitic structure does not attain the maximum value. The lower abrasive wear resistance of metals with a martensitic structure was also noted in [7].

Quenching the steel from a higher temperature (1170°C), resulting in a structure of retained austenite and carbides with a lower overall hardness (HRC 48), provides the highest wear resistance in an abrasive medium.

The continuing action of abrasive particles on the metal under high pressures increases the dislocation density in the austenite, which is indicated by the high hardness of the worn surfaces (H 1230). The creation of a stabilized structure with a high density of pinned dislocation pile ups during repeated deformation increases the static strength 150-200%, the plasticity remaining satisfactory [8]. Dislocations have a substantial influence on the metal under stress. Deformation of microvolumes by the abrasives pressing into the surface intensifies the activity of the dislocation sources. The dislocation density in the deformed metal can reach 10^{13} cm^{-2} [5]. Each dislocation is surrounded by a stress field, on the overall influence of which the strain hardening depends [10].

Under the influence of an abrasive, both positive and negative dislocations occur, moving in opposite directions at the same time. Positive dislocations moving along one plane interact with the stress fields of negative dislocations and migrate to a neighboring plane. To overcome the attraction of the dislocations requires an additional force to ensure their separate existence and movement in opposing directions. The increase of the load necessary to overcome the mutual attraction of the dislocations is manifest as strain hardening [11]. The degree of hardening increases with the dislocation density, increasing the resistance to the intrusion of the abrasive into the surface of the metal and the plastic deformation in cutting of a microvolume or a groove.

Of the four basic methods of hardening alloys recommended in [12], three can be considered for steel Kh12F1 quenched from 1170°C: 1) a general increase of dislocation density in retained austenite due to the influence of the abrasive; 2) mechanical inhibition of dislocation movements by the carbides in retained austenite; 3) pinning of the dislocations by solute atoms. During heating to the quenching temperature of 1170°C a large amount of chromium and vanadium passes into the solution. The chromium and vanadium atoms in the retained austenite concentrate at dislocations, pinning them. In the process of microplastic deformation during wear the stresses required for dislocation movements through the stress field around the foreign atom will increase, thus increasing the wear resistance of the steel.

These factors explain the maximum wear resistance of steel Kh12F1 after quenching from 1170°C when working in an abrasive medium. However, the mechanical blocking of dislocations by the second phase — carbides — is more substantial than the pinning due to solute atoms. With increasing quenching temperatures above 1170°C the carbides pass into solution. The number of chromium and vanadium atoms dissolved in the austenite increases at the same time and the degree of hardening due to pinning by the solute atoms increases proportionally.

The reduction of mechanical blocking due to the reduced amount of carbides is not compensated by the effect of the solute atoms. As the result, the general resistance to abrasive wear decreases by comparison with the maximum, corresponding to the optimal structure after quenching from 1170°C.

CONCLUSIONS

1. The maximum wear resistance of steel Kh12F1 is attained by quenching from 1170°C with about 70% retained austenite.

2. Hardening is due to the increased density of dislocations pinned by solute atoms of chromium and vanadium and mechanically blocked by carbides.

3. The relatively low wear resistance of steel Kh12F1 with a primarily martensitic structure after quenching from 1050°C is due to the low strength of interatomic bonds in martensite, the presence of cracks, and the disruption of coherence at the martensite-retained austenite interface.

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