# MECHANICAL PROPERTIES OF P92 WELDED JOINTS MADE BY GTAW TECHNOLOGY

HAVELKA Lukáš[1], MOHYLA Petr[1], VONTOROVÁ Jiřina[2]

*[1]VSB - Technical University of Ostrava - Faculty of Mechanical Engineering, Ostrava, Czech Republic*
*[2]VSB - Technical University of Ostrava – FMMI, Ostrava, Czech Republic*

**Abstract**

This article deals with the new results from measurement of mechanical properties of P92 welded joints. Tested specimens (welded joints of P92 steel) were prepared using GTAW technology (141). After the welding the different modes of Post Weld Heat Treatment (PWHT) were made and the values of hardness, tensile strength and impact toughness of weld metal and heat-affected zone (HAZ) were measured. The aim of the research is to find the dependence between the mode of PWHT and the mechanical properties of weld metal and heat-affected zone. This study contains mechanical properties of P92 welded joints obtained in the years 2011-2014.

Because P92 is modern heat-resistant high-alloy steel used in thermal power plants with supercritical parameters (600°C/30 MPa), it is necessary to find out the mode of Post Weld Heat Treatment where the advantageous combination of mechanical properties will be achieved.

**Keywords:** Steel P92, Post Weld Heat Treatment, Mechanical Properties, Gas Tungsten Arc Welding

## 1. INTRODUCTION

Due to increasing of energy consumption, which is driven by strong economic growth there is a demand to improve the efficiency of current power plants. Efficiency of these energy facilities can be improved mainly by using the higher values of temperatures and pressures (or both of these parameters). To make this possible it is necessary to use modern materials, which are able to resist this high steam parameters – one of them is a martensitic steel with a high creep resistance X10CrWMoVNb9-2 (also known under designation P92). It was found that P92 steel is very resistant against creep but its corrosion resistance at work conditions is problematic. [1] P92 could be used to construction of parts exposed to ultra super critical (USC) parameters of steam (300 bar / 600°C) [2].

In many construction blocks, there is a necessary to use welding as a sort of permanent connection of two parts. Welding is consider as a special process of connection because mechanical properties of welded materials and weld metal are very significantly affected by heat input. Due to heat input (which depends mainly on welding method and parameters), the weld metal and heat-affected zone become the most critical region of welded constructions in term of mechanical properties and creep properties. To improve the mechanical properties of welded joints the post weld heat treatment (PWHT) is carried out. In this group of 9-12 % Cr martensitic steels, the post weld heat treatment is necessary because of crack initialization. [3]

This article deals with a post weld heat treatment of welded joints created by gas tungsten arc welding (141) carried out on P92 plates (thickness 8 mm). The aim of this article is examine the mechanical properties (hardness, tensile strength and impact toughness) after the different PWHT modes and choose the mode of post weld heat treatment with optimal mechanical properties of weld metal and heat-affected zone.

## 2. EXPERIMENTAL RESULTS

The welding specimens were prepared from P92 base material where the 1/2 V notch was created (**Fig. 1**). As a welding consumable the Bohler Thermanit MTS 616 (EN 12070 – EZ CrMoWVNb 9 0,5 2 B 4 2H5)

∅2,4 mm was used, shielding gas was Arcal TIG/MIG (EG – č. 231-147-0). Welding process was carried out by GTAW technology (141) – with parameters according **Table 1**, preheat temperature 200 °C, the interpass temperature was controlled and did not exceed the 300 °C. After the welding the different modes of post weld heat treatment were made, see **Table 2**.

**Table 1** Welding parameters

| Current [A] | Voltage [V] | Speed of welding [mm.s$^{-1}$] | Heat input [kJ.mm $^{-1}$] |
|---|---|---|---|
| 130 – 160 | 12 – 16 | 0,71 – 1,77 | 0,529 – 2,163 |

**Table 2** Designation of tested specimens and their modes of heat treatment

| Specimen designation | Testing temperature | Duration of heat treatment | Specimen designation | Testing temperature | Duration of heat treatment |
|---|---|---|---|---|---|
| P92-0 | as-welded conditions | | | | |
| P92-730-1 | 730°C | 1 hour | P92-760-1 | 760 °C | 1 hour |
| P92-730-2 | | 2 hours | P92-760-2 | | 2 hours |
| P92-730-3 | | 3 hours | P92-760-3 | | 3 hours |
| P92-730-4 | | 4 hours | P92-760-4 | | 4 hours |
| P92-730-5 | | 5 hours | P92-760-5 | | 5 hours |
| P92-730-6 | | 6 hours | P92-760-6 | | 6 hours |

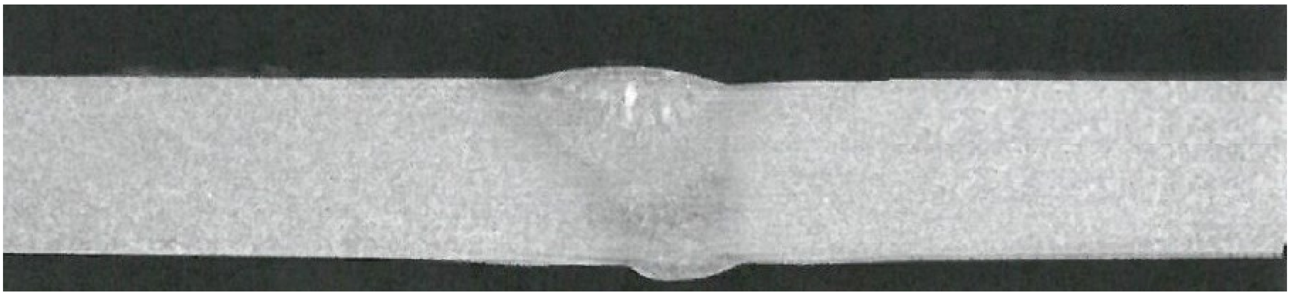

**Fig. 1** The example of specimen’s macrostructure

## 2.1. Tensile test

Transverse tensile test of welds were done according to EN 4136 [4], at temperature of 20°C. The minimal required value of tensile strength can be found in EN 10216-2 [5] – for P92 the values must lay in the range from 620 to 850 MPa. Graphical expression of average tensile strength - mode of heat treatment dependence can be seen on **Fig. 2**.

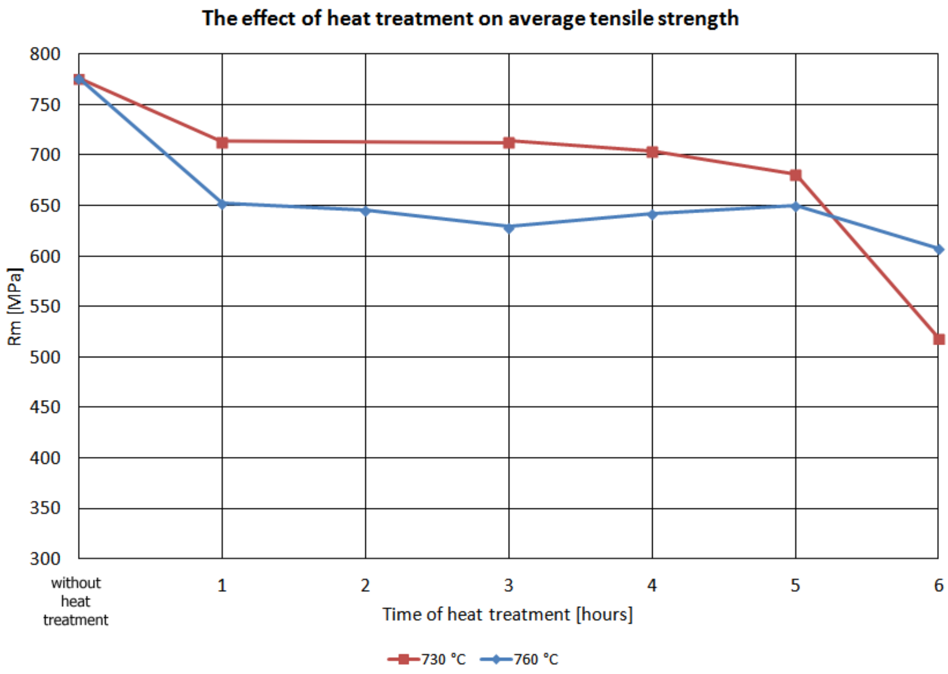


**Fig. 2** The effect of heat treatment on average tensile strength

**Fig. 2** shows decreasing trend of tensile strength with increasing dwell on annealing temperature. The maximum value of tensile strength is 776 MPa (without PWHT), the minimum value is 519 MPa (730°C / 6 hours). In the case of heat treatment mode 730°C/6 hours the value of tensile strength is not acceptable according to EN 10216-2.

## 2.2. Impact test

All specimens had modified dimensions 5x10 mm with V notch situated in VHT 2/2 (notch situated in heat-affected zone, 2 mm far from the fusion line, 2 mm below the surface). For the required impact energy cannot be used the values written in EN 10216-2, because this values are defined for standardized size of test specimens (10x10 mm). The value of impact energy from standard EN 10216-2 (27 J) have to be converted to our dimensions of specimens according EN 13480-2 [6] “Metallic industrial piping – Part 2”. From this standard, the required impact strength for specimens of size 5x10 mm is 14 J.

The effect of heat treatment on average impact energy is captured in **Fig. 3**.

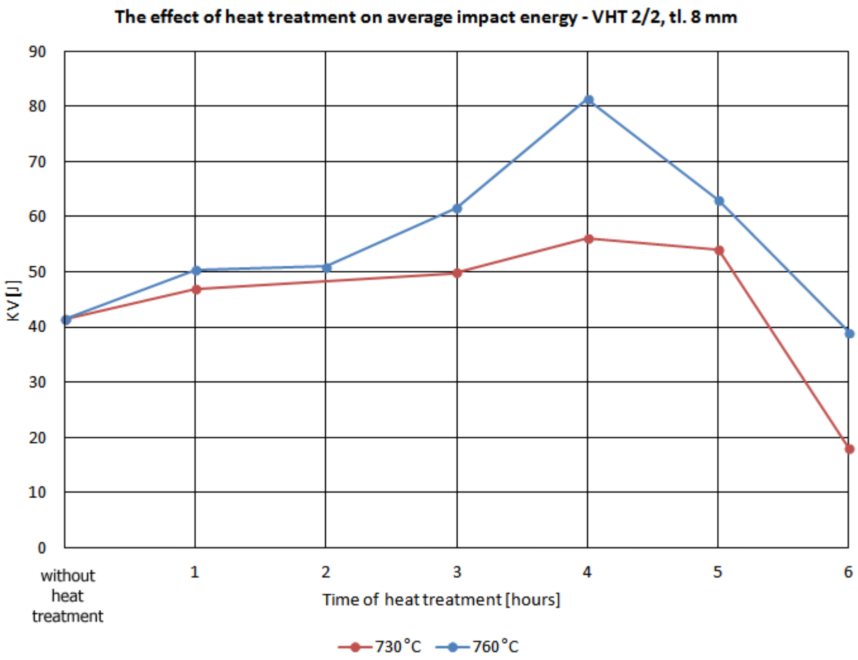


**Fig. 3** The effect of heat treatment on average impact energy – VHT 2/2

In **Fig. 3** can be seen noticeably increase of impact energy – VHT 2/2 in 4 hours (760°C). The maximum value in this time of tempering is 81 J. Minimum value of the impact energy reached in 6 hours (730°C) was 18 J. All results are acceptable according to standard EN 10216-2 [5].

## 2.3. Hardness

Hardness testing was performed according the ČSN EN 1043-1 standard – the testing load was 10 kg (HV10). In standard ČSN EN ISO 15 614-1 [7] there is a requirement that the maximum value of hardness cannot exceed the value of 350 HV.

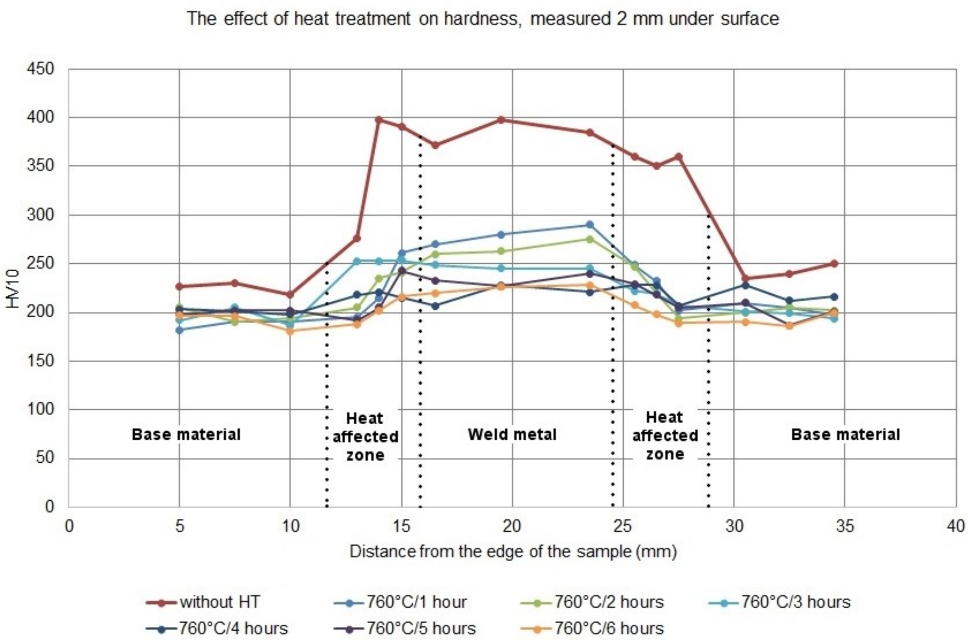


**Fig. 4** The effect of heat treatment on hardness

From comparison of hardness (**Fig. 4**) measured 2 mm under the specimen's surface can be seen that the hardness values mostly decreases with the time of the heat treatment. In **Fig. 4** can be also seen that the maximum values of hardness were obtained in weld metal region. From the graphical dependence of hardness on heat treatment is clear, that P92 steel has to be heat treated after the welding because in as-welded condition the values of hardness are above the allowed limit 350 HV. Specimens where the heat treatment was performed have acceptable hardness according to standard ČSN EN ISO 15 614-1.

The effect of heat treatment on average values of hardness in weld metal can be seen in **Fig. 5**.

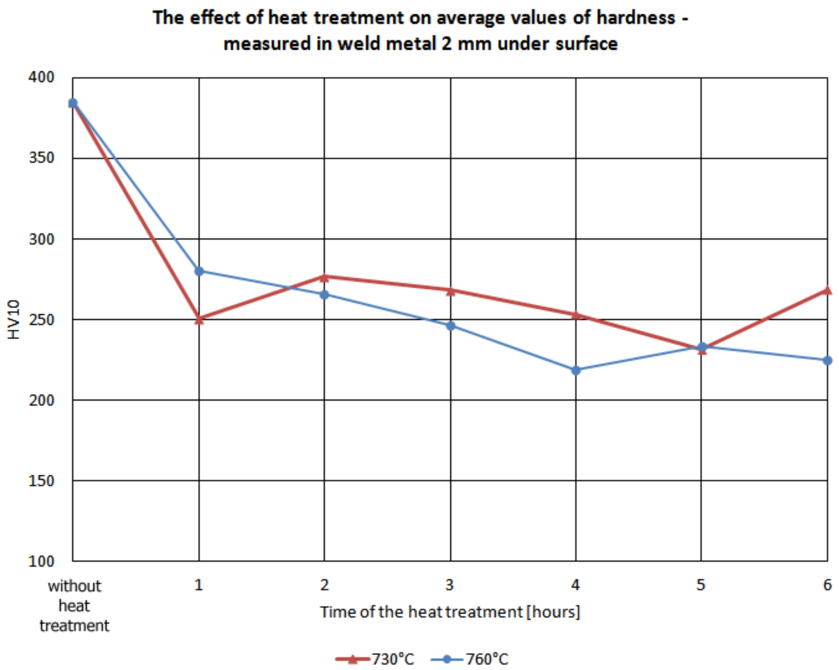


**Fig. 5** The effect of heat treatment on average values of hardness

## 3. CONCLUSION

P92 is one from the group of materials, which can work in the ultra-supercritical conditions. It has very good mechanical properties and resistance against creep, but during welding the properties are devalued due to heat input. To improve the mechanical properties the heat treatment is necessary. In order to find out the optimal heat treatment the series of experiments were made and the testing of tensile strength, impact energy and hardness was carried out.

Experiments showed, that tensile strength has decreasing trend with increasing dwell on annealing temperature. All values of tensile strength except the mode of heat treatment 730°C/6 hours are in the acceptable range from 620 to 850 MPa (according EN 10216-2).

The acceptable value of impact energy from standard EN 13480-2 called “Metallic industrial piping – Part 2” for specimens of size 5x10 mm is 14J. In 4 hours (760°C) the increase of impact energy – VHT 2/2 can be seen. The maximum value in this time is 81 J. Minimum value of the impact energy (reached in 6 hours/730°C) is 18 J. All results are acceptable according to standard EN 10216-2.

In hardness testing there is a requirement according ČSN EN ISO 15 614-1 - maximum value of hardness cannot exceed the value 350 HV. From presented results it can be seen, that the sample without heat treatment has got hardness above the maximum allowed value (350 HV). All modes of heat treatment fulfilled the criterium of maximum hardness according ČSN EN ISO 15 614-1.

Based on obtained results it can be confirmed, that after the welding process it is necessary to made post-welding heat treatment for P92 steel. From obtained results is also clear, that with the increasing dwell on annealing temperature the tensile strength decrease. The maximum value of the impact energy – VHT 2/2 was achieved in 4 hours (760°C), where also the values of hardness and tensile strength had optimal values. From this point of view tempering at 760°C/4 hours can be considered as optimal regime of post weld heat treatment of P92 welds made by GTAW.

## ACKNOWLEDGEMENTS

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