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Influence of Cyclic Heating Mode on the Wear Resistance of Steel

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ABSTRACT: Studies were performed on cyclic heat treatment of steel samples at different temperature conditions to increase their abrasive wear resistance. It is established that cyclic heating of parts made of steel 65G to a temperature of 450 °C increases their wear resistance by 30 % compared to traditional induction hardening.

KEYWORDS: wear resistance, dislocation density, hardness, cyclic heating, induction hardening.

I. INTRODUCTION

In Uzbekistan, agricultural - machinery manufacturers are constantly increasing their output of cotton- harvesting machines. Abrasive wear results in components such as gears and gear shafts in such machines. As a result, metal is consumed in great quantities each year for the production of spare parts. With each year, manufacturing technology becomes more complex, and its effective use depends on adequate repair resources.

Gear performance is closely related to its working life. As a rule, gears are made of low-carbon steel (0.1-0.25% C) and are subjected to heat treatment: cementing, quenching, or low-level tempering. The treatment time is shorter for cementation in gas. Considerable power and gaseous hydrocarbon is consumed in that process.

In recent years, researchers have proposed various types of heat treatment for gears. One option is repeated heating and cooling above the phase-transition temperature, which is known as thermocycling. Such treatment decreases the grain size and removes the internal stress, with consequent increase in strength and ductility of the steel.

II. THE MAIN FINDINGS AND RESULTS

As a rule, the wear resistance of steel depends greatly on the hardness and the dislocation density within the material.

Further increase in the wear resistance of steel is possible by nonstandard heat treatment, such that favorable structure is created after the maximum hardness has already been attained. Cyclic quenching may significantly change the dislocation density within the material, according to the data in [1]. That increases the wear resistance and changes other mechanical properties.

Experiments show that, after three heat-treatment cycles, the microstructure of the steel changes: microscopic clusters and submicroscopic spheroids of cementite appear in the marten site matrix [2].
In the present work, we aim to increase the endurance of steels in abrasive wear by cyclic quenching with inductive heating (by means of high-frequency currents). In other words, we use repeated heating and cooling of the steel so as to form a new structure and improve the mechanical properties.

In the experiments, we use 65Г steel samples. Their chemical composition is presented in Table 1.

The test samples measure 20×20×7 mm. The control sample undergoes traditional inductive heating to 900 °C, cooling in oil, and tempering at 180 °C [3]. The other samples are heated to T = 450, 570, and 700 °C. The maximum number of cycles is seven. The temperature is selected on the basis of existing thermocycling programs. After heating, the sample is cooled in air, with a draft (the traditional industrial method). After heating to 950 °C for the last time, the sample is cooled in oil, with tempering at 180 °C. Torecord the structural changes, some of the samples do not undergo final quenching and tempering. A VChG2-100/066 inductive-heating system is employed.

Table 1. Chemical composition of 65Г steel in comparison with 18ХГТ steel

Steel	Content, wt %						
	C	Si	Mn	Cr	Ti	S	P
65Г	0.68	0.25	1.15	-	-	0.03	0.03
18ХГТ	0.31	0.29	1.00	0.98	0.1	0.02	0.02

A heating rate of 110-120°C/s is consistent with uniform heating. To assess the influence of the temperature and the time, a thermocouple is attached to the sample; it is connected to a high-speed potentiometer for temperature recording. For comparison with production data at joint-stock company Aggregate Plant, selected 18ХГТ steel samples undergo cementation in a shaft furnace, together with a set of gears. In cementing the gear teeth, the temperature T = 900 - 950°C and the holding time is 8-10 h.

In wear tests, we consider slipping friction at unquenched abrasive material on a PV-7 machine [4]. The abrasive is dusty quartz sand, which is supplied in portions by means of a dosing unit at the sample surface and a polyurethane worm feeder. The system and method for the abrasive wear tests are selected on the basis that the wear on the PV-7 test machine resembles the wear of the plowshare seal of a cotton-harvesting machine in the fields of Uzbekistan: the configuration of the material and the relative wear resistance are the same [5]. The wear resistance is determined by comparing the mass loss (wear Q) of the samples, weighed before and after the tests on VLA-200M analytical scales (precision 0.1 mg), each experiment is repeated five times.

The structure is investigated by metallographic and X-ray structural analysis. A MIM8-M microscope (magnification ×100-1000) is used for the metallographic analysis. The sections are etched with 3% HNO_3 solution in ethyl alcohol. The boundaries of the austenite grains in the quenched steel are etched in a saturated aqueous solution of picric acid, with added detergents [6].

A DR0N-2.0 diffraction system is used for X-ray structural analysis. The physical width β_{me} of the (220) X-ray line is used to assess the quality of the crystal lattice. The dislocation density is calculated from the physical broadening of the X-ray interference [7].

On cyclic heating of 65Г steel samples and subsequent cooling in air, the initial plate structure of the steel becomes more spheroidal. This is especially clear on heating the steel to 450, 570, and 700 °C (Table 2).

The lattice defects in 65Г steel after cyclic treatment at subcritical temperatures hardly depend on the temperature *T* and the number *N* of cycles. Only heating above the critical temperature (Ac_1) and subsequent cooling in air will produce less uniform structure, with high defect content.

Table 2. Change in properties of critical temperature on cyclic heating with subsequent air cooling

N cycles	Heating to 450 °C		Heating to 550 °C		Heating to 700 °C	
	HRC	β_{me}, 10^{-3} rad	*HRC*	β_{me}, 10^{-3} rad	*HRC*	β_{me}, 10^{-3} rad
1	269	9.87	241	9.1	229	9.88
2	269	9.87	241	9.1	229	9.88
3	269	9.87	241	9.1	229	9.88
4	269	9.87	241	9.1	229	9.88
5	269	9.87	241	9.1	229	9.88

For final inductive quenching and low-level tempering, the results are somewhat different. The same microstructure, grain size, and hardness (59-60 HRC) are observed after different heat treatment. Only the defect content is different. A positive effect is observed after 2-5 heating cycles to 450 °C (Fig. 1). At 550 and 700 °C, either lower defect content is observed, or the effect is unstable. This may be attributed to microplastic deformation as a result of the considerable temperature differences. The presence of a second phase also facilitates microplastic deformation on account of the difference in thermal expansion of the phases [8].

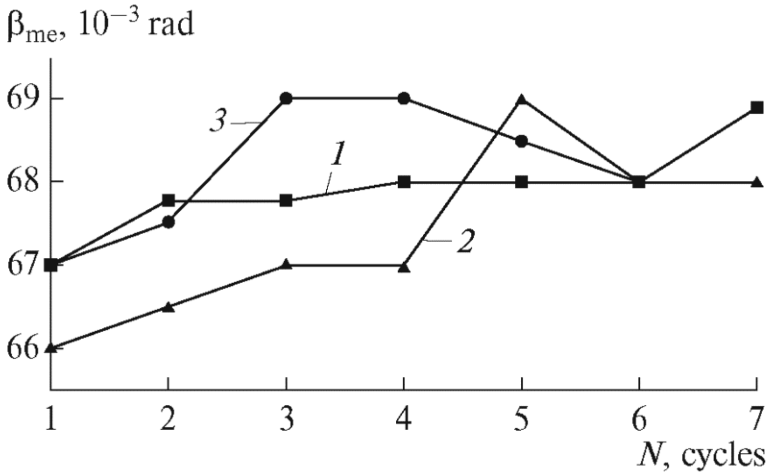

Fig. 1. Dependence of the physical width β_{me} of the (220) X-ray line on the number *N*of cycles at *T* = 450 (*1*), 570 (*2*), and 700°C (*3*).

Thus, dislocation structure develops, while high temperatures facilitate polygonization. No high defect content is observed. However, high thermal stability is noted. In repeated heating above the phase-transition temperature, polygonal structure gives rise to high dislocation density.

Cyclic treatment above 450°C leads to intense recrystallization; no polygonal structure is seen. However, inductive quenching after preliminary cyclic treatment at 450°C does not significantly increase the dislocation density in comparison with traditional inductive quenching. With the same hardness, the difference in the physical width of the X-ray line is $\beta_{me} = 5 \times 10^{-3}$ rad (Fig. 1).

The results of wear tests are consistent with microscopic and submicroscopic data for the samples. Abrasive wear tests with loose abrasive material also give consistent results (Fig. 2).

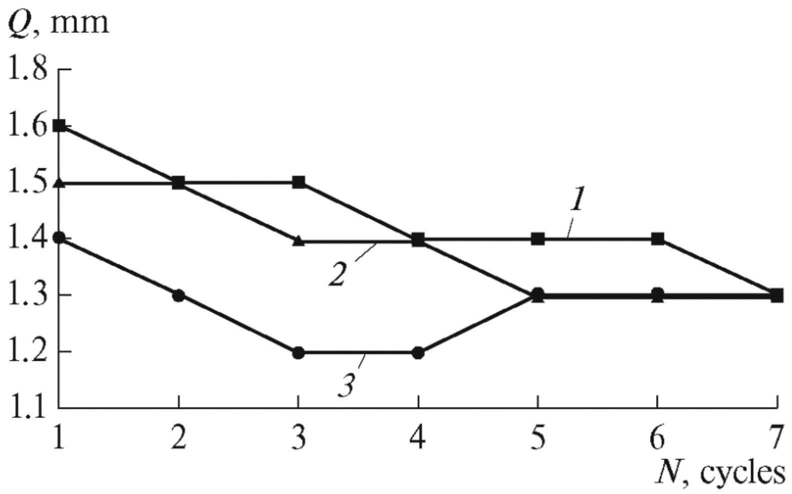

Fig. 2. Dependence of the abrasive wear *Q* of 65Г steel samples on the number *N* of cycles at *T* = 450 *(1)*, 570 (2), and 700 °C *(3)*.

The cyclic treatment of 65Г steel creates structure with a higher defect density. Preliminary cyclic heating to 450°C may be regarded as optimal.

Microstructural analysis shows that all the samples have martensitic structure. (Sections of lower bainiteare seen in the core of 18ХГТ steel.) With high density, small austenite grains are required to maintain the necessary viscosity. Such grains may be observed by etching (State Standard GOST 5639-65).

The 18ХГТ steel control sample contains austenite grains of mean diameter d_{me} = 0.02736 - 0.03315 mm.

We find by microanalysis and testing that the hardness and dislocation density are greatest for the 65Г steel samples after optimal cyclic quenching (Table 3).

Table 3. Properties of 65Г steel after heat treatment

Steel	Treatment	*HRC*	*Q*, mg	β_{me}, 10^{-3} rad
65Г	Inductive quenching	57-59	2.14	63.2
	Optimal inductive quenching	59-60	1.20	69.0
18ХГТ	Control	52-54	1.70	64.4

III. CONCLUSION

At present, further research on this topic is underway at joint-stock company Aggregate Plant and the mechanics faculty at I.Karimov Tashkent State Technical University.

Cyclic heat treatment of 65Г steel may create structure with high defect content. The optimal approach includes preliminary cycling with heating to 450°C.

Thus, optimal cyclic heat treatment of 65Г steel increases the abrasive- wear resistance by 30%. That is twice the increase in wear resistance of 18ХГТ steel samples after inductive heating to 900°C. As a result, we may expect significant savings of electric power and hydrocarbon gases.

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