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The 20Cr130 Alloy – Heat Treatments. Factors Influencing the Properties of Materials

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Abstract
This paper analyses the influence of heat treatments on the mechanical and structural properties of the 20Cr130 stainless alloy. There have been applied various heat treatment processes, varying austenitisation temperature, the holding time and the cooling methods, in order to determine the changes induced in the microstructure and resulting mechanical behaviour. The results showed that the treatment temperature and cooling rate have a major impact on the size of the grains, the secondary phase formation and hardness. The study provides practical insight into the optimisation of heat treatments for industrial applications requiring specific performance from the 20Cr130 alloy.

Keywords
stainless steels, properties, heat treatments

1. Introduction

In the context of the continuous development of high-performance materials, martensitic stainless steels have attracted researchers in the field due to their balanced combination of corrosion resistance, mechanical properties and relatively low production costs [3, 5]. The 20Cr130 alloy is a high chromium content martensitic stainless steel, used in industrial applications requiring good oxidation and corrosion resistance to moderate temperatures, as well as dimensional stability. In order to obtain optimal properties, heat treatments play an essential role, influencing the microstructure and, implicitly, the mechanical and chemical behaviour of the materials [1, 2, 4]. This paper analyses the influence of the main parameters of heat treatments – temperature, duration and cooling rate – on the structure and final properties of the 20Cr130 alloy.

The 20Cr130 alloy is a martensitic stainless steel with a high content of chromium (approx. 13%) and a low content of carbon (≈ 0.2%) with the chemical composition shown in Table 1.

Table 1. Chemical composition of 20Cr130 steel

Steel grade			Chemical composition [%]							
Numerical symbols	Alpha-numerical symbols	STAS 3583	C	Cr	Mn max	Si max	P max	S max	Mo max	Cu max
1.4021	X20Cr13	20Cr130	0.17-0.25	12-14	1.00	1.00	0.045	0.030	-	-

This type of steel exhibits good resistance to oxidative corrosion and good thermal stability [3, 4]. Its field of use requires the 20Cr130 steel to have high mechanical and chemical properties, as it often comes into contact with water or steam, being used, for example, for the manufacture of surgical instruments (pliers or forceps), turbine blades, conical valve seats, axles, etc.

The 20Cr130 steel most commonly undergoes the following heat treatments:

- Annealing - carried out at 750–850 °C, followed by slow cooling in the furnace;
- Normalisation - involves heating to about 900–950 °C followed by cooling in the air;
- Tempering - used to stabilise the martensitic structure, if necessary;

- Solubilisation treatment - dissolves carbides and improves corrosion resistance.

The main factors influencing the properties are the treatment temperature, holding time, cooling rate and chemical composition.

2. Experimental Research

There were made standardised samples from 20Cr130 steel for resilience testing, as well as 15 mm-thick samples from ϕ20 mm bars, to which the primary and secondary heat treatments in Tables 2 and 3 were applied.

The 20Cr130 alloy behaviour was analysed using samples which underwent heat treatments under different conditions.

The analyses were performed by determining hardness and analysing the microstructure using the optical microscope.

Tables 2 and 3 show the heat treatment options applied and the results obtained.

Table 2. Primary heat treatments applied to 20Cr130 steel and the results obtained

Item	Material	Mat. state	Primary heat treatment						Hardness [HB]
			Full/incomplete annealing			Stress relief annealing			
			Temp. [°C]	Holding [h]	Cooling	Temp. [°C]	Holding [h]	Cooling	
1	20Cr130	Delivery state	-	-	-	-	-	-	229
2			770	2	Cooling in the furnace down to 300 °C and afterwards in the air	-	-	-	187
3			650	2	air	100	2	air	207
4			700	2	air	150	2	air	198
5			750	2	air	200	2	air	187

Table 3 shows the secondary heat treatment options and the results obtained.

Table 3. Secondary heat treatment and results

Item	Applied heat treatment							Hardness [HB] (C+R)
	Annealing [°C]	Vacuum quenching			Tempering			
		Temp. [°C]	Holding [h]	Cooling	Temp. [°C]	Holding [h]	Cooling	
1	770	950	2	Recirculated nitrogen	150	2	Recirculated nitrogen	270
					510	2		245
		1040	2	Recirculated nitrogen	150	2	Recirculated nitrogen	320
					510	2		295
		1100	2	Recirculated nitrogen	150	2	Recirculated nitrogen	335
					510	2		310

In order to determine the fracture energy, (10×10×55) mm 20Cr130 steel tubes were mechanically processed. The test specimens were denoted from 1-6, and their determined fracture energy and results are listed in Table 4.

The analysis of metallographic structures was carried out further to the research.

Figures 1 to 7 show some representative structures for the applied heat treatments (primary and final) compared to the microscopic aspect of the initial state.

Table 4. 20Cr130 steel - fracture energy obtained from heat treatments

Sample no.	Normalisation				Fracture energy KV [J]
	Annealing [ºC]	[ºC]	Holding [hours]	Cooling medium	
1 (delivery state)	-	-	-	-	68
2	770	-	2	In the furnace to 300 °C and afterwards in the air	92
3	-	1000	1.5	oil	6
4	650	-	1.5	air	29
5	700	-	1.5	air	65
6	750	-	1.5	air	60

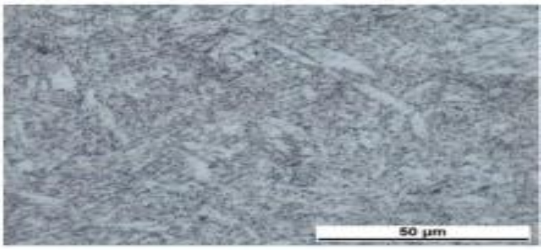

Fig. 1. 20Cr130 steel in delivery state.
Aqua regia etching. 1000:1 increase

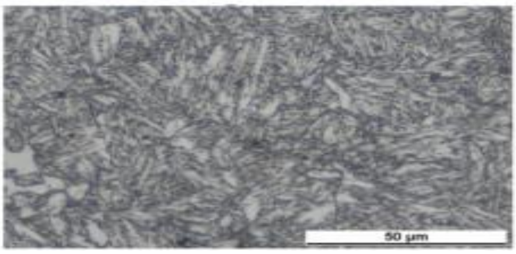

Fig. 2. 20Cr130 steel after full annealing.
Aqua regia etching. 1000:1 increase

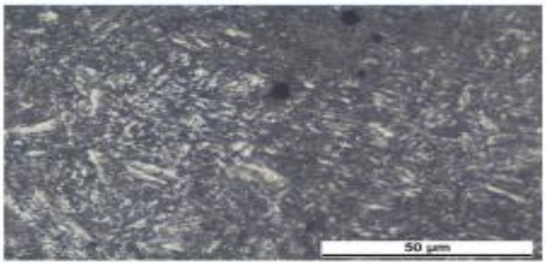

Fig 3. 20Cr130 steel after incomplete annealing at 650 °C and stress relief at 100 °C.
Aqua regia etching. 1000:1 increase

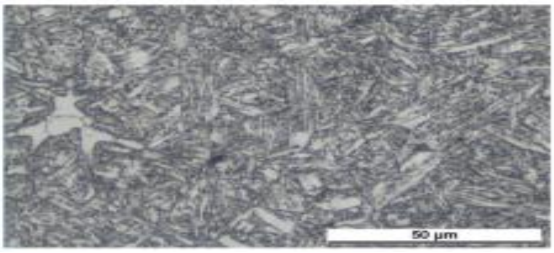

Fig 4. 20Cr130 steel after incomplete annealing at 700 °C and stress relief at 150 °C.
Aqua regia etching. 1000:1 increase

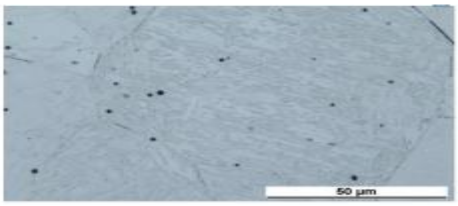

Fig. 5. 20Cr130 steel after quenching at 1040°C.
Aqua regia etching. 1000:1 increase

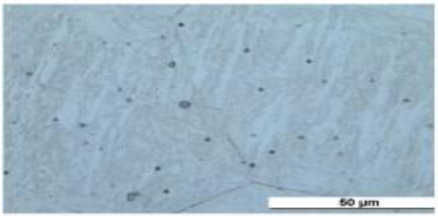

Fig. 6. 20Cr130 steel after quenching at 1040 °C and tempering at 150 °C.
Aqua regia etching. 1000:1 increase

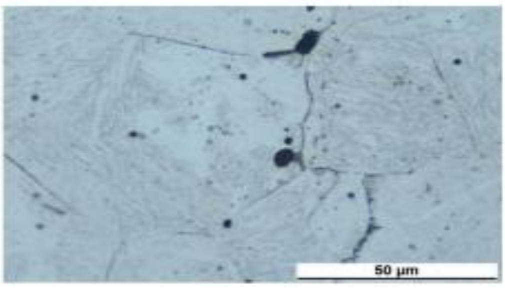

Fig. 7. 20Cr130 steel after quenching at 1040 °C and tempering at 510 °C.
Aqua regia etching. 1000:1 increase

It follows from the above that the 20Cr130 steel features higher hardness in the delivery state than after annealing; this indicates that the material in delivery state was slightly outside the equilibrium state due to cold drawing, a normalisation treatment, etc.

After annealing, the state of the material approached the state of thermodynamic equilibrium, which led to slight decreases in hardness, which was to be expected.

It is also worth noting that the application of different heat treatment processes led to differences in hardness.

It is found that the highest hardness was obtained for subcritical annealing. The lower the holding temperature, the higher the hardness.

The heating for quenching at 1040 °C led to the almost complete dissolution of the carbides (Figure 5). The application of low tempering at 150 °C led to obtaining a structure which is similar to the one obtained after quenching but with the tendency of occurrence of fine precipitates arranged in rows. The tempering temperature increase to 510 °C accentuates this tendency, the resulting structure having a bainitic appearance.

3. Results and Discussion

The difference between nominal raw hardness values decreased after the preliminary treatment.

The fracture energy of 20Cr130 steel in initial state was 68 joules. The highest fracture energy is exhibited by the sample in the annealed state at 770 °C, held for 1.5 hours and cooled in the furnace to 300 °C and in the air afterwards.

It is noted that hardness increases significantly in the case of quick cooling in water, while treatments followed by slow cooling in the air cause a decrease in hardness, while the structure is more stable. Thus, the optimal treatment should be selected according to the intended application.

4. Conclusions

The study of the heat treatments applied to the 20Cr130 alloy reveals a clear correlation between the parameters of the heat treatment process and the final properties of the material.

High temperatures and long holding times can lead to grain growth and a decrease in hardness, while rapid cooling can induce internal stresses in the material or lead to the formation of metastable phases.

For industrial applications where good mechanical strength is required, but also effective corrosion protection, the careful selection of a heat treatment process is essential. The solubilisation treatments followed by controlled cooling have proven effective in achieving a homogeneous structure and optimum performance.

Thus, the optimisation of heat treatments is a key factor in fully capitalising on the potential of the 20Cr130 alloy, adapted to modern technological requirements.

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