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CREEP PROPERTIES INVESTIGATION OF P23 STEEL WELDMENTS

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ABSTRACT
Low-alloy creep resistant steel P23 (2,25%Cr-1,6%W-0,25%V) has been developed for pipe lines in power engineering. Creep properties of weldments should be included in pipeline design. Weld strength and weld strength reduction factors, representing a ratio between creep strength of weld and base material, are possible to use for quantitative expression of welding effect. This paper reports the investigation of P23 weldment production possibilities. Evaluation of weld strength factor, based on long term creep tests of P23 steel pipe base material and optimum prepared similar circumferential welds, is performed in dependence on creep condition by a phenomenological model. Metallographic analysis of weld joints after creep exposition is a part of this work.
Keywords: creep, low-alloy steel P23, welding

1. INTRODUCTION
Progress was achieved in the area of low-alloy steels in relation to the initially hydrogen-resistant steel 3%Cr-0.5%Mo. This research, which was carried out in Japan and Germany, resulted in the T/P23 pipe steels (2.25% Cr-0.18% Mo-0.25% V-1.6% W, Nb, B) and T/P24 (2.4% Cr-1% Mo-0.25% V, Ti, B), intended for water walls and superheaters, with a working temperature up to 580°C [1,2]. It is obvious that the T/P23 steel is enriched by a major amount of W in comparison with the hydrogen-resistant material of the 3% Cr-0.5%Mo type. A decrease of Mo can also be registered; V and Nb were included in the alloying base and B and N in microalloys. The effect of this type of alloying is manifested in the better carbide steel strengthening and increased resistance to creep. Moreover, the C content was decreased (to 0.04-0.1 wt.%), which has a favourable effect on weldability.

The present contribution is the continuation of our previous works [3] and will focus on the P23 thick-wall steel, particularly on the possibility of making satisfactory weld joints and on the heat resistance of this system.

2. EXPERIMENTAL MATERIAL AND CREEP PROPERTIES OF THE P23 STEEL
The P23 test material was produced by the Vallourec and Mannesmann Tubes. It was supplied under heat designation 73 200 in the form of a seamless tube ∅219x30 mm, heat treated by the 1060°C/water+760°C/2h procedure. According to attest [4] the chemical composition (in wt.%) of recieved material of heat No.73 220 was as follows: 0.07 C, 0.54 Mn, 0.008 P, 0.004 P, 0.28 Si, 2.08 Cr, 0.08 Mo, 0.22 V, 1.65 W, 0.03 Nb, 0.002 B, 0.011 N, 0.018 Al. Also the attested mechanical properties ($R_{p0.2}$=496 MPa, R_m =597MPa,A=23.3 %, KCV=185(J)) fulfil the standard requirements

[4]. This material was used both for the evaluation of creep properties of the base material and for the welds creep strength determination.
The creep tests of the base material were carried out on air and at a constant load. Bars were used with a nominal diameter and length of ∅5x50 mm. Tests were performed at temperatures from 500°C up to 600°C and within stress range from 320 to 105 MPa. Altogether 22 tests were carried out. The test specimens were oriented in the direction of the pipe longitudinal axis.
The creep tests were evaluated by a standard regression model [5,6]

$$\log t = A_1 + A_2 \cdot \log\left|\frac{1}{T} - \frac{1}{A_5}\right| + C_3 \cdot \log\left[\sinh\left(A_6 \cdot \sigma \cdot T\right)\right] + + A_4 \cdot \log\left|\frac{1}{T} - \frac{1}{A_5}\right| \cdot \log\left[\sinh\left(A_6 \cdot \sigma \cdot T\right)\right] \quad \text{. . . (1)}$$

where T is temperature, t is time to rupture, σ is stress, A_1-A_6 are material constants.
The result of this evaluation is plotted in Fig.1; material constants are given in Tab. 1.

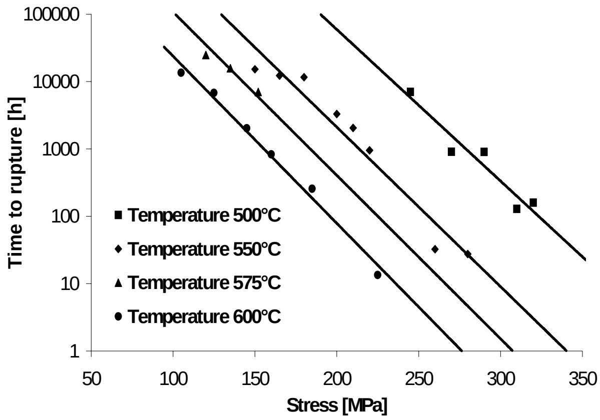

Figure 1. Creep strength evaluation of P23

Table 1: Material constants of relation (1)

A_1	8.9271E+01	A_4	-1.9198E-01
A_2	2.5663E+01	A_5	1.8784E+03
A_3	-2.6838E-02	A_6	6.1866E-04

Valid for T(K), t(h) and σ(MPa)

3. WELDS PRODUCTION

The detailed procedure for the production and quality examination of welds is described in [7]. Here we describe briefly only used technology. The composition of individual layers is in Fig.2 and the welding parameters are given in Table 2. The weld joints were made by the combination of the GTAW (TIG) and SMAW methods. This combination proved well during the production of pressure pipes. The use of the GTAW method enables good shaping of the weld root and minimisation of surface and internal defects. The bevel filling can already be welded with a coated electrode. Welding was carried out with a small electrode swing. The sense of this technique was to achieve on the one hand certain annealing of the weld layers, on the other hand to create the narrowest possible coarse grain band of the heat affected zone.
The technology indicated was used for the preparation of semi-finished products, from which test bars were made with a diameter and length of ∅6x60 mm. The weld joint was placed in the middle of the measured length.

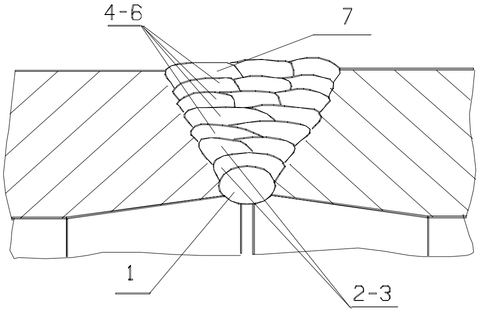

Figure 2. Order of welding metal layers

Table 2: Welding parameters of separate layers

Layer	Process	Filler material	Diameter (mm)	Electric current (A)	Voltage (V)	Heat input (kJ/mm)
1	GTAW	WZCrWV22	2.5	125-140	15-22	0.8-1.1
2-3	SMAW	Thermanit P23	2.5	75-40	20-25	0.9-1.3
4-6	SMAW	Thermanit P23	3.2	110-135	20-25	1.1-1.5
7	SMAW	Thermanit P23	4.0	150-180	20-25	1.2-1.7

4. THE EFFECT OF POST WELD HEAT TREATMENT

Immediately after welding, welds were annealed in order to decrease the residual stress. The following PWHT were investigated: **WELD I** 750-760°C/2h, **WELD II** 740-750°C/2h and **WELD III** 730-740°C/1h. As the criterion, creep tests at temperatures 500, 550 and 600°C were selected.

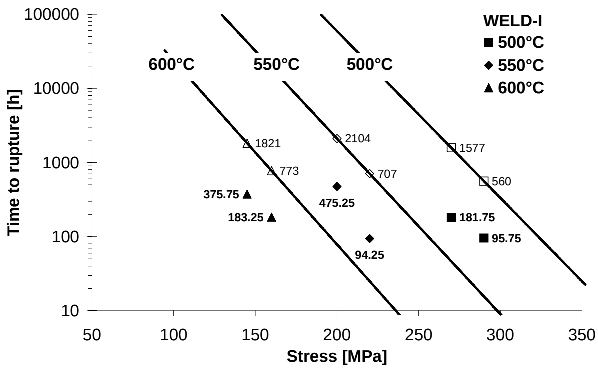

Figure 3. Creep strength of weldment – WELD I

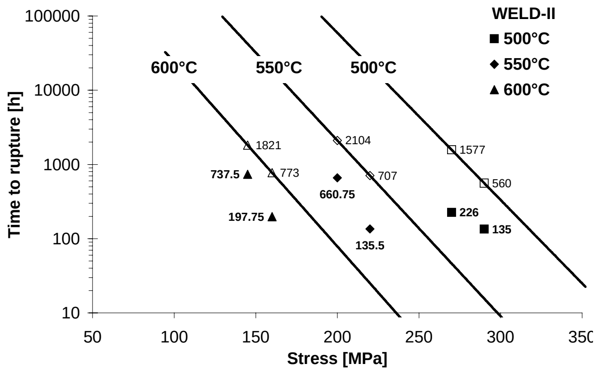

Figure 4. Creep strength of weldment - WELD II

The results for alternative I are illustrated in Fig.3. The creep strength of the base material is represented by solid lines, the test results are represented by full points. The open points on the isothermal lines represent the expected result if the welded results would be the same as the base material. It is obvious that there is a significant difference. The lifetime of the welded joints corresponds approximately to the 19% level of the base material.

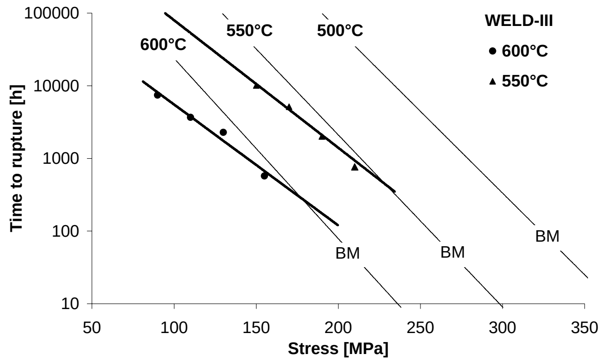

Figure 5. Creep strength of weldment - WELD III

The results of the tests of alternative II are represented in the same manner (see Fig.4). Lowering the annealing temperature increased the lifetime of the weld joints less. However, it was only at the 28% level of the base material. The expected result was achieved only in the third alternative. Further lowering of the annealing temperature and reducing of the exposure time had logical consequences: The creep strength of weldment decrease with the growth of the testing temperature and increased lifetime. However, the problem is that there already was a lack of the test material. It is obvious from Fig.5 only eight points documented the described effect.

5. CREEP PROPERTIES OF THE WELD JOINT

According to the methodology of the European Creep Collaborative Committee [8], the decreasing creep resistance of the weld joint with time can be characterised by a weld strength factor (WSF) that expresses the ratio of the creep strength of the weld joint and the basic material. The following relation is used for this purpose

$$WSF(t) = \frac{R_u(w)/t/T}{R_u/t/T}. \quad \ldots (2)$$

where WSF(t) is weld strength factor, $R_u(w)/t/T$ is creep strength of the weldment and $R_u/t/T$ is creep strength of the base material at temperature T and time to rupture t.

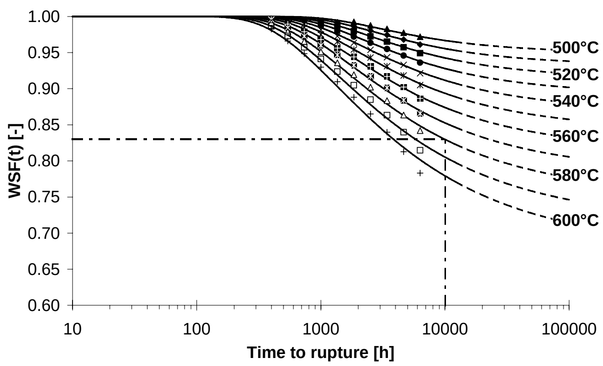

Figure 6. WSF(t) course in dependence on time and temperature of exposition for material P23

We used a mathematical model for the expression of WSF(t), which was used firstly for the 15 313.5 material [9]. This model was designed in following form

$$WSF(t) = 1 - S_1 \exp\left[-S_2 \cdot \ln(t_r + 1)^{-S_3}\right]. \quad \ldots (3)$$

where $S_1 = s_{11} + s_{12}.T + s_{13}.T^2$, $\ln S_2 = s_{21}.\exp(s_{22}.T)$, $S_3 = s_{31}.\exp(s_{32}.T)$, T is temperature (K), t_r is time rupture (h), s_{ij} (i,j=1-3) are material constants.

The reason for using this model was the fact that alloying the ČSN 15 313.5 and P23 steel is a similar, even if P23 has a significantly higher heat resistance. The time and temperature dependence of WSF(t) according to model (3) is shown for the P23 material in Fig.6. It is obvious that at a temperature of 580°C and time 10,000 hours, WSF(t)=0.83.

6. METALLOGRAPHY

From the point of view of the WSF(t) application to the P23 type of steels, it is suitable to know what part of the weld joints is critical for the given stress parameters. On the basis of the metallographic analyses of the weld joint tested at 550 and 600^{0}C, it can be stated that the fracture shifts from base material (BM) to heat affected zone (HAZ) with decreasing stress. At a temperature of 550^{0}C, this transition is somewhere between 150 and 190 MPa. Low stresses lead to the initiation of cracks of type IV (intercritically heated HAZ) or type III (fusion line). Fig.7 documents macroscopic views on the fracture in BM (test parameters 550°C/220MPa/262h), fracture in the intercritically heated HAZ (600°C/90MPa/7,439h) and the combined fracture of type III + IV (550°C/150MPa/10,097h).

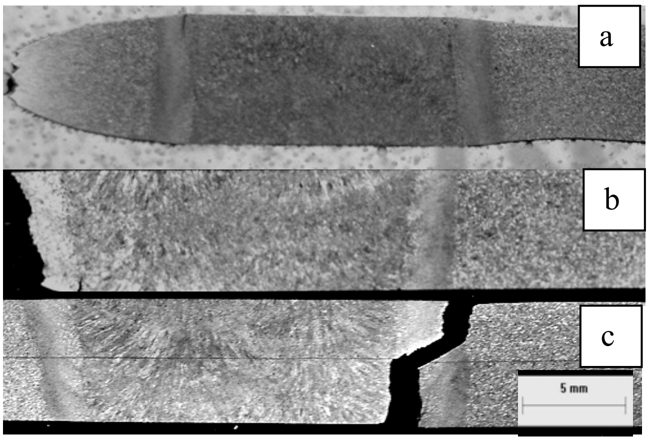

Figure 7. Damage type after creep tests
a) fracture in BM - 550°C/220MPa/262h
b) fracture in intercritically heated HAZ - 600°C/90MPa/7439h – type IV
c) Fracture in fusion line - (550°C/150MPa/10097h) – type IV + III.

7. CONCLUSION

This paper summarises knowledge on the heat resistance of the basic material and the weld joints of the P23 steel. The results obtained can be summarised as follows:

a) The welding procedure was determined and the optimum parameters were found for thermal processing.
b) By means of a mathematical model, the time and temperature dependence was determined for the WSF(t).

8. ACKNOWLEDGEMENTS

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