INFLUENCE OF POST WELD HEAT TREATMENT ON THE HAZ IMPACT TOUGHNESS ON P91 STEEL

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Abstract:

Appropriate post weld heat treatment is usually obligatory when creep resistant steels are welded for thermal power plant components which operate at elevated temperatures. Influence of different post weld heat treatments on microstructure and impact toughness were studied in this work. Heat treatments were performed at different temperatures (740°C and 760°C) in duration of two hours at different regions of artificially made heat affected zones. The coarse grain (CG HAZ), two different regions of the fine grain (FG1-HAZ and FG2-HAZ) and inter critical (IC HAZ) heat affected zones in comparison with base material were analysed.

1. INTRODUCTION

Some very important thermal power plant components like steam pipelines, steam boilers and heat exchangers operate at elevated temperatures and high pressures. Therefore those components through their lifetime need to be creep and corrosion resistant and need to have appropriate mechanical properties, especially good impact toughness at room and elevated temperatures. Mostly through their 30 to 40 year lifecycle they operate at elevated temperatures, but occasionally they are stopped because of planned or non-planned maintenance works thus they need to assure safe operability and safe stop of the whole thermal power plant. Similar properties are expected from weld joints from which the above mentioned components are built up.

Big attention needs to be devoted to choose appropriate welding technology [1-8]. Preheating before welding is needed to avoid cold hydrogen cracking [7-8]. Heat input during welding ought not to be too high to assure multipass welding with diameter of weld pass 2 or 3 mm and right cooling off of the weld joints. Interpass temperature during welding needs to be controlled and held above the preheating temperature. Welded components which have different thickness need to be cooled down slowly and the cooling needs to be controlled. Most of the welds joint need to be post weld heat treated with controlled heating and controlled cooling. Figure 1a shows welding technology and post weld heat treatment (PWHT) for P91 steel, which is also used in our investigation. During the planning of welding technology continuous cooling transformation diagrams (CCT) are very helpful. Figure 1b shows CCT diagram for our P91 steel.

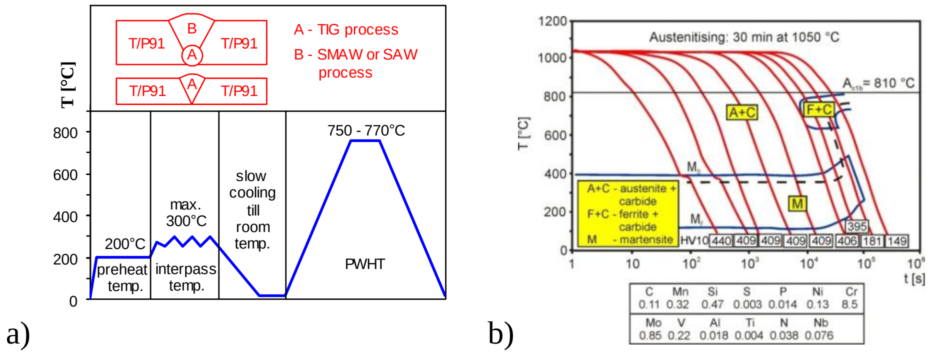

Figure 1. *Welding technology for P91 steel (a) and its CCT diagrams (b) [1,7]*

2. MATERIAL

Creep resistant P91 steel for elevated temperatures was used in this investigation. Specimens were cut out from the 22 mm thick pipe, which it had already been under operation for three years in thermal power plant Šoštanj. This pipeline in practice operates at maximal working temperatures between 580 to 600°C and at high pressure. The chemical composition of the P91 steel is presented in the Table 1 and its mechanical properties are listed in the Table 2.

Table 1. *Chemical composition of the P91 steel (% weight)*

C	Si	Mn	P	S	Cr	Ni	V	N	Nb/Cb
0.10	0.44	0.46	0.01	0.002	8.81	0.40	0.23	0.05	0.08

Table 2. *Mechanical properties of the P91 steel*

Yield stress $R_{p0.2}$ (MPa)	Ultimate tensile strength R_m (MPa)	Elongation A_5 (%)	Charpy impact energy A (J)
450	620	19	192 at +20°C

2.1 PREPARATION OF HAZs MATERIAL

Materials of the different HAZs were prepared on the weld thermal simulator Smitweld 1405 [9-11]. Specimens were heated and cooled down as HAZs in real in weld in practice by using the same heating rate and the same cooling rate. For preparation of the all different regions of HAZs the same cooling time between 800°C and 500°C (□$t_{8/5}$) from the real welding was used. Different regions of the HAZs distinguish by maximal temperatures attained during preparation of HAZs materials. They are shown on weld joint in Figure 1a.

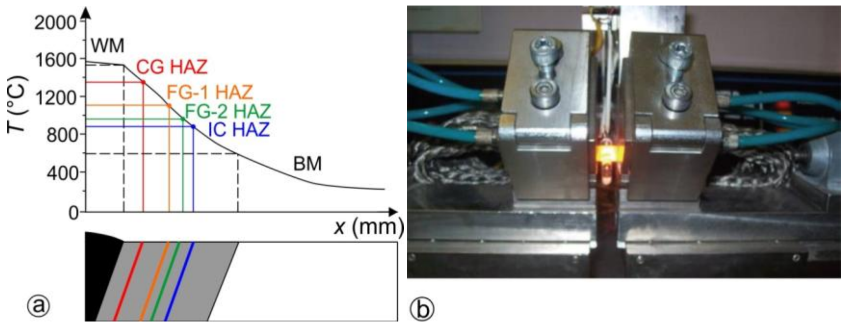

Figure 2. *Regions of CG HAZ, FG-1 HAZ, FG-2 HAZ, IC HAZ (a), preparation of HAZs material (b)*

The influence of the weld thermal cycle on different regions of the HAZs, which were used in this investigation, is presented in Figure 2a in the above weld joint. The maximal temperature during preparation of the coarse grain HAZ (CG HAZ) was 1350°C. Two regions of the fine grain HAZs were prepared, the first one FG-1 HAZ was produced by maximal temperature 1100°C and the second one FG-2 HAZ was made by maximal temperature 950°C. The last HAZ was inter critical HAZ (IC HAZ), where transformation into austenite during heating was not completed. The IC HAZ attained 870°C during HAZ material preparation. Preparation of HAZ material on the Smitweld weld thermal cycle simulator is shown in Figure 2b. All other parameters necessary for the HAZs material preparation are listed in Table 3.

Table 3. *Parameters for HAZs material preparation in weld thermal cycle simulator*

HAZ material	$\dot{T}_{heating}$ (°C/s)	T_{peak} (°C)	□$t_{8/5}$ (s)	T_{hold} (°C)	t_{hold} (°C)	T_{finish} (°C)
CG HAZ	150	1350	10	1350	0.5	220
FG HAZ-1	150	1100	10	1100	0.5	220
FG HAZ-2	150	950	10	900	0.5	220
IC HAZ	150	870	10	870	0.5	220

Table 4. *Different conditions and number of the specimens for each condition*

HAZ and BM material	“As Welded”	740°C/2h	760°C/2h
CG HAZ	3	3	3
FG HAZ-1	3	3	3
FG HAZ-2	3	3	3
IC HAZ	3	3	3
BM	3	3	3

The influences of the weld thermal cycle on the different regions of HAZs are presented in Figures 2a, 3a, 4a and 5a. Figures 2b, 3b, 4b and 5b show their dilatation curves. Firstly the CG HAZ is presented in Figure 3 by red lines, secondly the FG-1 HAZ is shown in Figure 4 by oranges lines, thirdly FG-2 HAZ in Figure 4 is marked by green lines and finally the IG HAZ is presented in Figure 5 by blue lines. The same designations and colours will be used in section of the results.

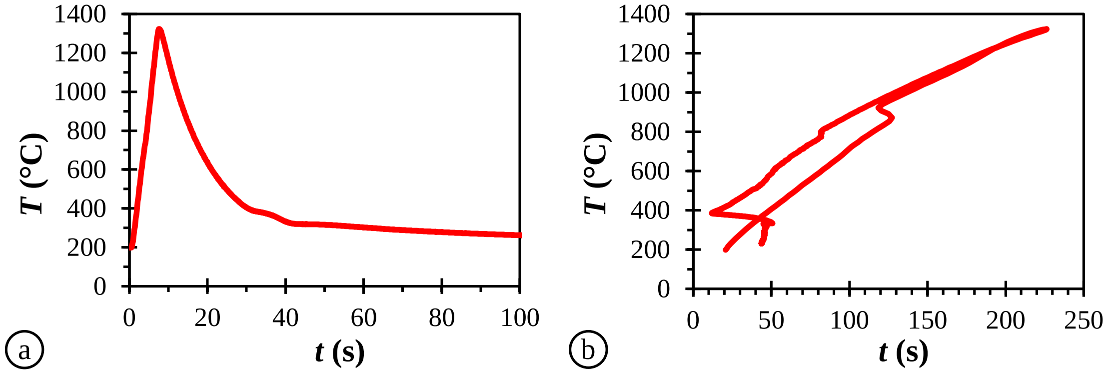

Figure 3. *Influence of the weld thermal cycle on CG HAZ (a) and dilatation curve for CG HAZ (b)*

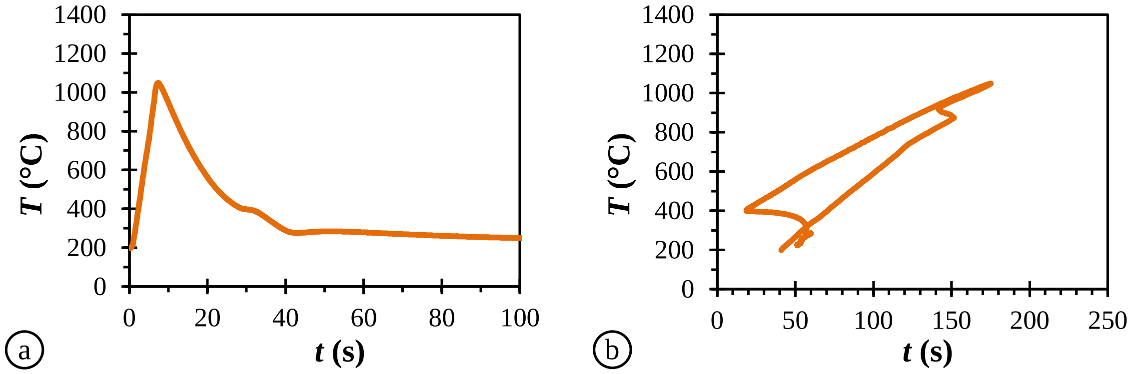

Figure 4. *Influence of the weld thermal cycle on FG-1 HAZ (a), dilatation curve for FG-1 HAZ (b)*

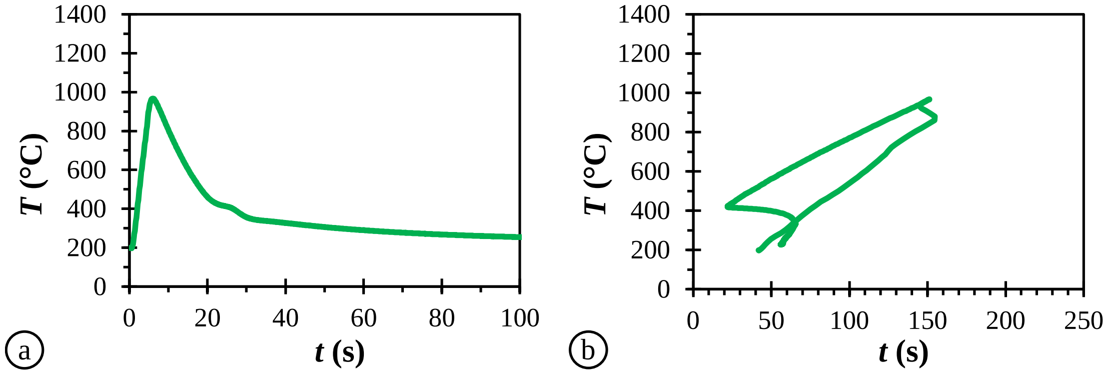

Figure 5. *Influence of the weld thermal cycle on FG-2 HAZ (a), dilatation curve for FG-2 HAZ (b)*

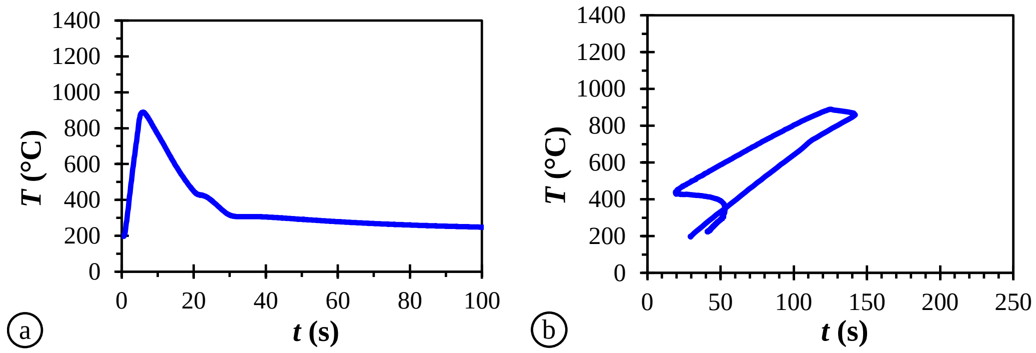

Figure 6. *Influence of the weld thermal cycle on IC HAZ (a) and dilatation curve for IC HAZ (b)*

3. POST WELD HEAT TREATMENT

All the post weld heat treatments were performed in the furnace Bosio EUP-K 20/1200. Two different post weld heat treatments were used in this investigation. One third of the specimens were heat treated for two hour at the maximal temperature 740°C and the second third of the specimens were heat treated for two hour at maximal temperature 760°C. In both cases the heating rate and the cooling rate were 150°C/h. When specimens were cooled down to 200°C specimens were cooled in only in furnace to room temperature. The regimes of the both heat treatments are shown in Figure 6. The last third of the specimens were not heat treated at all and they actually represent “as welded condition” of HAZs which in real welds appear eminently after welding.

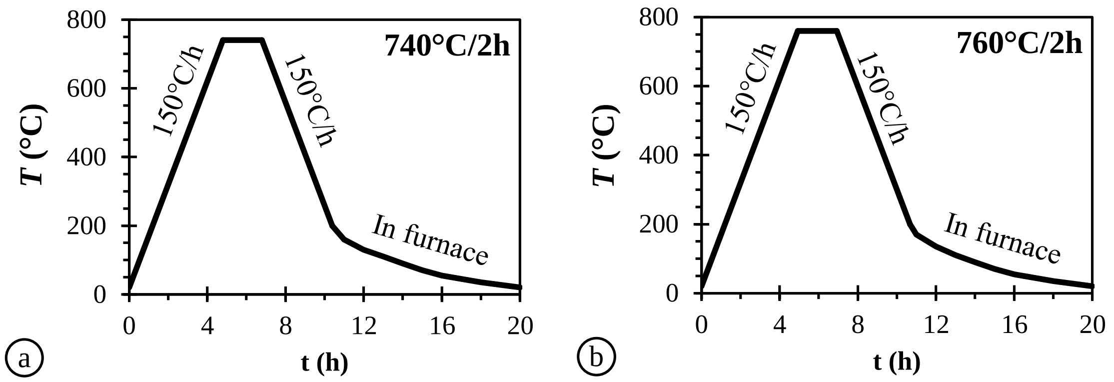

Figure 7. *Post weld heat treatments at 740°C/2h (a) and at 760°C/2h.*

4. RESULTS

4.1 Microstructures

The microstructure of the P91 steel is built up from tempered lath martensite, with expressed grain boundaries. Carbides of $M_{23}C_6$ type, where the metal element M is mostly chromium (Cr), were dispersed on prior austenite grain boundaries. Average grain size in microstructure is arround 20 μm.

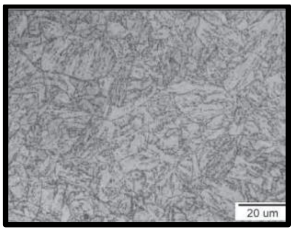

Figure 8. *Microstructure of the P91 steel*

The microstructures of the CG HAZs (red), FG-1 HAZs (orange), FG-2 HAZs (green) and IC HAZs (blue) are presented in Figures 9 to 11. The microstructures of different regions of HAZs at “as welded condition” without PWHT are shown in Figure 9. The CG HAZ's and the FG-1 HAZ's microstructures are mainly consisted from lath martensite. The IC HAZ's microstructure is only partly transformed, therefore the microstructure is mixed and contain lath and tempered martensite. Microstructures of different regions of HAZs which were heat treated at 740°C for 2 hour are shown in Figure 8. All microstructures are being built up from tempered martensite. Finally, the microstructures of different regions of the HAZs which were heat treated on 760°C for 2 hours are shown in Figure 9. All microstructures are mostly compounded from fine tempered martensite.

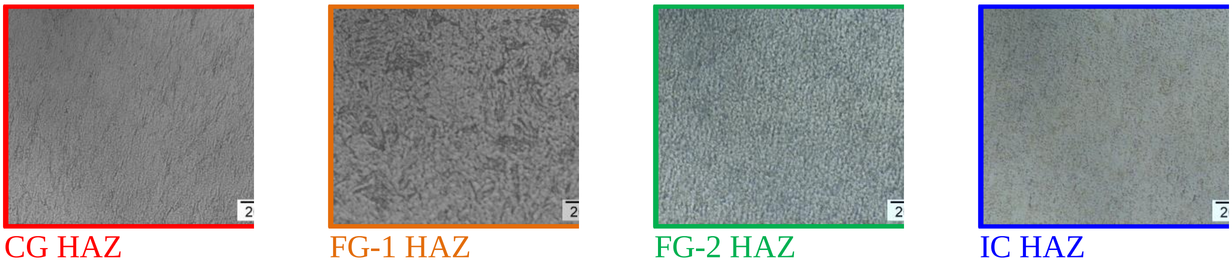

Figure 9. *Microstructures of different regions of HAZs without heat treatment*

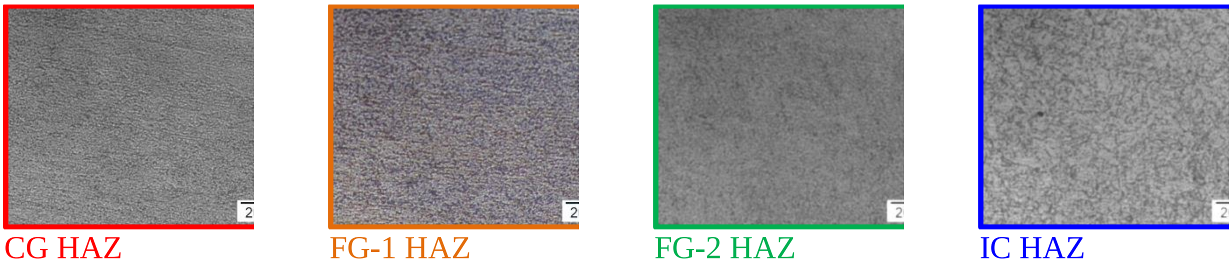

Figure 10. *Microstructures of different regions of HAZs heat treated at 760°C/2h*

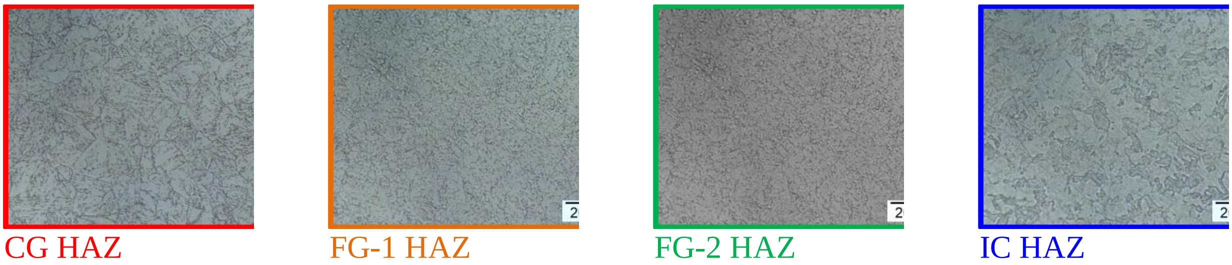

Figure 11. *Microstructures of different regions of HAZs heat treated at 760°C/2h*

4.2 Results of instrumented Charpy impact tests

Charpy specimens with ISO-V notch were made from the simulated HAZs and BM specimens. For each microstructure three specimens were prepared. Charpy specimens were tested on instrumented AMSLER Charpy pendulum RPK 300. Data acquisition was performed via the VuhiCharpy software with sample rate 4.000.000 samples per second.

Total Charpy impact energy was measured in two different ways trough encoder on Charpy pendulum and by integration of the force versus time signal during breakage of the Charpy specimen. Average results of the three specimens are shown in Figure 12.

total Charpy impact energy was split into energy for initiation and energy for propagation by analysing of the force versus time signal. The first one is necessary for crack initiation from the notch of the Charpy specimen. The ISO-V notch has radius 0.25 mm and it is 2 mm deep at 10 mm thick Charpy specimen. The second one is necessary for propagation when crack is already initiated. The energy for propagation somehow reflects the material's resistance toward crack propagation. Average results of the energies for initiation and energies for propagation of different regions of HAZs and BM are presented in Figure 12 and 13.

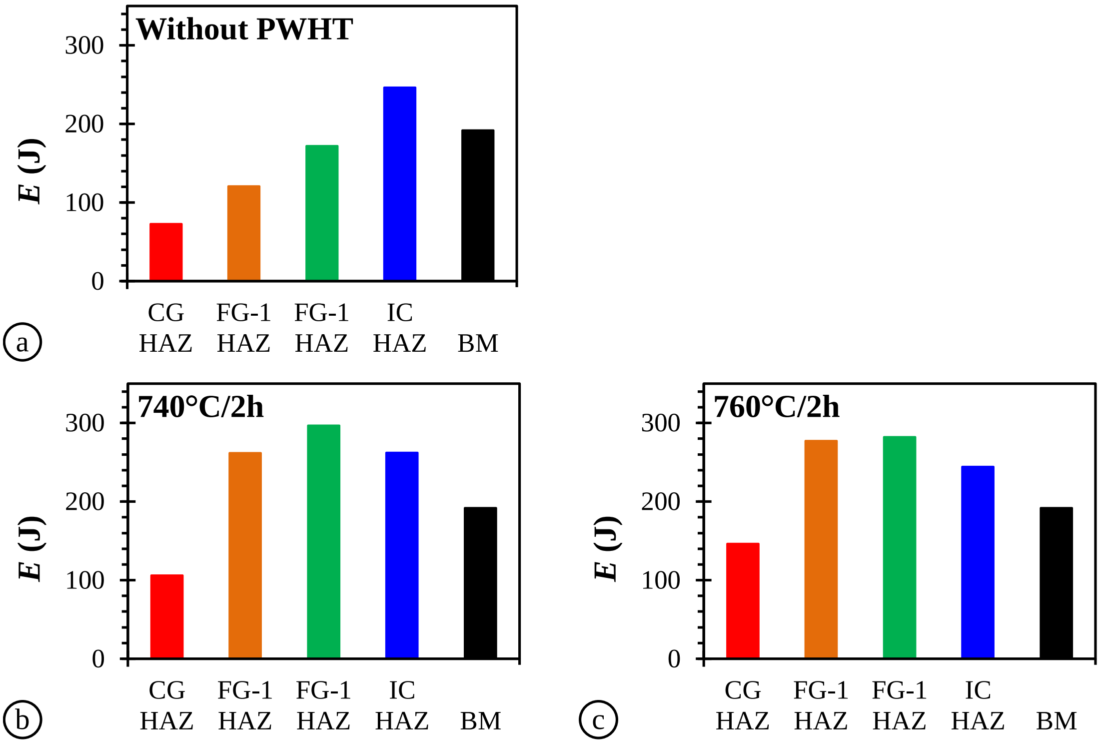

Figure 12. *Total impact energy in different HAZs and BM without PWHT (a) and with PWHT (b,c)*

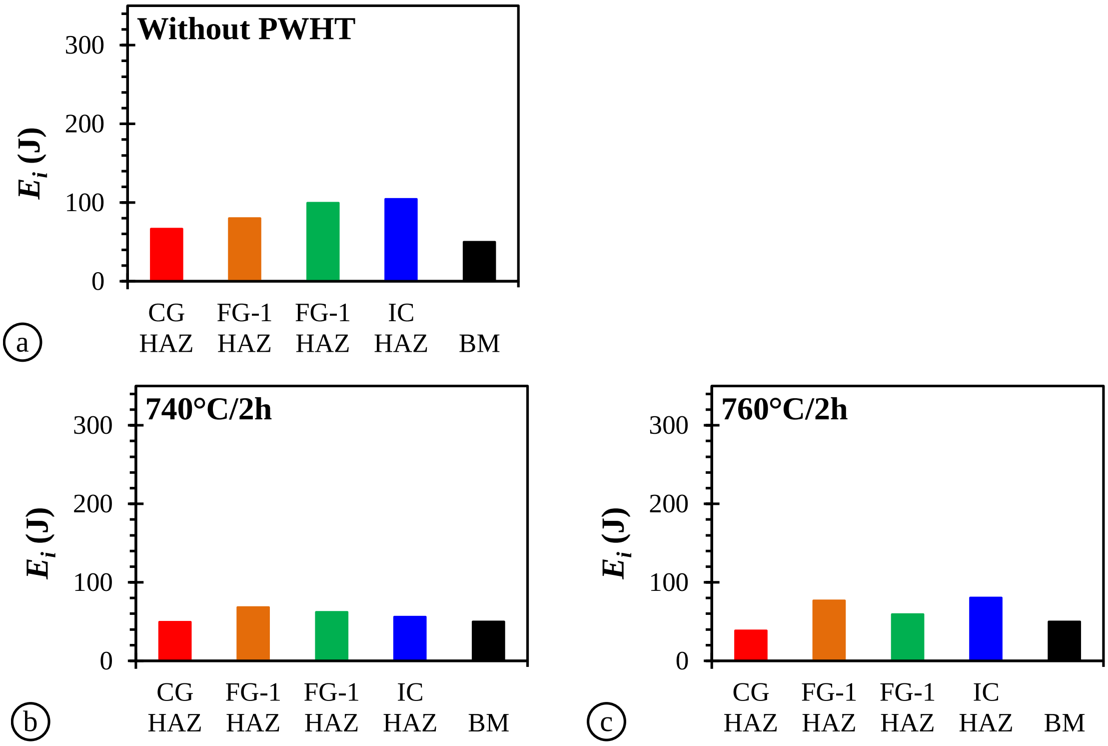

Figure 13. *Energy for initiation in different HAZs and BM without PWHT (a) and with PWHT (b,c)*

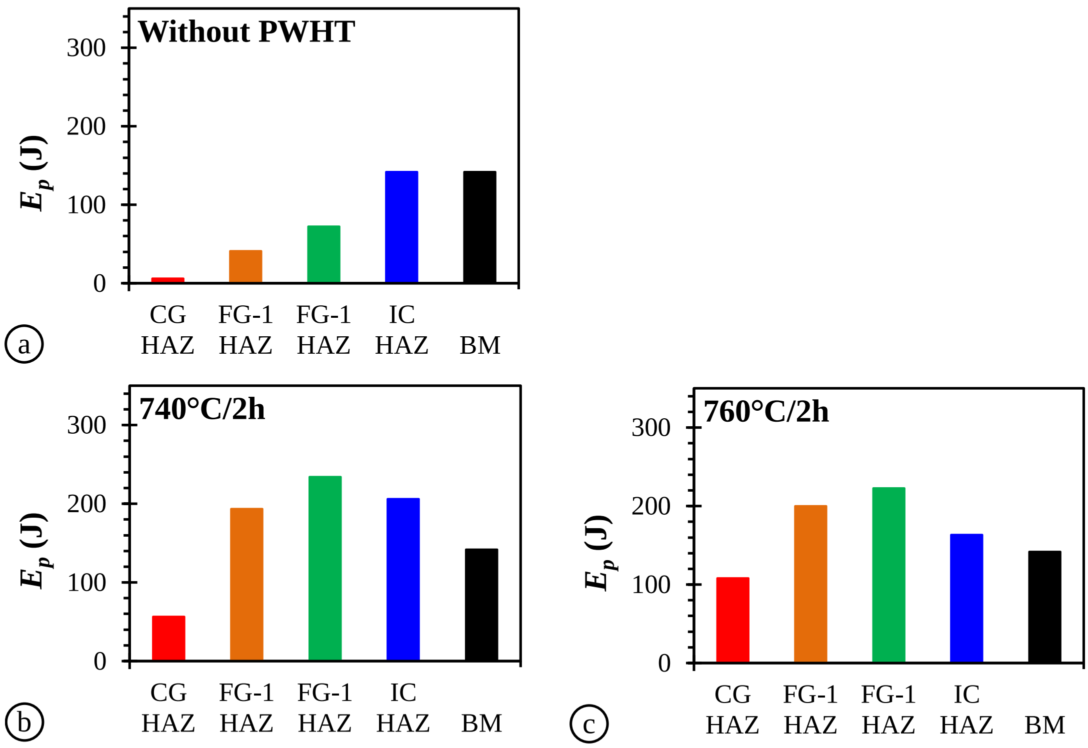

Figure 14. *Energy for propagation in different HAZs and BM without PWHT (a) and with PWHT (b,c)*

5. DISCUSION

The lower total Charpy impact energy and the energy for propagation are observed in CG HAZ in condition without PWHT, where the microstructure has big grains and it consists of newly formed lath martensite. Similar microstructures are in the FG1-HAZ and in the FG-2 HAZ. The total Charpy impact energy and the energy for propagation in those zones are a bit higher because the average grain sizes in microstructure are smaller. Finally both energies remain almost the same in IC HAZ in comparison to BM, where the microstructure is partly transformed and it is built up from fine ductile lath and tempered martensite.

The PWHT at 740°C for 2 hours improves the total Charpy impact energy and the energy for propagation at the all regions of HAZs, but improvement of both energies are not sufficient in IC HAZ due to fact that IC HAZ microstructure is not tempered enough.

The PWHT at 760°C for 2 hours improves both energies at all regions of HAZs. Improvements of them are sufficient at CG HAZ even if they do not reach them at BM.

The energies for initiation are little higher in HAZs in the condition without PWHT in comparison to impact energies of both PWHT conditions. But they are almost the same in all HAZs in both PWHT conditions.

6. CONCLUSIONS

Special attention needs to be devoted to choose and apply appropriate welding technology when the P91 steel for elevated temperature is welded.

Important part of the welding technology is also PWHT which is obligatory for that kind of steels eminently after welding.

The PWHT needs to be controlled during heating, holding on maximal temperature and cooling down. From PWHT is expected to be done correctly and precisely with small deviation of the holding temperature.

Investigation reveals that difference in the maximal temperature of 20°C during PWHT had significant influence on the total Charpy energy and energy for propagation in some regions of the HAZs, especially in CG HAZ.

The PWHT at 740°C for 2 hours is not sufficient in comparison to PWHT at 760°C for 2 hours to improve reduced total Charpy impact energy in "As Welded" condition without PWHT.

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