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EFFECT OF HEAT TREATMENT ON MECHANICAL AND ACOUSTIC PROPERTIES OF STEEL 9KhS

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Results of a study of the influence of the structural state of steel 9KhS on mechanical characteristics and parameters of elastic waves are presented. It is shown that the speed of elastic waves correlates with the values of impact toughness and hardness. A method for rapid determination of impact toughness and hardness from the speed of elastic waves is suggested.

Key words: tool steel, heat treatment, structure, hardness, impact toughness, speed of elastic waves.

INTRODUCTION

Quality of a product is always an important task. The material of the product plays here a very important role. For example, the condition of the steel used for making cutting and measuring tools determines the operating capacity of the tool itself and of the product fabricated with the help of it. Tool steel 9KhS has found wide application due to its high technical parameters. The steel is suitable for the production of articles possessing a high strength, hardness, wear resistance, elasticity, impact toughness, and resistance to contact dynamic loads.

The required physical and mechanical characteristics are provided in steels by heat treatment, the most important parameter of which is the cooling rate [1 – 3].

Determination of the mechanical characteristics after various modes of heat treatment requires expensive tests of special specimens for the tensile strength and impact toughness; the specimens are fabricated by the same method as the article itself. An urgent task is fast obtainment of data on the strength and ductility characteristics, presence of defects, etc. for estimating the correspondence of articles to the performance specification [4 – 6]. It is known that the state of a material affects its magnetic and electrical properties. Specifically, the parameters of the elastic waves propagating in a controlled environment depend of the mechanical characteristics of the environment [7]. The modulus of elasticity and the speed of propagation of elastic waves (the longitudinal one and the shear one) are related through the following dependences:

$$E = \frac{\rho C_t^2 (3C_l^2 - 4C_t^2)}{C_l^2 - C_t^2}; \quad (1)$$

$$G = \rho C_t^2; \quad (2)$$

$$\nu = \frac{C_l^2 - 2C_t^2}{2C_l^2 - 3C_t^2}, \quad (3)$$

where E is the elastic modulus, G is the shear modulus, ν is the Poisson coefficient, and C_t and C_l are the speeds of the shear and longitudinal waves respectively.

It should be noted that evaluation of the mechanical characteristics by the acoustic method does not require fabrication of specimens, and control is performed on the article itself without disturbing its operating capacity and characteristics.

The aim of the present work was to demonstrate the possibility of determination of the impact toughness and elastic characteristics of steel 9KhS with the help of the results of measurement of the parameters of elastic waves.

METHODS OF STUDY

We studied steel 9KhS of the following chemical composition (in wt.%): 0.85 – 0.95 C, 0.95 – 1.25 Cr, 1.2 – 1.6 Si, 0.3 – 0.6 Mn, up to 0.4 Ni, up to 0.2 Mo, up to 0.2 W, up to 0.15 V, up to 0.03 Ti, up to 0.3 Cu, up to 0.03 S, up to 0.03 P.

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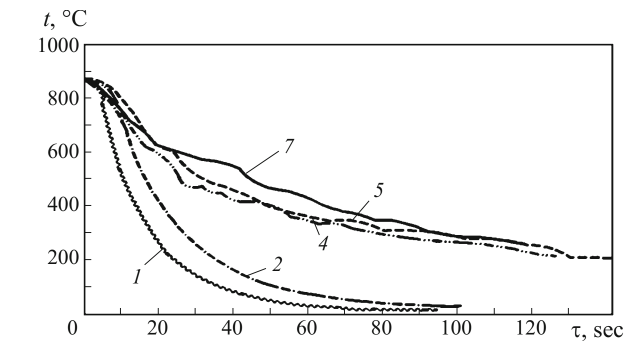

Fig. 1. Variation of the temperature of specimens of steel 9KhS during cooling in different environments from 850°C (the numbers of the modes of cooling are given at the curves, see Table 1): *1*) in water; *2*, *4*, *5*) in a 2%-, 6%- and 8%-aqueous solution of synthetic liquid respectively; *7*) in oil.

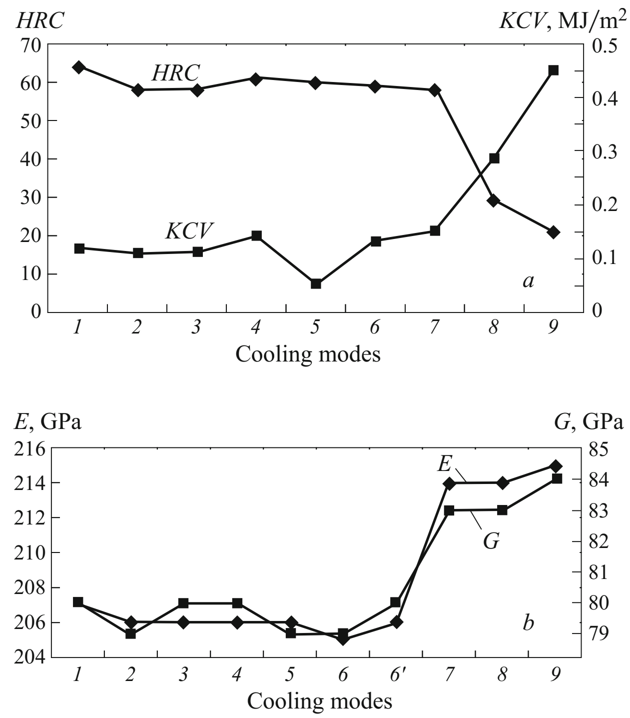

Fig. 2. Impact toughness and hardness (*a*) and modulus of elasticity *E* and shear modulus *G* (*b*) of steel 9KhS as a function of the mode of cooling from 850°C (mode *6′* involves cooling in 12%-solution of synthetic liquid).

We determined the properties of steel 9KhS after cooling from 850°C in different environments, i.e., water, oil and aqueous solutions of a synthetic liquid with concentration 2, 4, 6, 8, and 10%.

All the studies were performed on Charpy specimens using the following equipment and devices: SNOL 8.2/1100 muffle furnace, TK-2M hardness meter, and MK-30 pendulum impactor. The acoustic measurements were performed with the help of an “Astron” measuring and computing unit [4, 5]. We used a combined regime of reception and radiation of elastic waves (one sensor) in the experiments. To excite the shear waves we used a piezoelectric ceramic converter. The contact environment providing electromechanical connection between the converter and the controlled surface was a magnetic rheological liquid, i.e., iron powder (with particle size 1 – 10 μm) in mineral oil.

We measured the time of passage (delay) of longitudinal and shear waves at a frequency of 5 MHz. The accuracy of the measurement of the time parameters did not exceed 10^{-9} sec. The acoustic characteristics were evaluated for at least 10 points of one specimen. The data obtained were averaged, and the delay was determined for each type of the used elastic waves. The results of the measurements of the delay and of the thickness of the specimens were used to compute the speed of propagation of the elastic waves, i.e.,

$$C = 2h/t, \quad (4)$$

where C is the speed of the studied (longitudinal, shear) elastic wave (m/sec), h is the thickness of the specimen (mm), and t is the time of passage of the elastic wave through the specimen (nsec). Then we computed the moduli of elasticity of steel 9KhS by equations (1) – (3). The errors of the determination of the informative acoustic parameters and of the moduli of elasticity depended on the errors of the measured parameters, i.e., of the thickness of the controlled specimen $h = \pm 2 \times 10^{-3}$ mm and of the time of propagation of the elastic pulses of longitudinal and shear waves t_l and $t_t = \pm 2$ nsec. Then the error of measurement of the speed (4) of a shear wave C_t was ± 4 m/sec and that of the speed of a longitudinal wave C_l was ± 2 m/sec. Accordingly, the error of measurement, according to equations (1), (2), (3), of the shear modulus, of the elastic modulus, and of the Poisson coefficient was 1%.

The temperature on the surface of the specimens was controlled with the help of a chromel-alumel thermocouple. The microstructure of steel 9KhS was studied using a KEYENCE VHX-1000 microscope.

RESULTS

Variation of the temperature of specimens of steel 9KhS during cooling in different environments is presented in Fig. 1. It can be seen that the cooling rates virtually coincide in oil and in 8% aqueous solution of synthetic liquid. Close values of cooling rates are obtained in water and in 2% aqueous solution of synthetic liquid. This is confirmed by the virtually coinciding values of the controlled characteristics after cooling in these environments (Fig. 2*a*) and of the elasticity moduli computed by formulas (1) – (3) and presented in Fig. 2*b*.

The results of the evaluation of mechanical and physical characteristics of steel 9KhS after its cooling at various rates from 850°C are presented in Table 1.

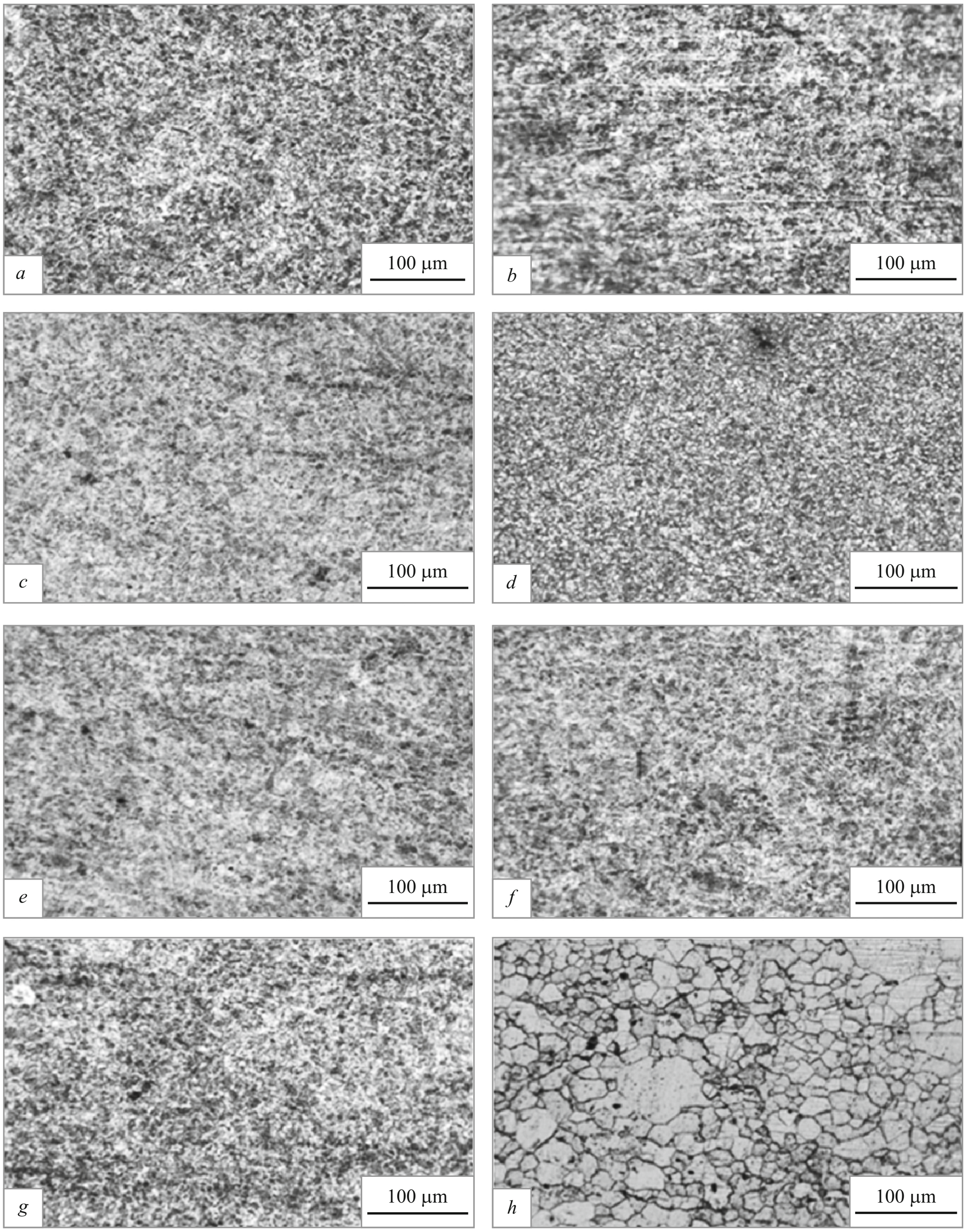

Fig. 3. Microstructure of steel 9KhS after cooling from 850°C in water (*a*), in oil (*b*), in 2%-, 4%-, 6%- and 8%-solution of synthetic liquid (*c*, *d*, *e*, *f*, *g*, respectively), and with the furnace (*h*).

Metallographic analysis of the specimens (Fig. 3) has shown that the microstructure of steel 9KhS changes from a martensitic one (water quenching) to a pearlitic one (cooling with the furnace) depending on the cooling rate.

Analyzing the data obtained we established that the hardness, the impact toughness and the speed of elastic waves in steel 9KhS heat treated for different structures (from martensitic to pearlitic ones) obeyed an almost linear correlation relation (Fig. 4). The approximation coefficient exceeded 0.9.

CONCLUSIONS

1. Heat treatment affects substantially the parameters of elastic waves in steel 9KhS. The speed of elastic waves is the lowest in the steel with a structure of quenched martensite and the highest in the steel with a structure of pearlite + ferrite.

2. The speed of ultrasound in metals and alloys is a structurally sensitive characteristic. The value of the speed of ul-

TABLE 1. Mechanical and Physical Characteristics of Steel 9KhS after Cooling in Various Environments

Cooling environment		*KCV*, MJ/m^2	*HRC*	C_t, m/sec	C_l, m/sec	*E*, GPa	*G*, GPa
Water	(*1*)	0.12	64	3202	5946	207	80
2% SL	(*2*)	0.11	58	3195	5915	206	79
4% SL	(*3*)	0.11	65	3191	5932	206	80
6% SL	(*4*)	0.14	61	3196	5912	206	80
8% SL	(*5*)	0.05	62	3196	5913	206	79
10% SL	(*6*)	0.13	59	3192	5922	205	79
Oil	(*7*)	0.15	58	3187	5889	206	80
Air	(*8*)	0.29	29	3264	5998	214	83
Furnace	(*9*)	0.45	21	3267	5976	214	83

Notations: SL) synthetic liquid; C_t) speed of shear wave; C_l) speed of longitudinal wave; *E*) elastic modulus; *G*) shear modulus.

Notes. 1. In all the cases the specimens were held for 30 min at 850°C before cooling.
2. The conventional numbers of the heat treatment modes are given in parentheses.

trasound in all heat treatment operations varies from 0 to 2% of the rated value determined by the relation $v \approx (E/\rho)^{1/2}$.

3. The speed of elastic waves may be used (at an appropriate calibration) for rapid analysis of the characteristics dependent on the structural state such as the hardness, the impact toughness, and the elastic moduli.

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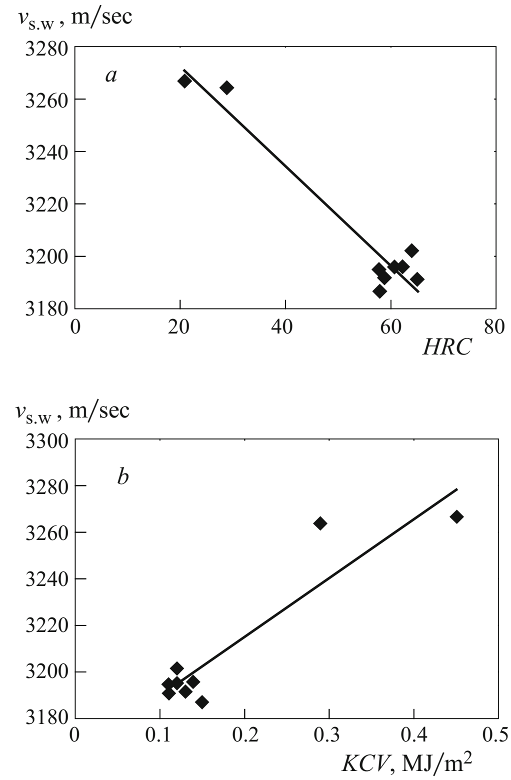

Fig. 4. Correlation dependence of the speed of shear wave $v_{s.w}$ on the hardness *HRC* (*a*) and impact toughness *KCV* (*b*) of steel 9KhS.

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