Archives of Materials Science and Engineering

Volume 49
Issue 2
June 2011
Pages 103-111

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Changes in the structure of VM12 steel after being exposed to creep conditions

A. Zieliński [a],*, J. Dobrzański [a], M. Sroka [b]

[a] Institute for Ferrous Metallurgy, ul. K. Miarki 12, 44-100 Gliwice, Poland

[b] Division of Materials Processing Technology, Management and Computer Techniques in Materials Science, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland

* Corresponding author: E-mail address: azielinski@imz.pl

Received 15.03.2011; published in revised form 01.06.2011

ABSTRACT

Purpose: of this paper is to present the changes of structure in material components of the power station boiler after long-lasting annealing made X12CrCoWVNbN12-2-2 (VM12) steel.

Design/methodology/approach: As a material for examination X12CrCoWVNbN12-2-2 steel was use in the form of a pipe ∅ 355.6×35 mm after long-lasting annealing and creeping at the temperature of 600 and 650°C over the time of up to 30 thousand hours.

Findings: The observations of changes in the image of the structure when the structure of VM12(X12CrCoWVNb12-2-2) steel was subjected to simultaneous influence of time, temperature and stress were carried out on the specimens after creeping. The analysis of phase composition of the release in VM12 steel in the input condition and after long-lasting annealing was carried out with the application of a diffractometer Philips PW 1140, using cobalt rays with the graphite monochrometer on the side of the deflected beam.

Practical implications: The presented method can be used for evaluation and qualification of structural changes in power station boiler components operating in creep conditions.

Originality/value: The presented results of changes in the mechanical properties, structure and in the precipitation processes are applied to evaluation the condition of the elements in further industrial service.

Keywords: Structure; Degradation after exposure test; Hardness; Creep

Reference to this paper should be given in the following way:

A. Zieliński, J. Dobrzański, M. Sroka, Changes in the structure of VM12 steel after being exposed to creep conditions, Archives of Materials Science and Engineering 49/2 (2011) 103-111.

PROPERTIES

1. Introduction

In order to satisfy a constantly growing demand for energy and to ensure safe functioning of the country's power system, the installed power capacity should be increased from 3000 to 5000 MW [1]. Therefore, a fast development of the power engineering sector is necessary. Such a fast development of the power engineering sector should allow for the installation of the most effective blocks of high efficiency and minimum negative impact on the environment, such as overcritical parameter boilers with the steam temperature of about 600°C and steam pressure of about 27 MPa. The manufacture of boilers having such parameters has become possible through the working out and implementation of new steels from the group of 9-12Cr into in the power industry, among others of the types P/T-91, P/T-92, E911, VM12 [2-21].

New generation martensitic steels have been produced in effect of the modification of chemical composition of steels applied to date in the power engineering. These steels are characterized by high mechanical properties, e.g. creep strength is higher at least by 20-25% than that obtained for steels applied to date. Yet the content of chromium in these steels, being at the level of 9%, is limiting their application to the temperature of 580-600°C. Higher content of chromium at the level of 12% is required to ensure the resistance to oxidation and gas corrosion during the exploitation at the temperature above 600°C. In order to meet such requirements, a steel containing about 12% of chromium has been found in Europe, with the reference symbol of VM12, for which the notation of X12CrCoWVNbN12-2-2 was accepted. This steel was supposed to be characterized by higher creep strength than the steel P/T92 and by the resistance to oxidation and gas corrosion comparable to the austenitic PT304/PT347 steels [2].

The paper presents the results of investigation studies on the structure of VM12 steel in the input condition and after long-lasting annealing and creeping at the temperature of 600 and 650°C over the time of up to 30 thousand hours.

2. Investigated material

The studies were carried out for the high-chromium steel of the type X12CrCoWVNb12-2-2 (VM12). The investigated material was in the form of a section of thick-wall pipe of the dimensions of ϕ355.6x35 mm, which was obtained in effect of the international cooperation within the program COST 536. The analysis of the chemical composition of the investigated material as compared to the requirements is presented in Table 1.

3. Obtained results

3.1. Structure of VM12 steel in the input condition

After the heating treatment, the X12CrCoWVNb12-2-2 (VM12) steel is characteristic of the structure of high-tempered lathe martensite of subgrain structure with numerous inclusions of carbides and carbonitrides (Figs. 1-2). The carbides (carboborides) $M_{23}C_6$ are created mainly along the grain borders of former austenite and along the borders of lathe of martensite, stabilizing the subgrain microstructure. Single carbides (carboborides) $M_{23}C_6$ are also observed inside ferrite subgrains. Small inclusions of nitrides or carbonitrides of MX type is observed mainly on the dislocations inside the subgrains and along subgrain borders. Fine-dispersion inclusions of this type is an effective obstacle for the dislocation movement, ensuring in this way high creep strength. This steel has also a tendency to form high-temperature ferrite. The amount of delta ferrite in this steel should not exceed 2%. Its higher amount has a considerable influence on lowering the plastic properties [2].

3.2. Influence of annealing temperature and time on the structure of VM12 steel

The research results involving the influence of annealing temperature and time of VM12(X12CrCoWVNb12-2-2) steel on the structure observed in the scanning electron microscope after about 6000, 10000, 15000 and 30000 hours of annealing at the temperature Tb=600°C, and after about 1000, 10000, 15000 h at Tb=650°C are presented respectively in Figs. 3-16.

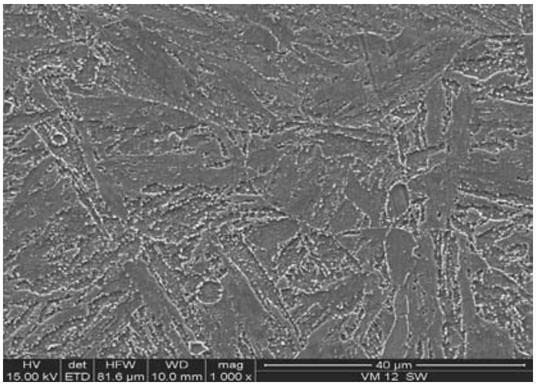

Fig. 1. Structure of the VM12(X12CrCoWVNb12-2-2) steel observed in the SEM (1000x)

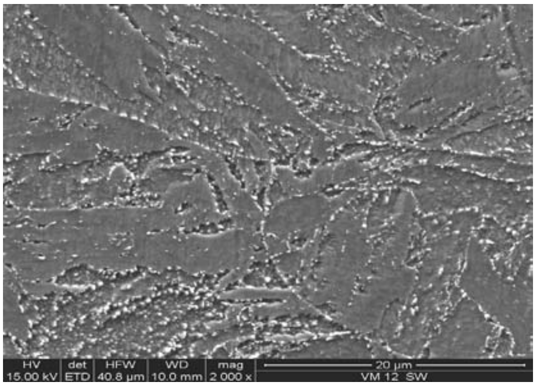

Fig. 2. Structure of the VM12(X12CrCoWVNb12-2-2) steel observed in the SEM (2000x)

Table 1.
Control analysis of chemical composition

Material type	Chemical composition, %											
	C	Si	Mn	Cr	Ni	Mo	V	W	Nb	Co	B	N
Steel X12CrCoWVNb12-2-2 (VM12) according requirements	0.11-0.14	0.40-0.60	0.15-0.45	11.0-12.0	0.20-0.40	0.20-0.40	0.20-0.30	1.30-1.70	0.03-0.08	1.40-1.60	0.0030-0.006	0.030-0.070
Cast analysis VM12 pipe ϕ355.6×35 mm	0.13	0.48	0.22	11.40	0.19	0.27	0.22	1.30	0.05	1.20	0.003	0.05

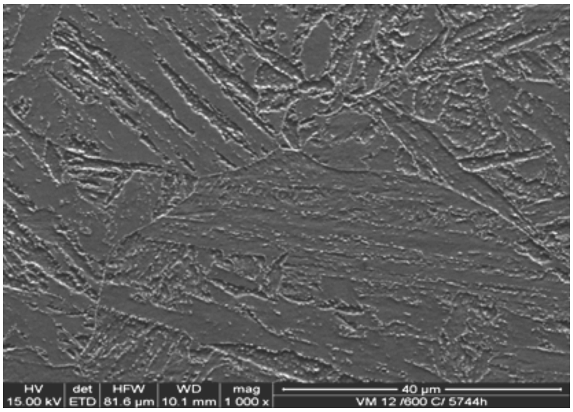

Fig. 3. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 5744 h observed in the SEM (1000x)

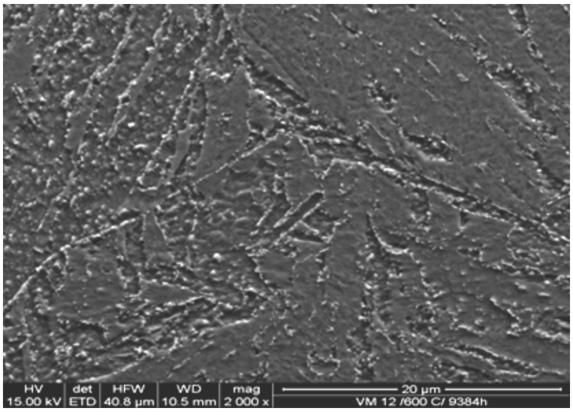

Fig. 4. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 5744 h observed in the SEM (2000x)

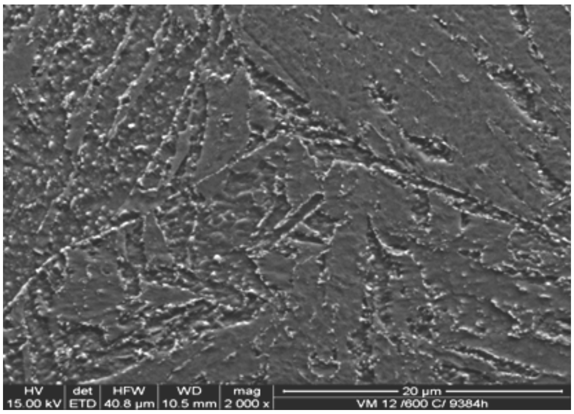

Fig. 5. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 9384 h observed in the SEM (1000x)

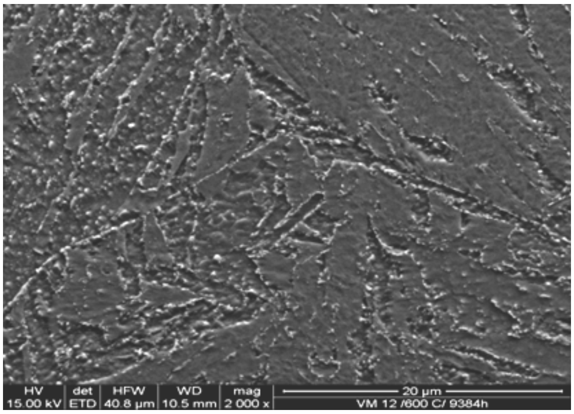

Fig. 6. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 9384 h observed in SEM (2000x)

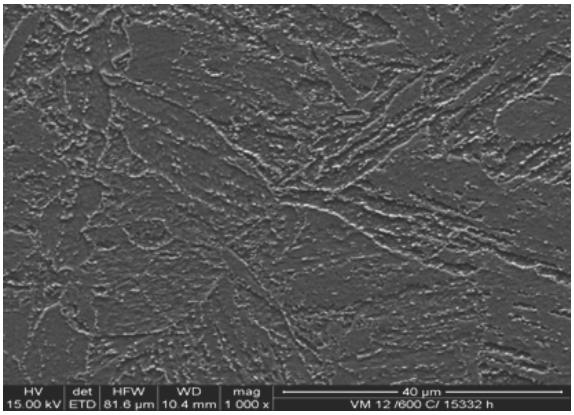

Fig. 7. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 15332 h observed in the SEM (1000x)

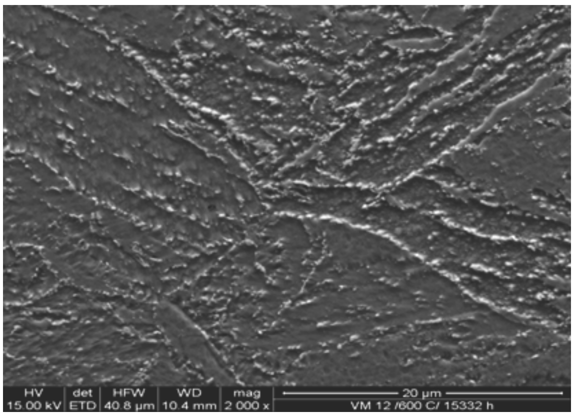

Fig. 8. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 15332 h observed in the SEM (2000x)

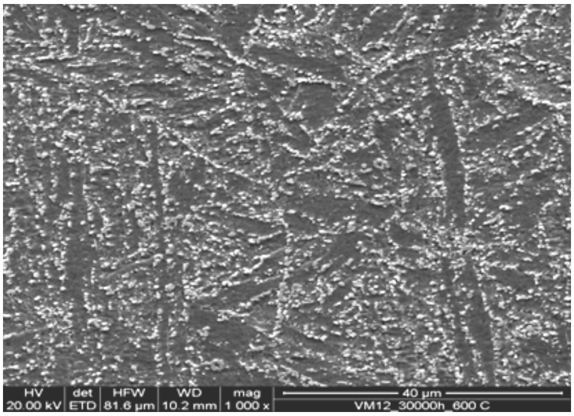

Fig. 9. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 30000 h observed in the SEM (1000x)

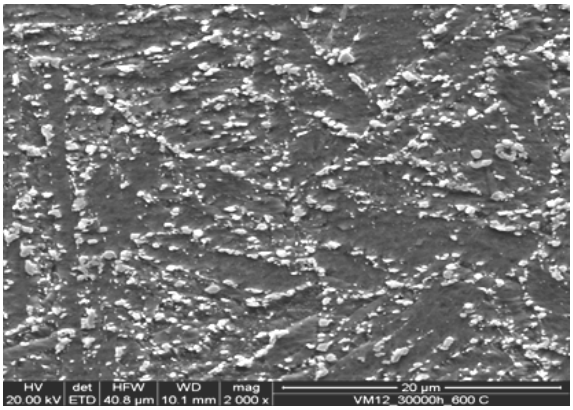

Fig. 10. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 30000 h observed in the SEM (2000x)

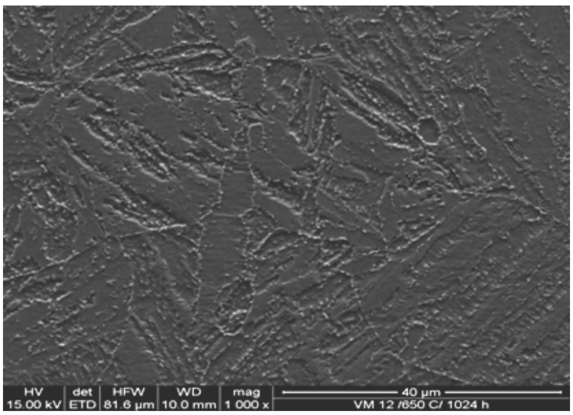

Fig. 11. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 1024 h observed in the SEM (1000x)

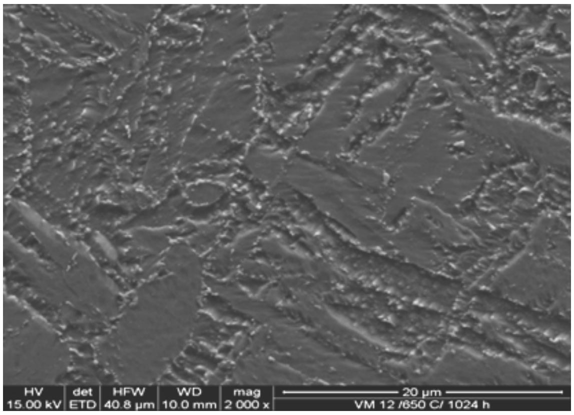

Fig. 12. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 1024 h observed in the SEM (2000x)

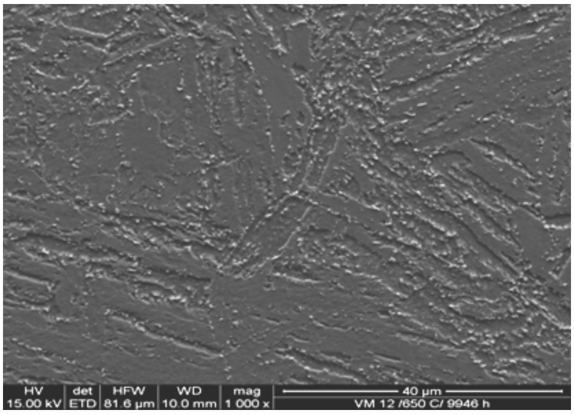

Fig. 13. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 9946 h observed in the SEM (1000x)

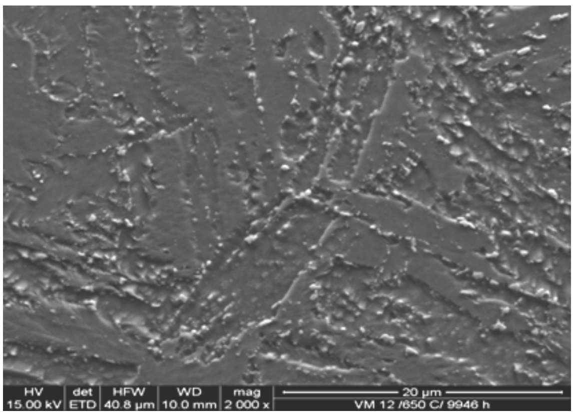

Fig. 14. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 9946 h observed in the SEM (2000x)

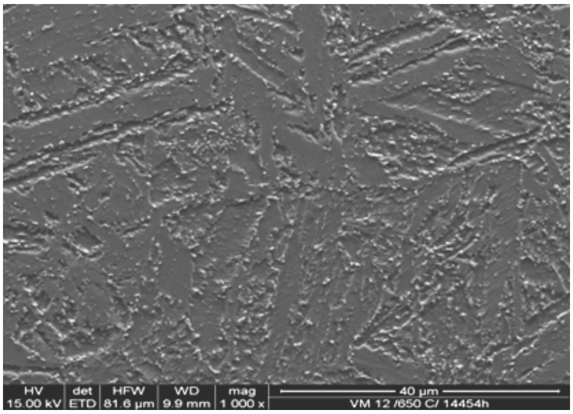

Fig. 15. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 14454 h observed in the SEM (1000x)

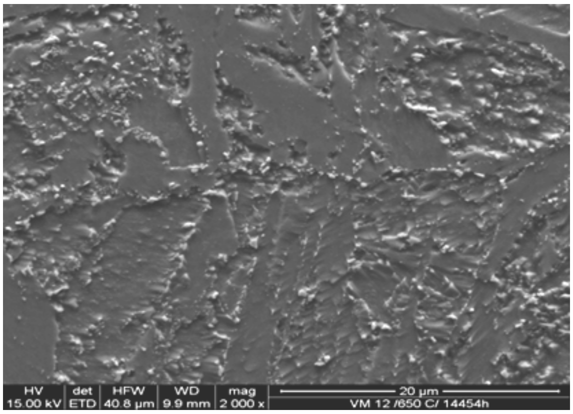

Fig. 16. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 14454 h observed in the SEM (2000x)

The image of the structure of the VM12(X12CrCoWVNb12-2-2) steel after around 10000 hours of annealing at the temperature of 600°C (Figs. 3-6) was not considerably changed as compared to the input condition of the structure (Figs. 1-2), being a lathe martensite with numerous inclusions of carbides and carbonitrides, mainly along the grain borders of former austenite and borders of martensite lathes, whereof number and size is not different as compared to the inclusions observed for this steel in the input condition. A slight but noticeable difference in the image of the structure of the investigated steel was observed after about 30000 hours of annealing at the temperature of 600°C. After that time, a partial decomposition of martensite lathes took place, and the rise of inclusions scope at the places of former martensite lathes was observed, as well as along the grain borders of former austenite. Similar changes were observed in the structure of VM12 steel after the annealing at the temperature of 650°C, but the described decomposition processes of martensite lathes and the inclusions processes were taking place faster and could be observed already after about 15000 hours of annealing at the temperature of 650°C (Figs.7-8).

3.3. Influence of temperature, time and stress on the structure of VM12 steel

The observations of changes in the image of the structure when the structure of VM12(X12CrCoWVNb12-2-2) steel was subjected to simultaneous influence of time, temperature and stress were carried out on the specimens after creeping after 5744, 9384 and 15322 hours at the temperature Tb=600°C, and after 1024, 9946 and 14456 hours at the temperature Tb=650°C. Characteristic images of the structure are presented in Figs. 17-28.

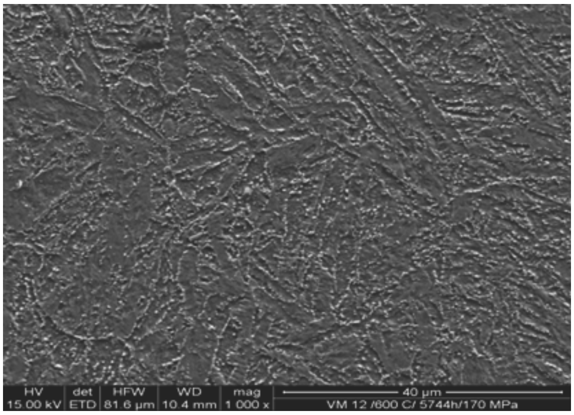

Fig. 17. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 5744 h and stress of 170 MPa observed in the SEM (1000x)

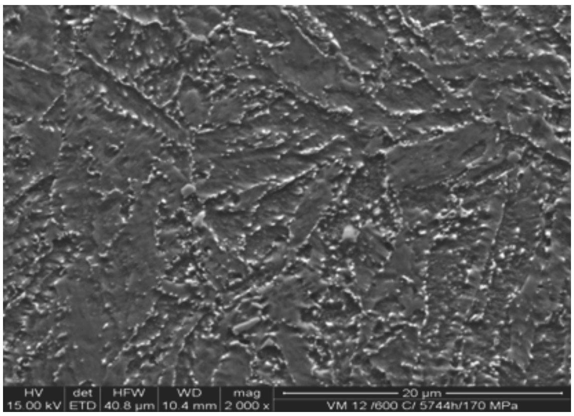

Fig. 18. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 5744 h and stress of 170 MPa observed in the SEM (2000x)

The structure of the VM12(X12CrCoWVNb12-2-2) steel after creeping at the temperature of 600°C, with the stress of 170 MPa and trial time of 5744 h observed in SEM with the magnification of above 1000x shows a partial decompositions of martensite lathes and a slight increase of size and number of inclusions along the martensite lathe borders and along the grain borders of former austenite (Figs. 17-18). A similar image of the structure is observed after the creep trial over 9384 and 15332 h also at the temperature of 600°C and stress of 160 and 140 MPa respectively (Figs. 19-22). The noticeable difference involves the rise of size and number of inclusions with relation to shorter times of creep trial. The hardness level did not change for the observed structures after creeping at the temperature of 600°C and was maintained at the level of about 230HV10. But with respect to the input condition, the hardness decreased by about 40HV10. The structure of the VM12(X12CrCoWVNb12-2-2) steel after creeping at the temperature of 650°C, trial time of 1024 h and stress of 125 MPa is close to the one observed in Figs. 23-24. The hardness is also at the similar level of 220HV10. But significant changes in the image of the structure can be noticed in Figs. 25-26 and 27-28, where the decomposition of martensite lathes can be observed as well as a considerable rise of inclusions inclusions, principally of carbides of the $M_{23}C_6$ type.

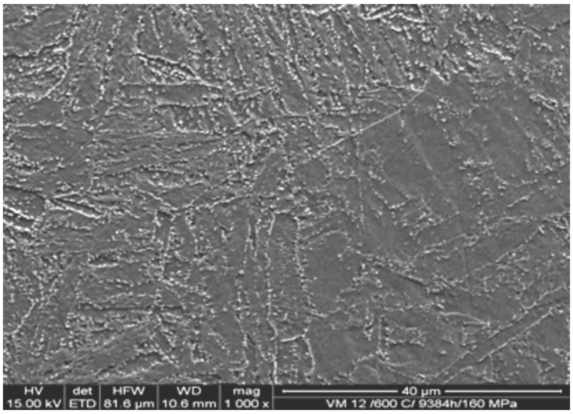

Fig. 19. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 9384 h and stress of 160 MPa observed in the SEM (1000x)

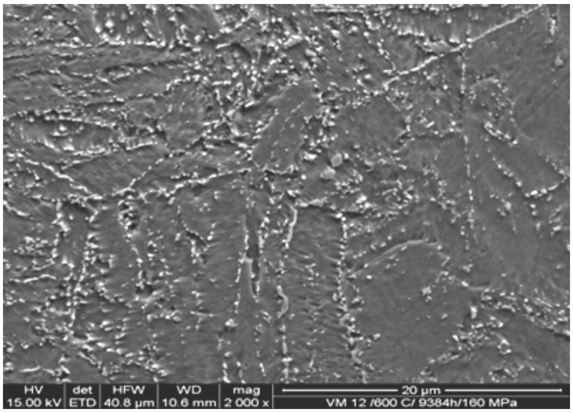

Fig. 20. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 9384 h and stress of 160 MPa observed in the SEM (2000x)

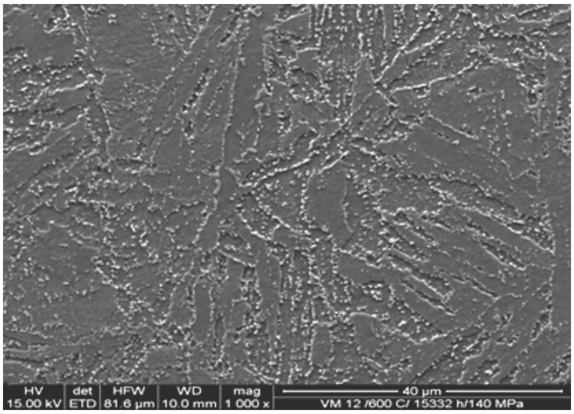

Fig. 21. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 15322 h and stress of 140 MPa observed in the SEM (1000x)

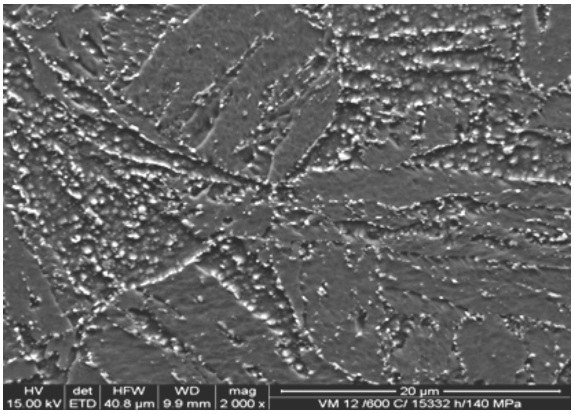

Fig. 22. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 600°C over the time of 15322 h and stress of 140 MPa observed in the SEM (2000x)

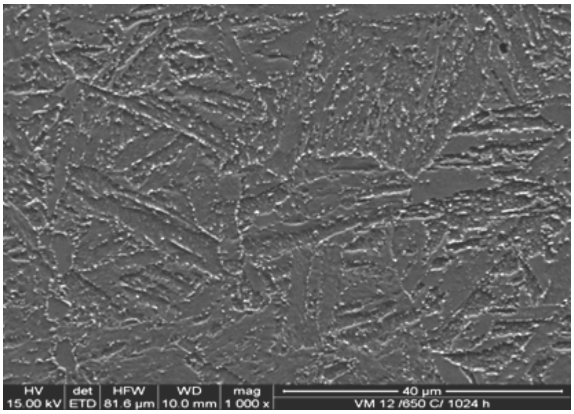

Fig. 23. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 1024 h and stress of 125 MPa observed in the SEM (1000x)

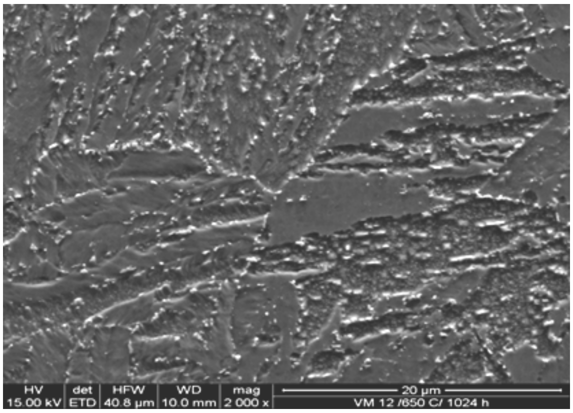

Fig. 24. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 1024 h and stress of 125 MPa observed in the SEM (2000x)

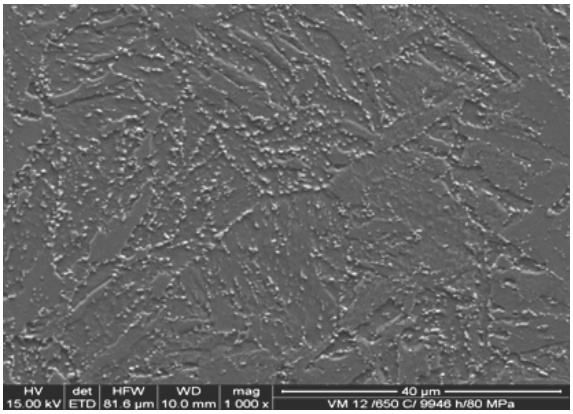

Fig. 25. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 9946 h and stress of 80 MPa observed in the SEM (1000x)

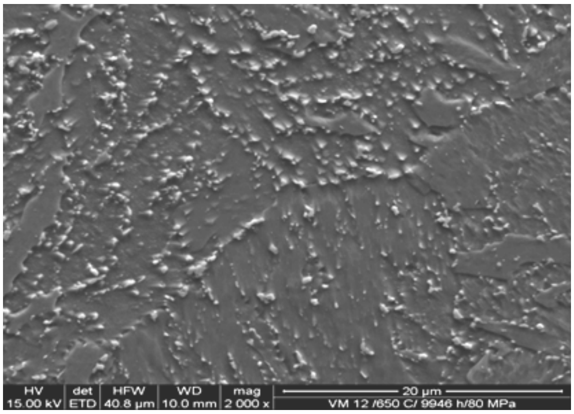

Fig. 26. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 9946 h and stress of 80 MPa observed in the SEM (2000x)

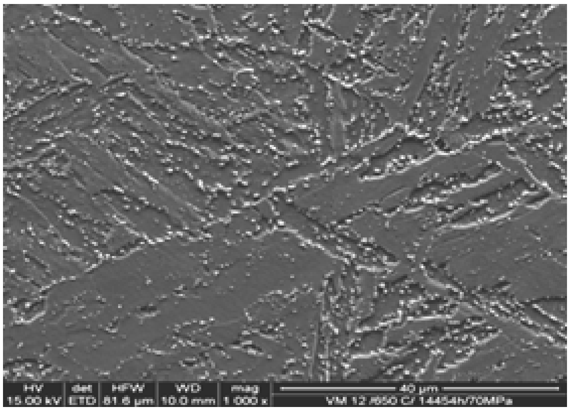

Fig. 27. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 14454 h and stress of 70 MPa observed in the SEM (1000x)

Table 2.
Phase composition of carbides in X12CrCoWVNb12-2-2 (VM12) steel after long-lasting annealing

Material state	Phase composition of carbides	
Initial state	f.g. $M_{23}C_6$	
Long-lasting annealing	T_b = 600ºC	T_b = 650ºC
1000 h	main phase $M_{23}C_6$ minute quantities of Laves phases Fe_2Mo, probably Cr_2N, VN	main phase $M_{23}C_6$ small amount of Laves phases Fe_2Mo probably Cr_2N, VN, CoWSi
5000 h	main phase $M_{23}C_6$ small amount of Laves phases Fe_2Mo	main phase $M_{23}C_6$ medium - Laves phases Fe_2Mo probably VN, CoWSi
10.000 h	main phase $M_{23}C_6$ small amount of Laves phases Lavesa Fe_2Mo	main phase $M_{23}C_6$ medium - Laves phases Fe_2Mo
30.000 h	main phase $M_{23}C_6$ small amount of Laves phases Fe_2Mo	main phase $M_{23}C_6$ medium - Laves phases Fe_2Mo

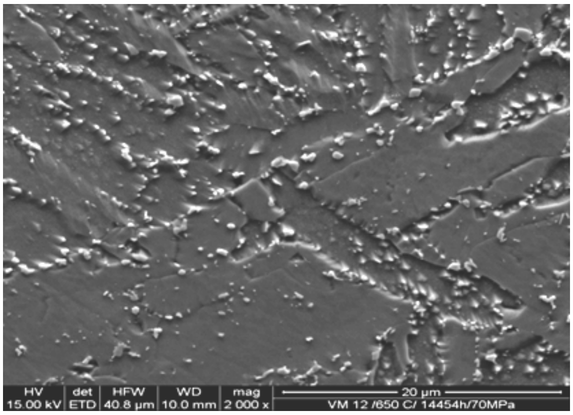

Fig. 28. Structure of the VM12(X12CrCoWVNb12-2-2) steel subjected to annealing at the temperature of 650°C over the time of 14454 h and stress of 70 MPa observed in the SEM (2000x)

3.4. Analysis of phase composition of the inclusions

The analysis of phase composition of the inclusions in VM12 steel in the input condition and after long-lasting annealing was carried out with the application of a diffractometer Philips PW 1140, using cobalt rays with the graphite monochrometer on the side of the diffracted beam. The qualitative analysis of carbide inclusions was carried out basing on the reference rentgenographic data from the International Centre for Diffraction Data PDF-4. The phase composition of carbide isolates is presented in Table 2.

4. Summary

The changes in the microstructure after annealing for up to 30000 hours should be accepted as considerable ones. A slow decomposition of martensite is taking place through the initiated process of martensite lathes decompositions with a simultaneous formation of subgrains. A similar assessment can be applied to the development of inclusions processes. The scope and number of inclusions is increasing along the borders of former austenite grains as well as on the martensite lathes. And through a simultaneous application of temperature, load and time to about 15000 hours, the ongoing processes of degradation and the development of inclusions processes are additionally intensified. The visible change is the decay of mrtenzite laths and increase of size and quantity of decrepitations mainly of $M_{23}C_6$ carbides. For observed structures after creep in temperature of 600-650°C the hardness level does not change and is equal to 220HV10

Acknowledgements

The authors wants to acknowledge the Polish Ministry of Science and High Education for funding part of this research project COST 536.

References

[1] J. Dobrzański, A. Zieliński, A. Hernas, Structure and properties of new high-temperature creep resisting ferritic steels, Materials and technology of supercritical boilers and incinerating plants, Multi-author work, A. Hernas (Ed.), Katowice, 2009.
[2] G. Golański, A. Zieliński, VM12 new steel with cobalt for energy powder, Metallurgist 3 (2011) 228-233.
[3] J. Dobrzański, J. Pasternak, A. Zieliński, Welded joints on superheater collectors made from new generation 9-12%Cr martensitic creep-resisting steels, Properties, experience, application, Proceedings of the 2nd International Conference „Super-High Strength Steels”, Peschiera del Garda, 2010.
[4] J. Dobrzański, A. Zieliński, Properties and structure of the new martensitic12% Cr steel with tungsten and cobalt for use in ultra supercritical coal fired power plants, Material Engineering 28/3-4 (2007) 134-137.
[5] A. Zielińska-Lipiec, T. Kozieł, A. Czyrska-Filemonowicz, Microstructure changes of martenzite steel 12% Cr decreasing their creep strength, Materials and technology of supercritical boilers and incinerating plants, Publishing House SITPH, Katowice, 2009.
[6] J. Dobrzanski, A. Zielinski, M. Sroka, The influence of simultaneous impact of temperature and time on the properties and structure of X10CrWMoVNb9-2 steel, Journal of Achievements in Materials and Manufacturing Engineering 34/1 (2009) 7-14.
[7] A. Hernas, Materials and technology for construction of supercritical boilers and waste plants, Multi-out work edited by A. Hernas, 2009.
[8] J. Dobrzański, A. Zieliński, A. Hernas, Microstructure and properties of new creep-resistance ferritic steels, Multi-out work edited by A. Hernas, 2009.
[9] J. Dobrzański, Materials science interpretation of the life of steels for power plants, Open Access Library 3 (2011) 1-228.
[10] V. Sklenicka, K. Kucharova, M. Svoboda, L. Kloc, J. Kudrman, Effect of nonsteady loading on creep behaviour of advanced 9-12% fossil power plant steel, Proceedings of the 8th International Conference on Materials for Advanced Power Engineering, Liege, 2006, 1127-1136.
[11] A. Zielińska-Lipiec, The analysis of microstructural stability of modified martensitic deformation, Cracow, 2005 (in Polish).
[12] B.J. Kim, B.S. Lim, Relationship between creep rupture life and microstructure of aged P92 steel, Experimental analysis of nano and engineering materials and structures, Proceedings of the 13th International Conference on Experimental Mechanics, Alexandroupolis, 2007, 269-270.
[13] G. Golański, P. Wieczorek, Electron microscopy investigation of the Cr-Mo-V cast steel, Archives of Materials Science and Engineering 30/2 (2008) 73-76.
[14] C. Chovet, E. Galand, G. Ehrhart, E. Baune, B. Leduey, Welding consumables for grade P92 steel for power generation applications, Safety and reliability of welded components in energy and processing industry, Proceedings of the 61th IIW International Conference, Graz, 2008, 443-448.
[15] 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 Manufacturing Engineering 18 (2006) 219-222.

[16] D. Renowicz, M. Cieśla, Crack initiation in steels parts working in boilers and steam pielines, Journal of Achievements in Materials and Manufacturing Engineering 21/2 (2007) 49-52.
[17] J. Okrajni, Fatigue aspects of an evaluation of the operational safety of components working in creep conditions, Journal of Achievements in Materials and Manufacturing Engineering 45/1 (2011) 51-58.
[18] G. Junak, M. Cieśla, Low-cycle fatigue of P91 and P92 steels used in the power engineering industry, Archives of Materials Science and Engineering 48/1 (2011) 19-24.
[19] G. Golański, Effect of the heat treatment on the structure and properties of GX12CrMoVNbN9-1 cast steel, Archives of Materials Science and Engineering 46/2 (2010) 88-97.
[20] L.A. Dobrzański, W. Sitek, M. Krupiński, J. Dobrzański, Computer aided method for evaluation of failure class of materials working in creep conditions, Journal of Materials Processing Technology 157-158 (2004) 102-106.
[21] A. Marek, G. Junak, J. Okrajni, Fatigue life of creep resisting steels under conditions of cyclic mechanical and thermal interactions, Archives of Materials Science and Engineering 40/1 (2009) 37-40.