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Increasing Mechanical Properties and Wear Resistance of Steel Ди42 by Obtaining the Multiphase Metastable Structure

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The results of research on formation polyphase metastable structure (tempered martensite, carbides and residual austenite) in steel ДИ42, self-transforming during loading for increasing its mechanical properties and wear resistance, are shown.

Keywords: METASTABLE AUSTENITE, DYNAMIC DEFORMATION MARTENSITE TRANSFORMATION, ABRASIVE WEAR RESISTANCE, INTERCRITICAL TEMPERATURE RANGE, MECHANICAL PROPERTIES

Introduction

At the present time in some cases steel ДИ42 is used for plates of dies manufacturing refractory bricks, chemical composition of which is presented in **Table 1**.

Table 1. Chemical composition of steel ДИ42, mass %

Steel	C	Mn	Si	Cr	Ni	Mo	W	P	S
5Х2ГСВМ	0.49	0.760	1.140	1.770	0.340	0.480	0.240	0.018	0.010

Stability of plates is not more than 1 month. They go out of order mainly because of abrasive wear, as evidenced by the numerous marks and scratches on the surface of the working parts (**Figure 1**).

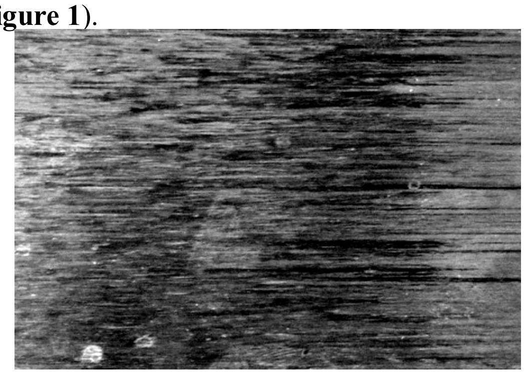

Figure 1. The appearance of the worn surface of the die plate

The objective of the study was to develop thermal treatment modes that improve the mechanical properties and abrasive wear resistance of steel ДИ42.

Typical heat treatment consists of quenching in air from 930 ° C with the pre-heated at 650 ° C and tempering at 300 ° C, 2 h.

In [1 and others] it is shown that obtaining of polyphase structure in steels in which, along with other components there is optimal for specific loading conditions of retained austenite which undergoes dynamic deformation martensite transformation (DDMT), allows to significantly improve the mechanical properties and wear resistance.

For the steel ДИ42 this structure was carried out quenching from intercritical temperature range. The temperature was 820 ° C. Exposure time varied from 30 to 120 min. In some cases, before cooling was carried out additional short austenitizing at 930 ° C, 5 min.

Usually, hardening of the ICTR is applied for low-carbon low-alloy steel deep-drawn in order to improve their mechanical properties at the expense of obtaining the structure of ferrite + martensite (~ 25%). However, in [2, etc.] the effectiveness of heat treatment, including hardening of pre-heating in the ICTR, subsequent short-term austenitizing and low tempering improve the mechanical properties and wear resistance of a number of structural steels with different carbon content. For steel ДИ42 relevant data are not available.

These results suggest that quenching after 30 min exposure to ICTR (tempering 180 ° C) causes a decrease in the yield stress of 90 MPa at the same time increasing tensile strength of 225 MPa compared to their typical level after heat treatment. Impact strength maintained at approximately the same level (**Table 2**). Increase in exposure to ICTR from 30 to 90 min does not change the mechanical properties after quenching and low tempering. After heat treatment at a shutter speed of 120 min ICTR tensile strength decreases slightly, but there is a significant decrease in the yield stress.

Lower than after standard heat treatment, the yield strength after heat treatment with heating in the ICTR is caused by presence of ferrite in the structure and appearance of retained austenite, which is a consequence of the redistribution of alloying elements between α-and γ-phase and enrichment of the last austenite-forming elements that lower the martensitic point. The latter is manifested most significantly after exposure in the ICTR 120 min. Increased tensile strength compared with its level after a standard heat treatment is due to grinding of the grain, the dispersion of the structural components, education of the sections of austenite enriched with carbon, martensite of high hardness and the occurrence of DDMT [2] and the dynamic dispersion of aging (the DDA) [3].

Table 2. The mechanical properties of steel ДИ42 after various types of heat treatment

Heat treatment modes	Hardness, HRC	σ_{02}, MPa	σ_B, MPa	δ, %	KCU, MJ/m^2
h. 650 °C, hl. 10 min + t. 930 °C, hl. 20 min,c. + t. 300 °C,hl. 120 min	51-53	1580	1940	7	0.56
h. 820 °C, hl. 30 min, c. + t. 180 °C, hl. 60 min	52-53	1490	2165	5	0.46
h. 820 °C, hl. 60 min, c. + t. 180 °C, hl. 60 min	50-52	1525	2175	6	0.30
h. 820 °C, hl. 90 min, c. + t. 180 °C, hl. 60 min	50-51	1465	2170	6	0.46
h. 820 °C, hl. 120 min, c. + t. 180 °C, hl. 60 min	48-50	1305	2100	7	0.58
h. 820 °C, hl. 30 min, c. + h. 930 °C, hl. 5 min, c. + t. 180 °C, hl. 60 min	51-52	1655	1965	7	0.43
h. 820 °C, hl. 60 min, c. + h. 930 °C, hl. 5 min, c. + t. 180 °C, hl. 60 min	51-52	1910	2265	8	0.65
h. 820 °C, hl. 90 min, c. + h. 930 °C, hl. 5 min, c. + t. 180 °C, hl. 60 min	50-51	1660	2205	8	0.59
h. 820 °C, hl. 120 min, c. + h. 930 °C, hl. 5 min, c. + t. 180 °C, hl. 60 min	48-50	1840	2170	9	0.29

*Note:h. – heating, hl. – holding, c. – cooling, t. – tempering

Saving of sufficient ductility and toughness after heat treatment with heating and aging in ICTR provides fine-grained structure and the presence of small parts - ferrite and retained austenite, as well as relaxation of the microstresses in the DDMT [4].

Results and Discussion

The highest level of mechanical properties, including in comparison with that after standard heat treatment, is obtained after heat treatment comprising heating and holding in the ICTR for 60 min, subsequent austenitizing at 930 ° C, 5 min, air cooling, tempering at 180 ° C . The result is the next level of mechanical properties: σ_{02} = 1910 MPa, σ_B = 2265 MPa, δ = 7 %, Ψ = 12 %, KCU = 0,65 MJ/m^2, after the typical heat treatment it is: σ_{02} = 1580 MPa, σ_B = 1940 MPa, δ = 7 %, Ψ = 9 %, KCU = 0,56 MJ/m^2.

Short austenitizing during hardening, held after the heating and soaking in the ICTR allows you to eliminate ferrite from the structure, save austenite heterogeneity and obtain after quenching heterogeneous carbon martensite. The latter is associated with the inability to align the chemical composition of austenite at short austenitizing. In addition to the previously discussed factors determining the mechanical properties of steel ДИ42 after heat treatment with heating in the ICTR other factors should be considered. Thus low-carbon martensite rack, derived from the austenite formed during austenitizing of ferrite after aging in the ICTR has improved ductility and toughness. It can be assumed that the enriched carbon and alloying elements, along with microscopic high hardness martensite retained austenite thin layers remain as well, which increase the ductility and toughness.

The data obtained show that in some cases it is advisable to create a microheterogeneity in the distribution of carbon and alloying elements in austenite after heating in the ICTR, keeping them in the final heating for quenching, and not to align structure, as recommended in most cases in the present time. This can be achieved not only by the use of concentrated sources of energy, or rf current, but with help of the heating furnace, if the pre-processing creates the heterogeneity of chemical composition, such as heating and exposure to the homogenization and eliminate in the ICTR for austenitizing. As a result, after quenching and low tempering a multiphase heterogeneous metastable structure is formed capable of self-transformation under loading that provides high strength properties combined with sufficient ductility and toughness.

Data on the effect of aging in ICTR followed by short austenitizing, quenching and low tempering on the abrasive wear resistance are shown in **Figure 2**. Its highest level in comparison with those obtained after the sample is achieved by heat treatment after holding in the ICTR is 120 min. This is ensured by obtaining the structure of martensite of increased hardness of the metastable austenite undergoes DDMT, the occurrence during wear in the DDA [3]. This result shows the possibility of a significant increase in abrasive wear resistance of steel ДИ42 by only some adjustments applicable standard heat treatment. This requires replacement of the pre-heating at 650 ° C for heating in ICTR while maintaining the same austenitizing temperature (930 ° C), air cooling and subsequent tempering, but lowering the temperature from 300 to 180 ° C.

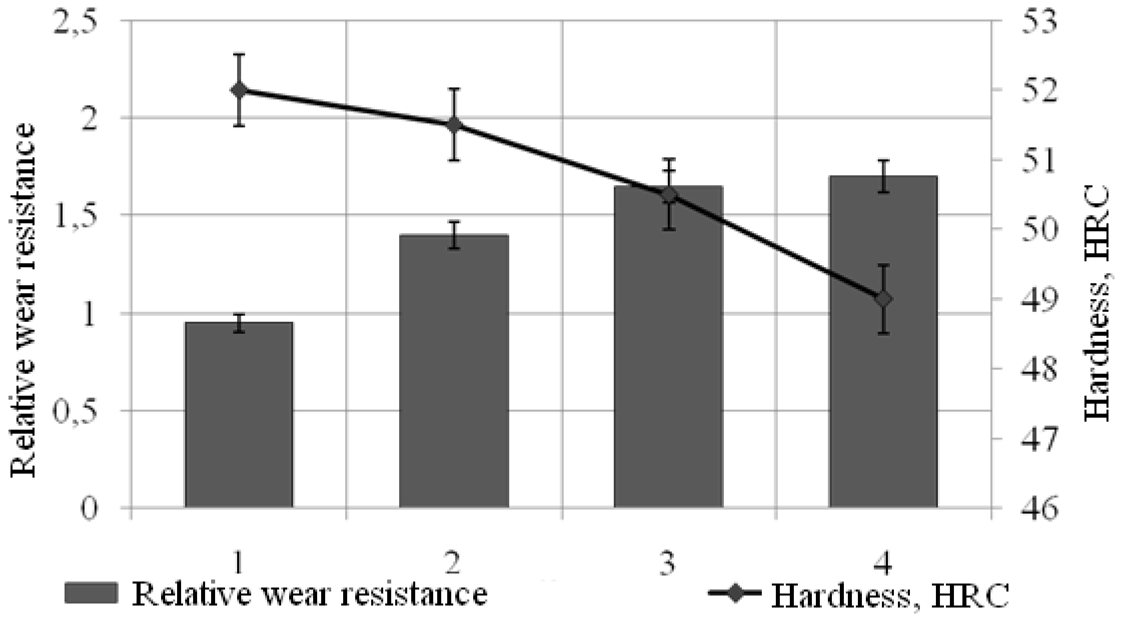

Figure 2. Effect of holding time in the ICTR and subsequent short austenitizing at 930 ° C, 5 min, with air cooling and tempering at 180 ° C, 60 min, on the hardness and abrasive wear resistance of steel ДИ42, min: 1 – 30; 2 – 60; 3 – 90; 4 – 120

Of undoubted interest is to study the abrasive wear resistance increased to a greater extent than in the previous case, by obtaining the steel ДИ42 multiphase structure consisting of high carbon martensite, carbides and an increased amount of austenite, as in [5] it is shown on a number of steels. Meanwhile, in the literature, including educational, the prevailing view is about the negative impact of increased amounts of retained austenite on the wear resistance.

Table 3. The amount of γ-phase in steel ДИ42 after holding in ICTR, short austenitizing and low tempering depending on holding time in ICTR

Holding time in ICTR, min	30	60	90	120
Amount of γ-phase, %	≥ 5	8	16	20

Data on the effect of cementation and subsequent quenching from different temperatures and the temperature of tempering after quenching from 1050 ° C are shown in **Figure 3**. With increasing heating temperature for hardening, pre-hardened specimens, a decrease in hardness occurs due to the increase in the structure of the surface layer of residual austenite as a result of dissolution of all the large amount of carbides in austenite before quenching and, therefore, the martensite point reduces.

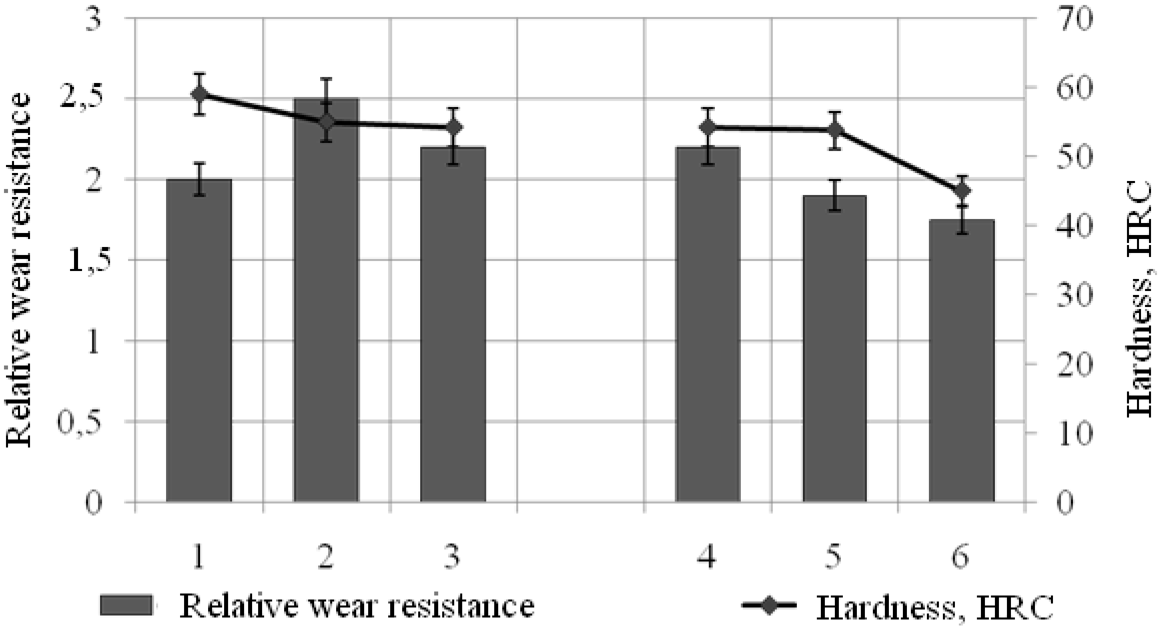

Figure 3. Influence of hardening and subsequent quenching in air different temperatures (1-3), 20 min and tempering 180 ° C, 60 min, and quenching from 1050 ° C and various tempering types (4-6) on the hardness and abrasive wear resistance of steel ДИ42: 1 – 950; 2 – 1000; 3 – 1050, 4 – 180; 5 – 450; 6 – 650 °C

The microstructure of the surface layer of carburized steel quenched from 1000 ° C is a mixture of high-martensite, carbides and austenite (**Figure 4**). The highest abrasive wear resistance of steel acquired after quenching from 1000 ° C and 180 ° C tempering. This is due to obtaining the structure of high carbon martensite along with a small amount of carbides and 46% retained austenite. At wear a large part of it (38%) is transformed into martensite of deformation, as evidenced by the diffraction pattern (**Figure 5**). It is important to emphasize that a significant part of energy of the external influence is consumed for DDMT and, accordingly, less its share goes to the destruction of the material [5].

Tempering at a higher temperature than 1000 ° C slightly reduces the abrasive wear resistance, due to a decrease in the share structure of martensite, carbides, and an increase in the stability of retained austenite in relation to the DDMT as its role in reducing the of energy the external influence that goes to the destruction is reduced . However, in this case, the abrasive wear resistance is twice higher than the level achieved after standard heat treatment. In addition to increasing the wear resistance factors and the already mentioned above, a major role can play DDA of martensite and austenite [3] and the formation of the wearing surface of the nanocrystalline structure [6], which has high resistance to breakage. , which leads to the disintegration of martensite and retained austenite reduces the abrasive wear resistance (see **Figure 3**). In this regard, to maintain a high abrasive wear resistance, achieved after quenching from high temperatures, should be held low tempering, providing a reduction in internal stresses.

These data confirm the need for the structure of hardened steel ДИ42 increased amount of metastable austenite with high carbon martensite and carbides, ensuring the flow of DDMT, which is an important factor in improving the abrasive wear resistance.

To achieve a good combination of steel ДИ42 mechanical properties of the core and the highest wear resistance of the surface it is advisable to perform quenching with pre-heating and aging in ICTR and subsequent short austenitizing after hardening.

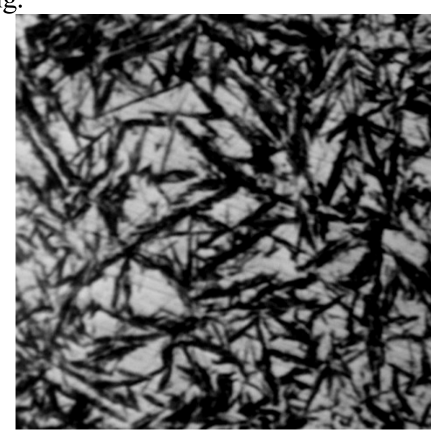

Figure 4. Microstructure of steel ДИ42 after carburizing and subsequent quenching from 1000 ° C, 20 min, air + tempering. 180 ° C, 60 min, × 500, × 1.6

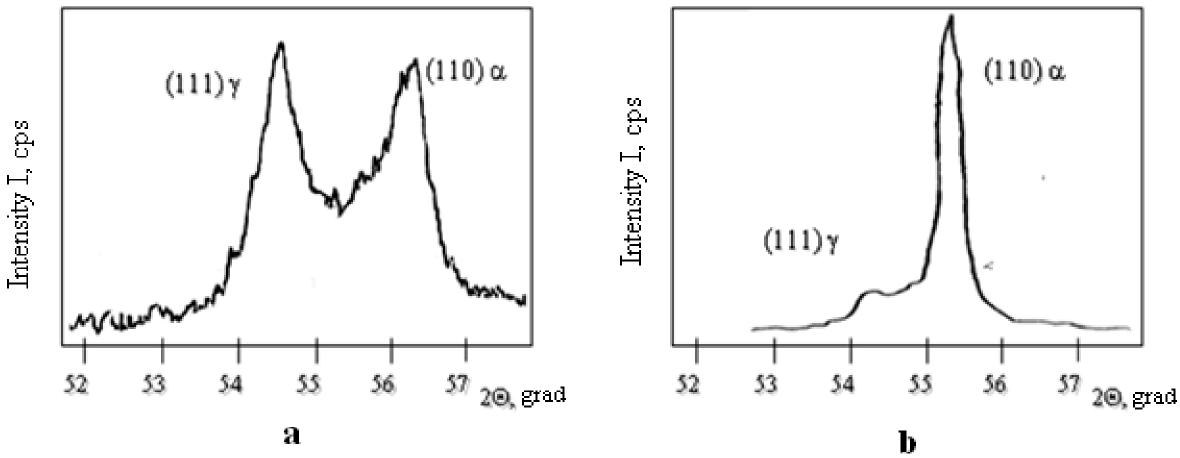

Figure 5. Diffraction patterns of steel ДИ42 after carburizing and subsequent quenching from 1000 ° C 20 min, air + tempering. 180 ° C, 60 min: a - before wear and tear (A_r = 46%), b - after wear and tear (A_r = 8%)

Conclusions

1. Obtaining in steel ДИ42 multiphase metastable self-transforming structure under heating and regulated holding in the ICTR, followed by a brief austenitizing, quenching and low tempering ensures the highest level of strength properties, sufficient ductility, toughness and high wear resistance.

2. The highest level of durability in the investigated steel is achieved by carburizing, followed by quenching from high temperatures (1000 ° C) and low-tempering, when the structure of high carbon, along with a small amount of martensite and carbides is formed by a large number (50%) of the metastable retained austenite which undergoes DDMT. Factors that increase the abrasive wear resistance can be the DSA and the formation of the nanocrystalline structure on the wearing surface.

3. To achieve a good combination of steel ДИ42 mechanical properties of the core and the highest wear resistance of the surface it is advisable to perform quenching with pre-heating and aging in ICTR and subsequent short austenitizing after hardening.

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Повышение абразивной износостойкости стали ДИ42 за счет получения многофазной метастабильной структуры

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В работе приведены результаты исследований по получению в стали ДИ42 многофазной метастабильной структуры (отпущенный мартенсит, карбиды, остаточный аустенит) самотрансформирующейся при нагружении для повышения её механических свойств и абразивной износостой кости.