

## **Problems occurred during welding of bainitic steel 7CrMoVTiB10-10 (T24)**

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### **Abstract**

A dynamic development of steels for components for use boilers used in fossil fired power plants creates new welding problems. Introduction of new combinations of alloying agents, which are used to improve mechanical properties, especially creep resistance, does not remain indifferent as to the weldability of the newest steels. Every new steel grade which will be used for pressure components in power plants boilers has to be precisely tested. The most important processes that require profound research are bending and welding. It is crucial to examine all new steel grades and use the knowledge to elaborate technologies which could be used during prefabrication and assembly of boiler installations. As an example 7CrMoVTiB10-10 also known as T/P24 is given.

Keywords:

T24, 7CrMoVTiB10-10, welding, power units, martensitic steel, dissimilar joints

### **1. Introduction**

Present and constant trend towards reduction of production costs in energy generation is directly connected with the increase in the efficiency of power units at conventional power plants. Improvement of the efficiency can be reached through the increasing of main parameters, i.e. steam pressure and temperature. At present it is possible only if steam boilers are made of modern structural materials, which are able to withstand operational loads as well as provide high enough heat resistance in increased temperatures. Modern martensitic steels, such as E911 or P92 allow designing of power plants where superheated steam temperature of 625°C is applied. The increase in the steam pressure and temperature has a direct effect on the condition of the operation of membrane walls. Conventional materials like 16Mo3 or 13CrMo4-5 are not suitable for boiler walls for supercritical applications. Therefore the investigations on new steel grades of mechanical properties and creep strength that would enable them to be used as a component of a boiler working at very high temperatures have been initiated. In addition while developing those materials there were an idea to eliminate post-weld heat treatment during welding of thin-walled components (up to 10 mm) as in production conditions, especially in case of the walls, this treatment is difficult and expensive.

As the result of long-term research two new steel grades have been developed: 7CrWVMoNb9-6 (T/P23) in Japan as well as 7CrMoVTiB10-10 (T/P24) of Vallourec&Mannesmann consortium.

## 2. General Characteristic of Examined Steel

Basic chromium-molybdenum steel containing 2,25%Cr-1%Mo i.e. 10CrMo9-10 (T/P22) was developed nearly 60 years ago. Steel 10CrMo9-10 and 13CrMo4-5 were first so-called “genuine” steels with the increased creep strength. Originally those steels were designed for the long-term operation in the temperature up to 550°C and continual and failure-free operation for 250 000 h (over 30 years) of boilers made of those steels has been noticed. The temperature of austenisation and the cooling rate as well as tempering conditions determine the structure and properties of steel in great measure. In chromium-molybdenum steels ferritic-perlitic (P22) and bainitic (P23 and P24) structures are most commonly obtained. Strengthened material with a predominance of bainite is characterised by the high creep strength, however it loses its strength more quickly than that with ferritic-perlitic structure due to lower structure stability [1].

TABLE I

Comparison of chemical composition of 2,25% Cr steels according to EN 10216-2 standard

Grade	Chemical composition, %									
	C	Si	Mn	Cr	Mo	Nb	Ti	V	B	W
T/P22	0.08-0.14	≤ 0.5	0.3-0.7	2-2.5	0.9-1.1	–	–	–	–	–
T/P23	0.04-0.1	≤ 0.5	0.1-0.6	1.9-2.6	0.05-0.3	0.02-0.08	–	0.2-0.3	0.0005-0.0006	1.45-1.75
T/P24	0.05-0.1	0.15-0.45	0.3-0.7	2.2-2.6	0.9-1.1	–	0.05-0.1	0.2-0.3	0.0015-0.007	–

T/P23 and T/P24 steels are another steel grade developed on the base of the steel containing 2% chromium with monitored alloying micro-additives amounts, which increase creep strength in the high temperatures. In case of P23 steel the molybdenum content has been significantly reduced and replaced with the highly carbide-forming elements, such as tungsten, vanadium and niobium. In P24 steel the content of molybdenum is on the same level as in P22 steel but it is enriched with the addition of vanadium, tungsten and boron which simultaneously influence the stabilisation of the structure. The carbon content is kept on very low level, what considerably improves the weldability and in theory makes possible to weld without preheating. The content of nitrogen has been reduced as well up to maximum of 0.01% in order to minimize the creation of the titanium nitrides. Addition of titanium and boron in P24 steel has revealed certain problems with welding of this steel. Because of the high affinity of titanium for oxygen during welding processes those elements are being burnt out. This phenomenon has an adverse effect on the creep strength and properties of the weld. Table I shows the chemical composition of steels of 2,25% Cr group compared, while in Table II the mechanical properties of P22, P23 and P24 steels are given.

TABLE 2

Comparison of the mechanical properties of 2,25% Cr steels according to EN 10216-2 standard

Grade	Mechanical properties								
	Re, MPa	Rm, MPa	A min., %		KV, J		R <sub>p0,2</sub> , MPa		
			w	p	w	p	500°C	550°C	600°C
T/P22	280	480-630	22	20	40	27	180	-	-
T/P23	400	510-740	20	18	40	27	330	299	266
T/P24	450	565-840	17	15	40	27	324	301	248

### 3. Subject of research

Subject of research was the tube  $\varnothing$  44.5×7.1 mm and 7CrMoVTiB10-10 (T24) grade. The chemical composition is shown in Table III.

TABLE 3

Chemical composition of tested T24 steel grade

Grade	Chemical composition, %								
	C	Si	Mn	Cr	Mo	N	Ti	V	B
T/P24	0,075	0,256	0,58	2,436	0,991	0,0082	0,087	0,235	0,0045

The mechanical properties of T24 steel in the initial state are shown in Table IV.

TABLE 4

Mechanical properties of tested T24 steel grade in the initial state

Grade	Mechanical properties			
	Re, MPa	Rm, MPa	A min., %	HV
T/P24	500	608	21,5	208

### 4. Plan of investigation

After the welded joints were produced the non-destructive testing, i.e.: VT, PT and RT was conducted. Testing was performed with the reference to the level B in accordance with PN-EN ISO 5817 standard. Once

the positive results of NDT were obtained, specimens were taken from the joints for mechanical testing as shown the diagram in Fig. 1

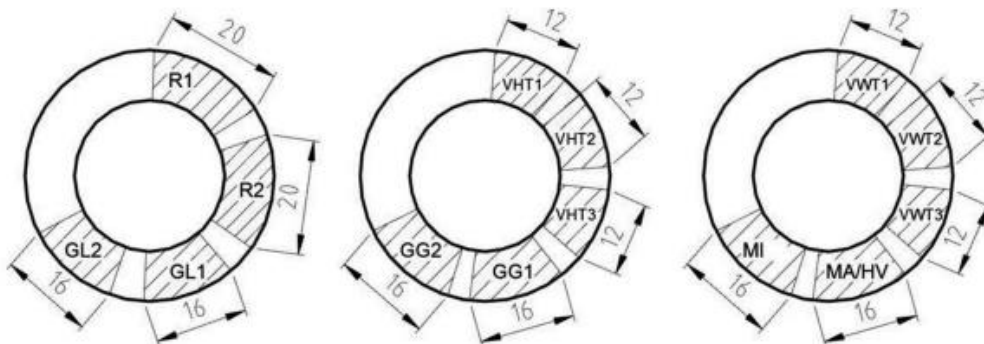


Fig. 1. The manner of cutting out of specimens from butt welded joints of tubes

The scope of mechanical testing included:

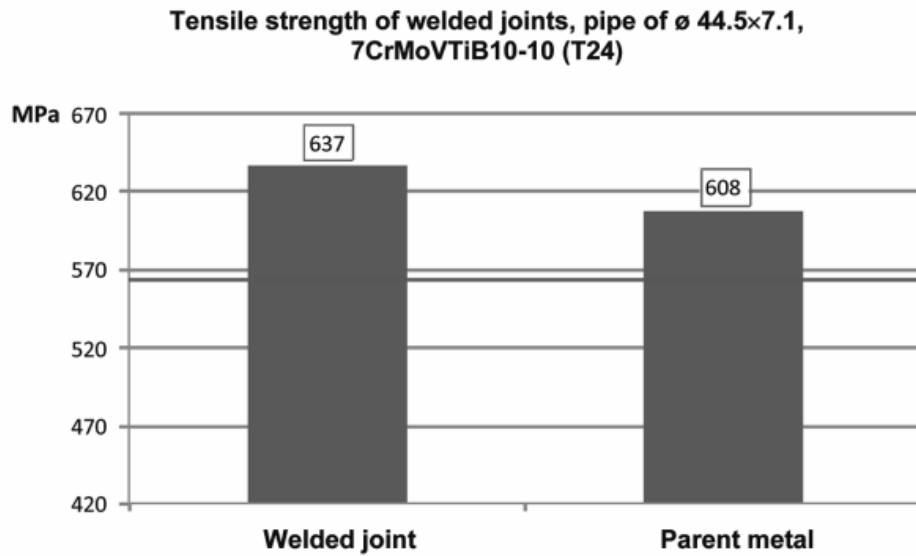
- static tensile test of welded joint (specimens R1 and R2),
- bend test (bending from face side GL1 and GL2 as well as root side GG1 and GG2),
- impact test (specimens VWT1÷VWT3 – notch in the weld; specimens VHT1÷VHT3 – notch in HAZ),
- hardness measurements (specimen MA),

## 5. Results of tensile strength test

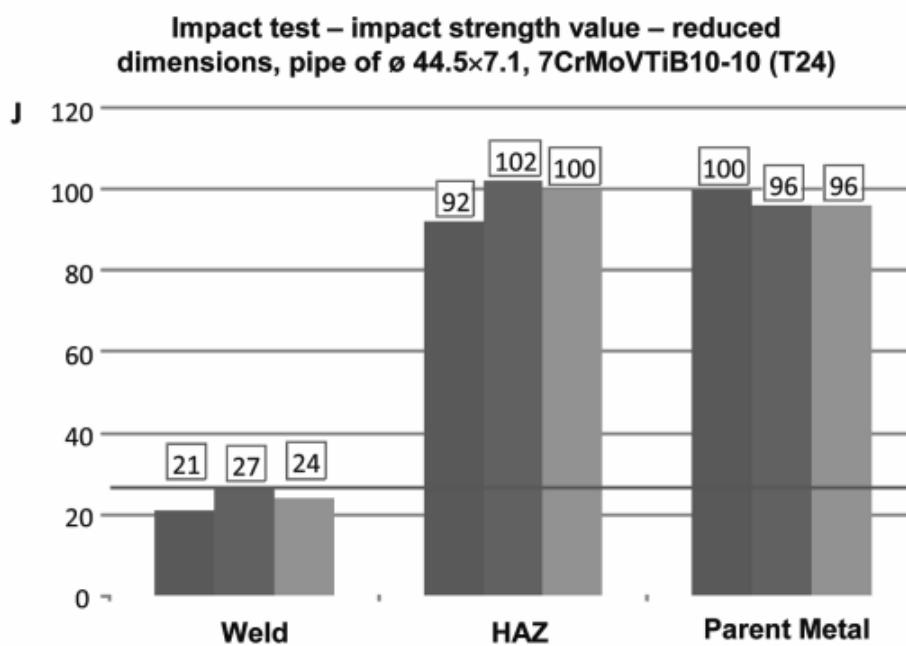
Testing was conducted in order to determine tensile strength of a weld ( $R_m$ ) and verify the results considering the required minimum  $R_m$  for parent material (PM), which is 565 MPa according to the PN-EN 10216-2 standard. This value is marked with heavy line in the diagram (Fig. 4). Research has revealed that all welded joints broke outside the weld, thus have met the strength requirements.

## 6. Results of impact test for weld and HAZ

Testing was conducted in order to determine the impact strength values for the weld and HAZ. Acceptance criteria imposed in PN-EN 12952-6 standard determine minimum impact value for samples of standard section (10×10 mm) in HAZ on the level of 24J in room temperature, while standard PN-EN 10216-2 determines minimum impact value for PM on the level of 27 J. Those values are marked with the heavier line (Fig. 5). Results of the impact values in a weld and the HAZ are higher than those required by standards mentioned above, as testing was conducted on the specimens of smaller section (5×10 mm). The results shown in Fig. 5 are in fact in the conformity with current guidelines according to impact testing of samples of smaller sections, i.e. they are proportionally (two times) higher.



**Fig. 2. Results of tensile test of butt welded joints of tubes of  $\varnothing 44,5 \times 7,1$**



**Fig. 3. Impact strength of weld metal in butt welded joints of T24 steel in tubes of  $\varnothing 44.5 \times 7.1$**

## 7. Results of bend test

Bend test with tensioning of weld face and root was performed in accordance with PN-EN 15614-1 and PN-EN ISO 7438. Standard provision states that acceptance criteria is to obtain the bend angle of  $180^\circ$  without scratches and fractures on the stretched surface of the specimen. The results of testing (Fig. 6 and 7) meet the guidelines of the standard.



Fig. 6. Results of bend test – face of weld



Fig. 7. Results of bend test – root side

## 7. Results of hardness measurements of welded joints

Hardness measurements were conducted in accordance with PN-EN 15614-1 and PN-EN 12952-6 standards. Maximum hardness in the above mentioned standards for joints in T24 steel not subjected to heat treatment is not specified. Therefore in the testing the criterion as for 6th materials group subjected to heat treatment, i.e. maximum 350 HV10, was adopted. The distribution of hardness measuring points is shown in Fig. 8 and the results of the measurements are given in Fig. 9. All results are lower than limits, but it should be noticed that the hardness of the weld in the root area is almost the same as that in HAZ in the face side. It may signify that the weld is hardened in the result of backing gas stream influence which caused quicker cooling of the weld comparing to next runs (layers).

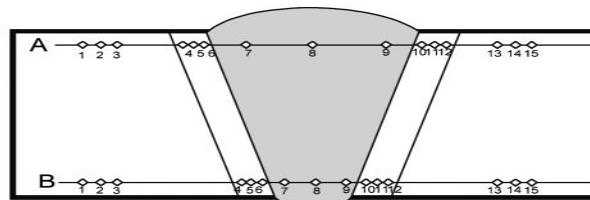


Fig. 8. Hardness measuring points in butt welded joints

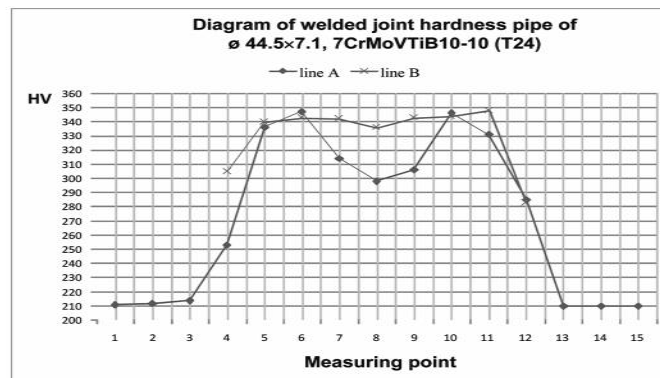


Fig. 9. Results of hardness measurement of butt welded joints of T24 tubes

## 8. Conclusions

On the basis of the aforesaid tests it was possible to come to the following conclusions:

1. Butt welds of  $\varnothing 44.5 \times 7.1$  tubes and 7CrMoVTiB10-10 (T24) steel grade welded in position H-L045 are of high quality, which confirmed by non-destructive and mechanical testing.

## 9. References

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