THE EFFECT OF TECHNOLOGY OPERATION LIKE BENDING ON PROPERTIES OF NEW AUSTENITIC STEELS FOR APPLICATION IN BOILERS WITH HIGHER STEAM PARAMETERS

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Abstract

This paper focuses on the influence of the cold bending process on stress - strain characteristics of materials SUPER304H, HR3C, Tp347HFG that can be used for superheaters and reheaters of newly built or refurbished power plant boilers. The qualification tests were carried out on bends in two dimensions of tubes and on several bending radii to verify the effect of cold bending technology. In the year 2013 there was tested new bend radius. To obtain reliable information, a tensile test, a hardness test and metallographic examination were used on material from the straight tubes of the bends, drawn and compressed parts whose results are presented in this paper and are an extension of the results obtained from the new bend radius compared to last year´s article. We have acquired new information about the stress-strain behaviour of advanced structural materials thanks to the realization this experimental program. We can give precision to correlation relations between SPT and conventional tensile tests for austenitic materials presented in the year 2013. In the context of the project there were performed simulation calculations that used the experimental results focused on verification of the deformation in bending parts, the thinning of the wall thickness and determination of the thermodynamic stability of phases. Some of them are described in this article. The tests have been carried out under the grant project of the Technology Agency of the Czech Republic TA01010181 with the name Bending-tubes-technology for superheaters and inter-superheater tubes for progressive boiler construction which VÍTKOVICE POWER ENGINEERING a.s. researches in cooperation with companies named UJP a.s. and SVÚM a.s.

Keywords: Austenitic steels, Small punch test, Cold deformation, thermodynamic stability of phases, creep

1. INTRODUCTION

Efforts to increase the efficiency of thermal power plants, as previously mentioned [1], leads to research of new materials, which have to resist the required temperature and corrosive conditions for a long period. This recent applies particularly to supercritical or ultra-critical boilers, where the pressure of superheated steam at critical boiler spots (super-heater and re-heater) exceeds 25 MPa and its temperature can achieve values of 600 - 700 °C. The corrosive environment on the flue gas part is given by coal used from a concrete area of mining and is therefore specific. Subject of the project TA01010181 is to asses and predict long-term live-time of the bends of selected materials. At first, it was necessary to asses and to verify the effect of cold bending technology on the properties of bends in short-term tests. As we mentioned in [1], there was found large strain hardening of HR3C a Tp347HFG, which in the drawn and pressed part of the bends exceeded the maximum limit of yield strength according to relevant material data sheets. That is why a new bending radius was tested below what is called R5, which approximates the bending radius, for which ASME Section I doesn`t require heat treatment. The foregoing materials of seamless tubes are already included in the ASME Code. The approach of product standards is very different in addressing the issue of heat treatment after cold-bending. Our goal is to experimentally verify and define the conditions under which heat treatment is necessary and when it is even useless. Because we know that the results of short-term tests are not critical in the application of these steels, these results are only the input information for long-term tests, which are extended in co-investigations.

2. CHARACTERISTIC OF STUDIED STEELS

As it was mentioned in [1], new austenitic creep resistant steels were tested with application in higher parameter boilers. Namely the experimental research part was carried out on materials SUPER 304H, HR3C a Tp347HFG.

2.1 Chemical composition and mechanical properties

For the new experiment there were used the steels as in previous tests mentioned in [1] produced in the SUMITOMO company. The tubes were delivered in a state after dealing with annealing, cold-rolled according to German material data sheets. [2] [3] [4] The chemical composition on randomly selected locations of the various tubes coming from different heats was examined and it was relatively homogeneous, therefore it is not necessary to continue monitoring the specific melting or group of supplies. Requirements of the material data sheets and the average value of the attests are shown in **Tables 1-3**.

Table 1 Chemical composition a mechanical properties Super304H [2]

C [%]	Cr [%]	Cu [%]	Ni [%]	N [%]	B [%]	Nb [%]	Al [%]	$R_p0.2$ [MPa]	R_m [MPa]	$R_p0.2^*$ [MPa]	A [%]	Type and dim.	KV [J]
0.07 0.13	17.0 19.0	2.50 3.50	7.5 10.5	0.05 0.12	0.001 0.010	0.30 0.60	0.003 0.030	≥ 235	590- 850	≥ 140	≥ 35	KV 2 10x10	≥ 85
0.08	18.3	3.04	9,0	0.11	0.004	0.49	0.007	318	635	210	46	10x2.5	30

Table 2 Chemical composition a mechanical properties HR3C [3]

C [%]	Mn [%]	Si [%]	Cr [%]	Ni [%]	N [%]	Nb [%]	$R_p0.2$ [MPa]	R_m [MPa]	$R_p0.2^*$ [MPa]	A [%]	Type and dim.	KV [J]
≤ 0.10	≤ 2.00	≤ 1.50	23.0- 27.0	17.0- 23.0	0.150- 0.350	0.20- 0.60	≥ 295	655- 900	≥ 160	≥ 30	KV 2 10x10	≥ 85
0.06	1.17	0.4	24.9	19.9	0.260	0.43	371	750	199	47	10x2.5	38

Table 3 Chemical composition a mechanical properties of Tp347HFG [4]

C [%]	Mn [%]	Si [%]	Cr [%]	Ni [%]	Nb+Ta [%]	$R_p0.2$ [MPa]	R_m [MPa]	$R_p0.2^*$ [MPa]	A [%]	Type and dim.	KV [J]
0.06- 0.10	≤ 2.00	≤ 0.75	17.0- 20.0	9.0- 13.0	8 x C	≥ 205	550- 750	≥ 131	≥ 35	KV 2 10x10	≥ 85
0.09	1.50	0.35	18.3	11.5	0.9	323	613	208	49	10x2.5	25

Note: $R_p0,2^* = R_p0,2$ at 600 °C

3. SCOPE OF WORK

To produce individual tests on the new bending radius there was used cold bending technology without a mandrel for pipes with a dimension 38 x 6.3 mm. Documents of the Japanese company Sumitomo [5], [6], [7] is the main source of information for technological operations of these steels. There are stated not only the recommended value of the deformation but also photos of bends. Information or, in some cases, the requirements for heat treatment (HT) after bending can be also obtained from the German material data sheets [2], [3], [4] , European standards and U.S. regulations and they are different. Therefore, the project tested the properties of cold bended tubes with and without HT at different radii. Bend testing was carried out in two testing houses, VTC (qualifying tests - exactly as required by the standards) and MMV s.r.o., where the properties of the individual parts of the bends were verified. The influence of deformation was newly studied on the radius in the article named R5 and these results were compared with previous results on bending radii R1<R2<R3 (or R4). [1]

3.1 Mechanical tests including SPT

To study the influence of plastic deformation it was necessary to extend the works beyond the required scope of the standards with the tensile tests from the deformed areas (drawn and compressed **Fig. 1**) [1]. Because it is not possible to locate a conventional tensile test specimen into pipe bends we used only small punch tests and miniaturized specimen to verify the mechanical properties on individual bend sides (**Fig. 2**). It was possible due to the project focused on miniaturized test technique which the MMV s.r.o dealt with Project No. CZ.1.05/2.1.00/01.0040 "Regional Materials Science and Technology Centre" within the frame of the operation programme. The method of testing of SPT was described in the article [1]. The acquired results were as in the year 2012 correlated with the results on miniaturised tensile specimens and were inserted into constructed correlation graphs. Because the new bend radius enabled making the tensile test specimens from the inside diameter bend location (it means from the compressed part) it was possible to fill in the correlation relations of these points. [8]

3.2 True stress - true strain tests

Within the project actual true stress-true strain curves have been measured and constructed in various defined bend locations for subsequent use in numerical simulation of bending technologies. Tests were carried out on equipment MTS servo-hydraulic testing machine 100 kN at a constant speed movement of the piston rod 0.5 mm/min. strain was measured by an extensometer with a base of 12 mm. During the tensile tests actual force as well as actual value of diameter were collected for following evaluation of true stress-true strain curves.[9] The obtained points, the actual true stress - true strain curves, were described [10] using function type (1):

$$\sigma = K * \varepsilon^n \tag{1}$$

Where: K [MPa].....strength coefficient

n ....exponent of deformation hardening

3.3 Creep

Also creep tests were provided for the study of the influence of plastic deformation on properties of named steels. The deformation level of these tests emerged due to the numeric analysis, which was performed by the ITSolution company [11]. Due to time limitation of the project we agreed the experiment period of 3000 hours only. The actual program creep tests were conducted on each of three tests carried out at temperatures of 650 and 700 °C, and such stress to achieve the longest test times to the rupture at about 3000 hours [12].(**Fig. 9**)

3.4 Numeric simulation of thermodynamic phase stability

Designing true stress- true relative strain curves was one of targets of the numeric simulation. It was obtained by the application of Finite Element Method supplemented of actual results from true stress-true strain tests [13]. The method which was used is described in [14]. The second target was to compare the geometry of the actual bend with simulations results. A very interesting result is from calculation of thermo-mechanical stability phases in a temperature range 500-700 °C. It was calculated in the Thermo-Calc-programme according to [15].

4. RESULTS

4.1 Results of mechanical tests including SPT

The following graphs **Fig. 3** to **Fig. 5** summarize results of yield strength, ultimate strength and hardness depending on the bending radius R. They can be considered as results of mechanical tests, depending on the deformation magnitude where R1 <R2 <R3 <R4 <R5 are bending radii. Deformation decreases with increasing bend radius. In each graph is also marked the maximum tensile strength value according to the relevant material data sheet.

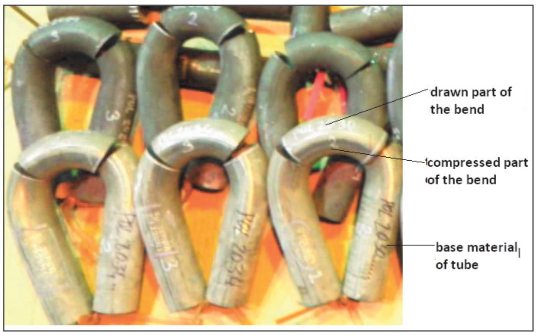

Fig. 1 Photo of bends prepared for corrosion tests

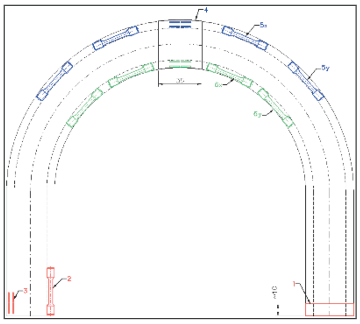

Fig. 2 Sampling plan

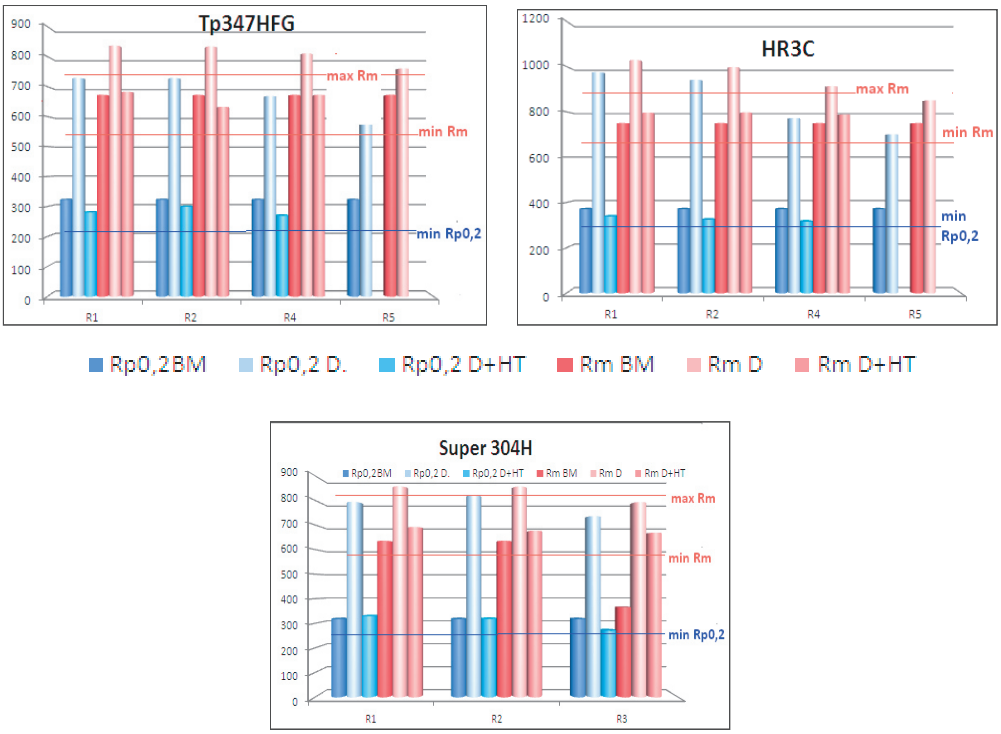

Fig. 3, Fig. 4 and Fig. 5 The effect of cold deformation (D) and heat treatment (D+HT) on $R_p0.2$, R_m

4.2 Results of true stress- true strain tests, creep test and results of numeric simulation

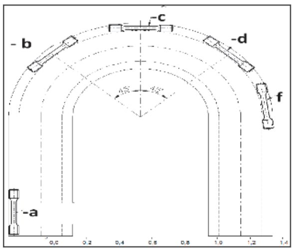

Fig. 6 Sample plan

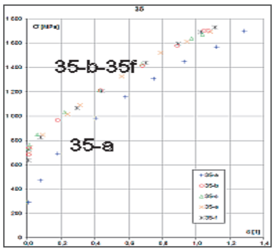

Fig. 7 True stress-true strain curves

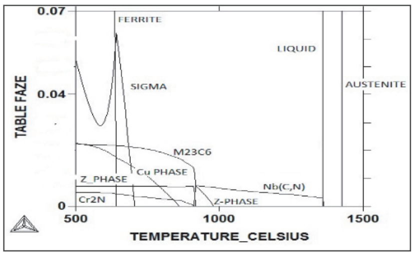

Fig. 8 Results of stable phase calculation for Super304H

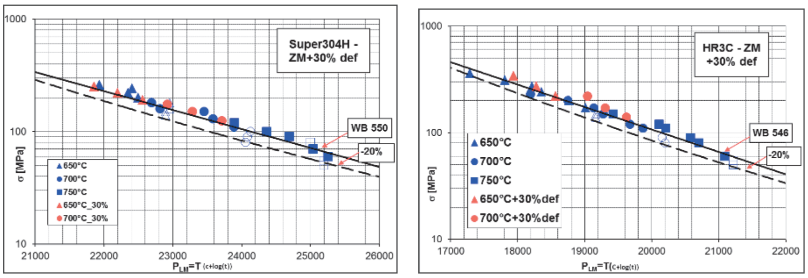

Fig. 9 The results of creep tests from straight tube before bend and for part of bend with 30 % deformation

4.3 Results of metalografic investigation

Metallographic investigations were also subjected to various parts of the bend. At **Fig. 10** to **Fig.13** are photo microstructures from the bend radius R5. The drawn section (D) is compared with a base material of tube (N) of materials Tp347HFG and HR3C. There was found no significant difference in the distribution of carbides (or precipitates) or their size, as well as in grain size between the individual parts of the bend.

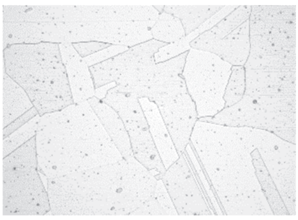

Fig. 10 HR3C R5 N

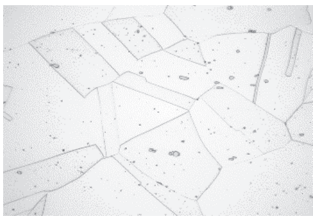

Fig. 11 HR3C R5 D

Fig. 12 Tp347HFG R5 N

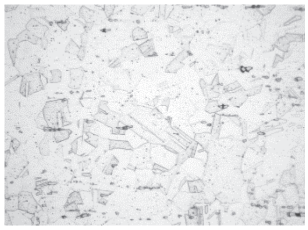

Fig. 13 Tp347HFG R5 D

4.4 Discussion of results

From these finding it can be concluded that the strain hardening of all tested was big, it means as is written below. The Super 304H material was subjected to hardening manifested by increased yield strength near the level of tensile strength, but the tensile strength did not exceed the maximum value specified in the material data sheet for straight tube even with the smallest bend radius. In contrast, the materials HR3C and Tp347HFG, even with less deformation, exceeded the maximum tensile strength given by the material data sheet. Up to radius R5, which is about 15 % deformation was the tensile test according to material data sheet (the maximum limit). The obtained correlations between the results of tensile tests and SPT for all types of studied material allows very precise share of the increase in strength properties in the critical part of the bend, which is found to be hauled page. Using these equations for the determination of mechanical properties in the compression location results in a somewhat elevated, but the difference is of conservative importance and on the side of safety. All the results obtained are used mainly for assessing the state from further degradation tests, such as the flue gas side corrosion and thermal degradation, which took place at our co-investigators UJP Praha a.s. and SVUM a.s.

CONCLUSION

The stress-strain characteristics of plastically deformed bends locations were obtained within the realized experimental program of the methods miniaturized tensile tests and SPT. Research performed in the last two years led to the establishment of basic correlations for the studied materials between the strength properties as determined by SPT and the results obtained by miniaturized tensile tests. We have got the results of creep tests after 30 % cold deformation without subsequent heat treatment. They do not reduce significantly the value of creep compared to standards and base material. But it necessary to remember that it is provided for a very short time, the time to rupture was only about 3000h. It will be possible to recommend maximum deformation without heat treatment only after the evaluation of long-term of tests.

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