MICROSTRUCTURE STUDY OF HEAT AFFECTED ZONE OF STEEL P92 USING THERMAL CYCLES SIMULATOR

HAVELKA Lukáš[1], MOHYLA Petr[1], KRAUS Martin[2]

[1] *VSB - Technical University of Ostrava, Faculty of Mechanical Engineering, Ostrava, Czech Republic, EU,* *Lukas.havelka@vsb.cz*

[2] *VSB - Technical University of Ostrava, Faculty of Metallurgy and Material Engineering, Ostrava, Czech Republic, EU*

Abstract

Martensitic heat-resistant steel P92 belongs to very progressive group of 9-12% Cr steels modified with vanadium and niobium, with controlled boron and nitrogen content. P92 has got excellent creep properties and it is used very often to build the most exposed parts of supercritical units in steam power plants.

The goal of this article is to compare the real welded joints with the simulated samples and to optimize the heat treatment and welding process of P92 steel. For that analysis of the microstructure with transmission electron microscopy was made. The measurement of trend of hardness along the welded joint was carried out, as well. The good accordance between the simulated samples and real welded joints were found.

Keywords: Thermal cycles simulator, steel P92, microstructure, heat-affected zone

1. INTRODUCTION

Steel P92 belongs to very progressive group of 9-12% Cr steels modified with vanadium and niobium. This material has got sufficient creep resistant strength that is why it is very often used for parts exposed to high temperatures and pressures (USC boilers). Creep resistance depends of P92 microstructure which has a great influence on mechanical properties. Precipitates which can be found in P92 steel effectively prevent the movement of dislocation and grain growth [1]. Welding is one of the important technologies for permanent joining parts created from P92. During the welding process the degradation of precipitation strengthening by heat occurs, especially in heat-affected zone (HAZ) [2].

Because the weakest parts of each construction are welded joints theirs research is very important. Heat affected zone, where the most significant changes of properties happened, has only very small size. That is why the classic mechanical properties testing cannot be carried out and it is very advantageous to use the thermal cycle simulator to “transfer” the properties of this small area to a bigger sample, where all the tests can be done without any complication [3].

2. SAMPLES PREPARATION

For experimental research two samples were prepared. First sample was taken from real weld made with TIG technology. This sample measured with the thermocouple on real weld was marked as “T_3” (the peak temperature of T_3 sample T_{max} = 1080 °C). On second sample the simulation cycle based on the real weld measurement was simulated. This sample was marked as “N”. After the real thermal cycle measurement and simulation of the thermal cycle on simulator the comparison of these samples were made. Microstructure was examined by transmission electron microscopy. After the microstructure research the hardness testing on both of these samples were realized.

The thermal cycle simulation was realized on simulator constructed at VSB-Technical University of Ostrava. The goal was to optimize the heat treatment and welding process of P92 steel. The simulations of specific areas of heat-affected zone were carried out.

Required thermal cycle curve (blue curve) was based on thermal cycle measurements, orange curve shows the simulated thermal cycle trend created on the thermal cycle simulator. From the comparison of these two curves the great accordance can be seen (**Figure 1**).

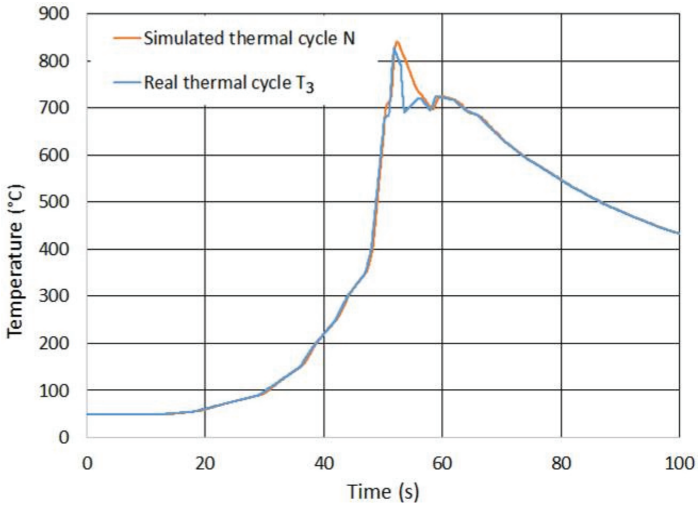


Figure 1 Simulation of the fine-grained area of HAZ

3. MICROSTRUCTURE EXAMINATION OF REAL WELD

In first part of experiment the evaluation of the microstructure of real weld joint was made. The base material P92 and the each area of the heat-affected zone was documented and the phase composition was described.

3.1. Basie material

The microstructure of base material and its precipitation is shown in **Figure 2**.

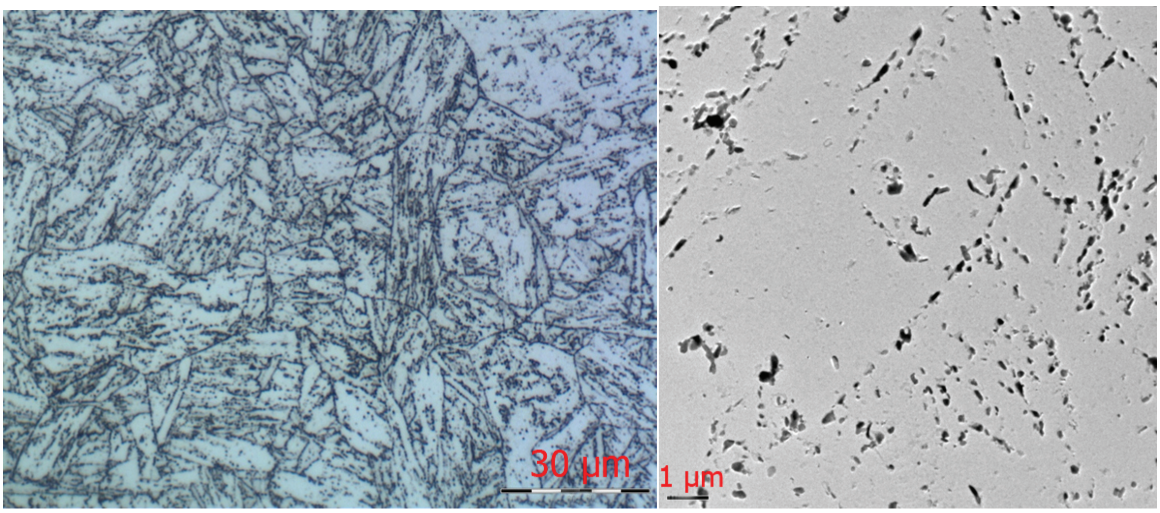


Figure 2 Microstructure and precipitation of base material P92 (sample T_3)

Microstructure of a base material contained numerous carbides $M_{23}C_6$, fine particles (V,Nb)X (secondary MX phase) and a little amount of NbX particles (primary MX phase). Precipitation of Laves phase during the thermal heat treatment to processing quality was not presented (his phase was not precipitated due to big nucleation barrier and a short time of tempering). Particles NbX which obstruct the grain growth during austenitization contain Ti, V and Cr.

3.2. Inter-critical zone

The microstructure of inter-critical area of HAZ and its precipitation is shown in **Figure 3**.

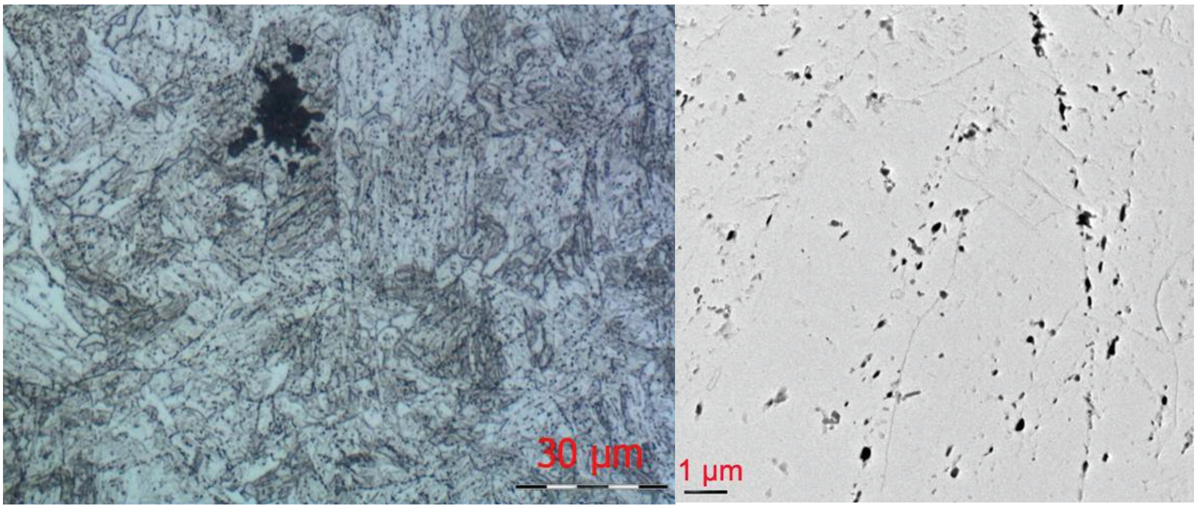


Figure 3 Microstructure and precipitation of inte-rcritical zone (sample T_3)

This picture shows the semi-dissolved particles of precipitates presented in base material. There could be found some areas of precipitate particles with “fresh” martensite (with defined martensitic laths) and recovered tempered martensite (big units without the grain boundaries) created during the inter-critical heating. In this area there were found the same kind of minority phases as in the base material ($M_{23}C_6$, NbX and (V, Nb)X). In the areas with the “fresh” martensite the cementite laths created during the cooling of the weld can be locally found.

3.3. Fine-grained zone

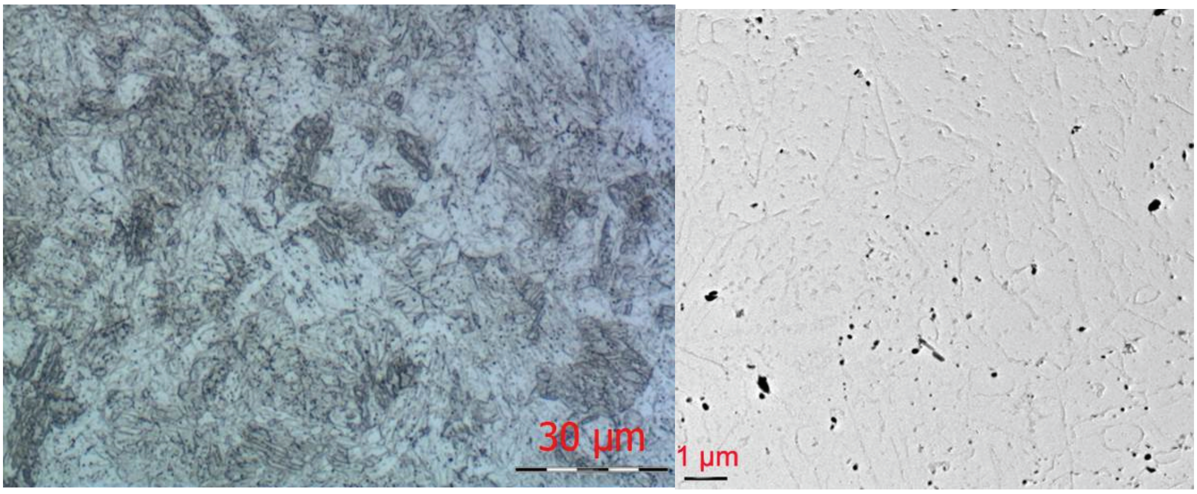


Figure 4 Microstructure and precipitation of the fine-grained zone (sample T_3)

In this heat-affected zone the semi-dissolution of the precipitate particles present in base material occurred during the welding process. As in this zone, the complete austenitization was finished, there can be found the imprints of martensitic laths (as can be seen in **Figure 4**). Laths were created when the disintegration of austenite during the cooling process of weld joint. In fine-grained zone all the minor phases, which can be found in base material was presented too. Except that, in some of the martensite laths the needles of cementite created during the cooling of the weld can be found.

3.4. Coarse-grained zone

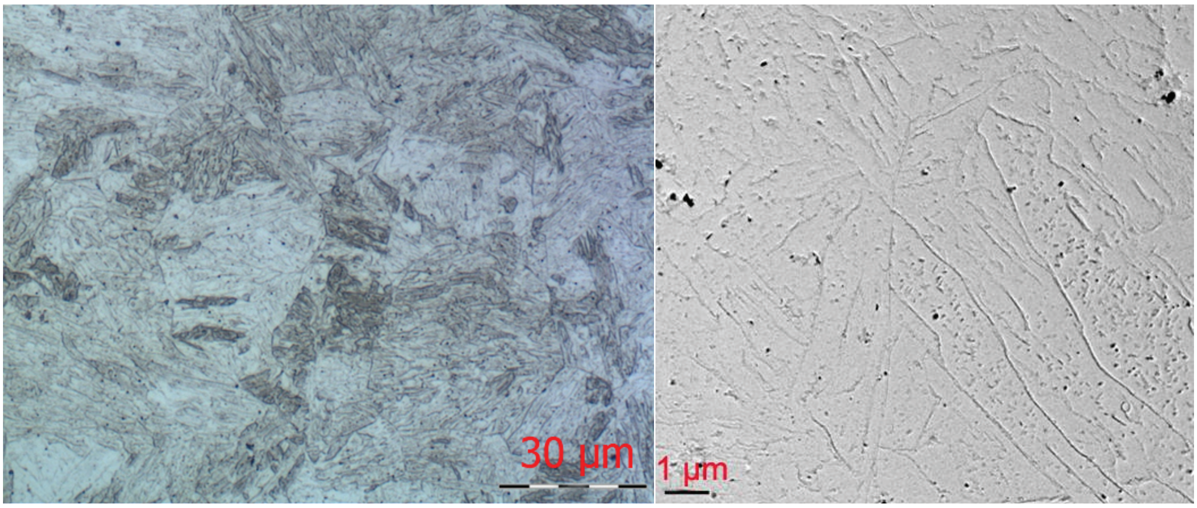


Figure 5 Microstructure and precipitation of the coarse-grained zone (sample T_3)

During the thermal cycle the complete dissolution of $M_{23}C_6$ particles happened. Globular particles presented in the microstructure were identified as the un-dissolved particles NbX. In these particles the Ti, V and Cr presence was found. Except the NbX particles there were found a small amount of fine grained particles (V,Nb)X in coarse-grained zone. Un-dissolved particles NbX in overheated zone effective slow down the growth of the austenitic grain. Typical size of the primary austenitic grains was in this area approximately 30 µm (see **Figure 5**).

4. MICROSTRUCTURE OF SIMULATED SAMPLE N

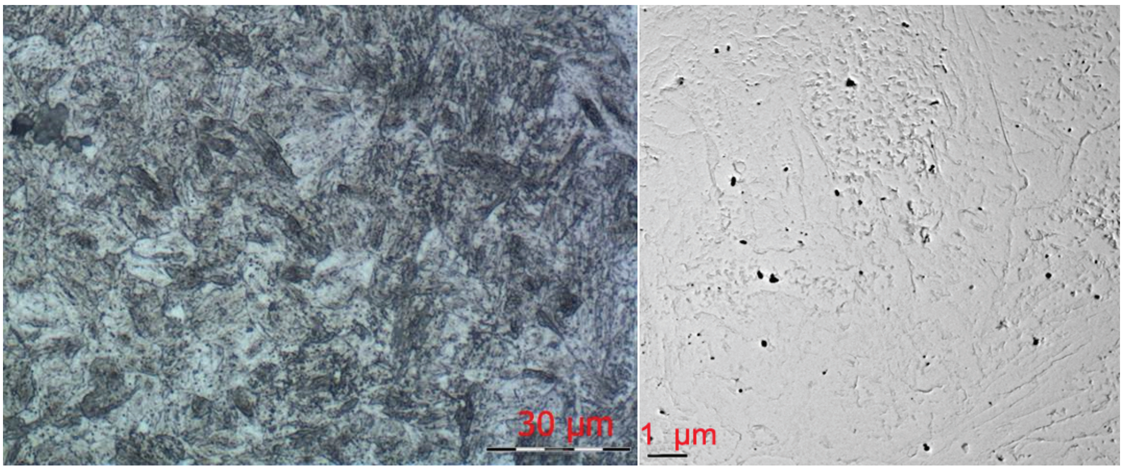


Figure 6 Microstructure and precipitation of simulated sample N

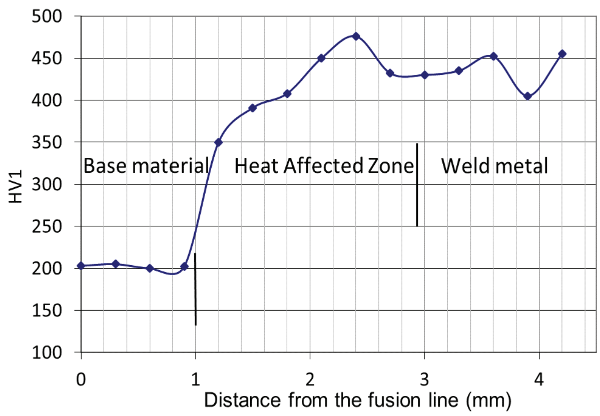
Precipitation of simulated sample N is documented on **Figure 6**. During the thermal simulation the complete dissolution of the $M_{23}C_6$ particles happened. The NbX particles can be found in the microstructure. These particles (consisted of Nb and small amount of Ti, V and Cr) are in 9-12% Cr steels usually called as primary MX particles. On carbon replicas the small amount of (V,Nb)X particles, so-called as secondary MX particles can be found. Inside the martensite laths there was a big amount of needle particles of cementite (Fe_3C). In studied sample the particles of cementite have to precipitate during the austenite dissolution on martensite.

Based on the comparison of results of metallographic and TEM examination performed on simulated sample N and the sample from the real welding process (T_3) can be seen that the microstructure in the middle of the length of the sample N is the same as the coarse-grained zone of heat affected zone.

5. THE MICRO-HARDNESS MEASUREMENT

To compare the real welded joint (sample T_3) and simulated sample from thermal cycle simulator (sample N) the measurement of the micro-hardness HV1 was carried out. In **Figure 7** (left) the micro-hardness trend of real welded joint can be seen. It is clear that the micro-hardness of the coarse-grained area of HAZ reached the values 450-460 HV1, in fine-grained zone around 400 HV1. In the inter-critical area of HAZ the micro-hardness decreases rapidly.

Longitudinal micro-hardness profile from the middle of the length of simulated sample N can be seen on **Figure 7** (right). It can be seen that the simulated area of HAZ on sample N reached length around 6 mm. This means that the complete length of the simulated HAZ has got the length 12 mm.



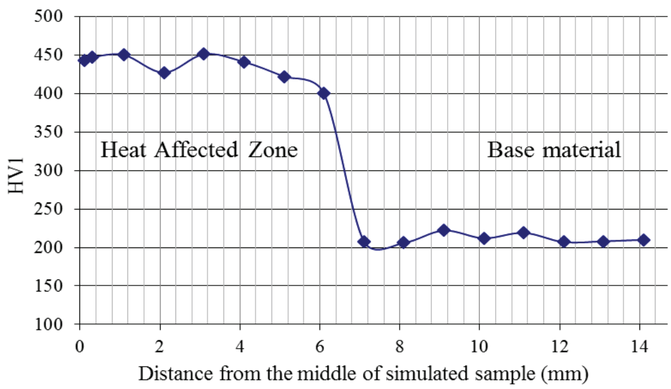


Figure 7 Micro-hardness trend of real welded joint T_3 (left) and longitudinal profile of hardness (HV1) from the middle of the simulated sample N (right)

CONCLUSIONS

Based on data from the thermal cycle measurement the simulation process was carried out. The goal of the simulation was to transfer the real weld heat affected zone (which was very small to realize the tests of weld joints) to the larger sample. The thermal cycle simulator is able to accurately copy the curve obtained from measurement of real weld joint.

After the simulation of the HAZ the microstructure research of real and simulated samples was carried out and the hardness was measured. From the microstructure research it can be seen that in the base material there were numerous carbides $M_{23}C_6$, fine particles (V,Nb)X and a little amount of NbX particles present.

In the inter-critical zone the semi-dissolved particles of precipitates $M_{23}C_6$, NbX and (V, Nb)X were found. There was some areas of precipitate particles with “fresh” martensite and recovered tempered martenzite created during the inter-critical heating. In the areas with the “fresh” martensite the cementite laths created during the cooling of the weld can be locally found.

In fine-grained zone the semi-dissolution of the precipitate particles present in base material occurred during the welding process. As in this zone the complete austenitization was finished there can be found the imprints of martenzitic laths. All minor phases found in base material were in this zone presented too. Inside some of the martensite laths can be found the needles of cementite created during the cooling of the weld.

In coarse-grained zone the complete dissolution of $M_{23}C_6$ particles during the thermal cycle happened. Globular particles presented in the microstructure was identified as the undissoluted particles NbX. Except the NbX particles there were found a small amount of fine grained particles (V,Nb)X.

After the microstructure research the micro-hardness HV1 comparison of real welded joint (sample T_3) and simulated sample from thermal cycle simulator (sample N) was carried out. Based on the experimental procedures and comparison the results from real welded joints and samples simulated on thermal cycle simulator is clear that the simulated sample N matches with coarse-grained zone of real welded joint.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Industry and Trade of Czech Republic in the project FR-TI3 / 206.

REFERENCES

[1] ZIELIŃSKA-LIPIEC, A., CZYRSKA-FILEMONOWICZ, A., Ennis, P.J., Wachter, O. The influence of heat treatments on the microstructure of 9% chromium steels containing tungsten. Journal of Materials Processing Technology, 1997, vol. 64, no. 1-3, pp. 397-405.

[2] SONDEL, M., SCHWARZ, D., KOUKAL, J., FOLDYNA, V. Microstructure and Mechanical Properties of Modified Chromium and Low Alloy CrMoV Steel's Weld Joints after Long Term Creep Exposure. In: Proceedings of the 12th International Conference on Creep and Fracture of Engineering Materials and Structures (JIMIS 11), Kyoto: The Japan Institute of Metals, 2012, pp. B42-B43.

[3] KOUKAL, J., SONDEL, M., SCHWARZ, D. Correlation of Creep Properties of Simulated and Real Weld Joints in Modified 9 %Cr Steels. Welding in the World, 2010, vol. 54, no. 1, pp. R27-R34.