

THE LABORATORY EXPERIMENTS REGARDING THE INTERCRITICAL HEAT TREATMENTS APPLIED ON THE LOW - ALLOYED STEEL

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ABSTRACT

The paper presents the research results regarding the influence of the intercritical thermal treatments carried out on some hypoeutectoid steel castings.

The purpose of this research at the laboratory scale is to measure the effect of the thermal treatment which precedes the intercritical thermal treatment as well as to establish the optimum experimental variant in order to replace the classical thermal treatments.

KEYWORDS: intercritical thermal treatments, steel castings, hypoeutectoid steel

1. Introduction

Thermal treatments carried out on steels provide, according to the classical technologies, the complete austenitizing (for hypoeutectoid steels) or incomplete austenitizing (for hypereutectoid steels) and subsequently, the austenite transformation by various treatments: annealing, quenching (hardening). [1]

The latest research showed that the convenient mechanical characteristics could be obtained by intercritical thermal treatment carried out on some hypoeutectoid steels as well as on low alloyed steels.

Heating a hypoeutectoid steel, in balance condition between A_1 - A_3 interval, its microstructure ferrite - perlite, initially will become ferrite - austenite one.

The structural modifications, produced in the A_1 - A_3 interval by heating, are very complex and are depending on the chemical composition of the steel by its initial structural condition and isothermal maintaining length, by the cooling way and - specific to such treatments - the way in which the given temperature is reached: "down to up" (by heating from environment temperature) or "up to down" (by preliminary complete austenitizing and cooling in the critical interval).

Afterwards, these heating - cooling possibilities are combined with various thermal treatments, for example: quenching + tempering,

normalization, annealing or, after the preliminary treatment carried out on the respective parts. [2]

A favorable influence of the intercritical treatments on the final characteristics came out.

2. Laboratory Experiments and their Results

The intercritical treatments of Cr, Ni, Mn, Mo, low alloyed and half-hard steels lead to satisfactory results only if the quenching temperature is $AC_3 - 50^\circ C$ but final characteristics are depending on the initial condition of the steel, heating speed of the intercritical quenching and final tempering (annealing) temperature. The toughness - strength tests made on both: positive - negative temperature values resulted in sensitive higher values than for classic hardening and tempering treatment.

As a result, some research was made following the use of the intercritical treatment ranges on 34MoCrNi6 steel castings from which various items are made for industrial equipment. Steel characteristics are shown in table no.1.

In the industrial condition, the final thermal treatment for such items consists in quenching and high tempering (annealing) to get core characteristics (290 - 300 HB) and a thermal-chemical treatment (ionic nitriding) for surface (700 - 900 HV) according to fig. 1.

Table 1. 34 Mo Cr Ni 16 Steel characteristics

Chemical composition[%]						Rm	Rpo2	KCU
C	Mn	Si	Cr	Ni	Mo	N/mm ²	N/mm ²	J/cm ²
0,3... 0,38	0,4...0,7	0,17... 0,37	1,4...1,7	1,4...1,7	0,15... 0,3	1180... 1370	980	min. 39

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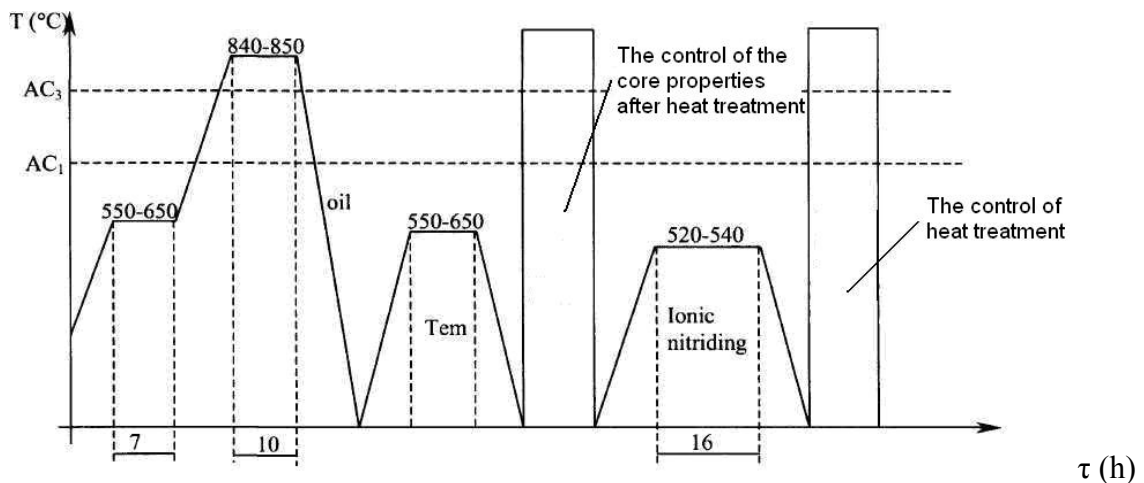


Fig. 1. Thermal and final thermal-chemical treatments of 34 Mo Cr Ni 16 steel castings.

The industrial treatment technology is complex, covering: the long time operation, expensive installation with high power and fuel consumption. As a result, the possibility of using the intercritical thermal treatment on such items and their influence on the structure and final mechanical characteristics were studied in the laboratory conditions.

The intercritical treatment conditions were used on castings after the following preliminary operation (table).

- 1 - initial condition: classical quenching + tempering after casting
- 2 - casted condition
- 3 - annealing after casting
- 4 - normalizing after casting

The intercritical treatment was made to the following diagram (fig. 2, table 2).

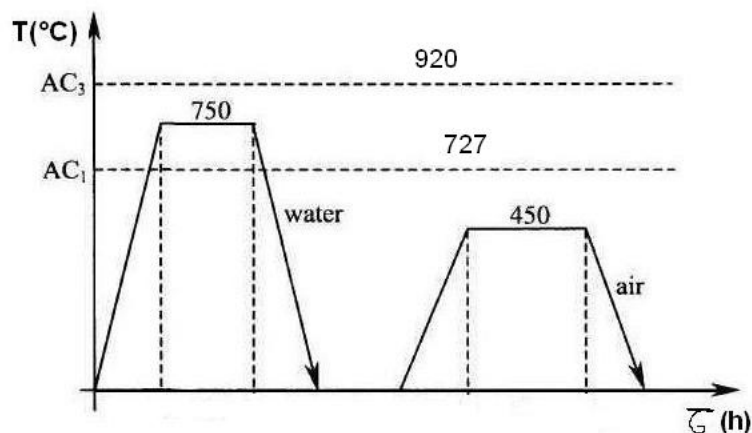


Fig.2. Treatment regime.

For 34 MoCrNi 16 the critical temperature values A_{c1} and A_{c3} were calculated by Grange relations, recommended for such steel grades: [3]

$$A_{c1} = 723 - 14 (0,56Mn + 1,47Ni) + 22 (0,4Si + 1,5Cr) = 727^{\circ}C$$

$$A_{c3} = 854 - 180 \cdot 0,33C - 14 \cdot 0,56Mn - 18 \cdot 1,47Ni + 45 \cdot 0,4Si + 1,7 \cdot 1,5Cr = 920^{\circ}C.$$

Table 2. The experimental conditions of the intercritical treatment

Experimental variants	Preliminary operations	Intercritical quenching		Tempering	
		Temperature	Time(hours)	Temperature	Time
Q ₁	Quenching + tempering	750°C	1	450°C	2,5min/mm
Q ₂	Quenching + tempering	750°C	5	450°C	2,5min/mm
C	Casted condition	750°C	5	450°C	2,5min/mm
A ₁	Annealing	750°C	1	450°C	2,5min/mm
A ₂	Annealing	750°C	5	450°C	2,5min/mm
N ₁	Normalizing	750°C	1	450°C	2,5min/mm
N ₂	Normalizing	750°C	3	450°C	2,5min/mm

As it was previously shown, the austenitization temperature is established at $A_{c3} - 50^{\circ}C$ for intercritical treatment and thermal retardation is chosen so that the distribution by diffusion of the alloying elements and their segregation to be avoided.

For experiments two holding times were chosen for quenching: 1h and 5h. The results were compared to those of the conventional treatments used in various working conditions of casting and considered as initial state for items - table 2 (table 3).

Table 3. Conventional treatments

Experimental variants	Treatment	Temperature(°C)	Time(min/mm)	Cooling agent
Q ₃	Quenching + Tempering	830 450	2 2,5	Water, Air
A ₃	Annealing	830	2	Furnace
N ₃	Normalizing	830	2	Air
N ₄	Normalizing + subcritical annealing	830	2	Air
		680	2	Air

According to [4] the intercritical treatments are used for casting parts after their preliminary treatments: quenching + classical tempering or hardening so that a fine and oriented structure to be assured. In the research framework, the quenching + tempering, annealing,

normalizing (according to table 3) were used as preliminary treatments. After treatments, the test specimens were taken and toughness-strength tests and microstructural analyses were made. Results are

shown in fig. 3(a-c). Temperature of the toughness - strength tests: 20°C; 0°C; -50°C.

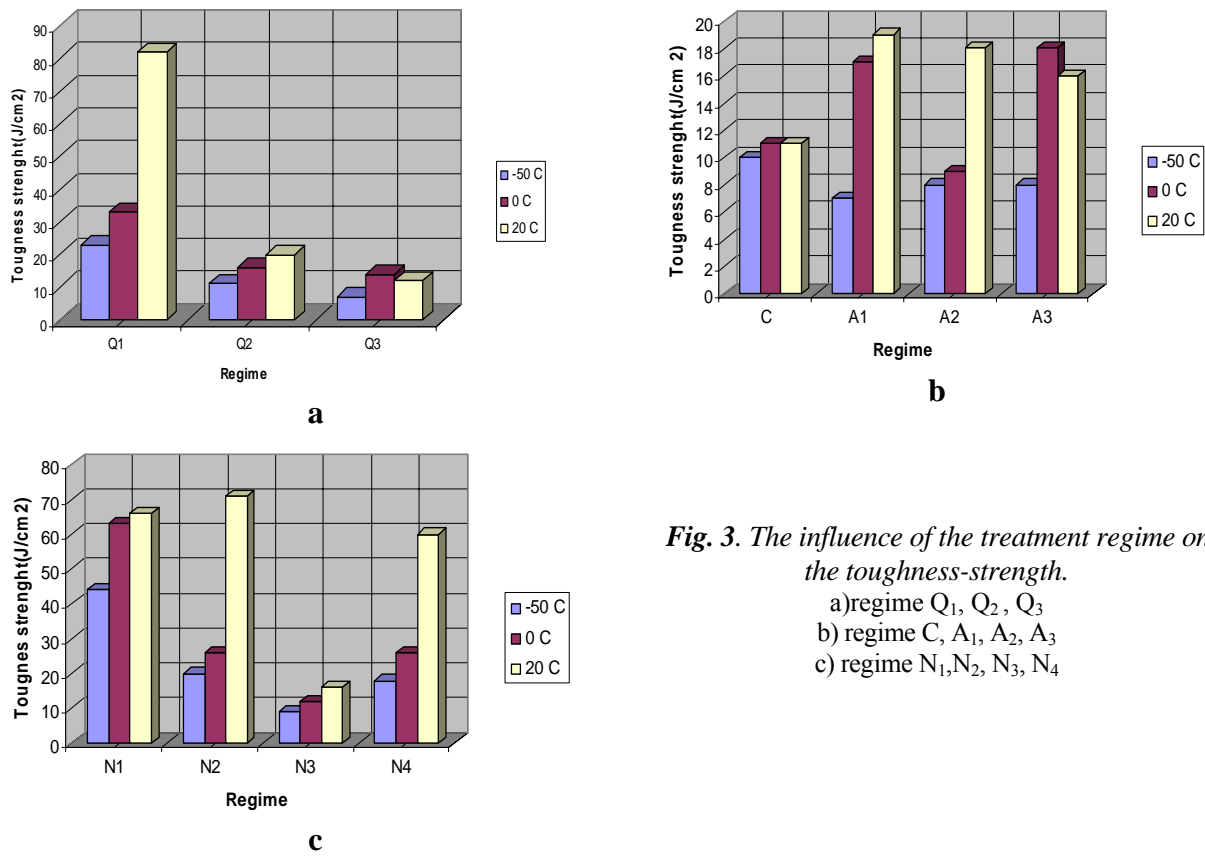


Fig. 3. The influence of the treatment regime on the toughness-strength.
 a) regime Q₁, Q₂, Q₃
 b) regime C, A₁, A₂, A₃
 c) regime N₁, N₂, N₃, N₄

The microstructures are shown in fig 4 (a-f).



a



b

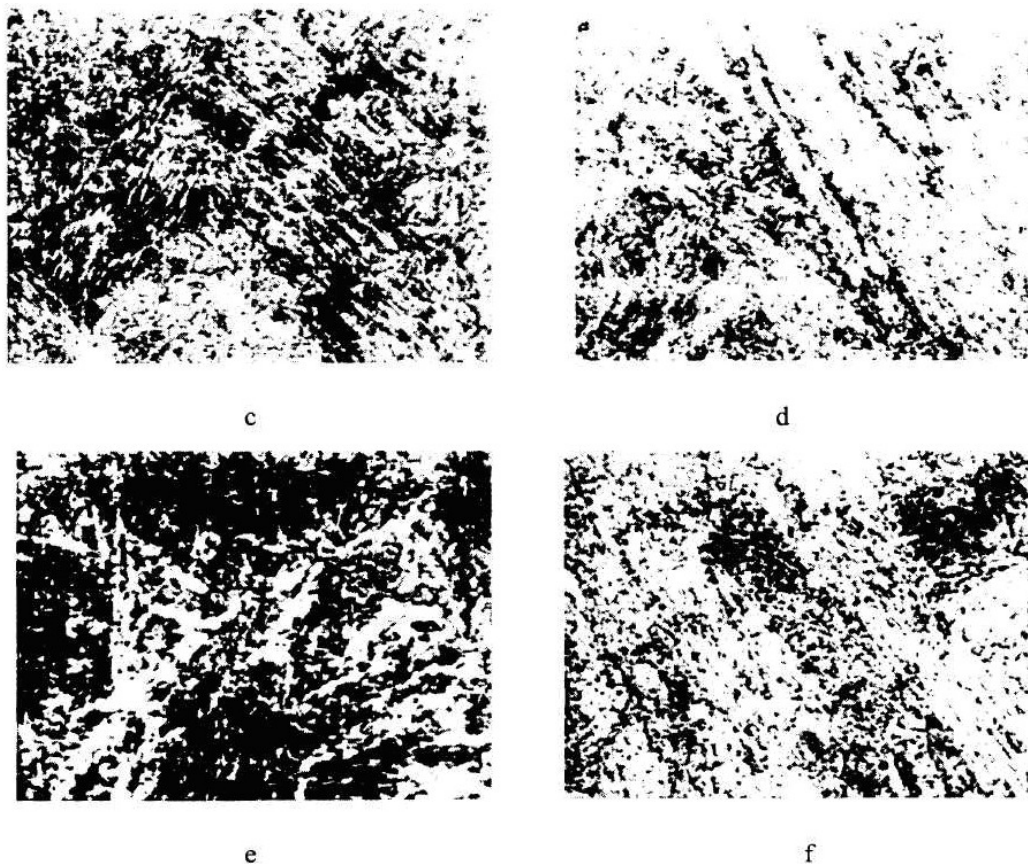


Fig.4 Microstructure aspects after intercritical treatments.(x500 magnification) etching: nital 2%.
a-steel cast; *b* - quenching + tempering (Q + T) of cast; *c*-Q + T(1h) of Q + T
d - Q + T (5h) of Q + T; *e* - normalizing; *f*-Q + T(1h) of normalizing; *g* - Q + T (3h) of normalizing.

3. Conclusions and discussions

From the result analysis the following are established:

- the highest values of the toughness-strength are obtained by an intercritical quenching treatment + tempering from normalizing initial condition, 1h at 750°C and tempering at 450°C, 2,5 min/mm - toughness-strength = 62 J/cm² at 0°C (according to STAS 8185-80, - toughness-strength = min. 39J/cm²).

- quite high values of the toughness-strength are obtained after quenching + tempering from initial condition of the quenching + tempering and also, after a quenching + tempering from normalizing initial condition (3h holding).

- It comes out that the increase of the heating holding time for quenching in the

intercritical domain doesn't improve the toughness-strength values.

The structure appearance (fig. 4) to a certain extent can explain the toughness-strength values. Thus, in the cast condition the structure is a rough acicular one (fig4a). After the intercritical thermal treatment a fine structure is obtained but with very low characteristics of tenacity yet (regime C). In the other cases, the preliminary treatments Q + T or N determine a fine and oriented structure, which, after the intercritical treatment, emphasizes the structural fineness. This characteristic was noted in the fracture surface (impact-bending test) too, which appears dull and silky (fibrously) unlike fracture surface of Q + T classic treatment where the appearance is crystalline, the fracture being on the former austenitic grains borders.

In acicular or globular austenite (initial structure) determines the martensite morphology when martensite is made, after the preliminary quenching treatment, that will result in the formation of acicular austenite at (the final treatment) the heating in the intercritical field.

As the heating is achieved in the intercritical field, besides austenite, there is also a quantity of ferrite. The increase of the holding time, at the quenching temperature, will determine a movement of the ferrite grains due to the austenite phase that is rising. Therefore the toughness might get lower to the increase of the quenching holding time (1h to 5h). Thus, for a quenching holding time $t_c = 1h$ a toughness value of $33 J/cm^2$ was obtained (at $0^\circ C$) while $t_c = 5h$, a toughness value of $16J/cm^2$ has resulted.

The tempering process brings back the toughness to higher values close to those of the initial structure.

Thus, the existence of the supersaturated ferrite with substitution and interstitial atoms, the internal tension resulted from the local transformation of the austenite into martensite, the high density of dislocation in the residual austenite grains and separation of some carbides determine the toughness values, after tempering treatment.

With the increase of the tempering temperature, the separation process of the interfaces between M plates of the lamellar carbides is emphasized, the latter becoming more

and more coarsen and with a tendency to spheroidize.

Therefore it was established that the temperature of $400 - 450^\circ C$ is the best for tempering, when the main phenomena are: density growth of the fine grains ($d < 5\mu m$) and the apparition of fine cementite at the border of the ferrite grains and sub-grains. These explanations given by the literature of specialty are confirmed in the experiments made on 34 Mo Cr Ni 16 steel.

Intercritical quenching and tempering at $450^\circ C$ might be used on the castings but only after a preliminary treatment that is Q + T. The experiments proved that preliminary normalizing + intercritical quenching and tempering at $450^\circ C$ can give better toughness values than preliminary quenching + tempering.

Intercritical treatment might replace some of the actual treatment of long time and high fuel consumption.

References

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