THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE IX. METALLURGY AND MATERIALS SCIENCE
N°. 4 - 2022, ISSN 2668-4748; e-ISSN 2668-4756
Article DOI: https://doi.org/10.35219/mms.2022.4.02

RESEARCH ON HEAT TREATMENT APPLIED TO HIGH STRENGTH CONSTRUCTION STEELS

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ABSTRACT

The paper presents the research carried out on a laboratory scale in order to establish the heat treatment parameters for the thick sheets used for naval constructions (welded joints). Investigations were carried out on steel sheets with two different chemical compositions.

In the same cooling conditions, returns were made at different times and temperatures. For the different sheet thicknesses of 15, 20, 22 and 24 mm, various heat treatment options were performed, by changing the cooling conditions of the sheets, respectively the cooling speeds, conditions that can be achieved in the industry.

The laboratory results showed that the required values for the mechanical characteristics are obtained only by cooling in water under pressure followed by a return at temperatures equal to or greater than 650 °C, a time greater than 70 min.

KEYWORDS: heat treatments, thick sheet metal, metal constructions, mechanical properties

1. Introduction

For high-responsibility metal constructions made by welding, such as ship hulls, the rules recommend the use of thick steel sheets with high mechanical property values [1, 2].

Obtaining these materials is done by adding alloying elements within the limits of weldable steel classes, by heat treatment [3, 4] if the technical conditions are ensured, by controlled lamination or by other methods.

Theoretically, the possibilities of improving the values of the mechanical characteristics for thick weldable steel sheets are multiple and depend on the technical endowment of the metallurgical industry, the experience and the possibilities of welding, which ensure at least equal values in the area where the sheets are joined with those of the base material for the properties of plasticity, toughness, mechanical strength and corrosion resistance [5].

For any of the methods by which it is possible to improve the values of the mechanical and technological characteristics, the specialty literature gives a series of data and principle indications regarding the brands of steels and the conditions in which the set of required properties is obtained [5].

In most cases, the mechanical transposition of data from specialized literature, without a verification of them in concrete manufacturing conditions, does not allow the systematic obtaining of satisfactory results in mass production [6]. For these reasons, it was first necessary to carry out some laboratory experiments, which take into account the possibilities created in the metallurgical industry for improving the values of the mechanical and technological characteristics of thick sheets through heat treatment [7]. The laboratory results were verified industrially to determine the thermal treatment (quenching and tempering) of the thick plates intended for the construction of ship hulls, with the joint by welding.

When establishing the quenching and tempering technology, it was aimed to ensure the obtaining of some physical-mechanical and technological characteristics corresponding to the quality prescriptions, on an economically advantageous scheme [7].

2. Experimental conditions

The studied materials were those provided by the norms [2] for the construction of ship hulls with welding. The recommended steels are produced in electric furnaces. The composition of the two steels

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on which the experiments were carried out is shown in Table 1.

Copper is prescribed as mandatory to improve corrosion behavior. The minimum 0.020% Al content is prescribed to ensure the austenitic grain equal to or finer than the one corresponding to score 5.

The behavior of steel during heating and cooling was studied in laboratory conditions by dilatometric determination of critical points at different heating and cooling rates. The Ms point was also determined for the two steels on several chemical compositions.

Table 1. *Chemical composition of the investigated materials*

Steel	**Chemical composition, %**								
	C max.	**Si**	**Mn**	**S max.**	**P max.**	**Cr max.**	**Ni max.**	**Cu**	**Al min.**
1	0.12	0.80... 1.10	1.30... 1.65	0.035	0.035	0.30	0.30	0.15-0.30	0.020
2	0.12	0.80... 1.10	0.50... 0.80	0.035	0.035	0.60... 0.90	0.50... 0.80	0.40... 0.65	0.020

For the different sheet thicknesses of 15, 20, 22 and 24 mm, various heat treatment options were performed, by changing the cooling conditions of the sheets, respectively the cooling speeds, conditions that are possible to achieve in the industry, namely: cooling in still air or in pressurized air, total or interrupted cooling by spraying water under pressure of 2.5 and 6 at on both sides of the plate in the laboratory installation sketched in Figure 1.

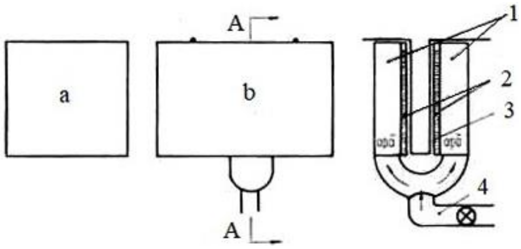

Fig. 1. *The laboratory installation for the treatment of flat samples (sheets) of different thicknesses: a - oven; b - controlled cooling device; 1 - water caisson; 2 - nozzles; 3 - centering support; 4 - water or air supply pipe under pressure*

For the same cooling conditions, returns were made at different times and temperatures. The conditions in which the optimal values of the mechanical characteristics were achieved in the laboratory were verified and completed in the experiments on an industrial scale.

In industry, due to large cooling surfaces [(1.4...3.15 m) x (8…15 m)] the panels deform slightly during cooling and therefore it was necessary to achieve the planning of the board at the temperature of return, when the remaining voltages in the board are also eliminated after planning.

The values of the mechanical characteristics imposed by the norms for the two brands of steels are presented in Table 2.

Table 2. *The values of the mechanical characteristics imposed by the norms for the studied steels*

Steel	**Sheet thickness [mm]**		**The values of the mechanical characteristics**					
		Delivery status	***R*** **MPa**	**R_c MPa**	***A_5*** **% min**	**Z, % min.**	***KCU_2*** **at – 40 °C kgf.m/cm^2**	**Bending**
1	10...32	Tempering + recovery	540...660	min. 40	19	50	min. 5	180°, 2 a
2	10...32	Tempering + recovery	540...660	min. 40	19	50	min. 5	180°, 2 a

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3. Experimental results

The values of the transformation points over a wide range of chemical composition, covering the prescribed chemical composition and ensuring the values of the mechanical characteristics, are presented in Table 3.

***Table 3.** values of transformation points over a wide range of chemical composition*

	Heating and cooling at 2.5 °C/min.				Heating and cooling at 100 °C/min.				Ms °C
Steel	Ac_1	Ac_3	A_{23}	A_{21}	Ac_1	Ac_3	Ar_3	Ar_1	
1	715... 735	890... 910	880... 827	693... 714	720... 756	906... 917	717... 770	477... 568	387... 400
2	750... 760	900... 910	800	678	760... 778	910... 918	700... 730	420... 520	390... 423

This results in a variation of the critical points in relation to the heating and cooling speeds and for each speed the transformation temperature has minimum and maximum values depending on the chemical composition of the shot.

Based on these experiences, it was established that for the thermal treatment of thick sheets, the optimal austenitizing temperature in industrial conditions is between 920…930 °C (plate temperature equal to 920 °C), and the austenitization time (heating and temperature maintenance) is 2…2.5 min/mm with the introduction of the plate directly at a temperature of 930 °C.

Under these conditions, a real fine and homogeneous austenitic grain results (Fig. 2) on the basis of which the tempering structure is formed (Fig. 3). These conditions ensure the systematic reproducibility of the characteristic values depending on the austenitic grain size (R, Rc, Z, A5, KCU.).

The level of the values of the mechanical characteristics varied depending on: the applied cooling speeds, the temperature up to which the cooling was done at speeds higher than the critical speed, therefore depending on the structures resulting from the decomposition of the undercooled austenite.

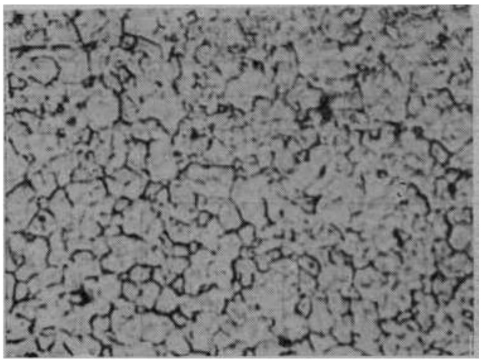

***Fig. 2.** Actual austenitic grain size (x100, Nital attack)*

The laboratory results showed that the values imposed for the mechanical characteristics are obtained only by cooling in water under a pressure of 60 MPa for a time equal to or greater than 20 s, followed by a return to temperatures equal to or greater than 650 °C, a time greater than 70 min.

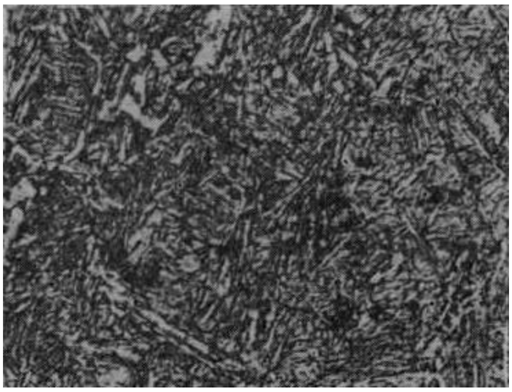

***Fig. 3.** Structure of hardened and unhardened plates (x100, Nital attack)*

The laboratory simulation of the possible treatment conditions to be achieved in the industry allowed the establishment of the minimum technological parameters for achieving the values of mechanical characteristics on an industrial scale.

Taking into account the fact that industrially the amount of metal is different, respectively the heating and cooling speeds can be different than those realized in the laboratory, the experiments led to the establishment of the limits in which the technological treatment process can be carried out to ensure the assembly optimal properties, as well as chemical composition limits.

For the coldest thicknesses (20 and 24 mm), the optimal chemical compositions are indicated in Table 4.

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Table 4. *Optimal chemical composition for the most common thicknesses*

Steel	Sheet thickness [mm]	Chemical composition, %								
		C	Si	Mn	S max.	P max.	Al min.	Cr max.	Ni max.	Cu min.
1	20	0.09... 0.12	0.85... 1.10	1.40... 1.65	0.035	0.035	0.020	0.30	0.30	0.15... 0.30
	24	0.09... 0.12	0.90... 1.10	1.45... 1.65	0.035	0.035	0.020	0.30	0.30	0.15... 0.30
2	22	0.09... 0.12	0.80... 1.00	0.50... 0.80	0.035	0.035	0.020	0.60... 0.90	0.5... 0.8	0.4... 0.65

Industrially, both the austenitization conditions and the tempering and tempering conditions were verified. The range of tests done covered a wide area. The cooling time with water under pressure was 90s until the complete cooling of the sheet.

After tempering, a lower bainite structure is obtained (Fig. 4) with a greater stability when returning. Very wide annealing conditions were experimented: annealing temperature between 650…725 °C, and the recovery time for certain temperatures between 80 and 140 min.

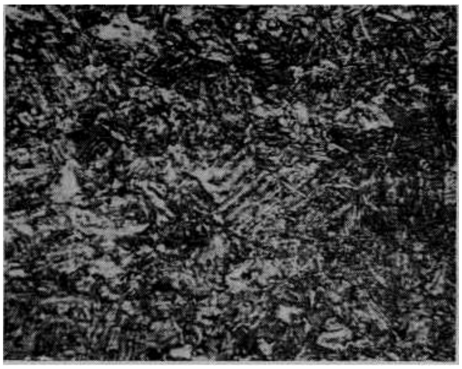

Fig. 4. *The structure of the board after a single comeback (x100, Nital attack)*

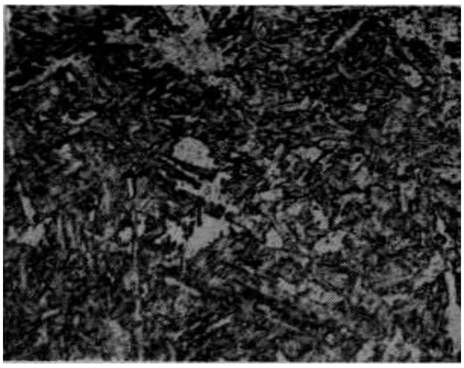

Fig. 5. *The bainite structure of the sheet after double tempering (x 100, Nital attack)*

Table 5 shows the limits of the values of the mechanical characteristics for the sheet with a thickness of 20 mm for a representative number of batches that were subjected to a tempering heat treatment with a holding time of 80 min at a temperature of 700 °C (furnace temperature), compared to the values obtained after the second heating for recovery, (at 690 °C) for 60 min, the results being presented in Table 6.

It follows that the technological parameters of heat treatment established ensure the values of the mechanical characteristics within a small gap.

The bainitic structure, which is formed by cooling with water at a pressure of 60 MPa for 20...90 s, gives after tempering a set of appropriate properties, stable even when the material is reheated either for a double tempering, or the heating during welding in the thermal influence zone where the temperature did not exceed Ac1.

It should be noted that this structure is influenced not only by the cooling conditions, but also by the specific chemical composition of the steel indicated for large-scale metal constructions (ship hulls) with welded joints.

The changes in the values of the mechanical characteristics after the second heating for recovery are very small, which shows that the bainitic structure is resistant to repeated heating (Fig. 5).

Due to the degree of dispersion and uniformity in the distribution of the carbide particles formed in the lower bainites, a high resistance (especially Rc) results, as well as a good plasticity, which are maintained during repeated heating at temperatures lower than Ac1.

The fact that through the cooling conditions of the filler material, used in the welded joints of the respective steel, a bainitic structure is also obtained, means that the material will behave better in corrosion compared to a welded joint where the structure is different from that of the base material.

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Table 5. *Values of the mechanical characteristics for the sheet with a thickness of 20 mm after a single recovery*

No. the test batch	After cooling in water and tempering at 700 °C, 80 min with planning from the tempering temperature				
	R **MPa**	***Rc*** **MPa**	***A₅*** **%**	***Z*** **%**	***KCU*, at -40 °C MPa**
1	605...635	47...49	23...24	56...57	89...110 ..11,0
2	615...66,0	43...49	21...24	50...59	63...95 .. 9,5
3	550...56,5	42...50	20...24	55...58	63...79 .. 7,9
4	610...620	47...49	20...22	50...53	70...83 .. 8,3
5	560...590*	45...49	21...24	58...61	68...84 .. 8,4

Table 6. *Values of the mechanical characteristics for the sheet with a thickness of 20 mm after a double recovery*

No. the test batch	After the second heating to return to 690 °C, 60 min and a replanning at the return temperature				
	R MPa	**Rc MPa**	**A_5 %**	**Z %**	**KCU at - 40 °C, MPa**
1	610...620 62,0	468...475 .47,5	23...25	58...61 .61	95...102 10,2
2	620...645 64,5	500...525 .52,5	21...24	59...61 .61	69...81 8,1
3	550...555 55,5	415...435 .43,5	25...27	55...59 .59	64...75 7,5
4	590...610 61,0	460...480 .48,0	21...23	56...57 .57	68...81 8,1
5	550...600 .60,0	405...470 .47,0	25...26	62...65 .65	68...78 7,8

4. Conclusions

The technological parameters of heat treatment of thick sheets in an industrial environment were established by modeling in the laboratory the industrial conditions of heat treatment.

The verification on an industrial scale led to obtaining sheet metal production with an optimal set of mechanical properties, the values of which fall within a small gap.

The temperature of the furnace was divided into zones: at the entrance, on 1/2 of the length of the furnace, the maximum temperature allowed in the furnace (930 °C) is ensured, and on the next length, the temperature prescribed for austenite (920 °C). The total maintenance time is: 2...2.5 min/mm of sheet thickness.

Heating at high speeds by introducing the sheets into the furnace at temperatures higher than the austenitizing temperature and maintaining in this area until the temperature of the sheet reaches the austenitizing temperature, then introducing and maintaining the sheet at the prescribed austenitizing temperature for the respective steel, ensures an austenitic grain really fine and homogeneous on the background of which the final structure is formed that gives high properties to the steel.

The bainitic structure, which is formed during cooling, confers after annealing a set of appropriate

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properties, stable even under the conditions in which the steel is subjected to reheating either for a double annealing or due to the thermal influence during welding.

In order to ensure the flatness of the sheets, with a smaller arrow or a maximum of 5 mm per linear meter, it is necessary to carry out planning at the return temperature, with an appropriately sized machine.

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