RESEARCH REGARDING THE HEAT-TREATMENT INFLUENCE ON THE PROPERTIES OF CA-15 MARTENSITIC STAINLESS STEEL

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ABSTRACT

The CA-15 steel in accordance with the ASTM A217 standard is one of the martensitic steels that meets the requirements of the standards regarding the use of the wellhead equipment under aggressive conditions.
The paper presents a theoretical and experimental research activity carried out in order to improve the properties of the CA-15 steel.
The results permit the selection of the right heat-treatment parameters that offer the best combination between the yield strength, tensile strength, elongation, necking, impact strength at low temperature, hardness and a crystalline refinement of the sorbite, in order to obtain a better behavior of the material under corrosive-environment conditions.

Keywords: CA-15, heat treatment, material properties

1. INTRODUCTION

This paper describes the research activity carried out in order to improve the wellhead equipment quality and performance and extend its field of application. The problems having been analysed and studied refer to the key-elements of that type of equipment, namely the bodies being under pressure as well as tubular suspending devices.
Extending the field of application of the wellhead equipment to its use under aggressive working conditions requires the use of some material brands capable to meet the requirements [9, 10], specific to the FF and HH API type materials. It is subsequently necessary to go deeply into a new field of research: that of the steel recommended by [10] for aggressive working conditions.
The CA-15 steel, one of the martensitic steels was selected to be studied. Its properties are in accordance with the ASTM A 217 standard and it meets the requirements in order to be used for manufacturing castings utilized within the wellhead equipment that works under aggressive working condition.
While the former stage of the research activity [1, 3, 4, 5] points out the importance of the steel smelting procedure and the influence of the steel chemical composition on the material behavior, this paper presents theoretical and experimental research regarding the influence of the heat-treatment on the mechanical properties of the CA-15 stainless steel.

2. RESEARCH METHODOLOGY

The research regarding the heat-treatment influence on the mechanical properties was carried out by going deeply into the following fields of research:

- theoretical study of the recommendations offered by the specialty literature regarding the parameter values of the heat treatment applied to that steel;
- experimental study of the mechanical properties of samples with the same chemical composition; those samples were applied various heat-treatment cycles consisting in quenching at the same temperature and two annealing operations under different-temperature conditions;
- study of the microstructures resulted for each type of heat-treatment;
- study of the corrosion resistance.

2.1. Theoretical Research

The CA-15 ferritic structure can be varied by the heat treatment so that a wide range of hardness (144 to 400HB) and other mechanical properties can be obtained. In the annealed condition the ferrite matrix contains agglomerated carbide particles [13]. Depending on the temperature of heat-treatment, the hardened alloy exhibits a pearlitic to martensitic structure that results in a tough, erosion-resistant material.
The melting temperature is 1510^0C. For maximum softness, castings may be annealed at minimum 788^0C and usually between 843^0C and 898^0C and slowly furnace cooled.
The alloy is hardened by heating to 982^0C -1010^0C and cooling in oil or air. After hardening, casting should be annealed as soon is possible at 315^0C max or in the range 593 - 815^0C. Annealing in the vicinity of 482^0C should be avoid because of low impact strength will result. Highest strength and hardness are obtained by annealing at 315^0C or below, and the alloy has best corrosion resistance in the fully hardened condition. When annealed above 593^0C casting have improved ductility and impact strength but corrosion resistance is decreased.
The corrosion resistance of these alloys is optimum when all carbide is in solution, a condition achieved by rapid cooling from the solution annealing temperature. However, carbide in solution will precipitate at grain boundaries when these alloys are exposed to temperature in the sensitizing range 427 to 871^0C, as may occur in service or during welding.

Mechanical Properties Variation with Annealing Temperature [13] *Table 1*

Mechanical Properties	Annealing Temperature [^{0}C]			
	315	593	649	788
Tensile Strength [MPa]	1380	931,5	793,5	690
Yield Strength, 0.2% offset [MPa]	1037	793,5	690	517,5
Elongation [%]	7	17	22	30
Hardness [HB]	390	260	225	185
Impact Strength [J]	11,02	7,37	14,75	25,81

The great influence of the annealing temperature and cooling rate on the value of the mechanical properties as shown in [6, 7, 8, 14] is described in the following figures. The Figure 1 shows a significant diminution of the impact strength in respect of the annealing temperature without important effects regarding the mechanical strength. The propensity of the annealing brittleness in conjunction with the cooling rate possible after the stress-relieving operation may be avoided when the transition from a cooling operation under another conditions featuring rates smaller than 40^0C/h is performed in accordance with [6]. The effect of the stress-relieving temperature is neglected regarding the impact strength if the annealing treatment is adequately applied (Figure 3).

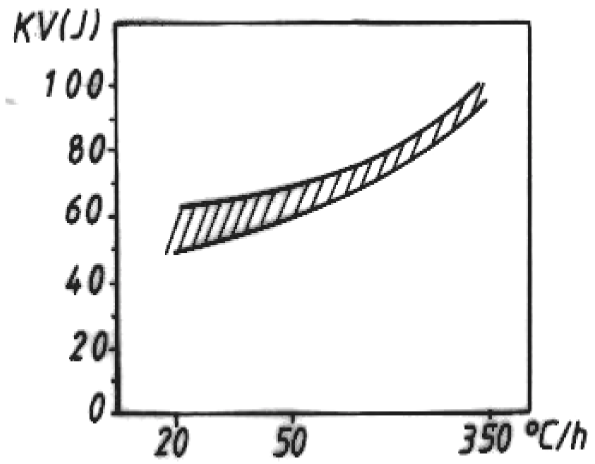


Figure 1. The effect of the cooling rate regarding the impact strength of the CA-15.

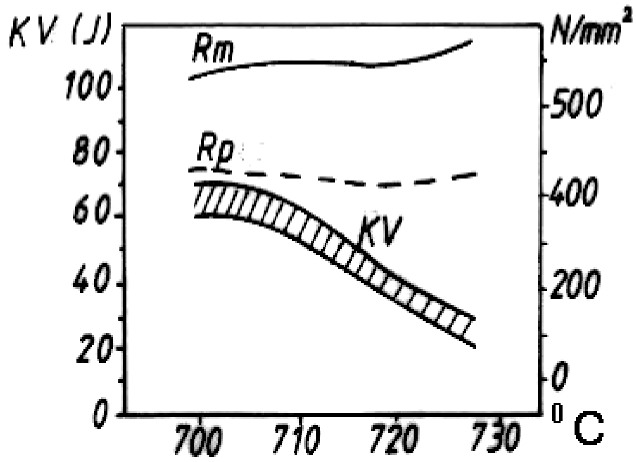


Figure 2. The effect of the annealing temperature regarding the mechanical properties of the CA-15.

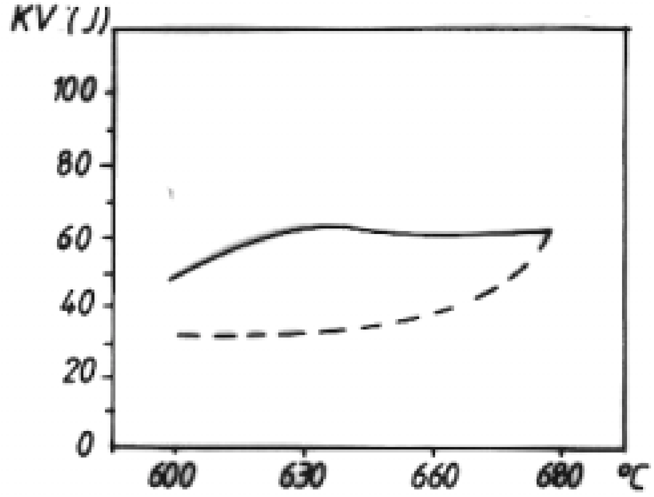


Figure 3. The effect of the stress-relieving temperature regarding the impact strength.

---------annealed at 720^0 C

——— annealed at 700^0C

2.2. Experimental Research

Determining the temperature values that generate the solid state of the steel was carried out by means of the dilatometric method. The dilatometric curves were recorded by means of a FEUTON Differential Dilatometer; its operational principle consists in correlating the structural transformations and volume

modifications occurred while the samples being studied are heated and cooled. In case of the CA-15 steel, the critical points of transformation are: $A_{C1} = 700^0$C, $A_{C3} = 880^0$C, $A_{r1} = 740^0$C, $A_{r3} = 840^0$C.
In order to study the heat-treatment influence on the mechanical properties several samples from the same heat whose chemical composition is shown in Table 2 were taken; those samples were applied various heat-treatment cycles consisting in quenching at the same temperature and two annealing operations under different-temperature conditions as shown in Table 3.

Chemical Composition *Table 2*

	Chemical Elements [%]								
	C	Mn	Si	S	P	Cr	Ni	Mo	Cu
Standard values	0.15	1.00	1.5	0.040	0.040	11.5-14	1.00	0.50	-
Measured values	0.13	0.66	0.45	0.010	0.025	12.5	0.31	0.08	0.29

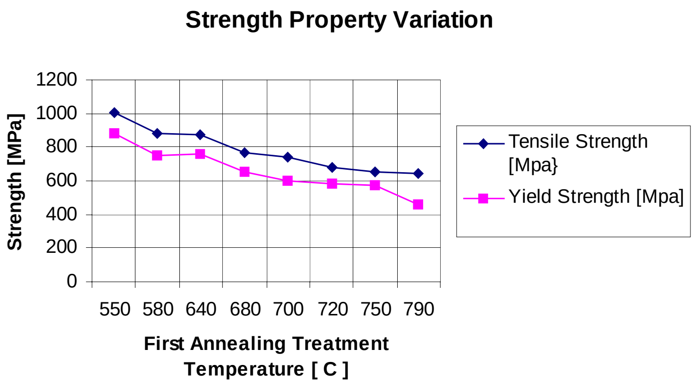
Heat Treatment Parameters *Table 3*

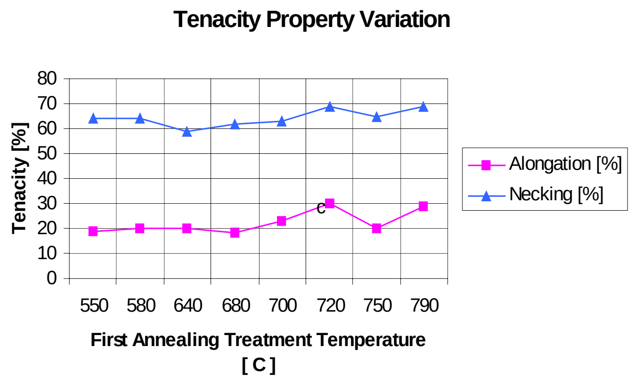
It.	Quenching Temp.	Holding Time	Cooling Environ-ment	Annealing Temp. I	Holding Time	Cooling Environment	Annealing Temp. II	Holding Time	Cooling Environment
	[^{0}C]	[min/mm]		[^{0}C]	[min/mm]		[^{0}C]	[min/mm]	
1	1030	8	oil	550	9	water	530	9	water
2	1030	8	oil	580	9	water	560	9	water
3	1030	8	oil	640	9	water	620	6	water
4	1030	8	oil	680	9	water	650	6	water
5	1030	8	oil	700	9	water	670	6	water
6	1030	8	oil	720	9	water	690	6	water
7	1030	8	oil	750	9	water	720	6	water
8	1030	8	oil	790	9	water	760	6	water

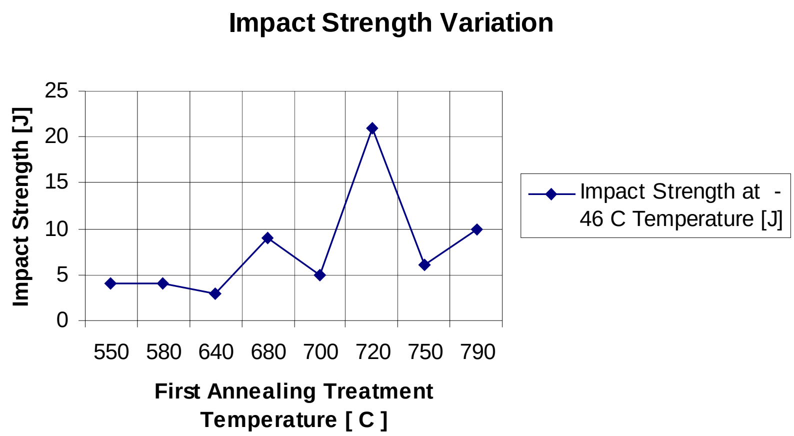
The mechanical properties induced to the specimens are shown in table 4 and specified for each variant of heat treatment. The variation of the mechanical properties depending on the annealing parameters is shown in Figure 4.

Mechanical Properties *Table 4*

It.	Hardness			Tensile Strength	Yield Strength	Elongation	Necking	Impact Strength
	After quenching	After the first annealing	After the second annealing	Rm	R_P	A	Z	$KV_{-46\,C}$
	HB	HB	HB	MPa	MPa	%	%	J
1	477	352	321	1010	880	19	64	4
2	477	285	277	880	750	20	64	4
3	461	285	269	870	760	20	59	3
4	477	262	248	770	650	18	62	9
5	477	253	230	740	600	23	63	5
6	461	233	205	680	580	30	69	21
7	461	229	229	650	570	20	65	6
8	461	200	190	640	460	29	69	10







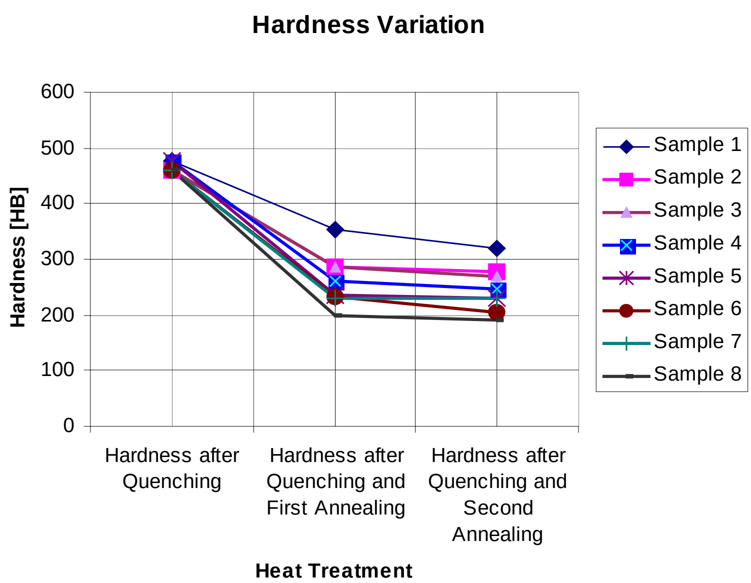
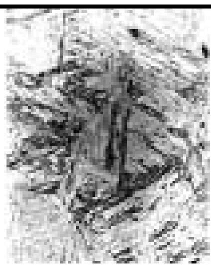
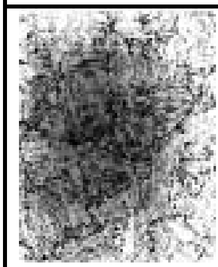
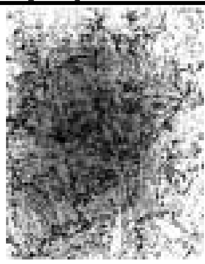
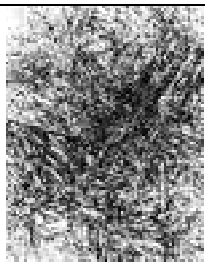
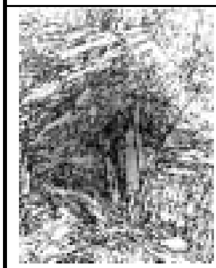
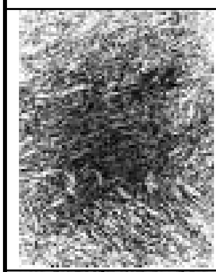
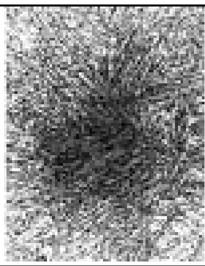
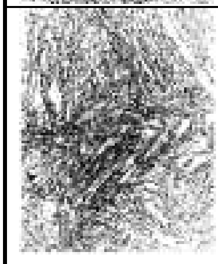


Figure 4. Mechanical Property Variation with Annealing Temperature.

2.3. Microstructure Study

The analysis of the microstructures gained for several variants of heat treatment was carried out through an electrolytic attack applied to the samples (oxalic acid as attack agent). The photos of those microstructures processed for 1000-time increases are shown in Table 5.

CA-15 Microstructures *Table 5*

 Sample quenched at 1030^o C	
 Sample 1 quenched at 1030^o and annealed at 550^o	 Sample 1 quenched at 1030^o and annealed at 550^o C and 530^0C
 Sample 2 quenched at 1030^o and annealed at 580^o C	 Sample 2 quenched at 1030^o and annealed at 580^o C and 550^0 C
 Sample 4 quenched at 1030^o and annealed at 680^o C	 Sample 4 quenched at 1030^oC, annealed at 680^o C and 650^o C
 Sample 6 quenched at 1030^oC, and annealed at 720^o C	 Sample 6 quenched at 1030^oC, annealed at 720^o C and 690^o C
 Sample 7 quenched at 1030^oC,and annealed at 750^o C	 Sample 7 quenched at 1030^oC, annealed at 750^o C and 720^o C

2.4. Corrosion Resistant Study

The last step of the research refers to the study of the corrosive agents existing within the well environment and their influence on the behaviour having been studied. The NACE tests in compliance with [10,11] permitted the researchers to include the steel having been annealed at 760^{0}C and 620^{0}C (how it was treated in the manufacturing company) to the class 55K (minimum Yield Strength value 380MPa) under corrosive environment, in acordance with [9]; that result confirms the necesity of applying the authors' recommendation regarding the proposed heat treatment, that it is presented in conclusions.

3. CONCLUSIONS

The theoretical and experimental research points out the fact that it is necessary to study the influence of the annealing parameters on the mechanical properties of the CA-15 steel in order to meet the requirements: integration into the class 75K (minimum Yield Strength value 520MPa) under normal environment, and the class 60K (minimum Yield Strength value 414MPa) under corrosive environment, a maximum hardeness of 22HRC requered by [9] and a minimum impact strength at –46^{0}C of KV_{-46C} =min 21J.

Analysing the obtained mechanical properties the conclusions are following:

- if the temperature of the primary heat-treatment of annealing increasses, the mechanical properties (i.e. the tensile and yield strength) decrease while their tenacity (elongation and necking) increase;
- the impact strength featuring the specimens annealed under temperature values up to 720^{0}C increasses considerably and then decreases suddently at 750^{0}C;
- similar variations of impact strength are also shown in other specialty papers [6, 7, 8], but the following shall be specified: a light increase of the strength properties was noticed in case of annealing above 700^{0}C; result that it is contradiction with other studies (Fig. 2).

Analysing the microstructures the conclusions are:

- the sample having been quenced shows a martensitic structure having islands of delta ferrite mixed with precipitations of chrome carbide at the limits of the grains;
- applying the heat treatment of primary annealing points out a better distribution of delta ferrite and precipitations of chrome carbide in the matrix of tempered martensite;
- applying the second operation of annealing contributes to the crystalline refinement of the substructure without eliminating the amount of delta ferrite; that fact could contribute to the steel behaviour improvement, the said improvement being visible both in case of mechanical stress and aggressive environment conditions;
- increasing the annealing temperature determines the appearance of a coarse sorbite (the sample 7) and some carbides precipitated in the shape of some globules being clearly visible and coagulated at the border of the grains.

In order to meet the requirements, the authors proposed the 6-th variant of heat-treatment, whose annealing temperature values were: t_I=720^{0}C, t_{II}=690^{0}C and not the values used in manufacturing company: t_I=760^{0}C, t_{II}=620^{0}C.

The study CA-15 steel behaviour under corrosive environment points out that the steel annealed at 760^{0}C and 620^{0}C is included to the class 55K (minimum Yield Strength value 380MPa). That result confirm the necessity of applying the authors' recomandation regarding the optimum heat-treatment parameters and also points out the need of validating that heat treatment for a better behaviour of the steel under corrosive environment conditions.

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