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High Temperature Internal Friction Related to Increased Wear Resistance of Hot Working Tool Steels

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Abstract
The paper presents the connection and mutual dependence between high temperature internal friction and service properties and the wear resistance of hot working tool steels in the temperature ranges of annealing and operation. It shows the role of the alloying elements and particularly that of nitrogen in the increased heat resistance of these steels related to the dislocation mobility and particularly that of their non conservative creep above certain critical temperature. A dependence is found out between the value of steel heat resistance and the temperature of internal friction high temperature background start of growth. It provides a possibility for preliminary assessment of the operational capabilities of the studied steel grades.

Keywords: internal friction, wear resistance, tool heat resistant steels

1. Introduction

The hot working tool steels are mainly used for manufacture of moulder tools operating at higher temperatures of the order of 650-700^{0}C. There is a large number of these steels possessing, in compliance with their alloying, various wear resistance, operating capability and correspondingly different price of the tool.
Up to now there is no standard criterion and unified methods providing possibility for fast assessment of material qualities which is of particular importance in the development of novel hot working grades. The purpose of the present paper is to demonstrate the resources of the internal friction method for empirical assessment of this type of steels by their relaxation spectra.

2. Material and methods

Seven standard hot working tool steels are examined which cover the main grades utilized for molder tools in practice, Table 1. With the numbers of the examined steels going up in the table (from 1 to 7) the quantity of the carbide formation ability of the alloying elements increases by this increasing the operation temperature they are used in [2, 3].
Practice has proved that additional nitrogen alloying of the hot working steels leads to higher strength and wear resistance compared to their corresponding "carbon" analogues [3,4]. That makes them particularly suitable for application in heavy duty conditions. Table 1 shows four nitrogen alloyed compositions of hot working steels developed in the Institute of Metal Science at the Bulgarian Academy of Sciences.
The temperature dependencies of the internal friction (20-650^{0}C), known in publications as dynamic relaxation spectra, are registered by fully computerized apparatuses for studying the internal friction of metals and alloys, type "reverse" pendulum, at operation frequency 1-3 Hz of the examined steels. The specimens of dimensions 0,8x1x50mm are studied after quenching from standard temperature [2, 3]. Steel X30CrMoV3.3.1 and its nitrogen alloyed analogue X30+17CrMoV3.3 after annealing are studied in addition.

Specimens of dimensions 30x30x30mm are treated under the same conditions of heat treatment for quenching and annealing. Their heat resistance is determined by non standard method and the values are given in Table 1. It is a conditional temperature after holding at which for four hours the preliminary heat treated specimens have hardness HRC=36.4 [2].

3. Experimental results and discussion

Fig. 1 presents the relaxation spectra of some of the examined carbon hot working steels after quenching from the standard for the respective steel temperature. They are characterized by several basic effects [4-6]:

- Snook-Koester maximum at temperature 200-220^{0}C;
- Internal friction low temperature background from room temperature to temperatures of 540-630^{0}C;
- high temperature background above these temperatures.

Table 1. Chemical composition and heat resistance of the examined steels

N	naming in accordance to DIN	C	N	Cr	Ni	Mo	W	V	heat resistance (ºC)	CHT (ºC)
1	X50CrNiMo1.1	0.52	-	0.73	1.65	0.22	-	-	560	530
2	X50CrNiMo2.1.1	0.49	-	2.00	1.45	0.92	-	0.53	590	540
3	X40CrMoV5.1	0.36	-	4.6	-	1,25	-	0.48	600	543
4	X30CrMoV3.3.1	0.30	-	2.80	-	2.93	-	0.52	650	575
5	X35CrWV2.8	0.37	-	2.42	-	-	8.2	0.33	660	590
6	X50CrWV1.2.1	0.49	-	1.13	-	-	2.23	-	670	602
7	X50CrWMo3.3.1	0.47	-	2.94	-	0.98	3.34	1.58	685	615
8	X50+12CrNiMo2.1.1	0.51	0.12	2.08	1.35	0.86	-	0.50	614	555
9	X40+17CrMoV5.1	0.42	0.17	5.31	-	1,27	-	0.48	634	565
10	X30+17CrMoV3.3.1	0.31	0.17	3.10	-	2.87	-	0.49	662	582
11	X50+15CrWMoV3.3.1	0.47	0.15	3.20	-	0.96	3.1	0.57	683	623

The value specified provides possibility to compare the heat resistance of different types of tool steels.

It is known that 200^{0}C internal friction maximum has a resonance nature [5, 6]. The height of this maximum depends on the foreign atoms concentration interacting with the dislocation lines in the solid solution and its temperature is proportional to the activation energy of this interaction. It is proved that substitution atoms in the solid solution considerably increase the maximum height and shift it towards higher temperatures [7, 8]. Our studies show that the role of the foreign atoms interaction with the dislocations in the martensite is of importance for the steel heat resistance only to the annealing temperatures of the order of 400^{0}C [8]. Therefore, that maximum does not concern the aims of the paper.

The low temperature part of the internal friction background [5] depends on the conservative dislocation motion /in a crystallographic plane/ and on all the relaxation processes in the solid solution. It turns out to be slightly dependent on the alloying and steel properties and therefore its values are negligibly distinguishable for steels with considerable differences in the properties. In this sense it is not indicative for the heat resistance of steel.

The high temperature background depends strongly on the temperature (Fig.1) and it is determined by the non conservative dislocation motion in the different crystallographic planes. We have shown that the low high temperature background values mean stable structure and high strength and temperature resistances [5]. To this effect, as characteristic temperature of dislocation structure stability we can accept the temperature of the start of the internal friction high temperature background growth. We can call it for simplicity “characteristic temperature” (CHT). This temperature can be determined either as a crossover point of the internal friction low temperature and high temperature background tangents or as temperature at one preliminary selected internal friction value close to the start of the high temperature background growth. The latter has been done in our case for internal friction value of 60.10^{-4}.

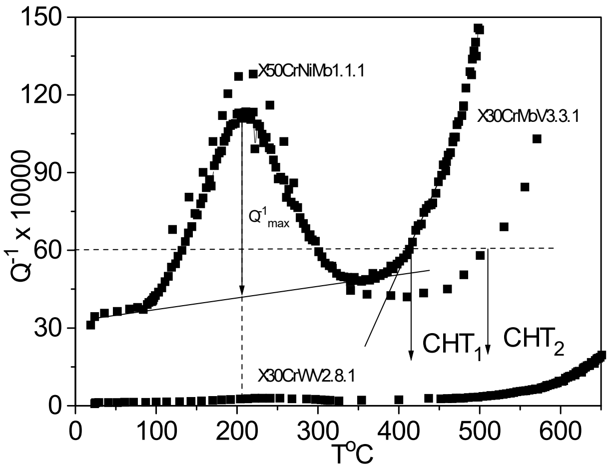

Fig.1. Relaxation spectra of some of the examined carbon hot working steels after quenching

Here we have to note that the physical interpretation of CHT determines the beginning of the massive, non conservative dislocation creep, i.e. the beginning of realization of the first irreversible microplastic acts in the metal matrix. This is also the start of the process of complete softening of the solid solution [9]. Therefore, it is directly connected with steel heat resistance. Fig. 2 presents the graphical dependence between a steel heat resistance and CT. It is seen that the dependence is close to linear and it is indicative for the possibility to determine the operational capabilities of steel by its relaxation spectrum in a purely empirical manner. More heat resistant is the steel whose high temperature background is shifted as a whole at higher temperatures. In the same way we can also check the rest life time of steel already been in operation and to assess to what extent it has retained its operational capability. Fig. 2 demonstrates as well the positive effect of the heat resistant steels nitrogen alloying.

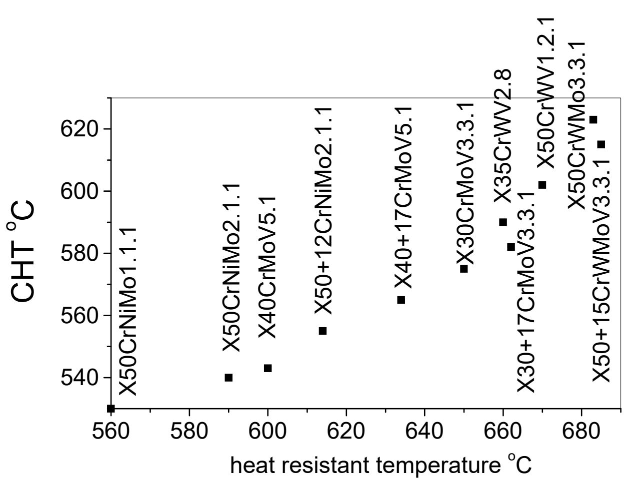

Fig.2. Dependence between a steel heat resistance and CT.

Fig. 3 shows the variation of CHT of the steel X30CrMoV3.3 and its analogue X30+17CrMoV3.3. It is seen that the additional nitrogen alloying of steel improves also its heat resistance in annealing, shifting CHT towards higher values. That is due to the presence of chemical elements in the steel which form more stable nitrides and carbonitrides difficult to coagulate. Grounds for this conclusion is also the fact verified by us, that the temperature dependencies of CHT follow exactly the run of the softening curves of these steels. The conclusions include as well the area of the secondary hardening at temperatures of the order of 5500C, Fig. 3, which is due to formation of disperse coherent carbides of the MeC type [8,9].

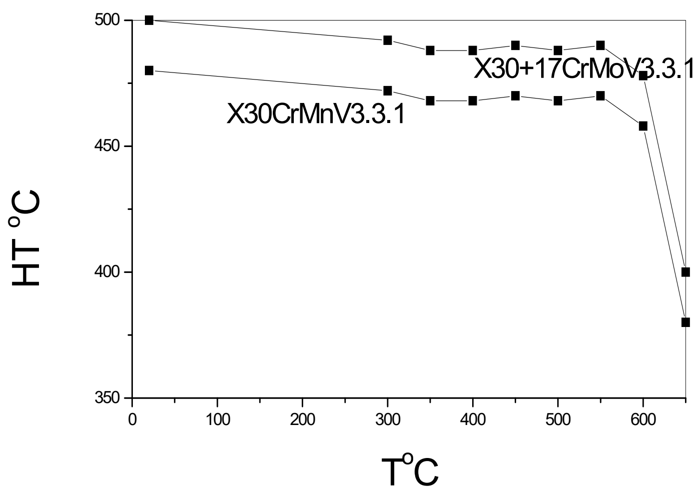

Fig. 3. Variation of CHT of the steel X30CrMoV3.3 and its analogue X30+17CrMoV3.3

At temperatures above 550^0C important part in the annealing processes starts to play the diffusion of the substitution atoms in martensite, namely chromium, molybdenum,

4. Conclusions

Our investigations have shown that there is a direct connection between steel heat resistance and the characteristic temperature of the start of internal friction high temperature background growth. The high temperature relaxation spectrum of an alloy can be a measure of its wear resistance. It is a sum indicator both of carbide reactions and coagulation processes run and of the behavior of its solid solution.

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