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The effect of extreme tempering temperatures and subsequent tempering on the structure-forming and properties of die steels

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ABSTRACT: As a result of the hardening of tool die steels from extreme temperatures, a structure is formed with the maximum level of imperfection of the crystal structure. The formation of an extremum is explained by the formation of an extremum of dislocation density in the austenitic region. Subsequent tempering relieves internal stresses and contributes to the polygonation and stabilization of dislocation structures. Such heat treatment can be used as final and as preparatory for subsequent additional hardening by thermal, chemical-thermal methods.

KEY WORDS: Heat treatment, extreme temperatures, dies steels, structure, dislocation density, heat resistance.

I. INTRODUCTION

In some cases, it is economically most expedient to develop new technologies on the basis of existing ones using existing technological equipment. One of such directions is the development of new methods of thermal hardening that promote the maximum use of the potential capabilities of the alloys. Of great importance is the reduction of consumption of tool steels, increasing productivity and durability of the tool for hot metal forming.

The wear resistance of a die tool is determined mainly by the flow rate of the deformable metal, the contact pressure and the temperature of the surface layer of the tool. To increase the wear resistance, cardio-forming elements are introduced into steel: chromium, tungsten, and molybdenum vanadium. Complex alloyed die steels are prone to re-hardening during tempering. Maximum hardening (peak of secondary hardening) is achieved after tempering at 500-550 ^{0}C. Hardness increases most rapidly during secondary hardening with increasing chromium and silicon carbon content in steel.

Currently, a large number of studies aimed at improving the durability of a die tool, mainly for cold forming, have been performed.

This is primarily heat treatment technology associated with the use of repeated phase recrystallization [1-3].

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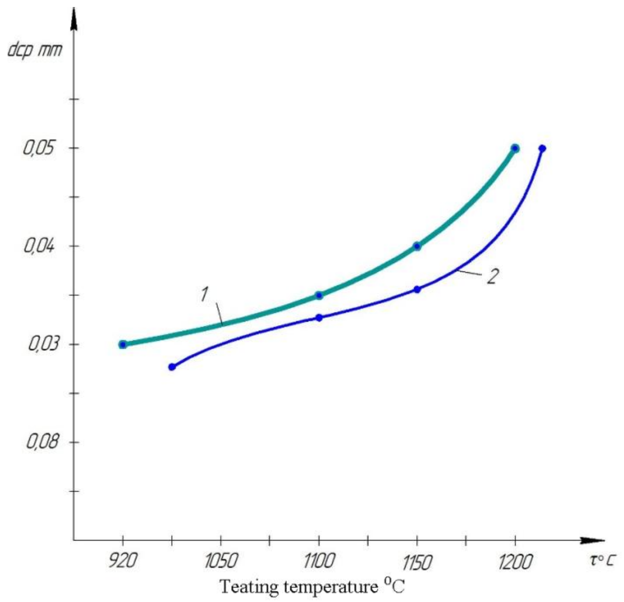

Fig.1. The amount of austenitic grain became depending on the quenching temperature
1-Steel 4XMΦC, 2-Steel 4X5MΦ1C

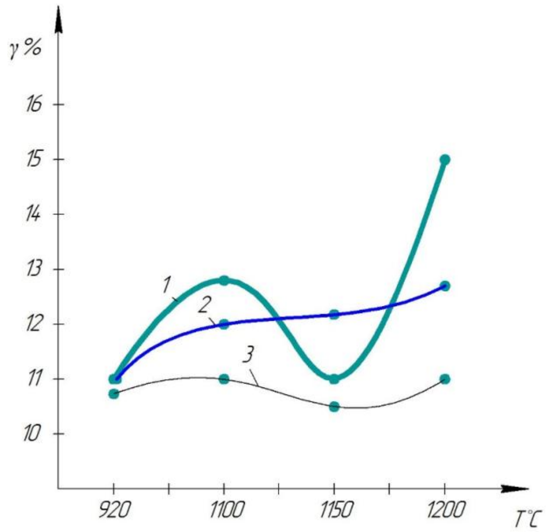

Fig.2. The content of residual austenite after quenching from different temperatures of steel 4XMΦC
1-vacation, 2-holidays 550 ^{0}C, 3-holidays 600 ^{0}C

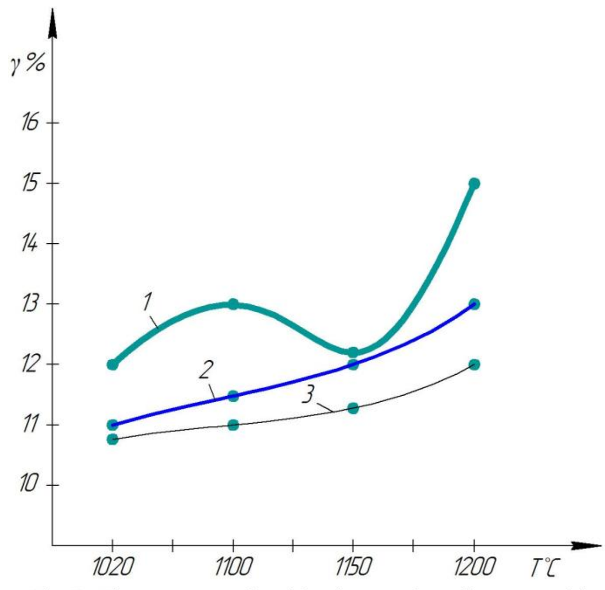

Fig.3. The content of residual austenite after quenching from different temperatures of steel 4X5MΦ1C
1-vacation, 2-holidays 550 ^{0}C, 3-holidays 600 ^{0}C

The main goal of these works is the grinding of carbide inclusions, their uniform distribution by volume. In this regard, the first phase recrystallization, in order to pre-dissolve the carbides, is carried out with heating to elevated temperatures. It was found that by setting optimal heat treatment conditions, the durability of cold forming dies can be significantly increased.

However, almost all of these works did not concern the formation of the structure of heat-resistant die steels of hot deformation. Hardening of steel from different heating temperatures usually implies an increase in austenitic grain, and when the steel cools, it produces large martensite. The presence of alloying elements somewhat reduces the increase in the intensity of austenitic grain. It is known [4] that the main barrier preventing the growth of austenitic

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grain is insoluble refractory phases. These are mainly carbides and nitrides. The main obstacles to the growth of austenitic grains for the steels under consideration are the carbides of Cr, Mo, V alloying elements. Rapid and accelerated cooling from extreme temperatures during γ - α transformation leads to the creation of a band structure with chemical micro heterogeneity, the fragmentation of mosaic blocks, the growth of crystal micro-distortions, the growth total dislocation density.

Heat resistant die steels are rather complexly alloyed and form a series of special carbides, the dissociation of which takes place at high temperatures. Therefore, the ranges of extreme temperatures during phase recrystallization may be different.

Carbide formation is associated with the diffusion of carbon atoms and alloying elements in the main phases of hardened martensite steel and residual austenite. Considering the above, the present study set the task to establish the features of structure formation after quenching from extreme temperatures and subsequent tempering of alloyed heat-resistant die steels and, on this basis, further develop the thermal hardening regimes of these steels, which significantly increase the tool life of the die tool.

To solve the stated problem, the following questions should be solved:
1. To establish how the extreme temperatures of heating of phase recrystallization of doped heat-resistant steels affect the value of austenitic grain.
2. To establish how the extreme temperatures of quenching and subsequent tempering affect the level of imperfection of the crystalline structure of residual austenite and heat resistance of alloyed heat-resistant steels.

II. OBJECTIVE OF STUDY

Heat-resistant die steels 4XMΦC and 4X5MΦ1C were selected as research objects. The following chemical composition:

Steel grade	C	Mn	Si	Gr	Mo	V	S	P
4XMΦC	0,40	0,50	0,50	1,50	0,90	0,40	0,025	0,025
4X5MΦ1C	0,39	0,40	1,10	5,20	1,4	0,95	0,030	0,030

Heating for quenching of these steel grades was carried out in salt baths NaCl and BCl2. The heating temperature was varied: for steel 4XMΦC from 920 to 1200 °C, for steel 4X5MΦ1C from 1020 to 1200 °C. Samples of steel 20x20x10 were heated. Heating time 0.3-0.5 min per 1 mm cross section. After heating, the oil was quenched. Then a vacation was held in the range of 550-600 ^{0}C for 1 hour. The state of the fine structure was determined by X-ray. The physical width of the x-ray line was determined by the method of approximation and using correction graphs [5] by determining the ratio of the intensity of the x-ray lines of (211)-phase and (200) γ-phase after heat treatment, the amount of residual austenite was determined.
The dislocation density was calculated based on the width of the x-ray line (220)

$$p = \frac{b^2}{2b^2} ctg\,\theta$$

ρ is the physical width of the x-ray line
b - Burgers vector for metals with a body centered cubic lattice
b = 0.25
θ - is the angle of reflection

The filming of x-ray lines was carried out on the installation of DRON-3M
The heat resistance test was carried out on specially prepared samples that underwent various heat treatment conditions by measuring the hardness in a cold state [6].

The prepared samples were subjected to two-hour tempering in a chamber furnace at a given temperature. To measure the hardness used Rockwell hardness tester TK-2.

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III. RESULTS

As a result of the research, it was established that during the hardening of steels, the austenitic grain grows from extreme temperatures [fig. 1]. The austenitic grain reaches its greatest growth at a heating temperature for quenching 1200 ^{0}C.

The content of residual austenite in steel 4XMΦC reaches its minimum values when quenched from 920 and 1150 °C with a release of 600 °C. With a 550 °C tempering period, the percentage of residual austenite begins to increase with increasing quenching temperature. During quenching without tempering, the percentage of residual austenite drastically changes depending on the quenching temperature, taking the minimum values at quenching 920 and 1150 °C (11%). Reaching the maximum value during hardening 1200 ^{0}C (15%). In steel 4X5MΦ1C, the nature of the curves showing the residual Austinite content is similar to that of steel 4XMΦC [fig. 2.3]. The minimum content of residual austenite is fixed when applying tempering 600 ^{0}C maximum during quenching without tempering.

The dislocation density was determined as an integral characteristic of the defectiveness of the crystal structure, which rather strongly affects the wear resistance of steel. Investigation of the effect of heat treatment regimes on the dislocation density [fig.4,5]

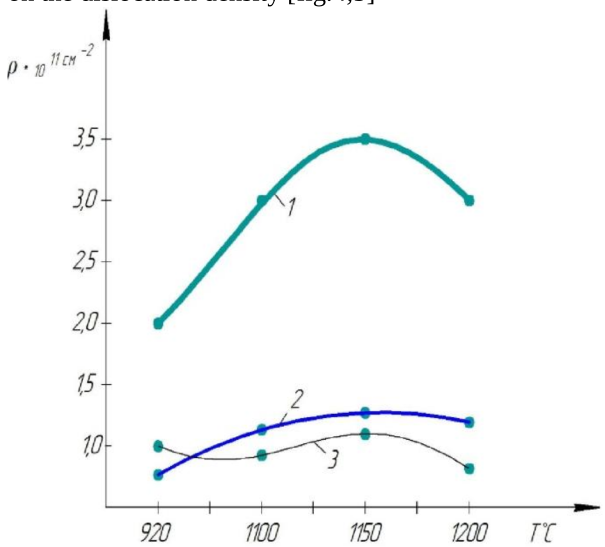

Fig.4. Influence of tempering temperature and tempering on the flatness of steel dislocations 4XMΦC
1-vacation, 2-holidays 550 °C, 3-holidays 600 °C

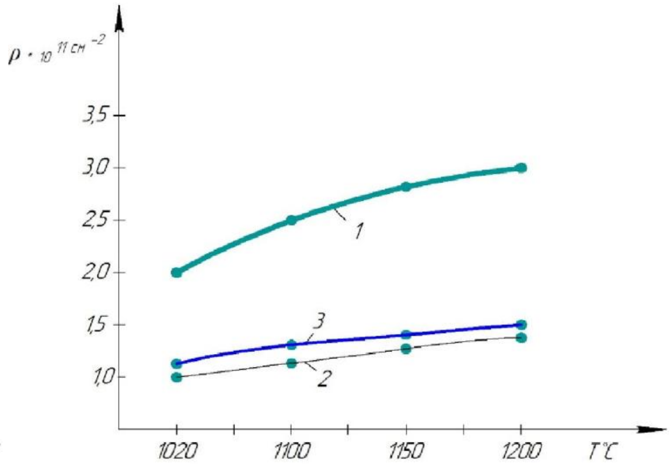

Fig.5. Influence of tempering temperature and tempering on the flatness of steel dislocations 4X5MΦ1C
1-vacation, 2-holidays 550 °C, 3-holidays 600 °C

Have shown that for both grades of steel the highest possible level of dislocation density is achieved during quenching without tempering. In this case, the extremum of the dislocation density is achieved by applying heating for quenching to temperatures of 1150-1200 °C. When using tempering steel, the dislocation density as a whole falls in comparison with quenching without tempering, but tends to increase with increasing quenching temperature. For steel 4XMΦC, where the preferred modes from the point of view of dislocation density are the following modes: quenching from temperatures of 1150-120 ^{0}C 0 and tempering 550 ^{0}C, and for steel 4X5MΦ 1C hardening from 1150-1200 ^{0}C and tempering 600 ^{0}C. To compare the level of heat resistance, two quenching modes were chosen: [fig. 6.7]

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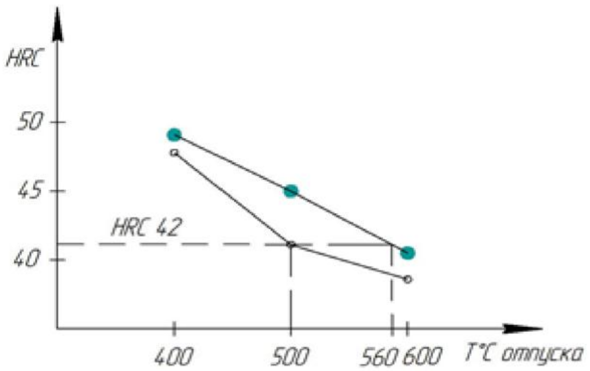

Fig.6.Influence of heat treatment regimes of steel 4XMФC at heat resistance

● - hardening 920 ^{0}C vacation 500 ^{0}C

○-hardening 1150 ^{0}C vacation 600 ^{0}C

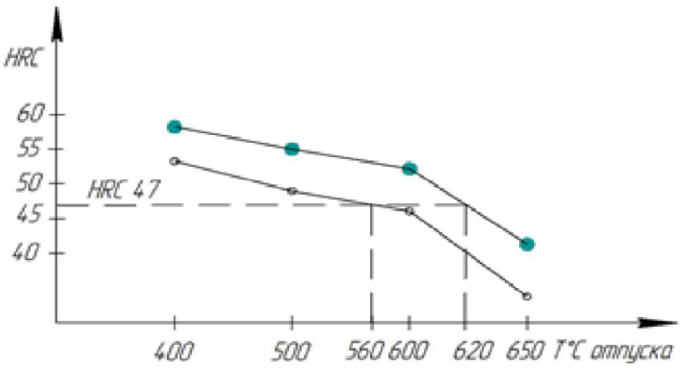

Fig.7. Influence of heat treatment regimes of steel 4XMФC at heat resistance

● -hardening 1020 ^{0}C vacation 500 ^{0}C

○ -hardening 1150 ^{0}C vacation 600 ^{0}C

1. The standard mode consisting in quenching from a heating temperature of 920 °C and tempering in the range from 400 to 650 °C.
2. Extreme hardening mode with a heating temperature of 1,150 °C tempering in the range from 400 to 600 °C.
3. The HRC 42 hardness was taken as 4XMФC for steel and 4X5MФ1C for HRC 47 for steel. The results of studies showed that for steel 4XMФC when using quenching from extreme temperatures of 1150 ^{0}C, the level of heat resistance increases to 560 ^{0}C, whereas when using the standard hardening mode makes 500 ^{0}C. For 4X5MФ1C steel, when applying the standard heat treatment mode, the level of heat resistance was 560 ° C, and when using the extreme quenching temperature from 1150 °C, it was 620 °C.

IV. CONCLUSION

For the studied steels, the use of extreme temperatures for quenching 1150-1200 °C leads to an increase in the alloying level of the solid solution. A high level of imperfection of the crystal structure is formed, which is reflected in an increase in the density of dislocations after quenching. When quenching is used with a heating temperature of 1150 °C, austenitic grain growth is insignificant, and in the process of tempering in the region of 550-600 °C, little dispersed carbides of alloying elements are released, which leads to an increase in heat resistance of steels by 50-60 °C.

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