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Influence of tempering temperature on mechanical properties of cast steels

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Abstract

The paper presents results of research on the influence of tempering temperature on structure and mechanical properties of bainite hardened cast steel: G21CrMoV4 – 6 (L21HMF) and G17CrMoV5 – 10 (L17HMF). Investigated cast steels were taken out from internal frames of steam turbines serviced for long time at elevated temperatures. Tempering of the investigated cast steel was carried out within the temperature range of 690 ÷ 730 ^oC (G21CrMoV4 – 6) and 700 ÷ 740 ^oC (G17CrMoV5 – 10). After tempering the cast steels were characterized by a structure of tempered lower bainite with numerous precipitations of carbides. Performed research of mechanical properties has shown that high temperatures of tempering of bainitic structure do not cause decrease of mechanical properties beneath the required minimum. It has also been proved that high-temperature tempering (>720 ^oC) ensures high impact energy at the 20% decrease of mechanical properties.

Keywords: Heat Treatment, Mechanical Properties, Cr – Mo – V cast steel

1. Introduction

Changes of mechanical properties of steel casts (especially decrease of impact energy) occurring during long-term operation do not limit the possibility of their further operation. Extension of safe operation time of the cast steels is obtained through regaining of the „new” structure by means of regenerative heat treatment [1 ÷ 4].

Regenerative heat treatment of steel casts, which is currently applied in industry, consists in normalizing or full annealing from austenitizing temperature with subsequent high-temperature tempering or under annealing. Ferritic – pearlitic or ferritic – bainitic structure, obtained as a result of such a heat treatment, ensures required impact energy KV > 27J and mechanical properties comparable to those after service [5, 6].

Modern hardening plants in Poland, where aqueous solutions of polymers are applied as cooling agents, make it possible to perform cooling of massive casts with programmed cooling rate. There by obtaining of an optimum structure is ensured. [7, 8].

Self study [9, 10] done on a few dozen frames and valve chambers revealed that bainitic structure or bainitic – ferritic structure with ca. 5% ferrite content was characterized by the slightest decrease of impact energy during long-term operation at elevated temperatures. Required impact energy KV > 27J of cast steel with bainitic structure after long-term service indicates that in the regenerative heat treatment there is the necessity to apply cooling rates which ensure obtaining of bainitic structure and to match optimum parameters of tempering.

The aim of the work was to determine the influence of tempering temperature on mechanical properties of bainite hardened cast steels: G21CrMoV4 – 6 (L21HMF) and G17CrMoV5 – 10 (L17HMF).

2. Material for research

Material for research was low alloy cast steels: G21CrMoV4 – 6 (G21) and G17CrMoV5 – 10 (G17). Samples for investigation were taken from internal frames of steam turbines serviced for around 186 000 hrs at the temperature of 540 ^{o}C and pressure: 13.5MPa, and also for 252 000 hrs at 535 ^{o}C and pressure of 9MPa, for G21 and G17 cast steels, respectively. Chemical composition of the investigated cast steels is presented in Table 1.

Table 1.
Chemical composition of the investigated cast steels, %wt.

cast steel	C	Mn	Si	P	S	Cr	Mo	V
G21	0.19	0.74	0.30	0.017	0.014	1.05	0.56	0.28
G17	0.15	0.65	0.26	0.012	0.018	1.60	1.17	0.30

3. Methodology of research

Heat treatment of the investigated cast steels was preceded by dilatometric tests in order to determine critical temperatures A_{c1} and A_{c3}. Calculated temperatures amounted to: 775 and 903 for G21 cast steel; whereas: 809 and 937 ^{o}C for G17 cast steel, respectively. Treatment of the investigated cast steels consisted in their austenitization for four hours at the temperatures 910 ^{o}C (G21) and 960 ^{o}C (G17) and their subsequent cooling at the rate corresponding to the process of bainitic hardening. Tempering (4hrs) was performed at the temperature range of: 690 ÷ 730 ^{o}C (G21) and 700 ÷ 740 ^{o}C (G17). Observation and record of microstructures was done by means of scanning microscope and transmission electron microscope. Research of mechanical properties was performed according to currently obeyed standards.

4. Self study

4.1. Post operational condition

In the post operational condition the G21 cast steel revealed degraded ferritic – pearlitic structure with numerous carbide precipitations located on grain boundaries and inside ferrite grains. Carbides precipitated on grain boundaries often formed „continuous grid" of precipitates. While in pearlite grains there were two processes observed: spheroidization and coagulation of carbides (Fig. 1a). The size of ferrite grain in the investigated cast steel was diverse, and ranged from 31 to 88μm, which corresponds to 4 ÷ 7 size according to ASTM standard scale.

The G17 cast steel in post operational condition was characterized by bainitic – ferritic – pearlitic structure. On grain boundaries and inside ferrite grains there were numerous carbide precipitations observed and their morphology was diverse.

In some places the number of carbides precipitated on grain boundaries was so large that they formed „continuous grid" of precipitates. On boundaries of bainite needles there were numerous plate-like and spheroidal carbides noticed. (Fig. 1b). The size of ferrite and bainite grain was diverse and lied within the range of 125 ÷ 62.5μm, which corresponds to the 5/3 size according to ASTM standard scale.

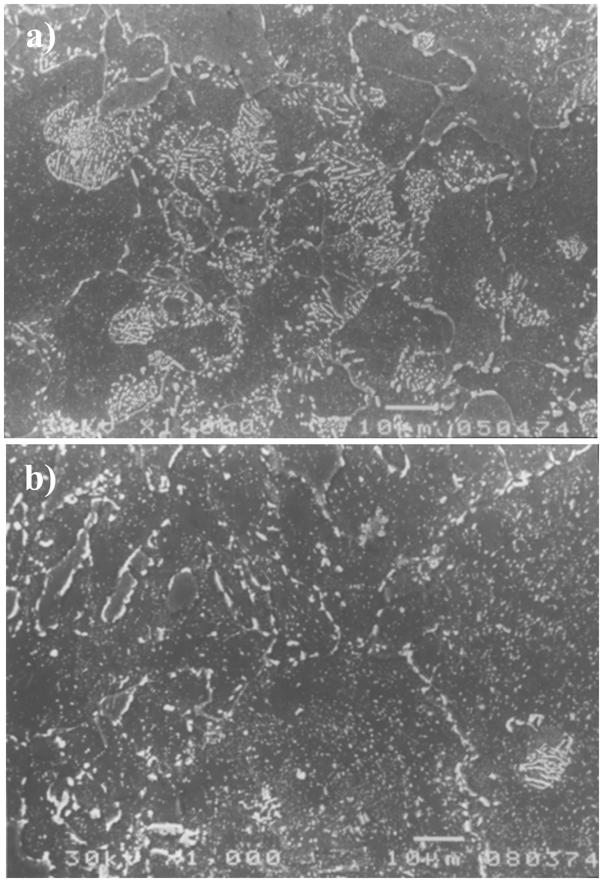

Fig. 1. Structure of the cast steel after service: a) G21; b) G17

Properties of the investigated cast steels after long term operation along with the standard requirements are presented in Table 2. The G21 cast steel after service met the requirements as to: tensile strength, elongation and hardness like for the new casts; however, it was characterized by very low impact energy and yield point lower by 15MPa than the minimum required. In the case of G17 cast steel all mechanical properties were lower than the minimum requirements.

4.2. Structure of the investigated cast steels after heat treatment

Applied heat treatment – bainitic hardening and high-temperature tempering – allowed to obtain the structure of high tempered lower bainite with high density of dislocation, with numerous carbide precipitations of diverse morphology. Performed identification of precipitates in the investigated cast steels revealed occurrence of carbides, such as: M_7C_3 and $M_{23}C_6$ on bainite packets' boundaries, as well as: MC and M_3C inside the packets. Sample microstructures of the investigated cast steels after heat treatment are illustrated in Fig. 2.

Table 2.
Mechanical properties of the investigated cast steels: G21 and G17 after service

	Material	TS [Mpa]	YS [Mpa]	El. [%]	KV [J]	HV30
G21	After service	545	305	26	10	156
	Polish Norm[1]	590 ÷ 780	min. 320	min. 20	27	140 ÷ 227*
G17	After service	491	241	14.4	12	133
	Polish Norm[2]	590 ÷ 780	min. 440	min. 15	27	---

1) PN – 89/H – 83157; 2) PN – EN 10213 – 2; * - hardness according to Brinell

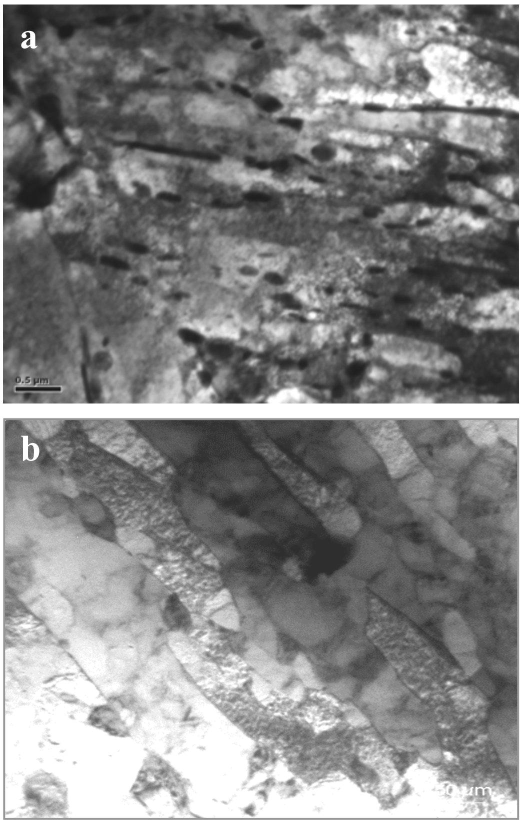

Fig. 2. Structure of the investigated cast steels after bainitic hardening and tempering: a) G21 and b) G17

4.3. Mechanical properties of cast after heat treatment

The results of tempering of bainitic structures in the investigated cast steels were as follows:

♦ in G21 cast steel: tempering at the temp. of 690 °C (the lowest tempering temperature for this grade of cast steel) contributed to obtaining of impact energy on the level of 68J with hardness of 255HV30. Elevation of tempering temperature up to 710 °C (maximum recommended by the standard), then up to 720 °C and 730 °C causes further increase of impact energy to the level of 92, 104 and 131J, respectively. Along with the impact energy increase there was also slight hardness decrease of ca. 12% in comparison to that after tempering at 690 °C (Fig. 3a, Table 3);

♦ in the G17 cast steel after tempering at the temp. of 740 °C (maximum temperature of tempering for this grade) almost twofold increase of impact energy could be observed in comparison with the one obtained at 700 °C (the lowest temperature of tempering). Together with the impact energy increase there was also ca. 15% decrease of hardness. Similar tendency could be noticed in the case of yield point and tensile strength (Fig. 3b, Table 3).

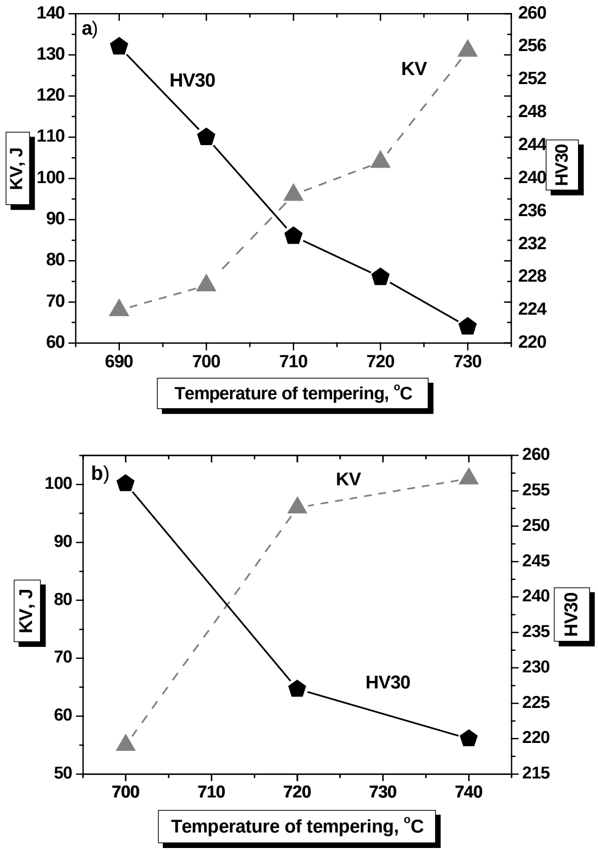

Fig. 3. Influence of the tempering temperatures on cast steels properties: a) G21; b) G17

Table 3.
Structure and properties of the cast steels after heat treatment

Material	Sort of heat treatment	TS MPa	YS MPa	El. %	KV J	HV30
G21	Temperature of tempering 720	728	620	18	104	228
G21	Temperature of tempering 730	702	583	22	131	222
G17	Temperature of tempering 700	794	606	17	55	256
G17	Temperature of tempering 740	675	486	19	101	220

5. Conclusions

1. Rise of tempering temperature causes increase of plastic properties (impact energy) with ca. 20% decrease of mechanical properties in the investigated cast steels.
2. Bainitic structure allows to apply high temperatures of tempering > 710 ^{o}C without any concern that mechanical properties might decrease below the required minimum.
3. Tempered bainitic structure ensures optimum combination of high mechanical properties and impact energy.
4. Proposed regenerative heat treatment of long term serviced steel casts allows to obtain mechanical properties on the level of new casts‘ properties.

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