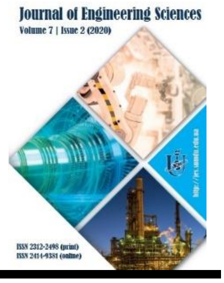
JOURNAL OF ENGINEERING SCIENCES

Volume 7, Issue 2 (2020)

Ivanov I. V., Mohylenets M. V., Dumenko K. A., Kryvchyk L., Khokhlova T. S., Pinchuk V. L. (2020). Carbonitration of a tool for pressing stainless steel pipes. Journal of Engineering Sciences, Vol. 7(2), pp. C17–C21, doi: 10.21272/jes.2020.7(2).c3



Carbonitration of a Tool for Pressing Stainless Steel Pipes

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Article info:
Paper received: July 22, 2020
The final version of the paper received: November 16, 2020
Paper accepted online: November 26, 2019

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Abstract. To upgrade the operational stability of the tool at LLC "Karbaz", Sumy, Ukraine, carbonation of tools and samples for research in melts of salts of cyanates and carbonates of alkali metals at 570–580 °C was carried out to obtain a layer thickness of 0.15–0.25 mm and a hardness of 1000–1150 HV. Tests of the tool in real operating conditions were carried out at the press station at LLC "VO Oscar", Dnipro, Ukraine. The purpose of the test is to evaluate the feasibility of carbonitriding of thermo-strengthened matrix rings and needle-mandrels to improve their stability, hardness, heat resistance, and endurance. If the stability of matrix rings after conventional heat setting varies around 4–6 presses, the rings additionally subjected to chemical-thermal treatment (carbonitration) demonstrated the stability of 7–9 presses due to higher hardness, heat resistance, the formation of a special structure on the surface due to carbonitration in salt melts cyanates and carbonates. Nitrogen and carbon present in the carbonitrided layer slowed down the processes of transformation of solid solutions and coagulation of carbonitride phases. The high hardness of the carbonitrified layer is maintained up to temperatures above 650 °C. If the stability of the needle-mandrels after conventional heat treatment varies between 50–80 presses, the needles, additionally subjected to chemical-thermal treatment (carbonitration) showed the stability of 100–130 presses due to higher hardness, wear resistance, heat resistance, the formation of a special surface structure due to carbonitration in melts of salts of cyanates and carbonates.

Keywords: needle-mandrel, matrix ring, pressing, heat treatment, carbonitration.

1 Introduction

The method of pressing produces a large number of semi-finished products made of ferrous and nonferrous metals.

The productivity of press installations, quality, and cost of finished parts mainly depends on the quality of the press tool, which forms up to 25 % of all press workshop costs [1]. The critical role in the pipe pressing process on a horizontal pipe press is played by matrix rings of complex matrices and mandrel needles.

The working tool works under the conditions of high temperatures, intensive sliding speeds, and considerable specific pressure that causes the necessity of using high-alloyed heat-resistant instrument steel as material so that it has increased viscosity and durability [2].

The operating conditions of the press tool are characterized by significant thermal and power loads on the tool. During hot pressing, the heating temperature of work pieces made of different materials varies from 400 °C to 1600 °C, and the working layers of the tool can be heated to 800 °C and above. The pressure on the engraving of the matrices reaches 1 GPa [3].

Considering the operating conditions, the following requirements apply to the material: high temperature stability; viscosity; resistance to thermal erosion; durability; heat resistance; high thermal conductivity [4].

2 Literature Review

The matrix is the most important tool in which the shape of the work piece changes, so it is the most worn out part of the press tool. Primary causes of destruction of matrices are loss of shape and size of the channel, brittle fracture, and expansion cracks (Figure 1).

Figure 1 – The wear of the matrix for the pipe press [5]

Press needles, or pipe mandrels, are tools that form the inner cavity (Figure 2). During pressing, the needles work in the most difficult conditions because they are subjected to tensile and compressive stresses at elevated surface layer temperatures due to metal friction and deformation's thermal effect.

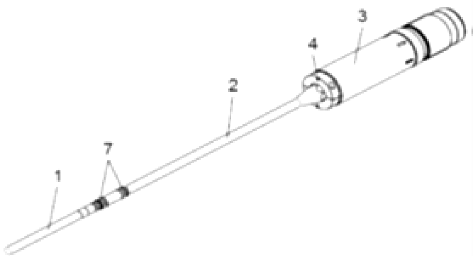

Figure 2 – Needle mandrel [6]

The material of the press tool must have the following properties:

– heat stability– the ability to maintain strength and formability characteristics at processing temperatures;

– heat resistance – resistance to oxidation during prolonged heating.

– resistance to thermal erosion – the ability to withstand repeated changes of intense heating and cooling;

– wear resistance – high resistance to abrasion;

– low coefficient of thermal expansion to maintain a constant size during heating and cooling;

– high thermal conductivity – for fast heat removal to avoid overheating [7].

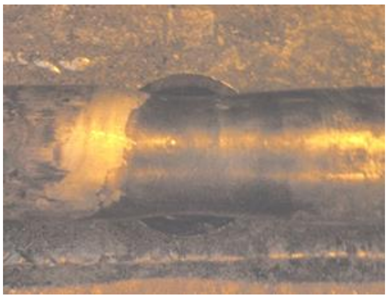

Figure 3 – The wear of the needle-mandrel pipe press [3]

The complex of the listed properties which the press tool should have, is reached by application at its manufacture of heat-resistant steels of austenitic and martensitic classes alloyed with chromium, tungsten, nickel, molybdenum; special heat-resistant alloys based on nickel and cobalt, containing tungsten, chromium, molybdenum, titanium, aluminum; hard alloys and mineral-ceramic materials [7].

The characteristic property of the production of pipes by pressing stainless and high-alloy steels is the press tool's low stability (Table 1).

Table 1 – Stability of the press tool [3]

Tool	Resistance for pipes from		
	Carbon steels	Stainless steels	Alloys and high-alloy steels
Matrix rings and inserts	300–500	≤ 5–7	≤ 5
Pipe mandrels needles	300–500	50–80	20–50
Internal bushings containers	2000–3000	400–600	≤ 300
Stamp heads	5000–10000	2500–5000	1000–2000

Secondary hardening stamped steels X40CrMoV5-1-1 and 30WCrV17-2 are most often used to produce needles-mandrels for pressing pipes and die rings, which are subjected to heat treatment [8]. Hardening is carried out to dissolve a significant part of carbides and obtain high-alloy martensite. Therefore, tempering temperatures are elevated and are limited only by the need to maintain fine grain and sufficient viscosity [9–11].

Subsequent tempering causes additional hardening due to dispersion hardening. To increase the viscosity, it is most often performed at higher temperatures to a lower hardness 45–52 HRC and troostite structure (Figure 4).

After hardening, these steels are recommended to be cooled in the air up to 950–900 °C, followed by cooling them in the oil.

The tempering operation is performed immediately after hardening to prevent cracks. As a rule, the tempering is made at a hardness of 45–52 HRC.

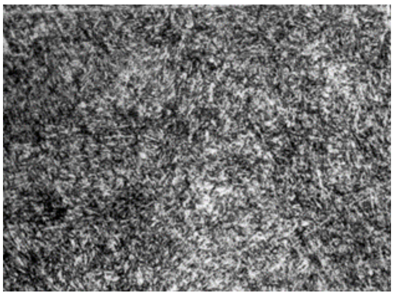

Figure 4 – Microstructure of steel X40CrMoV5-1-1
after hardening from 1070 °C and tempered at 550–570 °C
(1st temper), 530–550 °C (2nd troostit temper), x500 [8]

Since a lot of austenite is stored in the structure when heated for tempering, it is advisable to conduct a double tempering. The temperature of the second tempering can be 10–20 °C lower, and its duration is 20–25 % less than the first tempering. Cooling after the tempering is carried out in the air.

3 Research Methodology

An effective way to change the composition of the stamping tool's surface layer, providing the necessary set of properties of its working surface, is chemical-thermal treatment. As a result, the structure and properties of the surface layer change, the strength, wear, and heat resistance of steel increases during the heating process by forming stable carbides, nitrides, and borides [12].

Due to the low operational stability of matrix rings and needles-mandrels, this report offers the following brands: "Arcor", "Tenifer", "Tufftride", "Melonite", "QPQ", "Dyna-Blue", "BlackNitride" and others. This technology is an alternative to the gas nitriding, but in contrast to nitriding, more flexible and less brittle phases than in nitriding, carbonitride surface layers are formed. The process has indisputable advantages compared to other surface hardening processes such as surface hardening with high frequency currents, ionic nitriding, cementation, cyanidation, and nitrocementation galvaniza-tion, and phosphating. This technology's advantage is the high saturation rate, uniformity of heating and saturation in the melt, increased wear resistance and corrosion resistance of the surface, reduction of the friction coefficient by 1.5 – 5.0 times, and environmental friendliness and non-toxicity of cyanate salts. The process is carried out at a temperature of 540–600 °C, dwell time 4–6 hours, and layer thickness 0.12–0.3 mm [13].

The properties of the parts after carbonitriding largely depend on the degree of alloying of steel. The more alloyed steel with nitride-forming elements is (Cr, V, Mo, Al, Ti, W, Mn), the smaller the layer thickness and higher its hardness. The carbonitrated layer is the closest in its parameters to the nitrided (therefore, carbonitration is sometimes called "liquid" or "soft" nitriding) and cyanide layer, and it has advantages and no disadvantages of these technologies [14]. The main advantages of carbonitration are strengthening details from any steel and pig iron brands; high saturation rate. In 1–4 hours, a reinforced layer is formed on the surface, similar in depth and hardness to that obtained in 10–60 hours of traditional nitriding, uniformity of heating, and saturation. An absence of the deformation and high accuracy is provided. Finally, machined parts are subjected to hardening; no additional allowance is required; increase of fatigue strength by 50–80 %. The efficiency of the details working with cyclic loadings due to the creation of compressive stresses on a surface increases; increase in wear resistance of parts approximately 2–11 times compared to cementation, nitro-cementation, and gas nitriding. There is no fragility of the carbonated layer; increasing the corrosion resistance of steels; carbon and low-alloy steels after carbonitration acquire high-alloy stainless steels; reduction of the friction coefficient by 1.5–5.0 times. The carbonated layer acts as an additional lubricant in the friction pairs [14].

The sequence of operations at carbonitration: preliminary preparation – cleaning, washing, degreasing; heating of details to a temperature of 350–400 °C; oxidation of parts (optionally); carbonitration; cooling of parts (on air, in water or oil depending on steel grade); polishing (fine-grained abrasive, pastes, polishing wheels, glass jet polishing); re-oxidation of parts; washing, drying of details [15].

The main chemical reactions that occur in the melt during carbonitration:

1) $8CNO = 2CO_3 + 4CN + CO_2 + 4N + C$;
2) $4N + 12Fe = 4Fe_3N$;
3) $C + 3Fe = Fe_3C$.

The study of cyanate baths activity showed that to achieve high efficiency of strengthening the stamp, pipe tool made of high-alloy steels, it is most appropriate to use a bath of 75–85 % potassium cyanate and 15–25 % potassium carbonate. The bath of this composition has high chemical activity and good manufacturability [16].

In the tool's surface layer, a carbonitride zone is formed, which is characterized by high hardness, redness, and wear resistance. In the process of carbonitration on the surface of steels, a reinforced layer consisting of several zones is formed. The upper layer is a carbonitride type $Fe_3(N, C)$, under which is the diffusion zone (heterophase layer), consisting of a solid solution of carbon and nitrogen in iron to include micarbonitride phases, the hardness of which is much higher than the hardness of the core (Figure 5).

Figure 5 – Microstructure of the matrix ring made of steel 30WCrV17-2 after carbonitration, x600

4 Results

The results of measuring the tool's hardness (chick and holders-mandrels) and the breaks of the steels, which were previously measured, were guided in Tables 2–3, and the structures of the spikes were shown in Figure 6.

Table 2 – Modes of heat treatment of the tool

Steel brand	Processing	HV5
X40CrMoV5-1-1	Hardening + tempering + + carbonitriding	986, 966, 946
X40CrMoV5-1-1	Annealing + + carbonitration	494, 487, 532
30WCrV17-2	Annealing + carbonitration (1)	891, 857, 874
30WCrV17-2	Annealing + carbonitration (2)	795, 841, 781
30WCrV17-2	Hardening + tempering + + carbonitriding	1095, 1027, 1120

A study of stamped steels X40CrMoV5-1-1 and 30WCrV17-2 for the manufacture of die rings of complex matrices and needle-mandrels for pressing stainless steel pipes on pipe presses after different modes of heat treatment has been conducted [17, 18].

The samples of the studied steels' structures after quenching, after quenching, and double tempering, after carbonitration are shown in Figures 6–11.

Table 3 – The results of measuring the hardness of the test specimens of the tool after different modes of heat treatment

Sample number	Steel Brand	Hardening temperature, °C	Tempering temperature, °C		Carbonitration temperature, °C	Hardness, HV
			I	II		
1	X40CrMoV5-1-1	1070	550–570	530–550	–	600–650
2	X40CrMoV5-1-1	1070	550–570	530–550	560–580	986–1027
3	X40CrMoV5-1-1	1070	550–570	530–550	560–580	960–1030
4	30WCrV17-2	1080	550–570	530–550	560–580	1145–1171
5	30WCrV17-2	1080	550–570	530–550	560–580	1120–1197

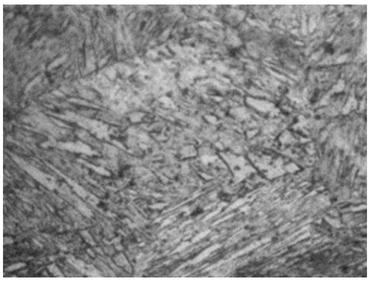

Figure 6 – Microstructure of steel X40CrMoV5-1-1 after hardening from 1070 °C (needle martensite, austenite residual and carbides), x500

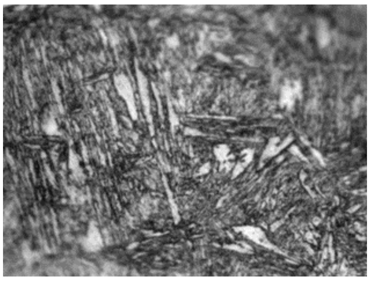

Figure 7– Microstructure of steel 30WCrV17-2 after hardening from 1080 °C (needle martensite, austenite residual carbides), x500

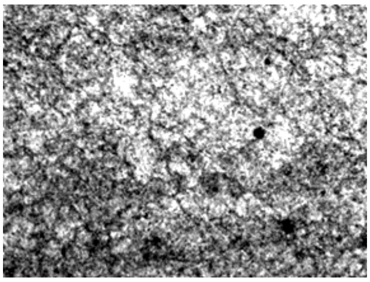

Figure 8 – Microstructure of steel X40CrMoV5-1-1 after hardening and double tempering (tempering troostite), x500

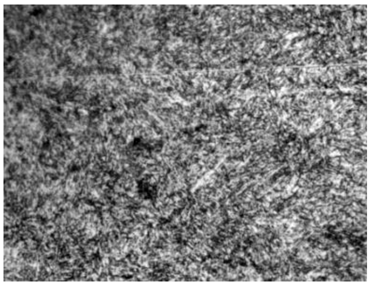

Figure 9 – Microstructure of steel 30WCrV17-2 after hardening and double tempering (tempering troostite), x500

Figure 10 – Microstructure of the needle-mandrel made of steel X40CrMoV5-1-1 after carbonitration, x600

Figure 11 –Microstructure of the matrix ring made of steel 30WCrV17-2 after carbonitration, x600

5 Conclusions

Upgrading the technology of the heat treatment of press tools (temper hardening followed by chemical-heat treatment instead of the usual technology of temper hardening) will increase the stability of the press tool by 30 % and reduce processing costs, as well as improve the quality of the inner surface of the pipes (absence of films, cuts and other defects of stainless steel pipes).

The use of carbonitriding is an alternative to gas nitriding. In contrast to nitriding in the surface layer, more flexible and less brittle, than in nitriding carbonitride, phases are formed.

This technology's advantage is in high saturation rate, uniformity of heating and saturation in the melt, increasing wear resistance and corrosion resistance of the surface, reducing the friction coefficient by 1.5–5.0 times, environmental friendliness, and non-toxicity of cyanate salts.

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