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STUDIES ON THE CORROSION RESISTANCE OF HIGH CHROMIUM ALLOY STEELS

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Abstract

The paper studies the corrosion resistance of 40Cr130 in different structural states. The material is thus characterized in the annealed, normalized, quenched, tempered state and, respectively, following a thermochemical treatment.
Good corrosion resistance was found in all states, and substantial improvements were noted following the thermochemical nitriding treatment.

Key words: chromium alloy steels, corrosion resistance

1. Introduction

The corrosion phenomenon, i.e. the spontaneous destruction of the state of the surface and, respectively, at relatively small depths on the material, is influenced by many factors [1]. These can be divided into two main categories, as follows: external factors, which depend on the environment in which the given material is located, and internal factors, which depend on the material itself. The performances of a given material are assessed according to its own characteristics. As external factors are usually imposed by the environment in which the process takes place, the manufacturer must adapt the properties of the product to the specific conditions in which the product will operate.

In the case of metallic materials, their corrosion depends on a number of factors, including the chemical composition, degree of purity and type of inclusions, structural state, grain size, occurrence of internal stresses, degree of surface finish, etc. [2, 3, 6, 8].In terms of quantity, by determining the corrosion rate and the wear rate, respectively; the corrosion rate is the mass of corroded material in the unit of time relative to the unit of surface; wear rate is the depth to which the corrosion process has penetrated relative to the unit of time, for example one year [4, 5, 7].

2. Experimental tests and results obtained

The experimental tests were conducted on 40Cr130, the chemical composition of which is shown in Table 1.

Samples were made of this steel, appropriate for the studies and tests to be performed.

The corrosion testing was performed on samples of the given steel in different structural states, obtained using heat and thermochemical treatments. Table 2 shows the range of treatments performed and the parameters thereof. The thermochemical treatment applied to some samples was gaseous nitriding, according to Table 3.

Table 1. Chemical composition of 40Cr130

Material type	Chemical composition [%]							
	C	Cr	Mn	Si	P	S	Mo	Cu
40Cr130	0.41	13.4	1.01	0.88	0040	0025	0.20	0.25

The samples used in the determinations were 20x20mm.

For the experimental tests we used:

- hardness measuring device: LECO LV 700AT4.1 and AQUASTYL RB-1E/AQ,
- Metallographic microscope LEICA DMLM,
- UTTIS vacuum heat treatment oven,
- NITRION 10 plasma nitriding installation.

The structures related to the states of the heat and thermochemical treatments conducted according to the table above are presented in figures 1-4.

Table 2. Heat treatments

Material type	Heat treatment	Temperature [°C]	Heating time [h]	Cooling medium	Hardness [HRB]
40Cr130	Initial state	-	-	-	195
	Vacuum quenching	950	1	Recirculated nitrogen	390
		1040	1	Recirculated nitrogen	477
		1100	1	Recirculated nitrogen	453
	Tempering after quenching at 1040°C	150	2	air	464
		510	2	air	316

Table 3. Applied thermochemical treatment

Material type	Vacuum quenching temperature [°C]	Vacuum tempering temperature [°C]	Plasma nitriding			Hardness HV5
			Temp. [°C]	Time [h]	Layer thickness [mm]	
40Cr130	950	150	520	20	0.2-0.3	566-580
		510	520	20		535-567
	1040	150	520	20		580-588
		510	520	20		573-598
	1100	150	520	20		552-565
		510	520	20		522-545

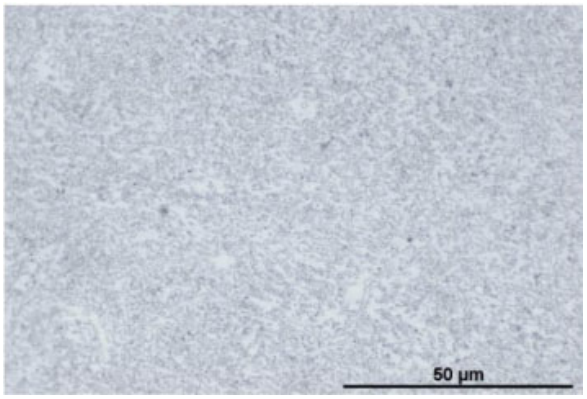

Fig. 1. 40Cr130 in initial state. Ferrite + carbides. Royal water etching. 1000:1.

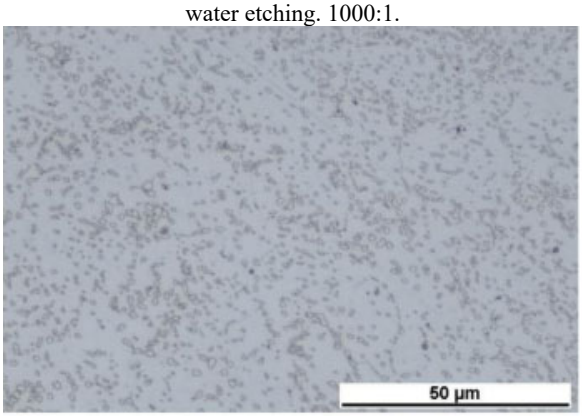

Fig. 2. 40Cr130 quenched from 1040°C. Martensite + carbides. Royal waterl etching. 1000:1

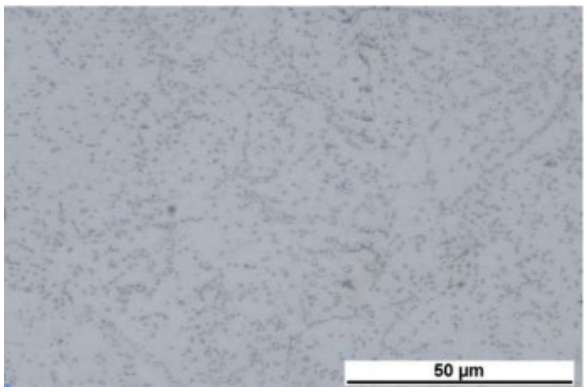

Fig. 3. 40Cr130 quenched from 1040°C and tempered at 510°C. Royal water etching. 1000:1

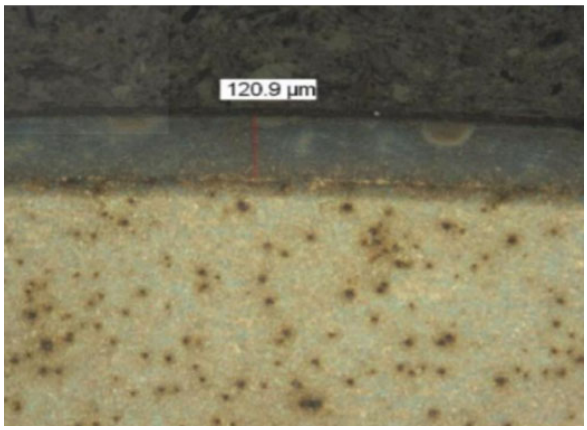

Fig. 4. 40Cr130 quenched from 1040°C and nitrided for 20 hours at 510°C. Nitrided layer. Aqua regia etching. 1000:1

The optical microscopy studies were supplemented by the SEM electron microscopy - Figures 5-7.

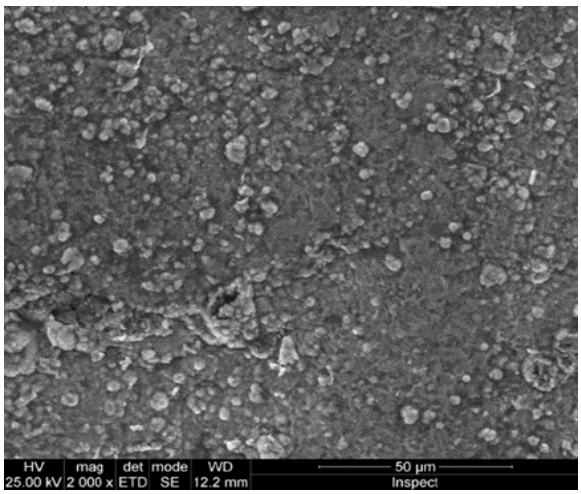

Fig. 5. 40Cr130 quenched from 1040°C and tempered at 510°C. 2000:1

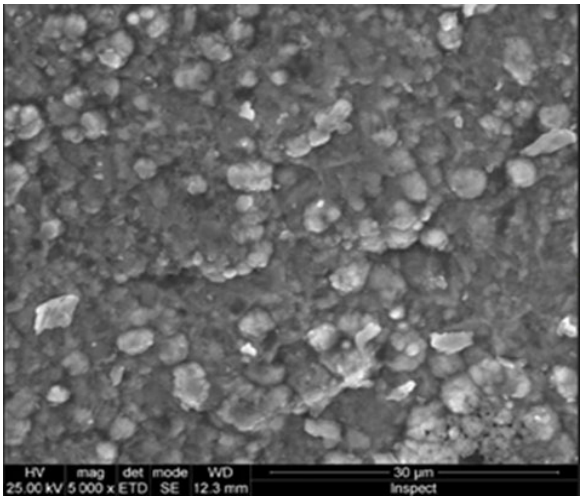

Fig. 6. 40Cr130 quenched from 1040°C and tempered at 510°C. 5000:1

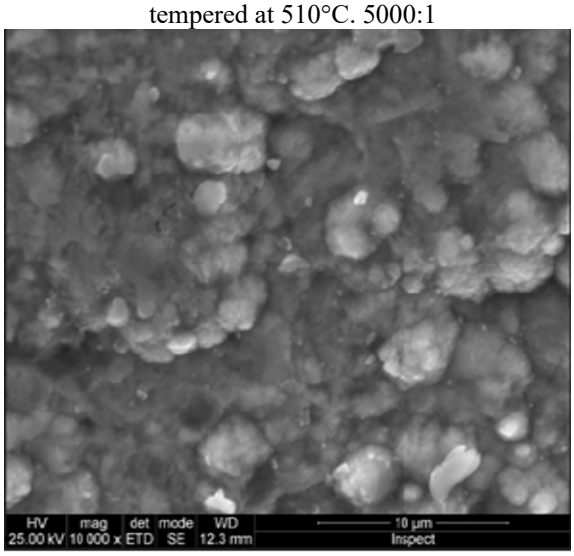

Fig. 7. 40Cr130 quenched from 1040°C and tempered at 510°C. 10000:1

There are found, in the solid solution, numerous globular Cr carbides, uniformly distributed in the base mass. The SEM analysis was also used for the quantity analysis of the core of the specimen, as well as of the nitrided layer (using a BRUKER detector attached to the SEM-TESCAN VEGA electron microscope).

Figures 8 and 9 and Tables 4 and 5 show the structure and chemical composition of the nitrided layer.

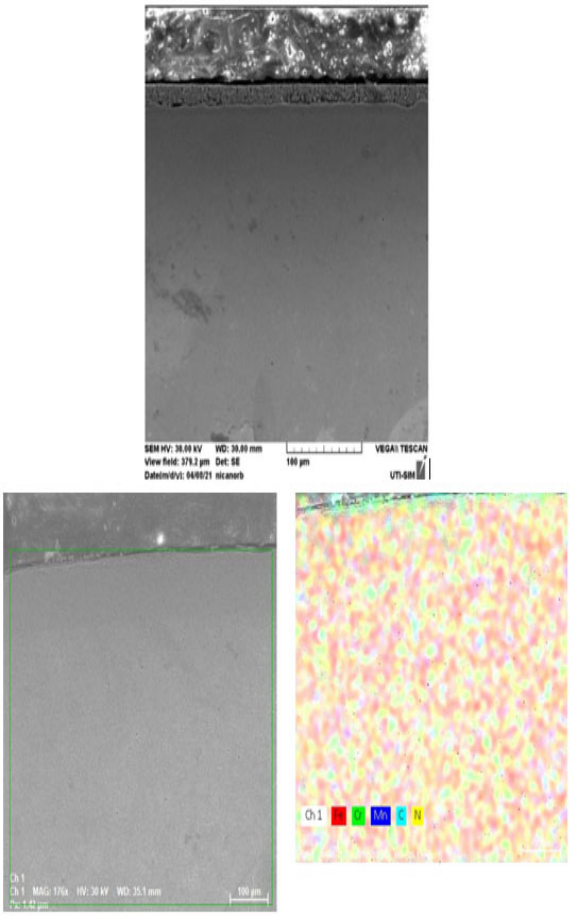

Fig. 8. SEM images of the nitrided layer of 40Cr130 quenched from 1040°C, tempered to 510°C and nitrided at 520°C

Table 4. Chemical composition of the layer

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
Iron	26	41137	70,81087	79,49236	65,72313	1,862706	2,630537
Chromium	24	10823	11,68184	13,11404	11,64553	0,363686	3,113265
Nitrogen	7	412	5,954374	6,684387	22,03527	1,988637	33,39792
Manganese	25	452	0,631755	0,709209	0,596066	0,098895	15,65394
		Sum	89,07883	100	100		

Table 5. Chemical composition of the core

Element	At. No.	Netto	Mass [%]	Mass Norm. [%]	Atom [%]	abs. error [%] (1 sigma)	rel. error [%] (1 sigma)
Iron	26	72980	70,03597	83,40508	82,42761	1,819378	2,597776
Chromium	24	22847	13,30383	15,84338	16,81737	0,390655	2,936411
Manganese	25	827	0,631071	0,751536	0,755017	0,08373	13,26791
		Sum	83,97087	100	100		

The differences in values for Cr and Mn between the surface and the core are due to the compounds that form in the layer during nitriding.

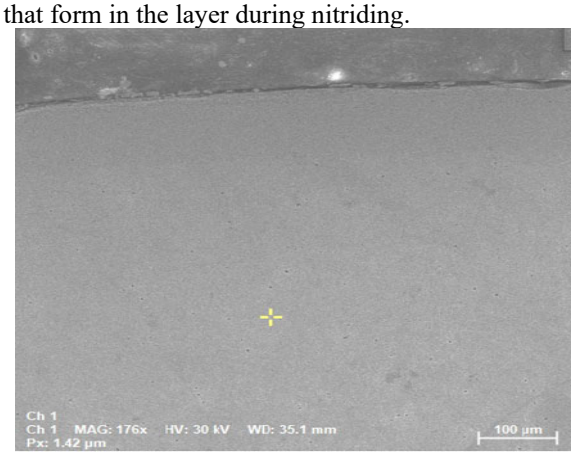

Fig. 9. SEM images of the 40Cr130 sample core, quenched from 1040°C, tempered to 510°C and nitrided at 520°C.

There can be noted the presence of nitrogen in the nitrided layer, an element not present in the material mass.

In order to determine the corrosion behaviour of 40Cr130 in different structural states, there was used the potentiostatic method, applying an increasing linear potential on the working electrode and measuring the corresponding current.

During the experimental research, the anode was the part subjected to corrosion, and the cathode was a platinum electrode, on which protons were discharged from the hydrogen-forming medium, as shown in the reaction:

$$Fe + 2H^{+} \rightarrow Fe^{2+} + H_2$$

The test equipment consisted of a PAR BioLogic VSP potentiostat galvanostat, and the tests were performed in an electrochemical cell with 3 electrodes:

- Working electrode (sample);
- Platinum counter electrode (1 cm^2 plate);
- Reference electrode (ESAE = 0.197 V).

Corrosion density:

$$Icor = \frac{Icor}{Asample} [A/m^2] \quad (1)$$

- Corrosion rate:

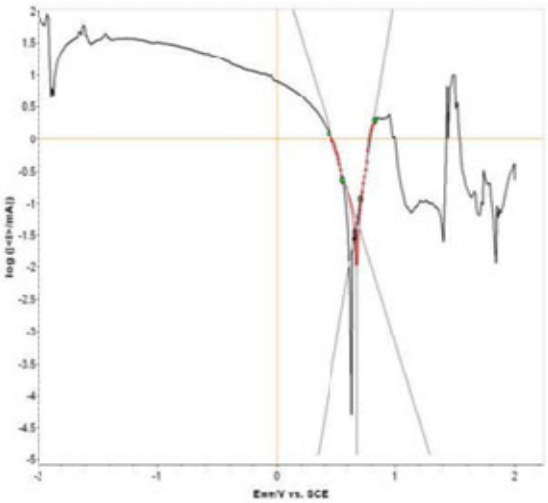

Fig. 10. Polarization curves determined experimentally for 40Cr130 quenched from 1040°C

$$Kg = \frac{Mmetal}{ZF} .Icor\ [\rho/m^2h] \quad (2)$$

where Mmet is the atomic mass of the metal, Z is the number of electrons exchanged by the metal in the oxidation process;

- Wear rate:

$$Pmm = \frac{Kg.8760}{\rho}\ [mm/year] \quad (3)$$

Figures 10-13 show part of the current-potential curves (processed using the ELab software), obtained for 40Cr130 samples.

Material type	Heat treatment		Thermochemical treatment	Vcor [g/m^{2}h]	Vwear [mm/year]
	Quenching [°C]	Tempering [°C]	Ionic nitriding		
40Cr130	950	150	-	8.22	9.16
		510	-	6.37	8.80
		510	yes	4.23	4.71
	1040	510	-	4.75	5.30
		510	yes	2.52	2.81
	1100	510	-	6.94	7.9
		510	yes	3.03	3.43

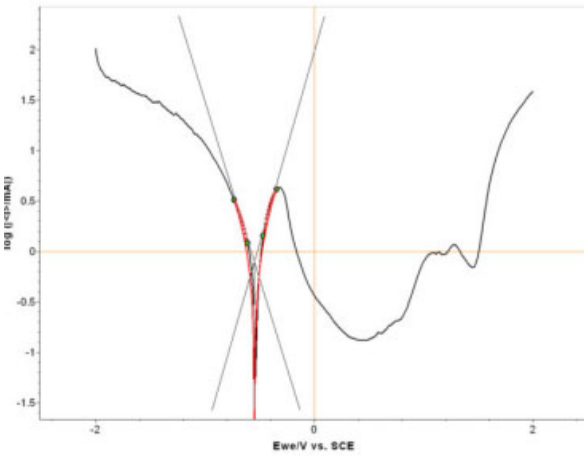

Fig. 11. Polarization curves determined experimentally for 40Cr130 quenched from 1040°C and tempered at 510°C and nitrided at 520°C

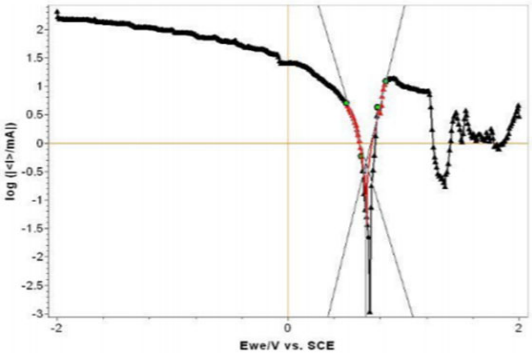

Fig.12.Polarization curves determined experimentally for 40Cr130 quenched from 1040°C and nitrided at 520°C

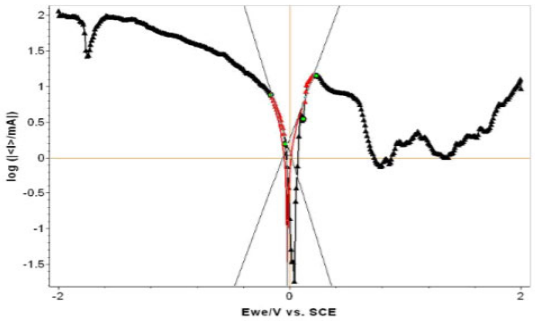

Fig.13. Polarization curves determined experimentally for 40Cr130 quenched from 1100°C, tempered at 510°C and nitrided at 520°C.

The corrosion and wear rates were determined using the polarization curves and performing the 1 ... 3 expressions calculations, as presented in Table 6

Table 6. Corrosion and wear rates

It is found in all cases that the corrosion rate decreases with the increase of tempering temperature.

3. CONCLUSIONS

The experimental results, in correlation with the metallic material analysed, led to several conclusions, among which the following stand out:

- The heating temperature for quenching is a significant parameter in terms of the influence on the structure and properties of 40Cr130; there was found that the optimum quenching temperature is 1040°C;
- Furthermore, the tempering temperature proved to be significant in terms of mechanical properties and of corrosion resistance; thus, the increase of the tempering temperature was found to lead to a slight improvement of the resistance in aggressive environments. This is also due to the decrease in the level of internal stresses;
- The quenching from 1040°C followed by tempering at 510°C had the best results in the corrosion test compared to other quenching temperatures followed by the same tempering at 510°C;
- The nitriding heat treatment performed after quenching and tempering or together with the tempering is also beneficial for the behaviour in aggressive environments. Thus, the improvement recorded increases between 40-60%. The increase is also due to the presence in the surface layer of nitrides in solid solution enriched in nitrogen.

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