THE IMPACT OF THERMAL CYCLES OF SUPERHEATED STEAM ON PIPES MATERIAL OF BY-PASS STATION OF STEAM AND GAS-STEAM TURBINES

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Abstract

The by-pass station of steam turbines is a device, used to by-pass the steam from boiler to condenser by bypassing the turbine. It is especially used while starting operating conditions of the boiler, before putting the turbine-generator unit in service, or in the cases when the amount of stem produced in boiler is higher, then the amount of steam needed for operation of turbine and its accessories. In common operating mode the station is on stand-by and waiting in so called “thermal reserve”. The by-pass station is equipped with a reducer, which reduces the pressure to the stated range, and further with cooler reducing steam temperature before entering the water-cooled condenser. It can happened (during the breakdown of cooling media supply) that the temperature of flowing steam behind the cooler will rise steeply for a short time and thus the pipes behind the cooler will by thermally loaded. The aim of the submission is to show, if and possibly how the impact of these thermal cycles influences material properties of output pipe of the by-pass station made of creep resistance C-Mn steel P235GH.

Keywords: Steam Turbine, P235GH Steel, By-pass Station, Material Properties, Gleeble

1. INTRODUCTION

Siemens Ltd belongs among the top world producers of steam and gas-steam turbines with the power up to 250 MW. Delivery consists of the by-pass stations and pipes (**Fig. 1**) used for bypassing steam from boiler to the water-cooled condenser by bypassing the turbine [1].

By-pass is used especially while starting operating conditions of the boiler, before putting turbine-generator unit in service, during turbine-generator unit fault, or during operating conditions when the amount of steam produced in boiler is higher, then the amount of steam needed for operation of turbine and its accessories. During a normal steady operation the by-pass station is on stand-by mode however it must be in thermal reserve (steam piping leading to by-pass station and reducer are permanently heated up by the steam).

The by-pass station consists of an overspeed valve, reducer and cooler made up of injectors, which are part of reducer output hub. Temperature 145 °C and pressure 1 bar are limiting values of flowing medium at the output from the by-pass station. These values are determined by construction of relating equipment, which is usually water-cooled condenser.

To prevent pressure exceeding, condenser and low-pressure part of turbine are equipped with breakdown membrane fuse set for overpressure 1 bar (in case of air condensing for 0.49 bar). In the case of malfunction of injection device preventing exceeding temperature at reducer output it is necessary to protect condenser by immediate closing of steam input. Therefore the overspeed valve is installed before reducer. The speed of shutting depends on the type of drive. These drivers are hydraulic, pneumatic or electrical drives, which are necessary to choose because of the non-existence of the other controlling medium (air, pressure oil). The electrical drives have maximal shutting time of 75 s.

Assumed lifetime of the by-pass station is usually 20 years. During this period the maximum of fifty shutting cycles are considered. It means that during its lifetime the by-pass station and piping can be exposed up to fifty thermal cycles caused by superheated steam at 535 °C lasting for 75 s. The supplier is interested whether and possibly how the material properties of by-pass station piping will be influenced by these thermal cycles.

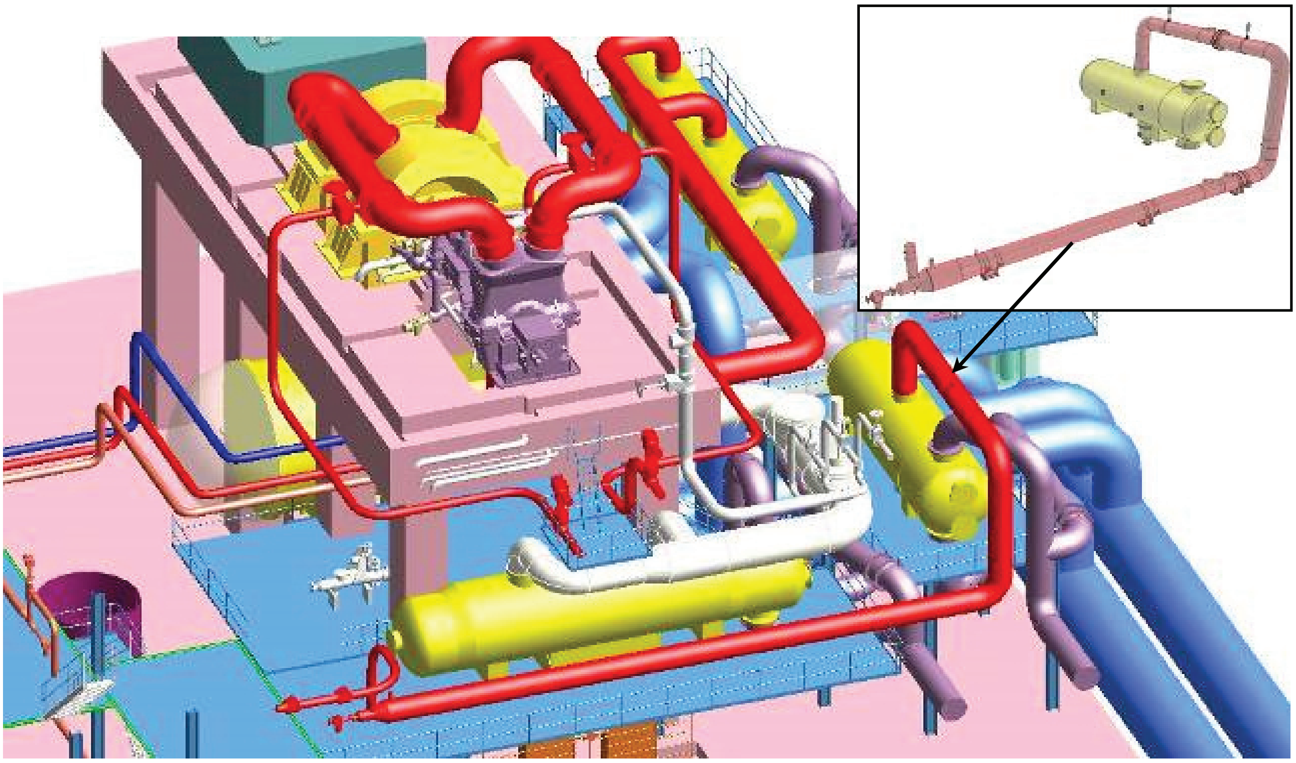

Fig. 1 The turbine equipment with by-pass station and input piping

2. STEEL P235GH CHARACTERISTICS

Creep resistant steels are especially used in power generating and chemical plants, where their material properties can be used. P235GH steel belongs to this group. The chemical composition of this steel (**Table 1**) makes it ideal for applications where elevated working temperature does not exceed 450 °C. That is the reason why it is used above all for manufacturing boilers, pressure vessels and pipes transporting hot liquids up to this scheduled temperature.

The individual creep resistant steels and their creep rupture strength by different working temperature are shown on the **Fig. 2** [2].

Table 1 Chemical composition of P235GH steel acc. to the material certificate

	C	Mn	Si	P	S	Al	Cr
wt. %	0.15	0.48	0.22	0.016	0.011	0.024	0.06
	Cu	**Mo**	**Nb**	**Ni**	**Ti**	**V**	**Cr+Cu+Mo+Ni**
wt. %	0.30	0.009	0.002	0.03	0.001	0.003	max. 0.70

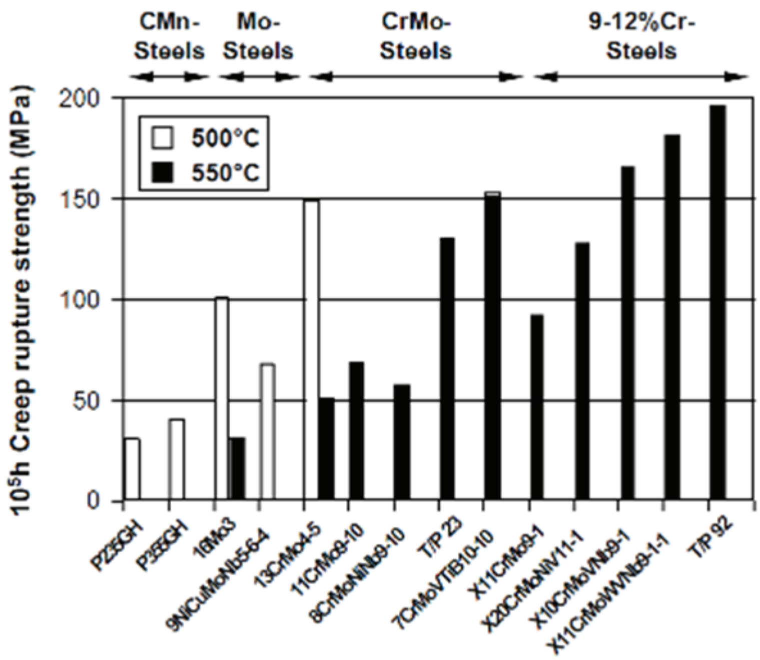

Fig. 2 Dependence of creep rapture on working temperature for individual creep resistant steels

Steel P235GH can be regarded as typical C-Mn steel with the ferrite and perlite microstructure. The carbon and manganese contents are the main factors affecting the mechanical properties, especially strength properties. This type of material is based on minimum proof strength values at low temperatures and creep rupture strength values at high temperatures. Both regimes are separated by the intersection of the proof strength with the creep rupture strength curve. In the case of P 235GH the intersection point is around 420 C. Over this temperature the creep changes starts to be striking.

Table 2 Strength limit values by the creep R_{mT} [MPa]

Temp. [C]	380	390	400	410	420	430	440	450	460	470	480
R_{mT} / 10^4	229	211	191	174	158	142	127	113	100	86	75
R_{mT} / 10^5	165	148	132	118	103	91	79	69	59	50	42
R_{mT} / 2.10^5	145	129	115	101	89	78	67	57	48	40	33

Yield strength of P235GH is 235 MPa when its thickness is less than 16 mm. In the case when the thickness is more than 16 mm, its minimal yield strength is 225 MPa. The tensile strength of this material grade is from 360 to 480 MPa and the P235GH min total elongation is 24 %. The impact energy of this material is 40 J in +20 degree. This type of steel may be welded by means of the usual welding techniques [3]. In the **Table 2** there are shown strength limit values by the creep R_{mT} and 10^4, 10^5 and 2.10^5 hours in the temperature range 180 °C ÷ 480 °C [4].

3. EXPERIMENTAL PART

For the experiment there was used a pipe with diameter 300 mm and wall thickness 6 mm. In the first part of experiment we monitored temperature fields caused by heating corresponding the temperature of 535 °C repetitively effects for 75 s. The pipe was fitted with four thermocouples of K type (Ni-Cr-Ni). Thermocouple TC1 was placed on inner side of the pipe, TC2 was placed at the distance of 1.5 mm from inner diameter in thickness direction, TC3 was placed in a half of the pipe thickness (3 mm in thickness direction) and the last thermocouple TC4 was placed on the outer surface of the pipe. At the same time the tested pipe was insulated with a case made of insulating material Sibral on the outer surface. The tested pipe with thermocouples was inserted into furnace preheated at 145 °C to simulate preheating of the pipe waiting in “thermal reserve”. After levelling the temperature in whole profile the pipe was put into secondary furnace preheated at 535 °C to simulate temperature effects of superheated steam. The time of exposure at this temperature was 75 s. Because of the positioning of furnaces close to each other the moving of the tested specimen took 3.8 s. During this period, the temperature of the inner side of the pipe dropped only by 0.9 °C according to temperature measurement. By inserting the specimen into the furnace preheated for 535 °C, the temperature of the inner side of the pipe increased rapidly up to 412.7 °C. After that, the specimen was moved back to the furnace preheated at 145 °C, where the temperature levelled again in the whole profile. This measuring cycle was gradually repeated twenty times and the average value of the maximum temperature during the singe cycle was 406.4 °C. Other specimens were exposed to 30, 40 and 50 thermal cycles.

To prove the impact of long-term effect of temperatures mentioned above on resulting mechanical properties, we also carried out the experiments where specimens were exposed to temperatures 145 and 535 °C for nine hours. The tensile test was also carried out for all the specimens. Results are shown in **Table 3**.

Table 3 Material properties determined from the tensile test

	Specimen 1				Specimen 2			
	R_e [MPa]	R_m [MPa]	A_g [%]	A_{30} [%]	R_e [MPa]	R_m [MPa]	A_g [%]	A_{30} [%]
Basic material	348	452	18,3	33.2	349	452	17.9	33.1
9 hours of 145 C	346	450	17.5	32.6	344	452	17.8	33.2
20 cycles	336	449	18.6	34.5	339	451	18.0	33.3
30 cycles	333	449	18.1	33.9	329	451	18.4	34.1
40 cycles	327	444	18.0	33.6	334	451	18.1	33.6
50 cycles	329	448	18.5	33.8	320	444	18.1	33.6
9 hours of 535 C	325	438	18.6	34.6	310	438	18.4	34.4

Table 4 Hardness HV1 for individual sticks in the thickness direction

Stick sequence	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Distance from the inner edge [mm]	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.6
Basic material	139	143	143	140	142	140	141	145	141	140	141	142	141	140
9 hours of 145 C	145	146	146	143	143	142	140	145	143	139	142	141	143	141
20 cycles	141	140	145	141	142	141	140	141	141	142	139	140	139	142
30 cycles	141	142	145	144	142	144	143	139	140	136	139	138	138	138
40 cycles	140	140	143	141	142	141	142	142	141	143	140	142	135	137
50 cycles	149	136	138	145	141	139	139	139	136	139	139	138	138	138
9 hours of 535 C	139	137	139	136	138	134	139	135	132	133	137	137	137	139

Further the hardness in the thickness direction was determined for all specimens. Totally we carried out fourteen sticks in the thickness direction for each of the tested specimen. The first stick was in distance of 0.4 mm from the inner diameter of the pipe and the sequence was 0.4 mm. In the **Table 4** there are shown the harness values HV1 for each stick for all determined specimens. During temperature tests simulating effect of superheated steam on pipe material, the maximal surface temperature reached 412.7 °C. Therefore we decided to load the specimens which were heated for operation temperature 145 °C by fifty cycles at temperature 535 °C for an interval of 75 s by using the thermal-mechanical Gleeble 3500 simulator. This device enables to expose the specimen to whatever temperature or mechanical cycle, eventually their combination. For simulation the worst possible conditions which can occur in tested piping, there was simulated ideal rigid fixing of specimen. During fixing the specimen is plastically deformed. It is caused by thermal expansion. It results in the depletion of plasticity and the fatigue life reducing. Heating and cooling rates of the specimen during the experiment was 5 C.s^{-1}.

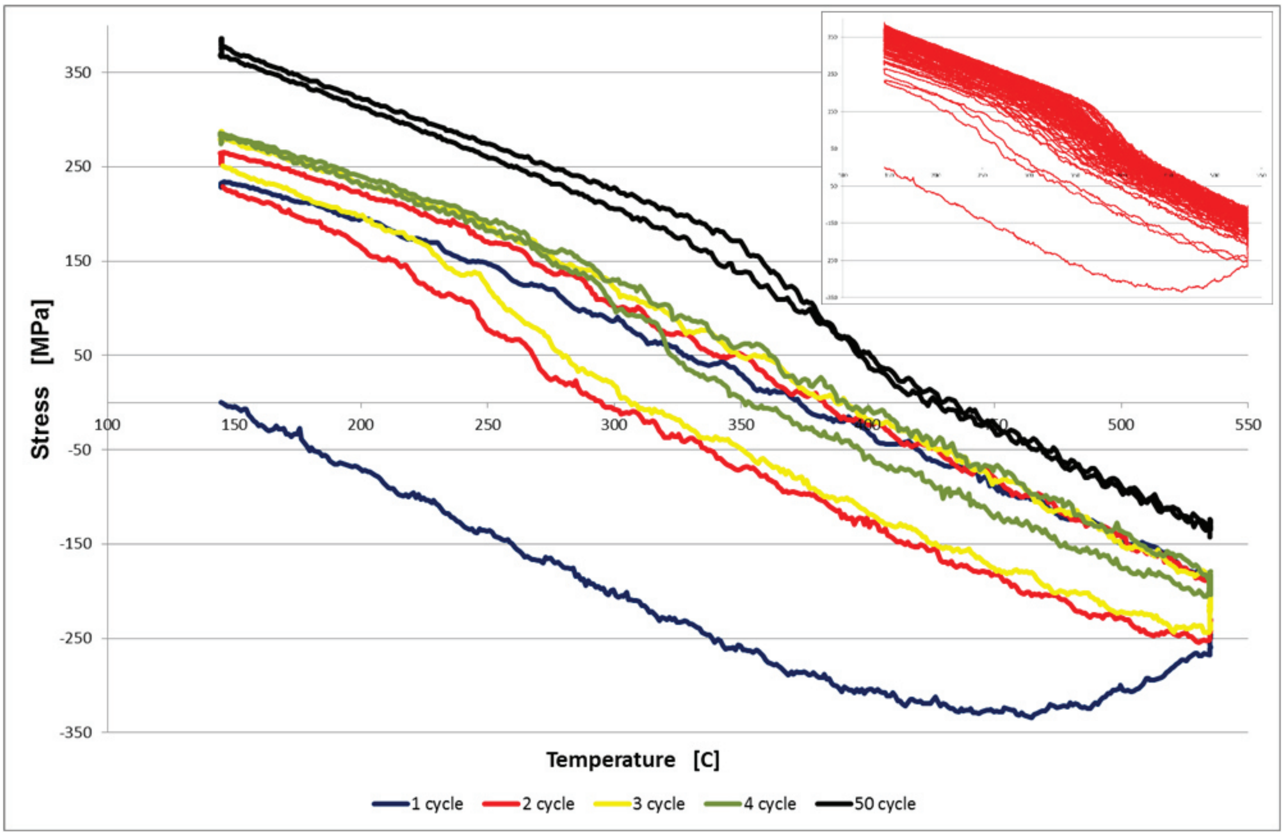

Fig. 3 Stress vs.temperature for temperature cycles 1, 2, 3, 4 and 50

Fig. 3 shows stress vs. temperature. For better demonstration only the first four cycles are shown and then cycle no. 50 (the stress process for all the cycles is marked red in the right top corner). From the stress course it is obvious leveling of the stress by plastic deformation. This effect is evident also during exposing to both temperatures (145 °C and 535 °C). The higher number of cycles, the narrover stress loops and the higher portion of tensile stress. The influence of Bauschinger effect reveals during cyclic loading when at the same time with increasing of plastic deformation increases also yield strength needed for this change. In addition, in this case yield strength in compression and tension also depends on the temperature. After cyclic loading of the specimens we carried out the tensile test with the following results: yield strength $R_{p0.2}$ = 317 MPa, ultimate strength R_m = 436 MPa, uniform ductility A_g = 5 % and ductility A_{30} = 14.6 MPa.

The Last phase of the experimental testing was determination of grain size for basic material, for specimen loaded by fifty cycles and specimen which was exposed to temperature 535 °C for nine hours. Because of the feritic-pearlitic structure of the steel, where pearlitic areas are strikingly smaller than feritic grains, we could not evaluate the test acc, to ISO 643. The average grain size was determined by the method of fifty biggest grains assessment in defined area by using Nis Elements AR 3.2 software. The grain size of basic material was 17.10^{-5} mm^2, for the specimen loaded by fifty cycles it was 21.10^{-5} mm^2 and for the specimen exposed to the temperature 535 °C for nine hours the grain size was 27.10^{-5} mm^2. **Fig. 4** shows the grain size for basic material (left) and for material exposed to temperature 535 °C for nine hours (right).

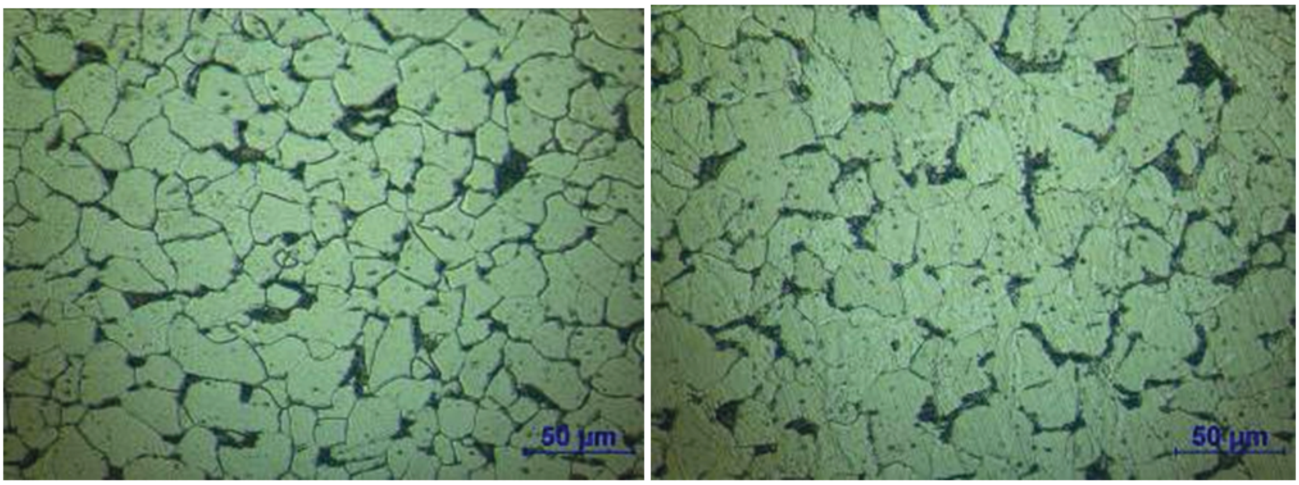

Fig. 4 Grain size for basic material (left) and for exposed material at 535 C for nine hours (right)

4. CONCLUSION

Creep resistant of C-Mn steel P235GH is ideally applicable up to temperatures 420 °C and its working temperature should not exceed 450 °C. Although the short-term exceeding of this temperature occurs, when it is used for the components of by-pass station of steam turbines, by the experiments we proved the suitability of chosen material for the particular use and only the small effect of the given temperature cycles on its mechanical properties and the structure. In light of mechanical properties, the yield strength only dropped by 7 % for the specimens after fifty cycles. Specimens with thermal exposure of nine hours at the temperature 535 °C showed descent by 9 %. Other mechanical properties remained almost unchanged. Considerable differences only occurred during testing on the Gleeble 3500 simulator when was used rigid fixing. The rapid descent of ductility occurred due to considerable plastic deformation of the specimen. Even though, the tested material is suitable for this particular use. The influence of temperature cycles on the structure reveals only the slight enlarging of grains. No considerable differences were also found by measuring of hardness HV1 towards the pipe thickness direction. The average hardness of the specimen dropped after fifty cycles only by 1.7 HV and for the specimen with thermal exposure of nine hours at the temperature 535 °C it decreased only by 4.7 HV.

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REFERENCES

[1] Turbine equipment 3D graphical documentation, Siemens Ltd, 2014.

[2] HAGEN, I., BENDICK, W. Creep Resistance Feritic Steels for Power Plants. From Conference International Symposium on Niobium, Warrendale: 2001.

[3] P235GH Pressure Vessel Steel, Masteel UK Ltd, Birmingham, UK, 2010.

[4] FÜRBACHER, I., MACEK, K., STEIDL, J. Lexicon of technical materials. 1. ed. Prague: Verlag Dashöfer, 2003.