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The influence of simultaneous impact of temperature and time on the properties and structure of X10CrWMoVNb9-2 steel

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Materials

ABSTRACT

Purpose: of this paper is to present the changes of the mechanical properties and structure in material components of the power station boiler after long-lasting annealing made of X10CrWMoVNb9-2 steel.
Design/methodology/approach: As a material for examination X10CrWMoVNb9-2 steel was use in the form of a pipe Φ 160 mm and wall thickness 40mm after normalization in 1050-1070°C/1h/air and tempering in 760-780°C/2h/air.
Findings: Investigations of mechanical properties and the structure of the steel in initial state confirmed that it fulfills the requirements for that steel in initial state. Long annealing in the temperature close to the exploitation one and the examinations of the hardness and impact strength allow to determinate the influence of long temperature and time acting on the properties and structure of X10CrWMoVNb9-2 steel.
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: Mechanical properties; Structure; Degradation after exposure test; Hardness; Impact energy

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1. Introduction

The majority, about 50 percent, of power units in Poland work more than 35 years that means they have exceeded an analytical exploitation time. Pressure devices working in higher temperature, including power units, are designed for determined exploitation time. In majority cases for power units being exploiting in Poland this time is equal 100 000 hours. That is why many modernizing works are being carried out to extend their exploitation time of about 100 000 or 200 000 hours and to increase essential efficiency. However modernization of old power units does not solve the problems connected with energetic security of country but only for few years allows to support current energy production what by fast increase of electric energy consumption being a result of economic growth, may be not sufficient. So it is so important to build new power units with vapor supercritical parameters being firing by hard and brown coal which resources in Poland will be the main sources of energy during the next decades. Building new power units with supercritical vapor parameters it is not only Polish power industry reconstruction but also adaptation to legal considerations connected with Poland association into the European Union which the main goal is the environment protection by limiting emission to the atmosphere of harmful greenhouse gases. Application of supercritical vapor parameters not only decrease the efficiency of devices but first of all increases the efficiency of devices. However it needs to use new generation materials for their building. The increase of currently efficiency of conventional power units from 33% up to 45% for units with supercritical parameters allows for decreasing CO_2 emission of about 41.8 mln ton per year – about 27%. However this state in Poland can be reached in 20-30 years after the new power units put in motion [1]. These aspects have oriented the development of Polish power industry which goal is the modernization of currently existing electric power stations and building new generation boilers with supercritical vapor parameters – currently the temperature up to 600°C and the pressure from 28 up to 30MPa, and in the next coming few years – temperature up to 620°C and the pressure of 30MPa. After 2015 it is being planned to build boilers with vapor ultrasupercritical parameters and temperature of 700°C and pressure up to 35MPa. That is a quarance of decreasing emission of CO_2, NO_x and SO_x gases to the allowable level determined by the directives of EU and standards EN [2].

Materials applied for strenuous constructional elements of boilers with adequate functional properties:

- time creep resistance not only for 100 000 hours but also for 200 000 hours,
- yield point and tensile strength in room and higher temperature,
- resistance for brittle cracking in boilers exploitation conditions,
- heat resistance in vapor and combustion gases environments,
- thermo-mechanical fatigue strength resistance, especially for low-cycle fatigue.

The diversification of working conditions in high-pressure boilers, especially very high range of working temperature causes that it is impossible to apply one universal kind of steel. Expected strength and technological properties for elements of membrane walls fulfill low alloyed bainitic steels and requirements for material on vapor overheaters – high chromium steels with the structure of tempered martensite with exploitation temperature up to 600°C and pressure up to 30MPa.

In the last years in the world there was a considerable development of new steels working in higher temperature and in the country many projects are in progress which goals is checking required level of strength and technological properties not only in the initial state but also after long-lasting exploitation [3-17]. Into these steels the following ones can be included: low alloyed steel 7Cr5WVNb9-6 (T/P23) and 7CrMoVTiB10-10 (T/P24) and high chromium steels 9-12% Cr - X10CrMoVNb9-1 (T/P91), X10CrWMoVNb9-2 (T/P92) and new worked out steel X12CrCoWVNb12-2-2 (VM12).

The Institute for Ferrous Metallurgy in cooperation with others research centers in the country and in the world (COST 522, 536) and the Boilers Factory Rafako – the leader in boilers production, makes investigations in the field of application mentioned new generation steels.

Present work shows results of investigations of strength properties in the initial state and the influence of long-lasting higher temperature on the X10CrWMoVNb9-2 (T/P92). steel microstructure, hardness and impact strength changes.

Paper presents only few results of investigations. There are also made some examinations of the precipitations phase composition, TEM observation of microstructure, quantitative and qualitative analysis of the precipitations kind and composition in X10CrWMoVNb9-2 steel both long-lasting annealing and creep tests.

2. Materials for investigation

As a material for examination X10CrWMoVNb9-2 (P92) steel was use in the form of a pipe ϕ 160mm and wall thickness 40mm after normalization in 1050-1070°C/1h/air and tempering in 760-780°C/2h/air.

Chemical composition according to ASME Case2179 is presented in the Table 1.

Table 1.
Material for investigation – chemical composition of investigated P92 (X10CrWMoVNb9-2) steel regarding AMSE Case2179

No	Chemical composition [%]													
	C	Mn	Si	P	S	Cr	Ni	Mo	V	W	Nb	B	Cu	Al	N
Control analysis	0.10	0.45	0.17	0.01	0.01	9.26	0.25	0.47	0.20	1.95	0.059	0.009	0.08	0.01	0.04
ASME Case2179	0.07-0.13	0.30-0.60	max 0.50	max 0.02	max 0.01	8.5-9.5	-	0.30-0.60	0.15-0.25	1.5-2.0	0.04-0.09	max 0.006	-	max 0.040	0.03-0.07

3. Mechanical properties and the structure in the initial state

Examinations of strength properties were made in the temperature range of 20-700°C and the results are shown in Fig. 1 and Fig. 2. Determined values of tensile strength T_s, yield point Y_s elongation A_5 and reduction of area Z fulfills requirements for this steel [1]. Obtained results show that with the test temperature growth a gradual decrease of tensile strength and yield point by simultaneous slight increase of elongation and reduction of area is observed.

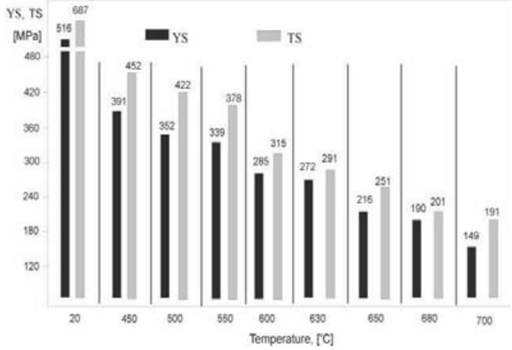

Fig. 1. Tensile strength T_s and yield point Y_s versus the examination temperature T_b of investigated pipe from X10CrWMoVNb9-2 (P92) steel

Structure investigations of X10CrWMoVNb9-2 steel in the initial state (annealing and tempering) made on light microscope and in scanning electron microscope with magnification in the range 300 up to 5000x (Fig. 3) shown that in the structure dominates lathe tempered martensite with few ferrite grains and boundaries of former austenite grains and boundaries of lathe martensite are densely surrounded by carbon $M_{23}C_6$ precipitations (M=Fe, Cr or Mo). There are also visible very small precipitations of carbons and carbonitrides MX (M= V or Nb and X=C or N) inside grains. Fig. 4 shows CCT diagram the influence of cooling rate on the structure and hardness changes.

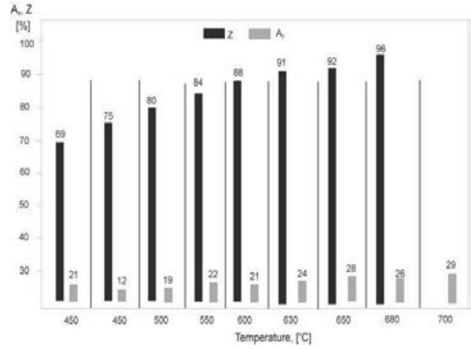

Fig. 2. Results of elongation A_5 and reduction of area Z during the tensile strength test in the temperature 700ºC of investigated pipe from X10CrWMoVNb9-2 (P92)

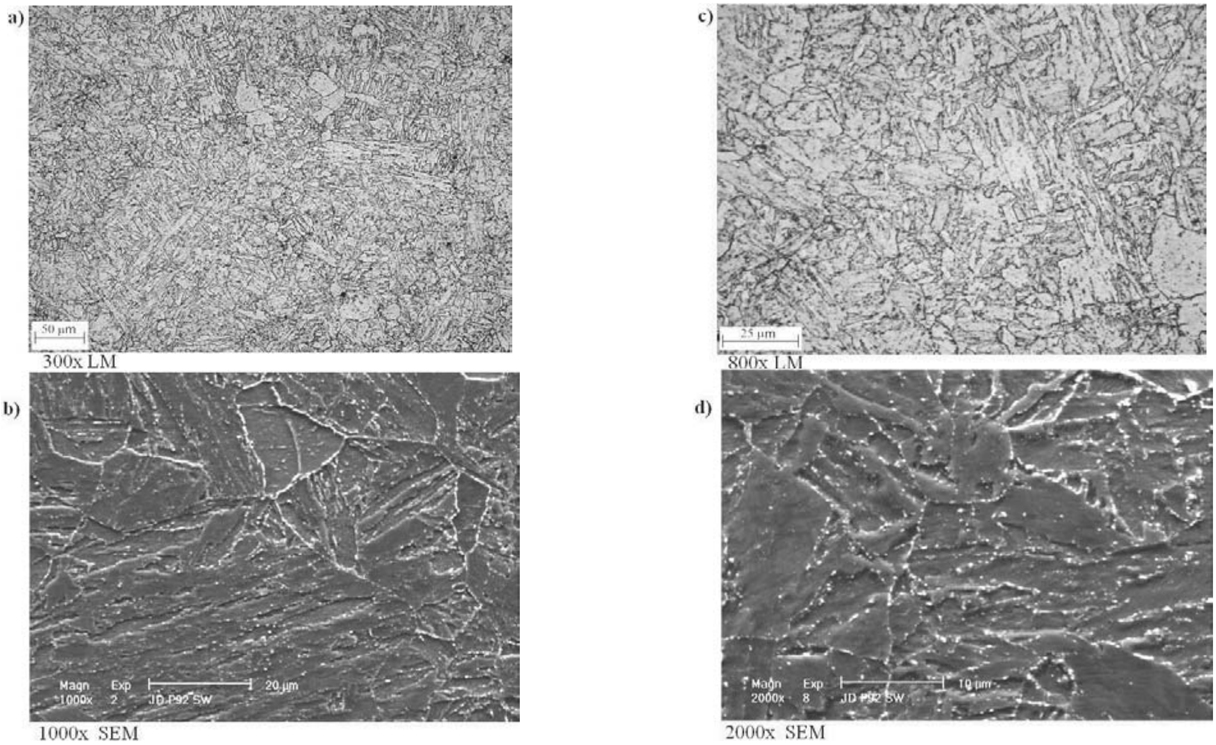

Fig. 3. Microstructure of X10CrWMoVNb9-2 steel in the initial state (N+0) observed: a)light microscope (magn 300x) b) scanning electron microscope (magn 1000 and 2000x)

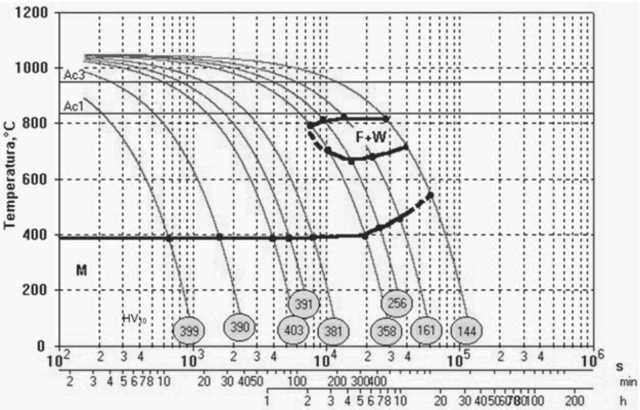

Fig. 4. CCT diagram for X10CrWMoVNb9-2 steel

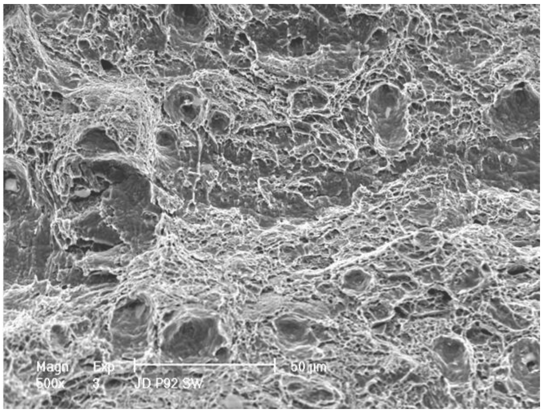

Fig. 6. Fracture of impact sample of X10CrWMoVNb9-2 steel in initial state (impact energy 161 J)

4. The influence of long-lasting annealing on the properties and structure X10CrWMoVNb9-2 steel

4.1. Impact energy

Examinations of impact energy were made in the room temperature on samples after long-lasting annealed in 600ºC and 650ºC in time from 0 up to 70000h. Changes of impact energy versus annealing time is shown in Fig. 5. The impact energy violently decreases in the range 160 to 70J after first 500h of annealing. While after long-lasting annealing constant slight decrease of impact energy is observed to 48J after annealing in temperature 600ºC and 32J after annealing in 650ºC during 70000h. Fig. 6-9 show chosen characteristic fractures of impact samples for initial state and after 1000, 10000 and 70000 hours of annealing observed in scanning electron microscope (magn 500x).

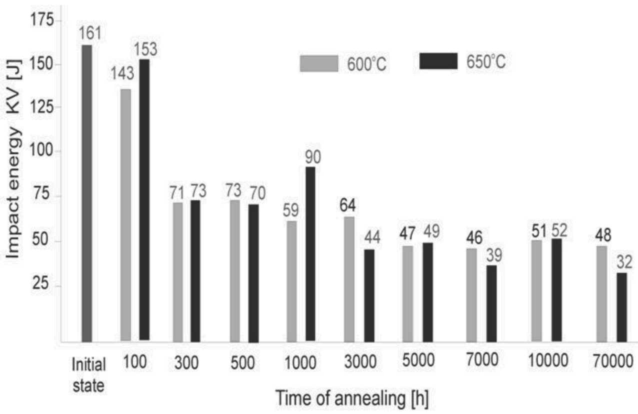

Fig. 5. Influence of annealing time in temperature of 600ºC and 650ºC on the impact strength for X10CrWMoVNb9-2 steel

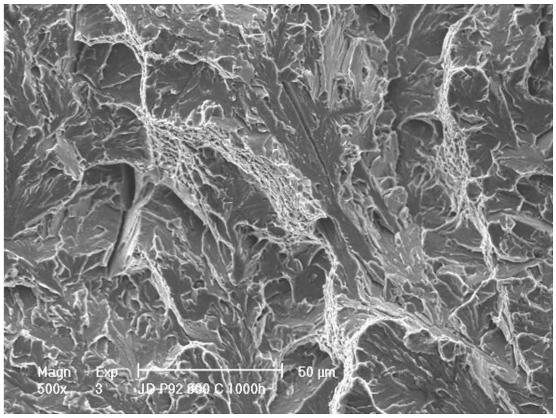

Fig. 7a. Fracture of impact sample of X10CrWMoVNb9-2 steel after 1000h annealing in temperature 600 ºC (impact energy 59 J)

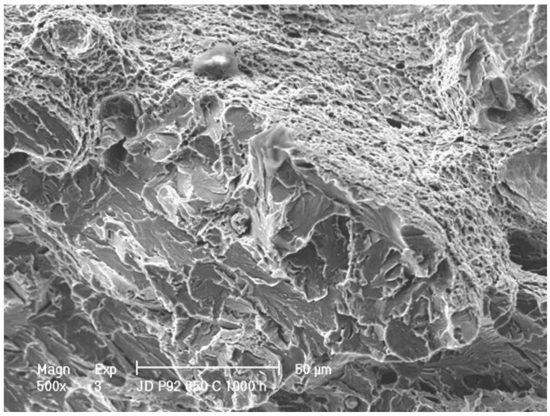

Fig. 7b. Fracture of impact sample of X10CrWMoVNb9-2 steel after 1000h annealing in temperature 650 ºC (impact energy 90 J)

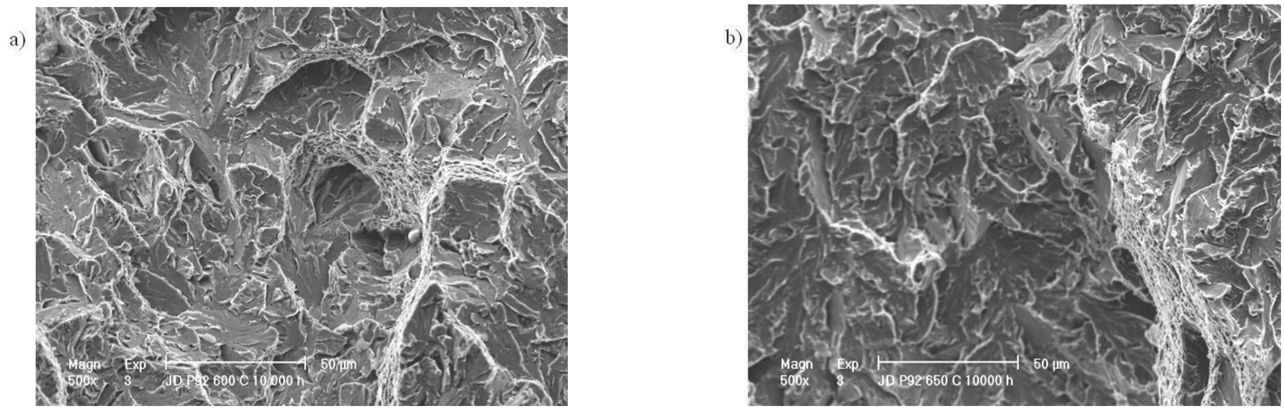

Fig. 8. Fracture of impact sample of X10CrWMoVNb9-2 steel after 10000h annealing : a) in temperature 600ºC (impact energy 51J) b) in temperature 660ºC (impact energy 52 J)

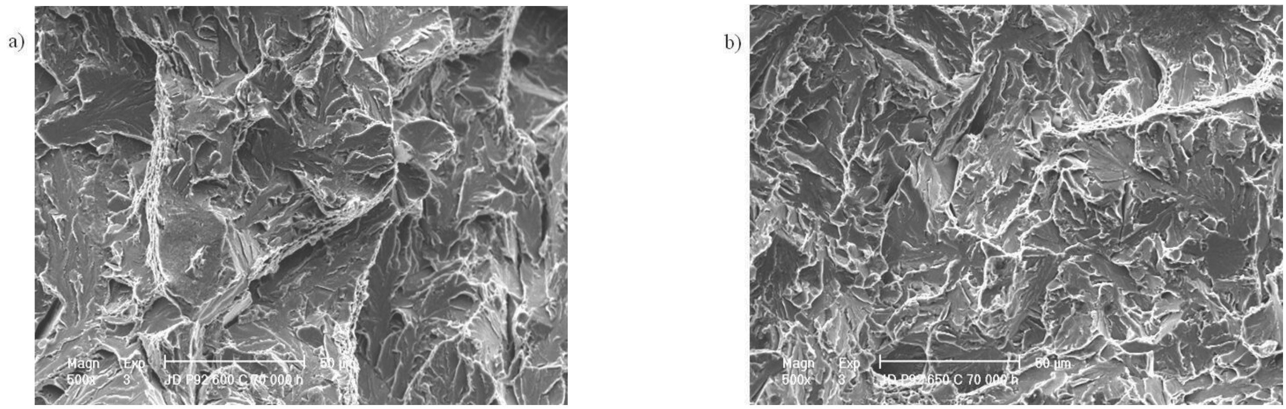

Fig. 9. Fracture of impact sample of X10CrWMoVNb9-2 steel after 70000h annealing: a) in temperature 600ºC (impact energy 48 J) b) in temperature 660ºC (impact energy 32 J)

Fracture of impact samples of X10CrWMoVNb9-2 steel in initial state and samples after annealing by 100 hours is ductile without brittle zones. While impact samples annealed both in temperature of 600ºC and 650ºC in time 300 up to 70000h are characterized by mixed fracture with small differences in the portion of ductile and brittle fracture. Portion of brittle fracture increases with annealing time increase.

4.2. Hardness

The hardness changes of samples annealed in temperature 600ºC and 650ºC in time from 0 up to 70000h are shown in Fig. 10. It was not found violent decrease of hardness which was observed in the impact strength measurements after annealing time up to 300h. However there was found a constant, slight decrease of hardness from 225HV10 for initial state to 200HV10 after annealing 70000h.

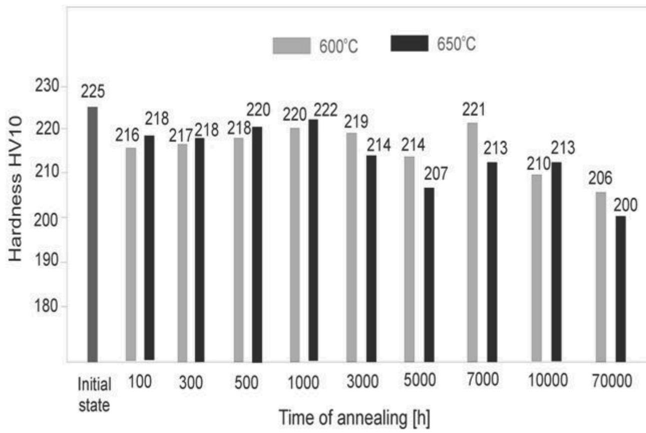

Fig. 10. The influence of annealing time in temperature 600ºC and 650ºC on X10CrWMoVNb9-2 steel hardness

4.3. Microstructure

Microstructure observation of samples after annealing in temperature close to exploitation one 600ºC and 650ºC in time 100 up to 70000h was made in the scanning electron microscope with magn 500 to 5000x. Typical microstructures after annealing 100, 1000, 5000, 10000, 70000h and in the temperature 600ºC and 650ºC are shown in Fig. 11-15. Significant changes in the microstructures of investigated steel was not observed after annealing up to 500h. Microstructures after annealing both in 600ºC and 650ºC show small differences in comparison with the microstructure in initial state. First, slight changes being a result of microstructure degradation are observed after 1000h annealing. It can be seen the growth of carbon precipitation size on the boundaries of former austenite, boundaries of lathe martensite and inside grains (Fig. 12). There was not observed degradation processes in decay of lathe martensite microstructure form. Visible changes in the microstructure in comparison with initial state caused by simultaneous temperature and time acting can be observed on samples annealed 5000h. After this time it was found further increase of precipitation size. Their size, as can be expected, is higher after long lasting annealing in 650ºC. In the microstructure of X10CrWMoVNb9-2 steel after 10000h (Fig. 13) can be observed effects of progressive martensite tempering processes. Their results are bigger and more densely located $M_{23}C_6$ carbon precipitations on the boundaries of former austenite grains and inside ferrite grains. After annealing in 650ºC the is visible partial decay of lathe martensite microstructure. Long lasting annealing time up to 70000h shows partial decay of lathe martensite microstructure of tempered martensite zones for examination temperature 600ºC. While in the microstructure of examinated steel annealed 70000h in temperature 650ºC there was found further disintegration of lathe martensite microstructure. This microstructure is characterize by considerable degraded zones of martensite with high portion of carbides on the boundaries of former austenite and insite its grains (Fig. 15b).

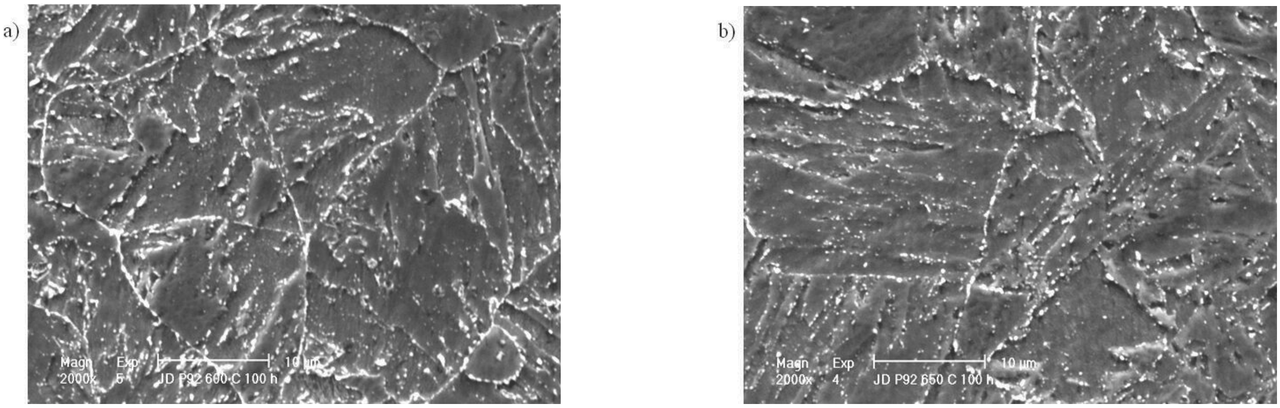

Fig. 11. Microstructure of X10CrWMoVNb9-2 steel after annealing 100h: a) in temperature 600ºC, b) in temperature 650ºC observed in scanning electron microscope

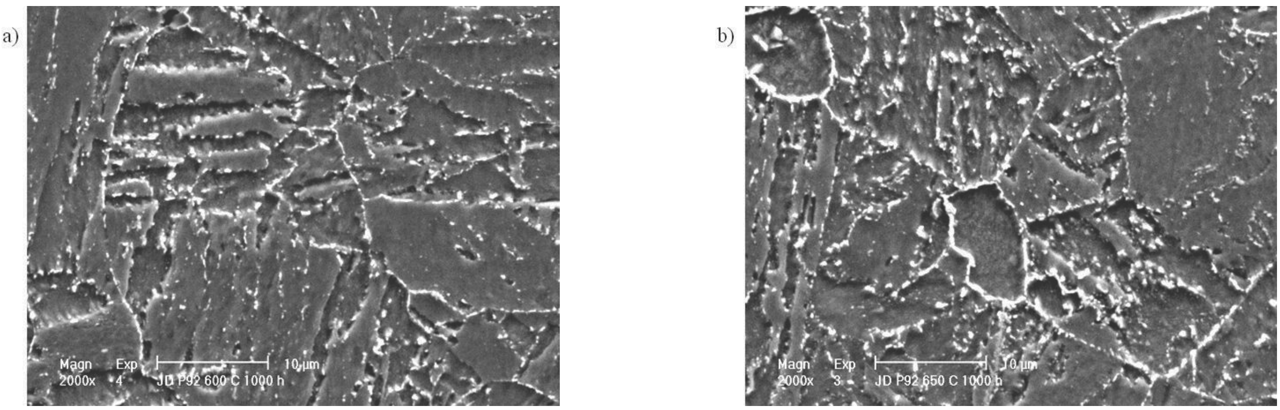

Fig. 12. Microstructure of X10CrWMoVNb9-2 steel after annealing 1000h: a) in temperature 600ºC, b) in temperature 650ºC observed in scanning electron microscope

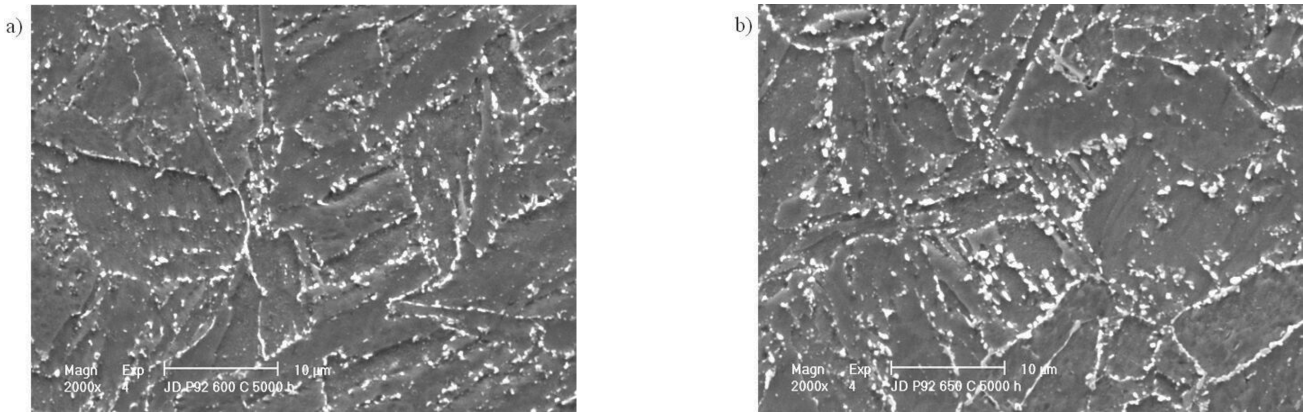

Fig. 13. Microstructure of X10CrWMoVNb9-2 steel after annealing 5000h: a) in temperature 600ºC, b) in temperature 650ºC observed in scanning electron microscope

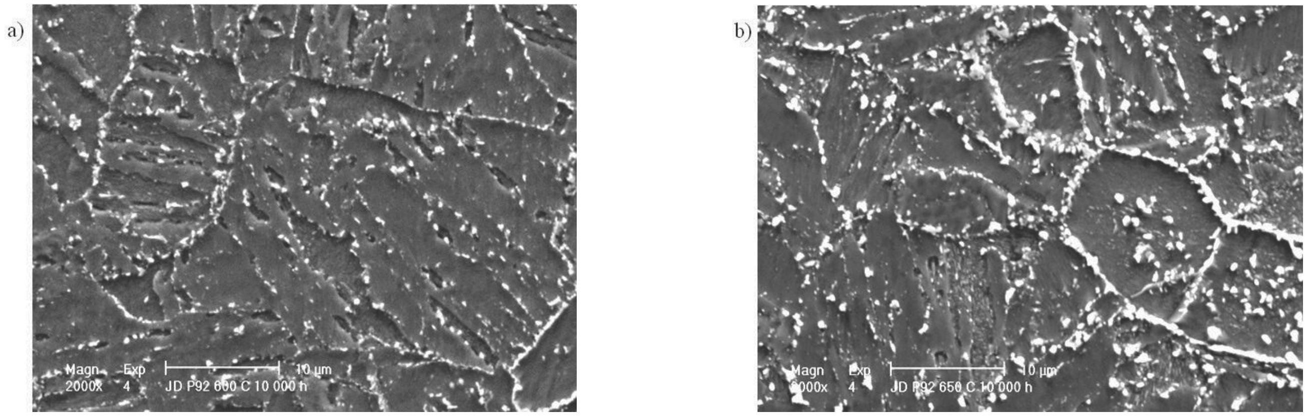

Fig. 14. Microstructure of X10CrWMoVNb9-2 steel after annealing 10000h: a) in temperature 600ºC, b) in temperature 650ºC observed in scanning electron microscope

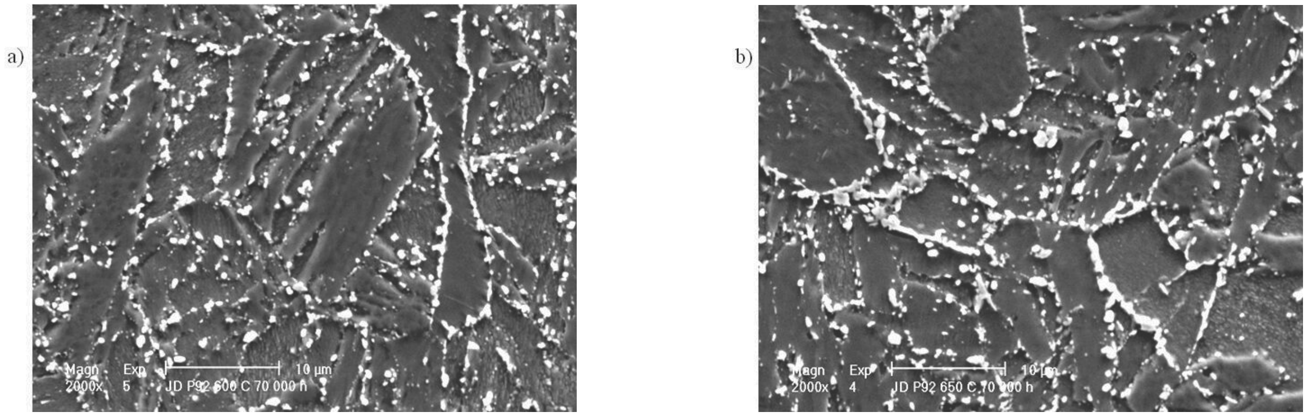

Fig. 15. Microstructure of X10CrWMoVNb9-2 steel after annealing 70000h: a) in temperature 600ºC, b) in temperature 650ºC observed in scanning electron microscope

5. Conclusions

Examinations allow to evaluate mechanical properties of X10CrWMoVNb9-2 steel in initial state and to compare them with results obtained after long lasting annealing in temperature of 600ºC and 650ºC.

1. Determined tensile strength T_s, yield point Y_s elongation A_5 and reduction of area Z in room and higher temperature fulfill the requirements for this steel.
2. On the base of impact strength tests in can be concluded that as a result of simultaneous temperature and time acting a decrease of impact strength was observed measured as impact energy from about 160J for initial state to 70J for steel after annealing 300h. Longer annealing caused uniform but slight decrease of impact strength to 40J after 70000h.
3. There was not observed significant differences of hardness. Hardness changes slightly from 225HV10 for initial state to 200HV10 for samples annealed 70000h.
4. Not significant differences were observed in the microstructure of X10CrWMoVNb9-2 steel after long lasting annealing (10000h). A comparison of microstructure created as a result of simultaneous temperature and time acting with the microstructure after creep tests – with simultaneous load acting, shown that the degree of microstructure degradation after annealing is small.
5. While after 6000h of creep test in temperature 650ºC and load 95MPa there was found whole decay of lathe microstructure in zones of tempered martensite with visible carbon precipitations on the boundaries of former austenite and insite ferrite grains [8]. Significant microstructure changes – partial decay of lathe martensite microstructure and increase of precipitations' number and size both on the boundaries and inside grains was observed after annealing 70000h. Besides there was found an essential difference in higher microstructure's degradation after annealing in 650ºC.
6. Results of investigations confirm literature [6] that X10CrWMoVNb9-2 steel w the condition of simultaneous temperature and time acting shows expected stable microstructure. It is shown in slight decrease of impact energy and hardness and microstructure changes, which could be expected for this kind of steel.

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