ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
ISSN: 1584 - 2665

ABOUT THE INFLUENCE OF HEAT TREATMENT OVER THE RESISTANCE AGAINST FRAGILE DESTRUCTION OF BH21 STEEL

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ABSTRACT:
The aim of the present work is to investigate the influence of the media of cooling for hardening over the resistance against fragile destruction of BH21 BS4659 (3Cr2B8F-GOST) steel. The critical crack opening and destruction stability - K_{Ic} at static strain δ_{Ic} is determined. The influence of the temperature of tempering has been considered for the three media of treatment – heating in a vacuum furnace for hardening and cooling with argon gas, heating in a salt bath for hardening and cooling in nitre bath, heating in a salt bath for hardening and cooling in oil. It is established that the chosen cooling media for cooling and heating for hardening of the steel significantly influence the resistance against fragile destruction expressed by the parameter δ_{Ic} and the toughness against destruction - K_{Ic}.
KEYWORDS:
Toughness against destruction - K_{Ic}., static strain δ_{Ic}

1. INTRODUCTION

Prints and press-forms are commonly used as tools for producing details in a hot state. They work in very hard conditions and therefore the requirements towards the material they are made of are basically the following: high heat resistance; high resistance against fragile destruction; high wear resistance of the working surfaces etc. Achieving these properties depends greatly on the right choice of a mode for heat treatment of these tools.

Most often the thermal treatment of tool steels for operation under high temperatures (hot work tool steels) is carried out in salt baths or in vacuum. The salt baths ensure reliable quality of the tools without any danger of either decarburization or carburization and a high level of deformation. When big and medium-sized prints are thermally treated, the application of salt baths is limited. The limited use results at present from the problems, related to environmental protection, safety at work and workplace conditions, as well.

The heat treatment of hot work tool steels in vacuum is preferred to treatment in melted salts due to: raised tool reliability resulting from the decarburized heating and the lack of carburization; degasification of the heated tools, which increases toughness and improves ductility; decreasing the deformations in the thermally treated articles as a result of adjusted heating and cooling implementation; increasing the wear resistance; retaining and even improving the tool surface roughness; easy and safe maintaining of the vacuum furnaces.

Reliability and exploitation stability of the hot work tools largely depend on the following two characteristics toughness against destruction (destruction stability) - K_{Ic} and critical cracking δ_{Ic} [1,2]. At present the criterion K_{Ic} is mostly used for comparative evaluation of the materials with respect to their resistance against fragile destruction. Critical crack opening δ_{Ic} is an integral characteristic of plastic deformation and a material constant, specifying its susceptibility to fragile destruction.

The aim of this work is to investigate the influence of heat treatment over the resistance against fragile destruction by defining the critical crack opening at static strain - δ_{Ic} and the toughness against destruction - K_{Ic} - of the material.

2. METHODOLOGY OF INVESTIGATION

The hot work tool steel BH21 BS4659 (3Cr2B8F-GOST) with chemical composition given in Table 1 has been subjected to investigation. Its chemical composition has been defined with the help of the device for automatic analyses „Spektrotest”.

Table 1. Steel chemical composition, weight percentage

Material	C	Mn	Si	Cr	V	W	S
BH21	0.30	0.26	0.18	2.70	0.29	8.0	0.015

Standard test-tubes, made of the steel under investigation, have been used for defining K_{Ic} and δ_{Ic} [5,6]. The summit of the section (cut) is completed on a thread (filiform) erosive machine with radius of roundness R= 0,090 mm and length 5mm. The conditions for testing the samples are given in [3,4]. All samples have been subjected to heat treatment under the modes given in Table 2.

In the metallographic analysis of the steel samples under investigation a metallographic microscope - Axioskop – has been used and metallographic pictures have been taken. The fracto-graphic analysis was carried out by means of the scanning microscope "Philips-Sem 515".

3. EXPERIMENTAL RESULTS AND ANALYSIS

3.1. Defining the crack opening - δ_{Ic} and the toughness against destruction - K_{IC}

The results from the three-point bending testing for defining the critical crack opening at static train - δ_{Ic} and the toughness against destruction K_{Ic}, are given in Table 2.

Table 2. Results from defining K_{Ic} и δ_{Ic}

Heating and cooling media	$t_{hard.}$ [°C]	$t_{temp.}$ [°C]	HRC	K_{Ic} [MPa $\sqrt{m}$]	δ_{Ic} [mm]
Heating in a vacuum furnace and cooling in argon 6 bar	1110	600 650 700	46 44 32	49 54 68*	0.00373 0.00385 0.00834
Heating in a salt bath and cooling in oil	1110	600 650 700	47 45 32	75 78 80*	0.00468 0.00484 0.01090
Heating in a salt bath and cooling in a nitre melt (t = 400 °C / 40 min).	1120	600 650 700	46 43 32	57 59 71*	0.01170 0.01490 0.03970
Tempering in a vacuum furnace	t_{anil} = 760°C		20	87*	0.43010
Note:* - values of K_Q, which do not satisfy the conditions for a flat deformation state					

It can be seen from Table 2 that after hardening in oil higher values of toughness against destruction - K_{Ic} are observed than with the other two methods of heat treatment – in a vacuum furnace and a nitre melt. This can be explained by the small amount of Chromium (Cr = 2,70 %) in the steel, which makes it very sensitive to the speed of cooling. The higher speed of oil cooling than of the other three media (gas argon 6 bar, nitre melt) impedes the release of carbide at the borders of the grains.

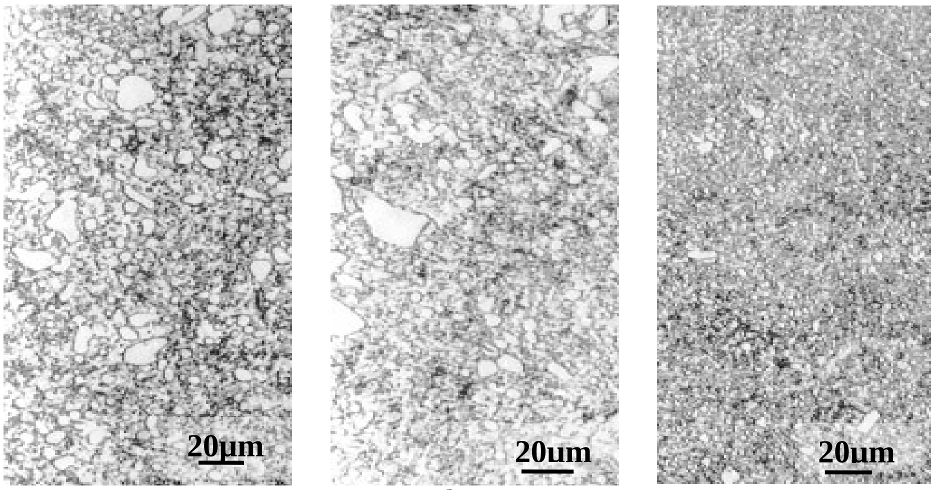
For the critical crack opening - δ_{Ic}, the highest values are obtained during the process of hardening in a nitre melt at 400 °C and time of staying 40 min. In this case a bainite structure is obtained, as well as an increased amount of residual austenite, which makes the structure more plastic than the two structures, formed by the other two methods of hardening.

The structure of BH21 steel after thermal treatment contains also certain amounts of non-soluble secondary carbides of M_6C type (Fig.1 b, c), which are sources of micro-cracks. A carbide particle cracks from the penetrating dislocation accumulation leading to forming a micro-crack, which propagates depending on the applied load [1]. Probably the availability of non-soluble secondary carbides of bigger size and varying density in the structure of the steel leads to reducing the critical value of the coefficient of stress intensity on the summit of the crack.

It can be noted that in all three methods of heat treatment, together with increasing the temperature of tempering, certain increase in the two parameters, defining the resistance against fragile destruction, is observed.

The surface of the tested samples after tempering is predominantly fragile with clearly defined internal crystal facets and micro-areas of toughness destruction. There are pores on the surfaces of the internal crystal destruction, which indicates that plastic deformation has occurred just in next to the summit of the crack. Deep secondary inter-crystal and internal crystal cracks are observed – Fig. 2.

From Table 3 it can be seen that after annealing the values of K_Q=87 MPa $\sqrt{m}$ and δ_{Ic} = 0,4301mm are higher than they are after hardening and tempering of the steel. This is confirmed by the conducted fracto-graphic analysis – Fig. 2, Fig.3.



a b c

FIGURE 1. Microstructure of BH21 steel after: a- hardening in oil and tempering at 700 °C; b- hardening in a vacuum furnace and tempering at 700 °C; c- hardening in nitre melt and tempering at 700 °C

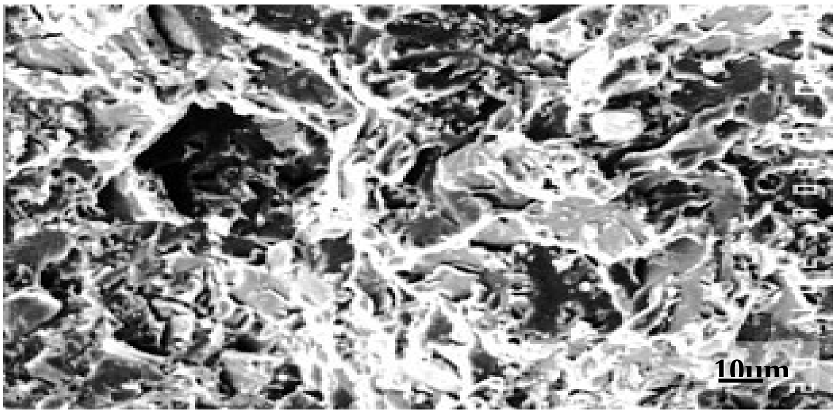


FIGURE 2. Fractograph of BH21 steel after annealing at 760 °C

The thermal treatment reduces the micro-areas of toughness destruction of the steel, and thus the resistance against fragile destruction reduces as well – Table 2.

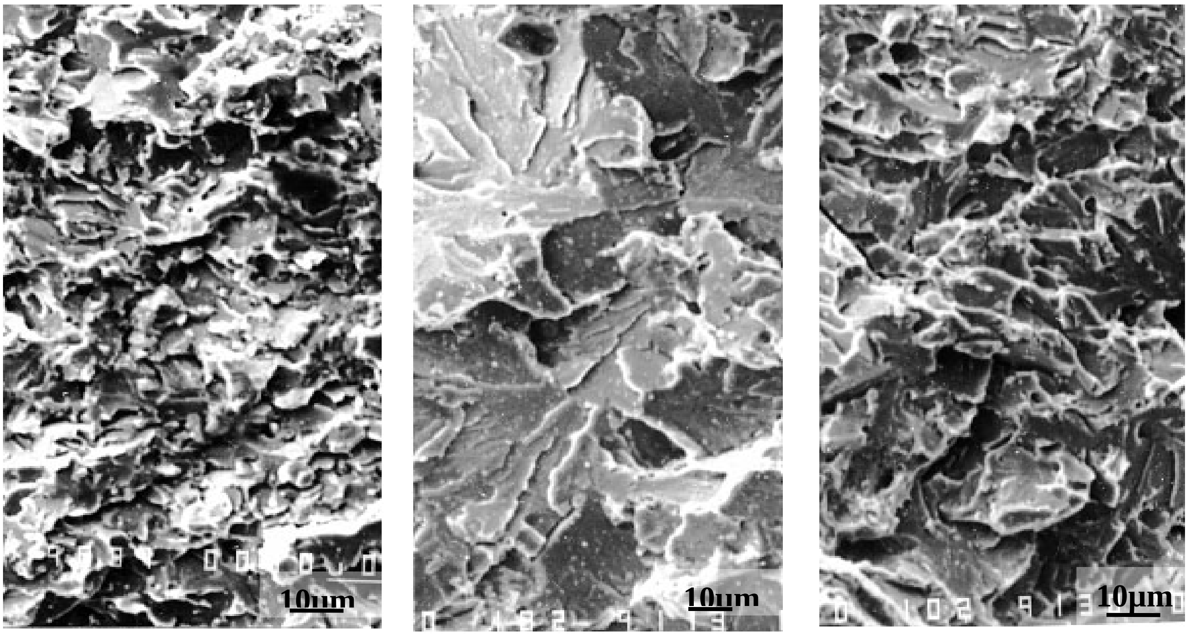
In the surfaces of the samples, hardened in oil and tempered at the three temperatures, smooth facets with no micro-pores or individual areas of fragile destruction are observed – Fig.3b. With increase in the temperature of tempering, the number of micro-areas of resilient destruction is increased, which increases the resistance against fragile destruction - K_{Ic}= 75-80MPa $\sqrt{m}$, δ_{Ic}= 0.00468 -0.01090 mm.

The surfaces of the samples, hardened in a nitre melt and tempered at different temperatures, are defined as quasi-fragile. Smooth facets with no pores are observed, as well as a smaller number of micro-areas of resilient destruction than the samples hardened in oil have – Fig. 3a. However, the surface is with finer fragments than the one, resulting from the other methods of heat treatment – Fig.3. Probably this has favorably influenced the critical crack opening in the root and at the moment of propagation.

In the steel surfaces, thermally treated in a vacuum furnace, areas of internal crystal destruction with no pores and a very small number of micro-zones of resilient destruction (Fig.3b) are observed, which indicates the smallest resistance against the fragile destruction (K_{Ic}= 49-68 MPa $\sqrt{m}$, δ_{Ic}= 0,00373 - 0,00834mm), with respect to the other two media: melted salts - K_{Ic}= 57-71 MPa $\sqrt{m}$, δ_{Ic}= 0,0117 - 0,0397mm and oil - K_{Ic}= 75-80 MPa $\sqrt{m}$, δ_{Ic}=0,00468 - 0,0109 mm).

Inter-crystal and internal crystal cracks can be observed. For the three media of thermal treatment, the increase in the temperature of tempering causes an increase in the number of micro-areas of resilient destruction in the samples.

The fracto-graphic analysis of the thermally treated steel samples under investigation shows that the mechanism for destruction is of a mixed type. Internal grain separation and inter-grain destruction of the samples is observed. These two mechanisms are with low energy consumption for the crack development. The mixed type of destruction is possible when the effective stresses of separation at the borders of the grains and the inter-grain separation are almost equal.



a b c

FIGURE 3. Fracto-graphs of BH21 steel: a-hardening in nitre melt and tempering at 700°C; b- hardening in vacuum furnace and tempering at 700°C; c-hardening in oil and tempering at 700°C

Based on the obtained results from Table 3 and the conducted fracto-graphic analysis it can be noted that in the process of samples hardening in a vacuum furnace and oil, the values of critical crack opening -δ_{Ic} complete well the toughness against destruction - K_{Ic}, while during hardening in oil and in a nitre melt it is not observed. The big amount of unsolved secondary carbides available in the structure of BH21 steel and the method of heat treatment obviously influence the crack formation and propagation significantly.

4. CONCLUSIONS

4.1. It has been established that from the three types of heat treatment of BH21 steel, the highest toughness against destruction - K_{Ic} is observed during the process of hardening in oil.

4.2. It has been proved that the biggest critical crack opening - δ_{Ic} is obtained after heating in a salt bath and cooling in a nitre melt at t = 400 °C and time of staying 40 min.

4.3. It has been established that toughness against destruction K_{Ic} can be used as a criterion of resistance against fragile destruction for both temperatures of tempering. For the temperature of 700°C, however, the size of the samples should be changed.

REFERENCES

[1] *M. Lozev, A. Zyumbyulev, V. Toshkov. Fracture mechanics of ion-nitrided steel, Materials Science, pp. 433-439, Vol. 28, No. 2, 1993.*

[2] *T. Okuno. Effect of microstructure on the toughness of hot work tools, Steel AINI, H13, H10, H11, Transactions ISIY, pp.51-55, Vol.27, 1987.*

[3] *V. Toshkov, A. Zjumbilev. Thermal and Thermochemical Treatment of Tool Steels in Vacuum", 1st lnternational Conference on Heat Treatment and Surface Engineering of Tools and Steels, Pula - Croatia, pp. 229-234, 08-11 June, 2005.*

[4] *V. Toshkov, A. Zlumbilev and M. Lozev. On Some Aspects of the Fracture of Heat Treared and Ion Nitrided Steels, Proceed, of 5th International Seminar on "Heat Treatment and Surface Engineering", p265-270, 26-29 IX 1995, Isfahan, Iran.*

[5] *BDS 12268-74. Determining the toughness of destruction -K_{Ic} in the static load.*

[6] *BDS 12840-75. Determination of crack opening –δ in static bending*