Archives of Materials Science and Engineering

Volume 28
Issue 6
June 2007
Pages 341-344

International Scientific Journal published monthly as the organ of the Committee of Materials Science of the Polish Academy of Sciences

Optimisation of regenerative heat treatment parameters of G21CrMoV4-6 cast steel

G. Golański*, S. Stachura, B. Gajda-Kucharska, J. Kupczyk
Institute of Materials Engineering, Czestochowa University of Technology,
ul. Armii Krajowej 19, 42–200 Czestochowa, Poland
* Corresponding author: E-mail address: grisza@mim.pcz.czest.pl

Received 11.04.2007; accepted in revised form 15.05.2007

ABSTRACT

Purpose: of the paper was to design the optimal parameters of regenerative heat treatment of G21CrMoV4–6 (L21HMF) cast steel after long-term serviced at elevated temperature.

Design/methodology/approach: The data obtained from dilatometric curves were used to determine the optimal cooling rates leading to acquire the bainite microstructure with the ferrite amount lower than 10%. Structures were investigated using light optical microscopy and scanning electron microscopy. In order to determine stability of carbide precipitates the equilibrium temperatures of precipitates dissolving were defined using thermodynamic databases of Thermo – Calc software.

Findings: The tempered bainitic microstructure of the Cr-Mo-V cast steel has the very good mechanical properties and impact energy. The optimal bainite or bainite with a small amount of ferrite (<10%) structure can be obtained after cooling with the cooling rates

13.64 K/s $\geq v_{8-5} \leq$ 33. 33K/s. The optimal tempering temperature range of the bainitic G21CrMoV4–6 cast steel equals 710-720 ^{o}C and ensures high mechanical properties and impact energy.

Practical implications: The above mentioned heat treatment is the new type of regenerative heat treatment of elements long – term serviced at elevated temperatures. Heat treatment leads to the obtaiment of very good mechanical properties and high impact energy.

Originality/value: The paper shows the possibilities of regenerative heat treatment long term serviced cast steels for lifetime extension.

Keywords: Metallic alloys; Ductility; Heat treatment

MATERIALS

1. Introduction

Long-term operation of cast steels at elevated temperatures (450-550 ^{o}C) causes decrease of strength – greater in the case of yield point than in the case of tensile strength – and decrease of impact energy. Deterioration in functional properties is caused by changes in the cast steel microstructure due to long-lasting operation. These changes include: privileged carbide precipitation on grain boundaries and segregation of phosphorus on grain boundaries [1-6].

Reduction of impact energy caused by long-term operation of the cast steel at elevated temperature depends to a large extent on the initial cast steel structure. Individual research [7-8], carried out on samples taken from a few dozen frames and valve chambers, proved that impact energy decrease caused by long-lasting operation is the least in the case of tempered bainite structure – Fig.1.

However, changes of the structure and properties of long-term serviced cast steels do not limit the possibility of their further safe operation. Extending the operation time of long-term serviced cast steels is possible through the process of cast steel revitalization. It includes removing of deformations and fractions through welding and regeneration of the cast steel structure through heat treatment for the improvement of plastic properties (increase of impact energy, decrease of transition temperature) [9-13].

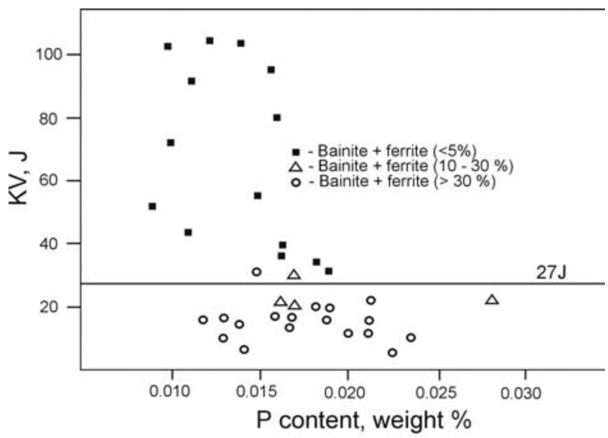

Fig. 1. Influence of the phosphorus content and microstructure on the impact energy G17CrMoV 5-10 cast steel for its long term operation at a temperature of 535 ^{o}C [7]

2. Investigated material

The material of research was G21CrMoV4 – 6 (L21HMF) low alloy cast steel taken from the internal turbine frame, serviced for over 186 000 hours at the temp. of 540 ^{o}C and the pressure of 13.5 MPa. Chemical composition of the investigated cast steel is given in Table 1.

Table1.
Chemical composition of the investigated cast steel(wt.%)

C	Mn	Si	P	S	Cr	Mo	V
0.19	0.74	0.30	0.017	0.014	1.05	0.56	0.28

After long-lasting operation the investigated cast steel had degraded ferritic-pearlitic structure – Fig.2, with numerous carbide precipitations located on grain boundaries and inside ferrite grains. Carbides precipitated on grain boundaries often formed a continuous grid of precipitates. In pearlite grains the process of spheroidization of carbides was observed. Identification of carbides by means of extraction carbon replicas revealed the presence of $M_{23}C_6$ carbides precipitated on ferrite grain boundaries and in the areas of degraded pearlite. Inside ferrite grains apart from $M_{23}C_6$ carbides there were also MC and M_2C carbides. Ferrite grain size in the investigated cast steel was diverse, ranging from 88 to 31μm, which corresponds to the grain size 4 ÷ 7 according to ASTM standards.

Table 2.
Mechanical properties of cast steel after service

	TS MPa	YT MPa	El. %	KV J	HV30
after operation	545	305	26	10	156
according to the Polish Standard*	500 ÷ 670	min. 320	min. 20	min. 27	140 ** ÷ 197

*- PN - 89/ H - 83157; ** - hardness according to Brinell

Properties of the investigated cast steel are presented in Table 2. The cast steel after service met the requirements concerning: tensile strength, elongation and hardness for the new casts. However, the investigated cast steel had very low impact energy of 10J and yield point lower by 15MPa than the minimum value defined by the Polish Standard [13].

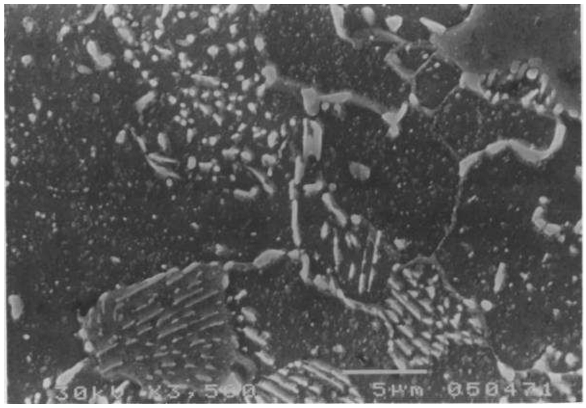

Fig. 2. Structure of the investigated cast steel after service

3. Purpose and assumptions of the experiment

The aim of regenerative heat treatment of the cast steels is obtaining of the required plastic properties with a particular consideration for the impact energy. For this reason some changes are necessary in the structure degraded by long-lasting operation. These changes are:

1. grain size reduction allowing to increase the crack resistance, decrease the transition temperature and raise the yield point;
2. dissolving of carbides in austetnite, particularly the carbides precipitated on grain boundaries;
3. obtaining of tempered bainite structure in the entire cast.

3.1. Grain size reduction

The basis for determining the optimum heat treatment parameters is determining of the critical temperatures A_{c1} and A_{c3}, which amounted to 775 and 903^{o}C, respectively (for the investigated G21CrMoV4-6 cast steel). Due to austenite coarsening propensities of the cast steel [14] it is necessary to define the influence of austenitization temperature on the grain size – Fig.3.

Austenitization at the temperature range of A_{c3} + 10 ÷ 30 ^{o}C allows to obtain fine-grained structure. Temperature higher by 40^{o}C than the estimated A_{c3} contributes to coarse-grained structure formation. Austenite grain mean diameter at the temperature higher by 40 ^{o}C than $A_{c3,}$ increased by over 40% in relation to the grain size at the temperature range of A_{c3} + 10÷30^{o}C. The above-mentioned interrelation has been confirmed for another cast.

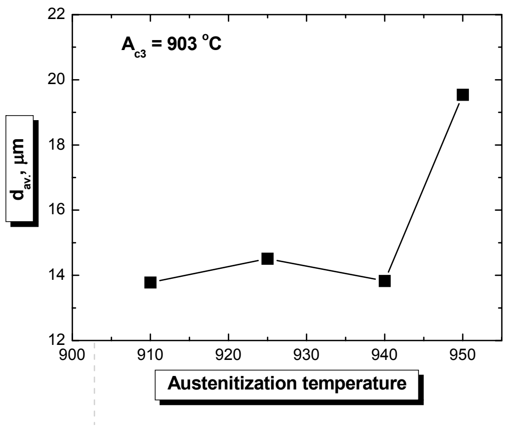

Fig. 3. Changes of the austenite grains mean diameter depending on the austenitization temperature

3.2. Dissolving of the carbides in austenite

In order to determine stability of carbide precipitates the equilibrium temperatures of precipitates dissolving were defined. Calculations were made on the basis of the data provided by thermodynamic databases of Thermo – Calc software – Fig. 4.

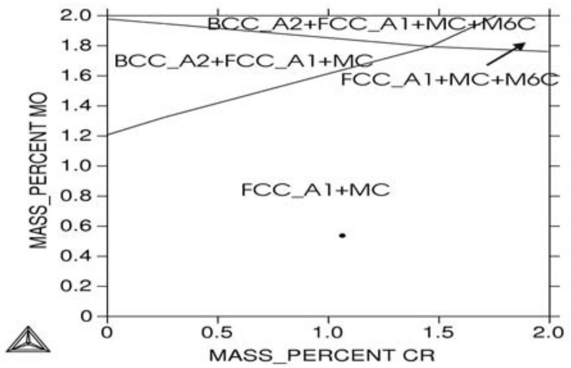

Fig. 4. Isothermal section of investigated cast steel calculated using THERMO – CALC at 1180K, position of the cast steel is marked by solid circle

The calculations proved that during the austenitization process, dissolving of carbides in matrix takes place, excluding MC carbides. Carbides of MC type are stable up to the temperatures of above 1100 °C, due to their high thermodynamic durability.

3.3. Obtaining of the required structure and properties

On the basis of the dilatometric curve analysis for the investigated cast steel, it has been proved that austenite cooled at the rate of 0,869 K/s ≥ v_{8-5} ≤ 33.33 K/s is transformed into ferrite and bainite with the increasing fraction of bainite as the cooling rate rises. Cooling rate of v_{8-5} ≥ 13.64 K/s ensures obtaining of the bainitic – ferritic structure with ferrite fraction of about 10%. The optimum range of cooling rate for G21CrMoV4 –6 cast steel, in order to obtain bainitic or bainitic-ferritic structure with a slight ferrite fraction (< 10%) is presented in Fig. 5.

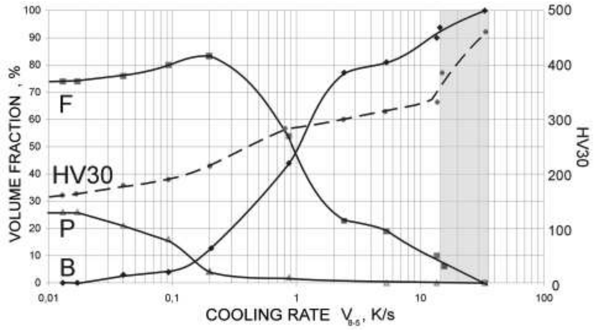

Fig. 5. Influence of the cooling rate on structure and hardness of the cast steel

In order to determine properties of the cast steel with bainitic structure, heat treatment was carried out. It consisted in austenitization of samples at the temperature of 910 °C for 3 hours and cooling in order to obtain bainitic structure. Then the samples were tempered for 4 hours at the temp. of 690 ÷ 730 °C. Long, i.e. three- and four-hours' holding time is applied for massive casts. Such heat treatment with the above mentioned parameters allowed to obtain the structure of high tempered bainite with numerous carbide precipitates on former austenite grain boundaries and on the lath boundaries – Fig. 6.

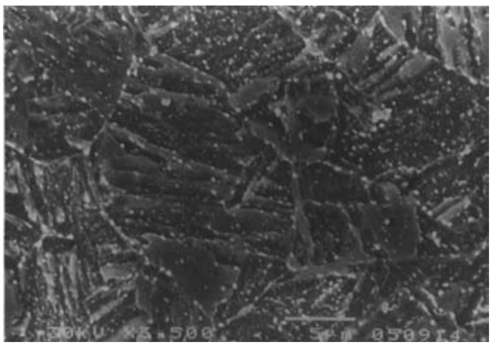

Fig. 6. Structure of the cast steel after regenerative heat treatment

Bainitic structure, gained due to heat treatment, allows to apply high temperatures of tempering, which are necessary to obtain optimum combination of strength and ductility. Influence of tempering temperature on the properties of the investigated cast steel is shown in Fig.7. and Table 3.

Tempering of the investigated cast steel at the temperature of 690 °C contributes to gaining hardness of 255HV30, with the impact energy amounting to 68J. Raising of the tempering temperatures up to 710 °C (maximum recommended by the norm) and up to 720 and 730 °C results in impact energy increase to 92, 104 and 131J, respectively. Together with the impact energy rise, there is also a slight decrease of hardness (about 10%), in comparison with the tempering temperature of 690 °C.

High tempering temperature not only ensures the required functional properties, but it also contributes to the increase of structure stability, slowing down the processes of structure degradation.

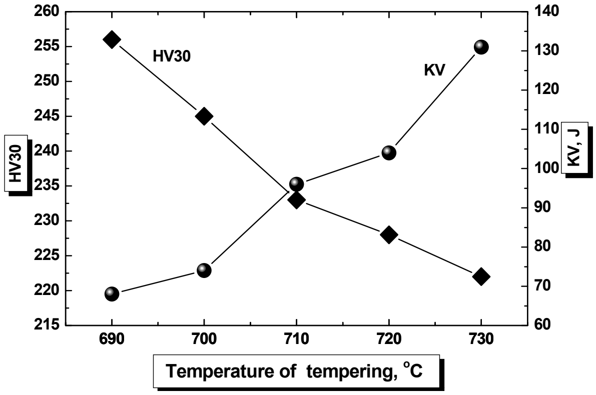

Fig. 7. Influence of tempering temperature on changes of hardness and impact energy

Table 4.
Structure and properties of the G21CrMoV4 – 6 cast steel after regenerating heat treatment

Parameters of the heat treatment	TS MPa	YP MPa	El. %	KV J	HV30
910 °C/ 3h/ 33,33 K/s + 720 °C/4h	728	620	18	104	228
910 °C/ 3h/ 33,33 K/s + 730 °C/4h	702	583	22	131	222
According to Polish Standard *	500 ÷ 670	min. 320	min. 20	min. 27	140 ** ÷ 197

*- PN - 89/ H - 83157 ** - hardness according to Brinell

4. Conclusions

1. Tempered bainite structure in regenerated Cr – Mo – V cast steels ensures obtaining of the optimum combination of mechanical properties and impact energy.
2. Obtaining of the optimum structure of: bainite or bainite with a slight amount of ferrite (< 10%) requires cooling of the steel castings at the rate of $v_{8-5} \geq 13.64$ K/s.
3. The optimum range of tempering temperature for G21CrMoV4 – 6 cast steel with bainitic structure is 710-720 °C.

Acknowledgements

Scientific work funded by the Ministry of Education and Science in the years 2006-2008 as a research project No. DWM/46/COST/2005.

References

[1] O.I Balyts'kyi, I.V Ripei, Kh. A Protsakh, Degradation of the cast elements of steam turbines of thermal power plants made of 20KhMFL steel in the course of long – term operation, Materials Science 41 (2005) 423-426.
[2] D. Renowicz, A. Hernas, M. Cieśla, K. Mutwil, Degradation of the cast steel parts working in power plant pipelines, Journal of Achievements in Materials and Manufracturing Engineering 18 (2006) 219-222.
[3] W. Brunne, Material fatigue degradation of cast HP pipe cross, Energetic 2 (1999) 103-109 (in Polish).
[4] J. Okrajni, K. Mutwil, M. Cieśla, Chemical pipelines material fatigue, Proceedings of the 13th Scientific International Conference on Achievements in Mechanical and Mechanical Properties 2005, 497-502
[5] Z. Lu, R.G. Faulkner, P.E.J. Flewitt, The role of irradation – induced phosphorus segregation in the DBTT temperature iun ferritic steel, Materials Science and Engineering A 437 (2006) 306-312.
[6] M.A. Islam, J.F. Knott, P. Bowen, Kinetics of phosphorus segregation and its effect on low temperature fracture behaviour in 2.25Cr - 1Mo pressure vessel steel, Materials Science and Technology 21 (2005) 76-84.
[7] S. Stachura, J. Kupczyk, M. Gucwa, Optimization of structure and properties of Cr – Mo and Cr – Mo – V cast steel intended for use at increased temperature, Foundry Review 54 (2004) 402-408.
[8] G. Golański, S. Stachura, B. Gajda, J. Kupczyk, Influence of the cooling rate on structure and mechanical properties of L21HMF cast steel after regenerative heat treatment, Archives of Foundary 6 (2006) 143-150 (in Polish).
[9] J. Trzeszczyński, E. Grzesiczek, W. Brunne, Effectiveness of solutions extending operation time of long operated cast steel elements of steam turbines and steam pipelines, Energetic 3 (2006) 179-184 (in Polish).
[10] J. Dobosiewicz, Present experience connected with the revitalization of steam turbine cylinders, Energetic 1 (1996) 39- 41 (in Polish).
[11] A. Rehmus – Forc, Change of structure after revitalizatrion cylinders of a steam turbine, Materials Science and Engineering 3 (2006) 265-267 (in Polish).
[12] K. Dudziński, K. Dudziński, L. Pękalska, G. Pękalski, Welding and regenerative heat treatment of steam turbine castings, Materials Science and Engineering 6 (2003) 712-715 (in Polish).
[13] PN–89/H–83157–Steel castings creep resistant at elevated temperatures. Grades (in Polish).
[14] G. Golański, J. Kupczyk, S. Stachura, B. Gajda Regenerative heat treatment of Cr –Mo–V cast steel after long term serviced, Materials Science and Engineering 3 (2006) 147-150 (in Polish).