

Influence of Heat Treatment with Heating in the Intercritical Temperature Range on the Properties of Steels 60C2A and 60C2XΦA

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Data on the influence of heat treatment with heating in the intercritical temperature range on the properties of steels 60C2A and 60C2XΦA providing production in them multiphase structures with metastable retained austenite are presented.

Keywords: HARDENING, TEMPERING, MARTENSITE, LOWER BAINITE, METASTABLE AUSTENITE, INTERCRITICAL TEMPERATURE RANGE, THE EFFECT OF SELF-QUENCHING DURING LOADING

Introduction

Steels 60C2A and 60C2XΦA (**Table 1**) are used as spring steel, but they are used for parts and tools, operating in conditions of abrasive and shock-abrasive wear. Typical heat treatment for them is hardening and medium-temperature tempering, providing the mechanical properties which are listed in **Table 2**.

The objective of this paper was to explore the possibility of getting in the studied steels mechanical properties, abrasion and shock-abrasive wear resistance, which are not usually implemented in them, to expand their field of application. Heat treatment, substantially different from the standard was used, including heating in the intercritical temperature range (ICTR), allowing to obtain multiphase structure consisting of martensite and lower bainite, ferrite, a small amount of carbides and residual austenite, which is converted into martensite of deformation under load (the effect of self-hardening while testing properties during loading) [1].

Results and Discussion

Considering that for steels 60C2A and 60C2XΦA critical points are, respectively, as follows: $Ac_1 = 750$ °C, $Ac_3 = 820$ and $Ac_1 = 760$, $Ac_3 = 837$, 60C2A heating was performed at 790, and 60C2XΦA at 800 °C. Holding at these temperatures varied from 20 to 90 minutes. Hardening in oil and subsequent tempering was carried out at 250°C for 1 hour or isothermal

hardening from the ICTR [2] with holding at 350°C, 10, 30, 60 min. For performing the latter method [3] was applied, which consists in that after heating and holding in ICTR the samples were cooled in water to a temperature of the isotherm in the area of lower bainite and not in molten salts, as it is usually done, and then they were kept at a predetermined temperature in the furnace and cooled in the air.

Metallographic, durometrical researches and testing of stretching mechanical properties were conducted. Phase composition was determined by X-ray in ДРОН-4 in the iron K_α radiation. Abrasive wear resistance was tested on the unit type Brinell-Haworth [4]. Sand with particle size 0.3-0.5 mm was used as abrasive material. Tests of shock-abrasive wear resistance were carried out at the facility, in which attached to a rotating disc the samples collided with cast iron grit $\varnothing 0.8$ mm. The standard samples were of suitable steel after standard heat treatment.

The data obtained show that 60C2A hardening from ICTR (tempering 250°C 1 h) with increasing hold time from 20 to 60 minutes improves its strength and plastic properties. Longer residence of the samples in ICTR (90 min) reduces these characteristics (**Table 2**).

Appearance of the residual austenite in the structure is caused by high content of carbon in austenite before hardening in comparison with what can be obtained in it by heating in the austenitic area to 870°C, as it is commonly accepted. Causes of obtaining higher level of

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mechanical properties after heat treatment with heating in ICTR can be grain fineness and dispersity of martensite, higher than in steel, the content of carbon in it, presence of undissolved carbides. The contribution to the increase in plasticity compared to standard heat treatment with high strength bring the residual austenite settling down on the boundaries of martensite crystals, which undergoes dynamic deformation martensite transformation (DDMT) during testing mechanical properties, as well as a small amount of ferrite, purified from carbon and nitrogen, which passed into austenite during the redistribution of elements

between α - and γ - phases in ICTR [5]. The transformation of residual austenite into martensite under stretching of samples is evidenced by the fact that the in the area of uniform elongation the amount of residual austenite decreases from ~15 to ~7%. During DDMT not only hardening takes place, as it is usually assumed, but the relaxation of microstresses. In addition, a significant portion of the external influence energy is spent on the development of martensitic transformation and, consequently, less its share goes to the destruction [1].

Table 1. Chemical composition of steels 60C2A and 60C2XΦA

Steel	Chemical elements, %								
	C	Mn	Si	Cr	V	Ni	Cu	S	P
60C2A	0.59	0.75	1.90	0.21	-	0.12	0.10	0.016	0.012
60C2XΦA	0.62	0.56	1.60	1.15	0.13	0.21	0.15	0.020	0.015

Table 2. Heat treatment modes and mechanical properties of steels 60C2A and 60C2XΦA

Steel	Heat treatment mode	Mechanical properties			
		$\sigma_{0.2}$, MPa	σ_b , MPa	δ , %	ψ , %
60C2A	Hardening from 870 °C, tempering 460 °C	1400	1600	5	20
60C2XΦA	Hardening from 870 °C, tempering 410 °C	1700	1900	5	20

Table 3. Mechanical properties of steel 60S2A (ϵ_1) and abrasive wear after hardening from the ICR (790 ° C) with different holding and tempering at 250°C for 1 hour

Hold time in ICR, min	HRC	$\sigma_{0.2}$, MPa	σ_b , MPa	δ , %	ψ , %	ϵ_1
20	46	1400	1548	3	30	1.89
60	48	1968	2199	8	36	1.95
90	47	1556	1698	3	32	1.75

Table 4. Mechanical properties, abrasive (ϵ_1) and shock-abrasive (ϵ_2) wear resistance of steel after isothermal hardening from ICTR (790°C, 60 min) and different holding at 350°C

Time, min	HRC	Mechanical properties				Wear resistance	
		$\sigma_{0.2}$, MPa	σ_b , MPa	δ , %	ψ , %	Abrasive, ϵ_1	Shock-abrasive, ϵ_2
10	33	750	1100	16	43	1.80	1.25
30	35	810	1130	23	50	1.65	1.45
60	36	850	1160	14	41	1.43	1.69

Appearance of the residual austenite in the structure is caused by high content of carbon in austenite before hardening in comparison with what can be obtained in it by heating in the austenitic area to 870°C, as it is commonly accepted. Causes of obtaining higher level of mechanical properties after heat treatment with

heating in ICTR can be grain fineness and dispersity of martensite, higher than in steel, the content of carbon in it, presence of undissolved carbides. The contribution to the increase in plasticity compared to standard heat treatment with high strength bring the residual austenite settling down on the boundaries of martensite crystals,

which undergoes dynamic deformation martensite transformation (DDMT) during testing mechanical properties, as well as a small amount of ferrite, purified from carbon and nitrogen, which passed into austenite during the redistribution of elements between α - and γ - phases in ICTR [5]. The transformation of residual austenite into martensite under stretching of samples is evidenced by the fact that the in the area of uniform elongation the amount of residual austenite decreases from ~15 to ~7%. During DDMT not only hardening takes place, as it is usually assumed, but the relaxation of microstresses. In addition, a significant portion of the external influence energy is spent on the development of martensitic transformation and, consequently, less its share goes to the destruction [1].

This factor, along with a high content of carbon in martensite and carbides cause increased abrasive wear resistance in comparison with the standard heat treatment.

According to the data [6] an important role in wear resistance can play dynamic strain aging and formation of nanocrystalline structure.

Reduction of mechanical properties after heat treatment with holding in ICTR for 90 minutes can be explained by the dissolution of more carbides in austenite compared with holding 60 min, obtaining after hardening and low tempering in the martensite of high carbon content, which determines its fragility, as well as an increase in the number and stability of the residual austenite enriched with carbon (and possibly nitrogen). This is indicated by a decrease of deformation martensite at stretching (< 5 %). This reduces the possibility of relaxation of the microstresses during DDMT and energy consumption for its development. The same reasons can explain the decrease in abrasive wear resistance as compared to the level achieved by heat treatment with holding in ICTR 60 minutes.

For obtaining multi-phase structure in which the main components are the lower bainite and residual austenite, isothermal hardening from the ICTR is applied [2]. As noted above, after cooling in water to 790 ° C (holding 60 min) to 350 ° C, the samples of steel 60C2A were held at this temperature for 10, 30 and 60 min. The mechanical properties, abrasive and shock-abrasive wear resistance after heat treatment are shown in **Table 4**.

From **Table 4** it follows that after holding for 30 min at 350 ° C the highest percentage of elongation not obtained from continuously

improved steels with comparable strength is achieved. Thus, in steels 40XΦA, 35XC, 30XMA and several others after hardening and high tempering the required mechanical properties are as follows: $\sigma_{0,2} = 750-800$ MPa, $\sigma_h = 900-950$ MPa, $\delta = 10-12$ %, $\psi = 45-50$ %.

Mechanical properties obtained after isothermal hardening from the ICTR of steel 60C2A at 350 ° C for 30 minutes are determined by obtaining lower bainite and metastable residual austenite in the structure with the most favorable kinetics of DDMT during testing stretching samples [1]. Determination of the amount of residual austenite in steel 60C2A after isothermal hardening from ICTR and various holdings at 350 ° C showed that it makes ~30% after 10 min, 30 min ~20%, and after 60 min ~15%. Diffractograms and microstructures after various residence duration of the samples at 350°C are shown in **Figures 1, 2a, b**. With increasing holding hardness and strength properties of steel 60C2A increase and ductility decreases due to an increase in the structure the amount of lower bainite, a decrease in the proportion of residual austenite and increase of its stability in relation to the DDMT. Increasing the strength properties, while maintaining high ductility is possible due to the use of short austenitizing (900 ° C, 3 min) after holding in ICTR (790 ° C, 60 min) before the isothermal hardening (350 ° C, 30 min). As a result the following level of mechanical properties is obtained: $\sigma_{0,2} = 870$ MPa, $\sigma_h = 1180$ MPa, $\delta = 19$ %, $\psi = 44$ %.

The result obtained is determined by excluding ferrite from the structure and retaining austenite-bainite structures with a little more bainite due to its additional formation from austenite formed during heating higher than A_{c3} with $\alpha \rightarrow \gamma$ - transformation. The highest abrasive and the lowest shock-abrasive wear resistance are achieved by holding (10 min), when there is ~30% of residual austenite in the structure and its basic amount is converted into deformation martensite as evidenced by the diffractograms (**Figure 1c, d**). In this case hardness is the lowest (**Table 4**). With increasing duration of isothermal holding at 350 ° C to 60 min abrasive wear resistance is reduced, and shock-abrasive one increases. This is caused by a decrease in the amount of residual austenite in the structure and an increase in its stability relative to the DDMT [6]. Abrasive wear resistance of steel 60C2 can be improved by conducting a short austenitizing (900 ° C, 3 min) after heating in ICTR (790 ° C, 60 min) prior to isothermal

hardening (350 ° C, 10 min), which eliminates ferrite and saves the microheterogeneity emerged during heating in MKIT , which determines an increased amount of metastable residual austenite. These data show that for different test conditions it is necessary to have different number and stability

of the residual austenite.

A good combination of mechanical properties, abrasive and shock-abrasive wear resistance after rational heat treatment modes, similar to those considered above, was obtained in steel 60C2XΦA (Table 5).

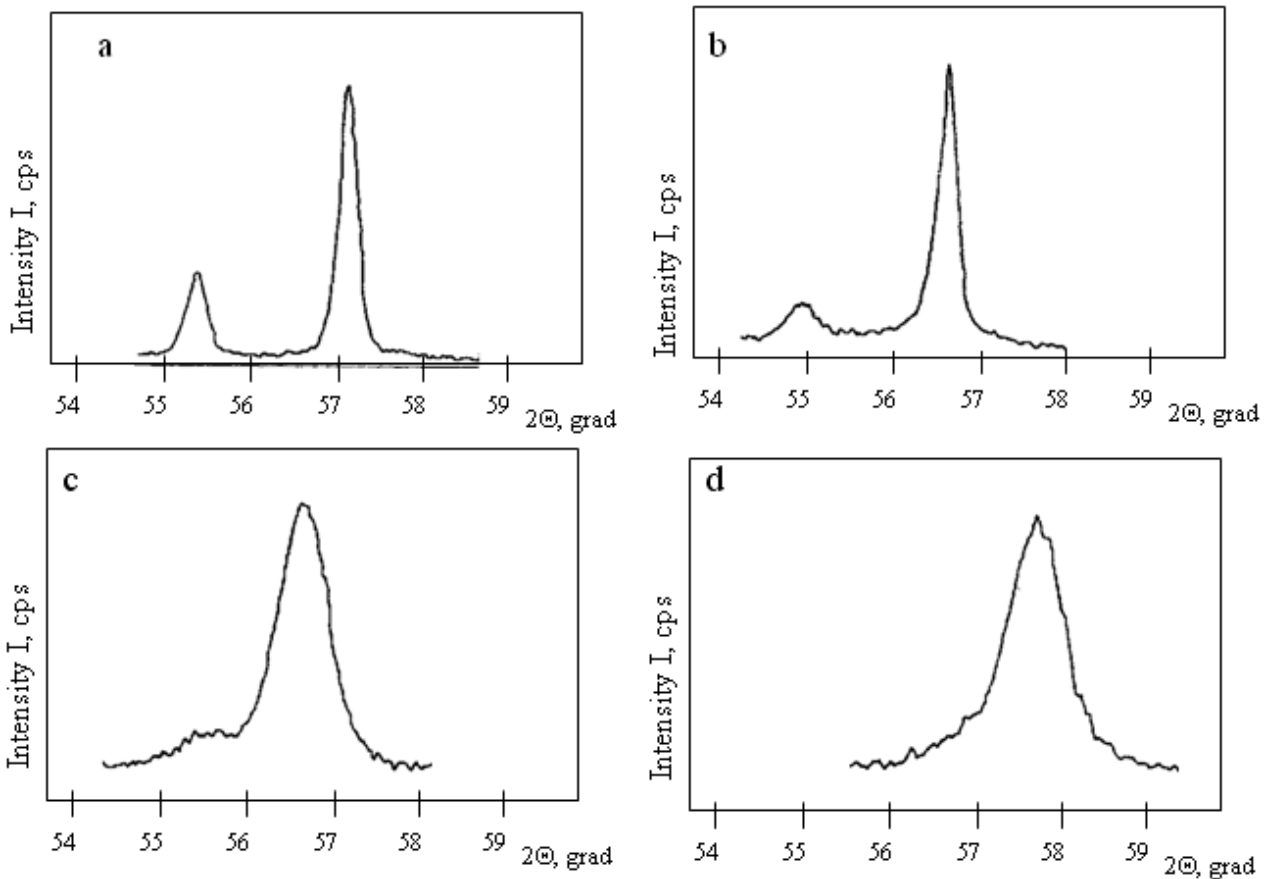


Figure 1. Diffractograms of steel 60C2A after heating at 790°C, 60 min and isothermal hardening at 350°C: a - holding at 350°C, 10 min, b - holding at 350°C, 60 min, c - the same as in a, but after abrasive wear, d - the same as in a, but after the shock-abrasive wear

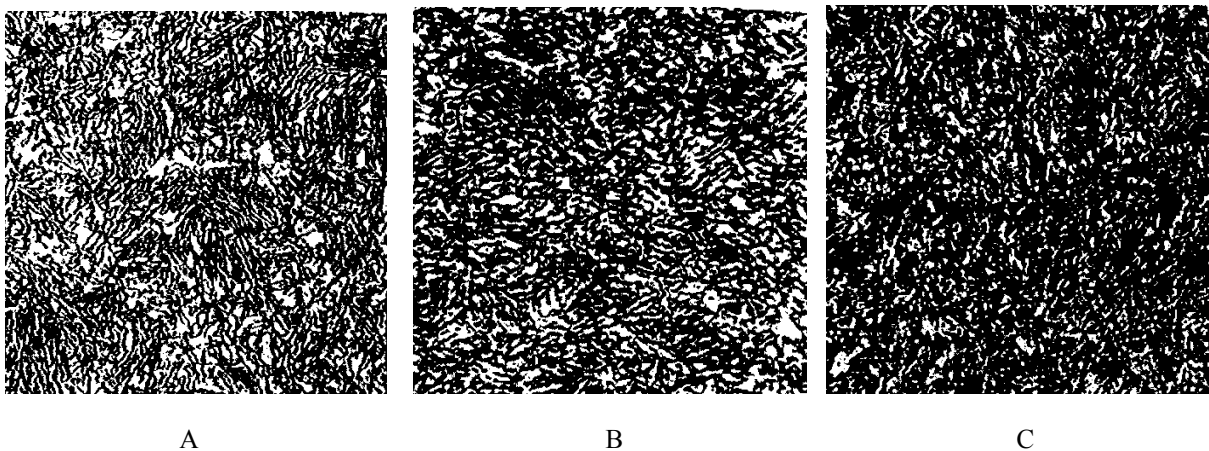


Figure 2. Microstructure of steels 60C2A (a, b), 60C2XΦ (c) after isothermal hardening at 350°C from the ICR, × 500: a - heating at 790°C, 60 min, holding at 350°C, 10 min, b - the same as a but holding at 350°C, 60 min, c - heating at 800°C, 60 min, austenitizing at 920°C, 3 min, holding at 350°C 30 min

Table 5. Mechanical properties of steel 60C2XΦA after isothermal hardening of their ICTR, including after a short austenitizing

Heat treatment mode	Properties			
	$\sigma_{0.2}$, MPa	σ_b , MPa	δ , %	ψ , %
Heating to 800 ° C, holding 60 min, cooling in water to 350 ° C, holding 30 min, cooling in air	820	1220	25	44
Same as 1 but before isothermal hardening after aging at 800 ° C, heating to 900 ° C with 3 min holding	1090	1450	21	42

Table 6. Influence of hold time at 350 ° C on the abrasive (ϵ_1) and shock-abrasive (ϵ_2) wear resistance of steel 60C2XΦA . Heating before isothermal hardening at 800 ° C, 60 min, followed by austenitizing at 920 ° C, 3 min

Time, min	ϵ_1	ϵ_2
10	1.70	1.10
30	1.40	1.50
60	1.20	1.85

As well as in steel 60C2A in order to obtain high level of mechanical properties (compared with improved steels) and high elongation, not achievable by standard heat treatment ($\delta = 5\%$), it is necessary to obtain fine-grained dispersed multiphase structure consisting of lower bainite, a small amount of carbides and metastable austenite ~25%, which undergoes during loading DDMT.

It is permissible to have a small amount of ferrite ($\leq 10\%$). Such structure is achieved by isothermal hardening from ICTR (800 ° C, 60 min) at 350 ° C, 30 min. Similarly the was already considered method for steel 60C2A in steel 60C2XΦA mechanical properties and abrasive wear resistance while maintaining high plasticity can be improved by short austenitizing (900 ° C, 3 min), carried out after holding before isothermal hardening.

As well as for steel 60C2A , for 60C2XΦA the highest level of abrasive and low shock-abrasive wear resistance was obtained after holding 10 min at 350 ° C, when the number of metastable austenite is ~28% (Figure 2c), and it is almost completely transformed into deformation martensite on the wearing surface. Increasing the duration of isothermal holding reduces abrasive and improves shock-abrasive wear resistance (Table 6).

By changing the quantitative ratio of structural components and the stability of the residual austenite due to heat treatment modes the required properties can be raised according to specific loading conditions.

The results obtained show that the creation fine-grained dispersed multiphase structure with

metastable austenite in the studied steels can implement in them high strength with sufficient plasticity and high plasticity with moderate strength as well as high wear resistance. This requires the use of non-traditional for them ways of heat treatment, which include heating in ICTR. The quantity and stability of the residual austenite due to heat treatment modes should be optimized taking into account the properties that are necessary to obtain.

Conclusions

1. Creation of fine-grained dispersed multiphase structure with metastable austenite by heat treatment involving heating and regulated holding in the ICTR allows to obtain in steels 60C2A and 60C2XΦA properties, making it possible to use them for different operating conditions, not only as spring material.

2. An important role in the properties of the studied steels plays the amount and stability of the residual austenite towards DDMT. They need to be managed for specific requirements, characteristics and loading conditions.

3. In some cases, it is rational to perform short austenitizing after the heating and soaking in ICTR before hardening. Conducting of isothermal tempering according to the scheme of water-furnace is efficient.

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Влияние термообработок с нагревом в межкритический интервал температур на свойства сталей 60С2А и 60С2ХФА

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Приведены данные по влиянию на свойства сталей 60С2А и 60С2ХФА термообработок с нагревом в межкритический интервал температур, обеспечивающих получение в них многофазных структур с метастабильным остаточным аустенитом.