Ministerul Educației Naționale
ROMÂNIA
UNIVERSITATEA DE MEDICINĂ, FARMACIE, ŞTIINŢE ŞI TEHNOLOGIE DIN TÂRGU MUREŞ

Acta Marisiensis. Seria Technologica
Vol. 16 (XXXIII) no. 1, 2019
ISSN 2668-4217, ISSN-L 2668-4217

STUDY ON THE INFLUENCE OF CARBON ON STANDARDIZED AND NON-STANDARDIZED STEEL

Liviu Dorin POP

University of Medicine, Pharmacy, Sciences and Technology of Târgu Mureș
Gheorghe Marinescu Street, no. 38, 540139, Târgu Mureș, Romania
liviu.pop@umfst.ro

Abstract

The way a piece or tool behaves in operation is determined by the quality of the material from which it is made, the precision of execution and heat treatment applied. In the present research, it is highlighted the differences that take shape after heat treating different materials (low carbon steel and high alloyed steel) including heating to dissimilar austenitic phases (880°C and 1020°C), holding for non-identical times, tempering at low temperature (260 °C) and then cooling by using separate cooling mediums (oil, air and water). The results show no noticeable increase in the hardness and mechanical properties for the low carbon steel after the heat treatment, but on the other hand, the high alloyed steel, reveals distinguishable changes in both hardness and mechanical properties. There is a close link between the structure, the parameters of the thermal processes and the properties that are desired so that future specialists have to assimilate the basic knowledge related to the phenomena that occur during a heat treatment but at the same time it is important to equip the companies with machines and measure devices, like a spectrometer.

Key words: heat treating, ferrous alloy, spectrometer, hardness, quenching, cooling mediums

1. Introduction

The succession of heating and cooling under well-defined conditions, applied to alloys, aims at obtaining optimal structures that provide the desired properties [1,3]. Modification of ferrous alloys properties, e.g. hardness, plasticity, mechanical strength are obtained by heating and maintaining them at a certain temperature for a period of time, followed by slow, medium or sudden cooling according to a diagram of the heat treatment cycle [2]. The properties resulting from heat treatments are the effect of changes in the shape and distribution of constituents, the appearance, disappearance, or change in the proportion of the various constituents making up untreated material [4,5].

The purpose of heat treatments (annealing, normalizing, hardening, tempering and surface hardening) is to change the grain size, to modify the structure of the material and relieve the stress set up in the material [6,7]. Generally speaking, carbon adds hardness to the material which improves durability. Carbon having an atomic diameter less than the interstices between the iron atoms passes into the solid iron solution distorting the original crystal lattice of iron. External applied strain interferes with this distorsion blocking it, thus providing mechanical strength. If more carbon is added to the iron, the distortion is increasing resulting raised mechanical strength [10].

If a company wants to produce different types of steel knives, for example, and the amount of carbon in the semi-finished products received from the supplier does not correspond to the chemical composition provided in the standard, it will not be possible to obtain the properties and the desired values after the heat treatments applied. To this purpose we analyze the influence of carbon on a standardized and a non-standardized steel.

2. Experimental

2.1 Materials

First of all, a **C2D1/1.1185** was chosen for demonstrating how the microstructures of a low carbon steel are formed and what type of differences occur in mechanical properties, after a heat treatment is applied. The chemical composition of C2D1 (Table 1) was determined with the help of an optical emission spectrometer, and confirmed, that the steel meets the standards [8].

Table 1: Chemical composition [%] of low carbon steel C2D1/1.1185

C2D1/1.1185	C	Si	Mn	Ni	P	S	Cr	Mo	N	Al	Cu
EN 10016-3: 1995	max. 0.03	max. 0.05	0.2 – 0.35	max. 0.1	max. 0.02	max. 0.02	max. 0.1	max. 0.03	max. 0.007	max. 0.01	max. 0.1
spectrometer	0.028	0.003	0.208	0.03	0.012	0.012	0.032	0.003	-	0.027	0.059

On the other hand, the material, received from the supplier and used for the high alloyed steel study is a non-standardized. The spectrometer provided clear results. However, besides from the carbon content, the material matches the chemical values of a standardized cold work tool steel. In other words, despite the non-identical carbon content, the material was treated like a **D2/1.2379 / X153CrMoV12** (Table 2) and the heat treatment was also applied after the standardized tool steel recommendations.

Table 2: Chemical composition [%] of high alloyed carbon steel D2/1.2379

D2 / 1.2379	C	Si	Mn	P	S	Cr	Mo	V
EN ISO 4957: 2000	1.45 – 1.6	0.1 – 0.6	0.2 – 0.6	max. 0.03	max. 0.03	11 – 13	0.7 – 1	0.7 – 1
spectrometer	1.03	0.544	0.332	0.022	0.003	11.4	0.9	0.743

2.2 Heat treatement and measurements

2.2.1 Low carbon steel

The experiment was realized using five samples, where three of them were flat tensile specimens (each of them marked, from one to three) and one 23x35 size square sample (Fig.1)

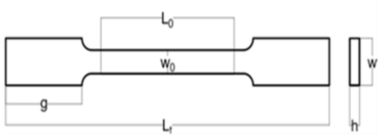

Fig. 1: Test specimen

All of the samples had the same 3 mm thickness (Table. 3)

Table 3: Test specimen dimensions

C2D1 Steel	L_0	w_0	w	h	g	L_t
Nr.1	66	11	20	3	40	170
Nr.2	65.75	11	20	3	40	170
Nr.3	58	10.75	20	3	40	170
D2 Steel	**L_0**	**w_0**	**w**	**h**	**g**	**L_t**
Nr.1	66	10.5	20	2.6	40	170
Nr.2	59.7	11.2	20	2.6	40	170
Nr.3	62	10.8	20	2.6	40	170
Nr.4	62	11.2	20	2.6	40	170
Nr.5	63.8	11	20	2.6	40	170
Nr.6	60	11.2	20	2.6	40	170

First of all, a hardness measurement was realized on the semi-finished (not heat treated/work performed) laminated metal sheet to determine the reference point for hardness. The hardness measurement, ***119HV***, was performed on the HV Micro-Vickers hardness tester CV-400AAT applying a test load of 500 gF, in a time t = 15s.

Secondly, a diagram (line chart) of the heat treatment process was realized displaying the relationship between the two variables, time and temperature (Fig. 2). The line chart was made using the help of the iron-carbon phase diagram and with some accumulated knowledge in metallurgy. Thanks to it, the next step was possible, to write a program for the chamber furnace. The heating process was realized in a Nabertherm model N 11 / HR.

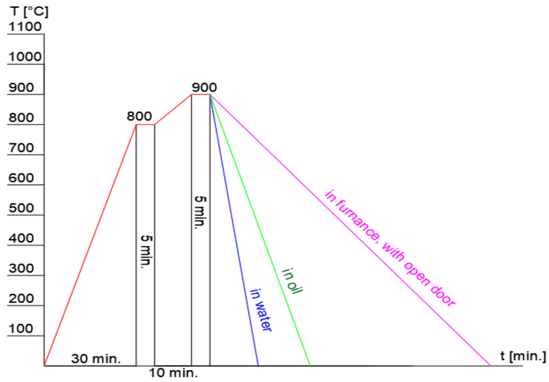

Fig. 2: Heat treating process for C2D1 (hardening)

At 800°C, after 5 min heat maintenance the nr.1 tensile specimen was extracted to verify if the temperature was enough high to pass the Curie point (in the phase diagram it is show as point A2). It is the temperature above steels lose their permanent magnetic properties (paramagnetism). The test was conducted by using a very strong magnet. After the experiment was over, the sample was put back in the furnace for further heating. At 900°C, slowly, one by one, the samples were extracted and fast cooled (quenched) in 2 different cooling mediums (water and oil). For the oil quenching, it was adopted an out of the common liquid, canola oil, which is a vegetable oil, used for cooking (oil was preheated at 40-50°C, to lower its thickness).

The nr.2 tensile specimen was quenched in oil, after that, the nr.3 tensile specimen was also quenched, but this time, in water, and lastly the square sample and nr.1 tensile specimen was normalized (cooled in air).

Finally, the samples were polished and hardness measured, with the same hardness tester, mentioned above. After all of this, the mechanical properties of tensile specimens were determined using an electrical universal testing machine, in which the samples were subjected to a controlled tension until failure. Thanks to a program, the data is collected from the testing machine, monitored and processed in different type of diagrams and data sheets.

2.2.2 High alloyed steel - D2/1.2379

For this type of steel, the experiment was conducted on six flat tensile specimens and six 25x21 size flat square samples (each of them marked, from one to six). All of the samples had the same 2.6 mm thickness (Table 1).

The fabrication of samples started with a 270x240x20 mm metal block, delivered in annealed condition. First the length was cut down to 200 mm with a metal cutting bandsaw, milled to an estimate 3mm thickness with a disc milling cutter and finally surface grinded to 2.6 mm, and to obtain the square sample (30x20x2.6) we cut down one of the end of the 200x20x2.6 metal sheet. Thus, from what was left (170 mm length), the final form of the tensile specimens was granted using an angle grinder and a bench grinder.

All of the experiments, mentioned above, such as: hardness measurement before, ***318HV***, and after heat treatment and the tensile tests, were all repeated with the same steps, and also, with the same machines.

However, there was made a new diagram of the heat treatment process, more precisely, one for the quenching - and one for the tempering operation. The heating process for the quenching operation lasted 105 min, up to 1020 C, with 5 min holding time at both 650°C and 900°C (Fig. 3). These holding times were necessary to slow down the heating process, and to minimalize the apparition of internal thermal tensions, caused by fast heating. After the heating process was done, one by one, the samples were extracted, and put to quench. For oil quenching, it was used the same canola oil, (preheated at 50°C), and the samples were: nr.1 & 5 tensile specimens and nr.4 & 5 square samples. The nr.3 & 4 labeled tensile specimens were water quench, together with nr.3 square sample. Lastly, nr.2 tensile specimen was quenched in air and nr.1 square sample was normalized, letting cool in furnace to 200°C after that it was extracted to cool in air. For nr.6 tensile specimen & square sample there was not applied, in any form, a heat treatment.

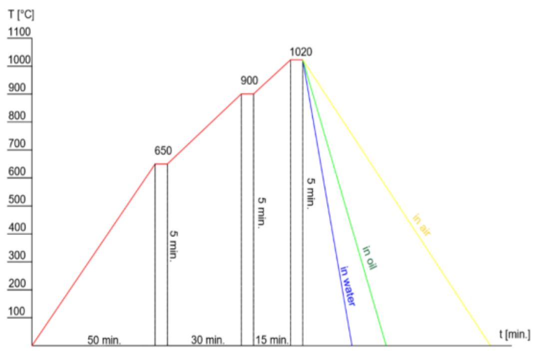

Fig. 3: Heat treating process for D2 (hardening)

Finally, to eliminate the internal tensions, caused by rapid cooling, a tempering was made. Thanks to this operation, we can increase the toughness of the steel; however, the drawback is we lose hardness. The oil and water quenched samples were slowly heated, up to 260°C, maintaining this temperature for 30 min. and slowly cooled in the furnace, with closed door, down to 150°C, followed with an air cooling (Fig. 4).

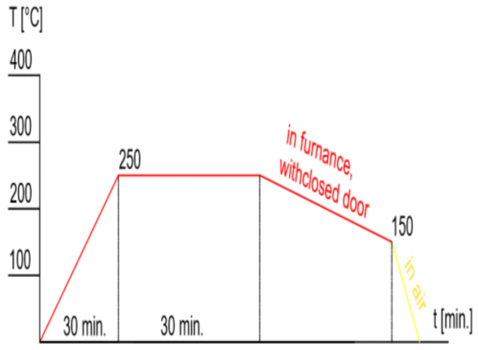

Fig. 4: Heat treating process for D2 (tempering)

3. Results

To obtain the most accurate results for hardness measurements we removed the formed oxide layer (polish down 0.4 mm material). Each hardness results listed in tables are the arithmetic average of five measurements (Table 4).

Table 4: Hardness and mechanical properties of low carbon steel steel C2D1 (tensile specimens)

Tensile specimens	**Nr.1**	**Nr.2**	**Nr.3**
Heat treatment applied	Norm.	Oil. Q.	Water Q.
Vickers Hardness (HV)	**122.3**	**130.1**	**140**
Rockwell C Hardness (HRC)	-	-	-
Max force applied (kN)	12.6	10	15.1
Yield point R_{eH} (MPa)	189	139	337
Tensile strength R_m (MPa)	**327**	**267**	**391**
Elongation ε (%)	**25.7**	**31.1**	**17.58**
L_0	66	65.75	58
L_u	83	86.2	68.2
ΔL	**17**	**20.45**	**10.2**

The measurements show the values of the mechanical characteristics of the C2D1 steel and also the fact that this steel can not be quenched (Table 4, Fig. 5).

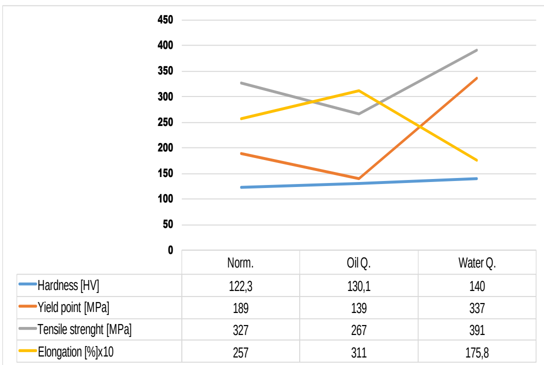

Fig. 5: Hardness and mechanical properties of low carbon seel C2D1

Meaurements for D2 steel are presented below (Table 5, 6).

Table 5: Hardness and mechanical properties of high alloyed steel D2 (tensile specimens)

Tensile specimens		Nr.1	Nr.2	Nr.3	Nr.4	Nr.5	Nr.6
Heat treatment applied		Oil Q.	Air Q.	Water Q.	Water Q.+T.	Oil Q.+T.	None
Vickers Hardness (HV)		**592.98**	**405.42**	**624.52**	**559.52**	**451.56**	**313.28**
Rockwell C Hardness (HRC)		54	41	54	52	45	33
Max force applied (kN)		8.79	21.34	4.15	17.45	24.2	19.93
Yield point R_{eH} (MPa)		150	-	114	-	-	-
Tensile strength R_m (MPa)		**322**	**733**	**148**	**599**	**846**	**684**
Elongation ε (%)		**0.3**	**1.67**	**0.16**	**0.48**	**0.78**	**2.03**
	L_0	66	59.7	62	62	63.8	60
	L_u	66.2	60.7	62.1	62.3	64.3	61.3
	ΔL	**0.2**	**1**	**0.1**	**0.3**	**0.5**	**1.3**

The reasons for choosing this type of oil are based on:

- it has close characteristics to a quenching oil
- it is cheaper / more accessible
- it doesn't release harmful gasses when the oil lights up / burns (like used motor oil).

Table 6: Hardness and mechanical properties of high alloyed steel D2 (square sample)

Square sample	Nr.1	Nr.2	Nr.3	Nr.4	Nr.5	Nr.6
Heat treatment applied	Norm.	Water Q.+ T.	Water Q.	Oil Q.+ T.	Oil Q.	None
Vickers Hardness (HV)	**595.98**	**551.42**	**697.62**	**535.86**	**595.8**	**331.1**
Rockwell C Hardness (HRC)	**54**	**52**	**57**	**51**	**45**	**34**

The results show no noticeable increase in the hardness and mechanical properties for the low carbon steel after the heat treatment, but on the other hand, the high alloyed steel, reveals distinguishable changes in both hardness and mechanical properties (Fig. 6).

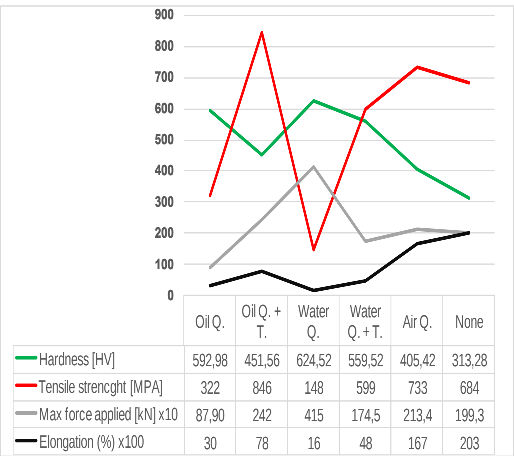

Fig. 6: Hardness and mechanical properties of high alloyed steel D2

Analyzing the data, it can be observed that, for example, the hardness value for nr.5 tensile specimen quenched in oil, is 45HRC (Table 5) although it should be approximately 60 HRC (Fig.7)

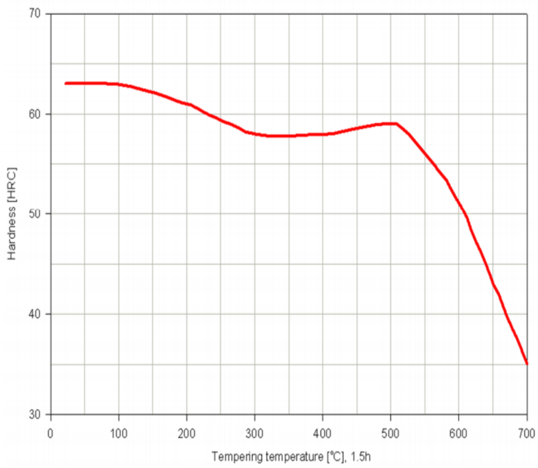

Fig. 7: Hardness of high alloyed steel D2 [9]

4. Conclusion

Steel exists in several phases that can be manipulated through heating and cooling process to produce steel with specific mechanical properties [11] but a company that produces different parts or tools of this material, and it doesn't have a spectrometer in-house to verify the chemical composition of the material, received from the supplier, risks having problems with the desired properties, after heat treatments.

Therefore, this study highlights (points out) the need of a spectrometer for dispatching the problems that can occur during productive activity, besides that, if the future specialists want to assimilate the basic knowledge about the phonemes that occur during heat treatment, the place where they work or study needs to provide the necessary equipment's. Its need to be understandable that there is a close connection (link) between the structure, parameters of thermal processes and the properties which are wished to be obtained.

Generally speaking if a product is rejected, because the heat treatment process failed, it will cause high costs, in other words, besides the material losses, we also lose labor and energy (electricity).

References

[1] Socaciu, T., Moisoiu, A. (2011), *Heat treatments*, „Petru Maior" University Press of Târgu-Mureş, Romania.

[2] Tonea, A., Aries, I., Baltac M. (2004), *Raw materials and materials*, Ed. Aramis, Bucuresti, Romania.

[3] Socaciu T. (2011), *Elements of materials science and engineering*, „Petru Maior" University Press of Târgu-Mureş, Romania.

[4] Ciurea, A., Bordei, M., Saban, R. (2007), *Elements of materials science and engineering*, Ed. Galati University Press, Galati, Romania.

[5] Wanyorek, C. (1983), *Heat treatments*, University of Brasov, Romania
[6] Tool steels guide, Dorrenberg Edelstahl, 2000
[7] Pop, L., Socaciu, T. (2016), *Manufacturing technologies,* „Petru Maior" University Press of Târgu-Mureş, Romania.
[8] http://www.steelnumber.com/en/steel_composition_eu.php?name_id=783
[9] https://www.gfsknifesupplies.com/Portals/0/Documents/1.2379%20Data%20Sheet.pdf
[10] https://engineeringresaerch.org/index.php/GJRE/article/download/969/901/
[11] https://www.huyett.com/getmedia/0a058e9e-bad2-4187-a94f-c42a53e41a3a/GLHuyettEngineeringHandbook-2014-Web.aspx