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Abstract. This paper presents two possibilities of martensitic (fine grain and coarse grain) microstructure preparation. These microstructures are present as sub-zones in the heat-affected zone of welded joints. Due to the narrow region of HAZ in a real weld, only a few tests are possible to perform such as micro-hardness. Welding simulator and laboratory furnace were used as methods for the preparation of the specimens. The material used in this study was a Nickel Molybdenum alloy steel (18CrNiMo7-6). Investigation of the mechanical properties of sub-zones of the HAZ of this particular alloy steel, were done by applying proper thermal cycles. Hardness and diameter of grain size were measured, tensile strength is calculated and Charpy instrumented test of both microstructures were performed in room temperature. The difference in Impact toughness was remarkable due to the difference in microstructure, energy for initiation and propagation were calculated by comparing (F-t and E-t) diagrams for both microstructures. The study revealed that the preparation of specimens with microstructure as at welded condition is possible, and it could lead to prepare samples for investigation of other mechanical properties such as fatigue crack growth and fracture toughness test.

Key words: Weld joint, laboratory furnace, welding simulator, fine grain HAZ, coarse grain HAZ

Introduction

Welding process is becoming one the most economical and effective manufacturing processes to join metals permanently, hence it is a vital component of our manufacturing economy. It is estimated that over 50% of global domestic and engineering products contain welded joints and in Europe the welding industry has traditionally supported a diverse set of companies across the shipbuilding, pipeline, automotive, aerospace, defense and construction sectors. In weld joint consumable material and a part of a base material are melted and solidified into weld metal during the cooling. The heat input needed for welding increases material temperature in the vicinity of the weld metal. As result of heat input some transformation in microstructure will occur at high heated area of base material which is not melted [1,2], this region known as heat affected zone (HAZ) of the weld joint. Heat affected zone (HAZ) microstructures is very inhomogeneous and complex, its microstructure usually consist of Coarse Grain HAZ, Fine Grain HAZ, Inter Critical HAZ and Over Tempered HAZ. The part of the HAZ which is heated the most is located near to the fusion zone, therefore crystal grains are coarsening during due to long period time of the thermal cycle. The coarse grain microstructure, called the coarse grain heat affected zone (CG HAZ), the fine grain microstructure (FG HAZ) is the next sub-region of HAZ results from this process; see Figure 1.

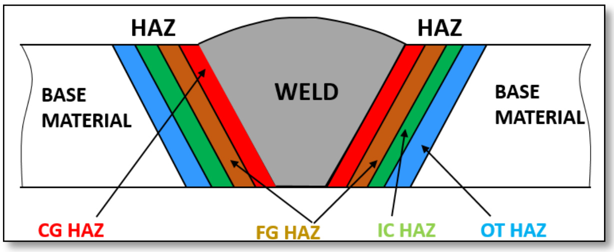

Figure 1. Welded joint; BM (base material), HAZ (heat affected zone), WM (weld material)

Behavior of the material during process of welding in the view of the metallurgical aspect, thermal cycles and metastable phase diagram Fe-C is shown in the Figure 2.

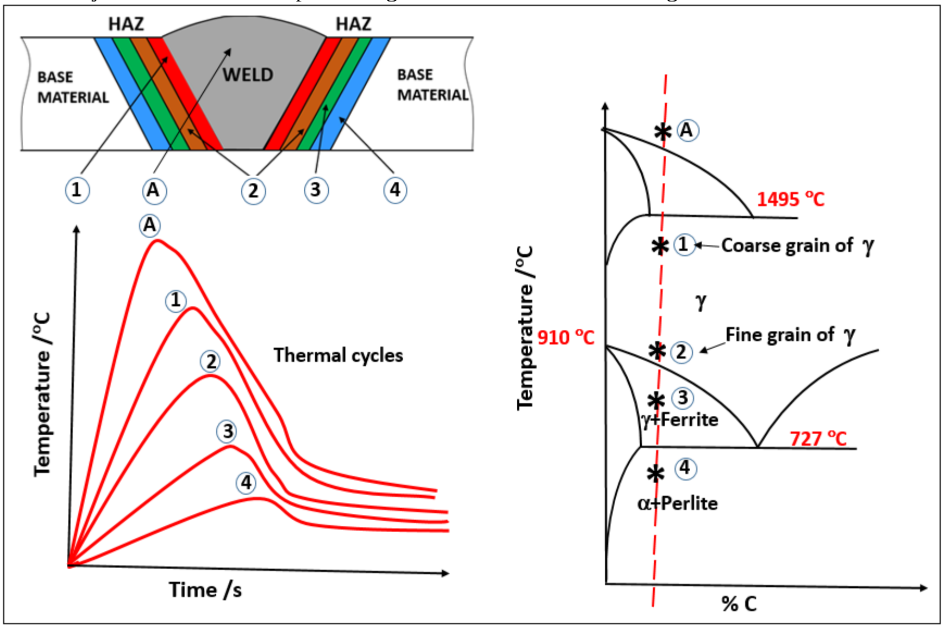

Figure 2. Weld thermal cycles and material behavior during welding

Material

Nickel-molybdenum alloy steel 17CrNiMo7 was used to prepare samples of FG HAZ and CG HAZ microstructure. Chemical composition and mechanical properties of the steel are shown in Tables 1 and 2.

Table 1 Chemical composition of the steel (weight /%)

C	Si	Mn	P	S
0,18	0,22	0,43	0,012	0,028
Cr	Ni	Cu	Mo	Al

1,56	1,48	0,15	0,28	0,023

Table 2 Mechanical properties of the steel

$Rp_{0.2}$ / MPa	R_m / MPa	A_5 / %	Z / %	Hardness / HV 10
489	633	26	72	217

Experimental procedure

Four types of specimens were prepared by welding simulator SMITHWELD machine and laboratory furnace. First type of specimens microstructure is prepared by simulation using weld thermal cycle simulator. In order to form fine grain microstructure on heat affected zone FG HAZ using weld thermal simulator a thermal cycle with $\dot{T}$ =150˚C/s, T_p =1100˚C, $\Delta t_{8/5}$= 10s is simulated. After simulation specimen were cut by saw machine in proper size to polish surface and prepare for microstructural observation.

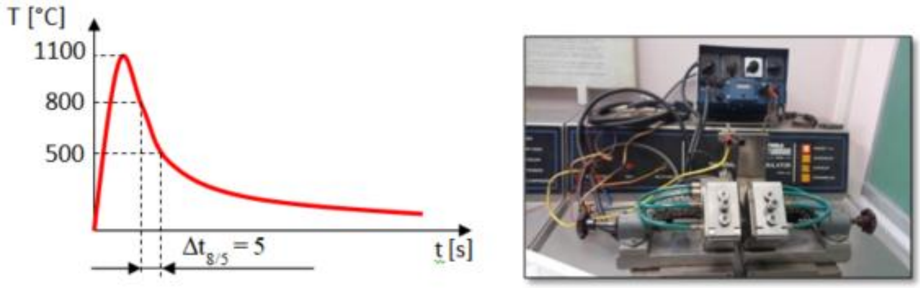

Figure 3. FG HAZ specimens prepared in welding simulator

Second type of the specimens were prepared using laboratory furnace, specimen were polished after heat treatment. In order to simulate fine grain microstructure as it is in heat affected zone laboratory furnace is used. Heat treatment is applied in this conditions T= 870˚C and held for 45min, after that specimens were cooled into water.

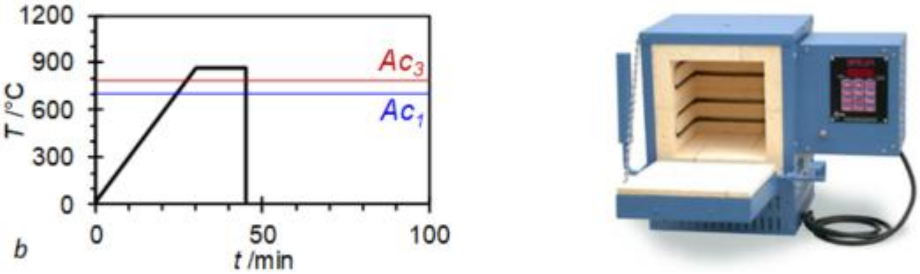

Figure 4. FG HAZ specimens heat treatment cycle prepared in laboratory furnace

Third type of the specimens were prepared using laboratory furnace with the described cycle in figure 5. In order to simulate coarse grain microstructure as it is in heat affected zone, heat treatment is performed on specimens in conditions: 3 hours coarse grain annealing at 1100˚C then temperature was lowered at 870˚C and after that quenched.

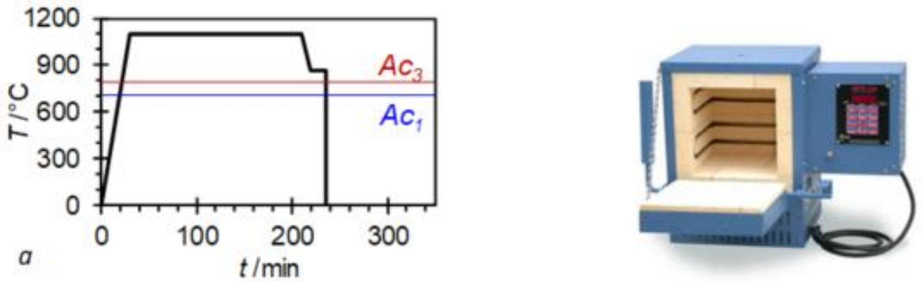

Figure 5. CG HAZ specimens heat treatment cycle prepared in laboratory furnace

Fourth type of specimens microstructure is prepared by simulation in SMITHWELD machine using weld thermal cycle simulator as it is described thermal cycle in figure 6. Simulation of coarse grain microstructure as it is in heat affected zone, is prepared by using weld thermal simulator with thermal cycle $\dot{T}$=150˚C/s, Tp=1350˚C, Δt8/5= 5s is performed. After simulation specimen were polish in order to prepare for microstructural observation.

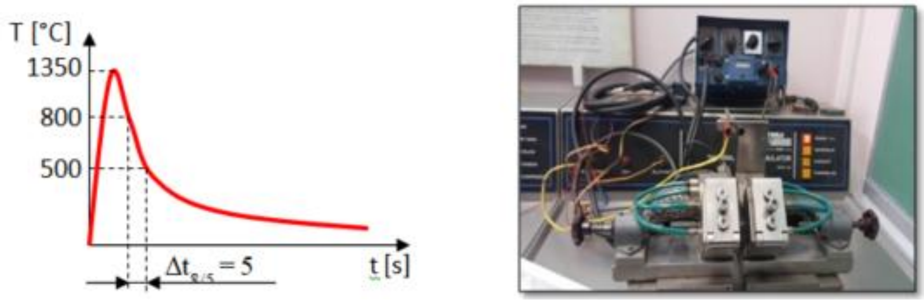

Figure 6. CG HAZ specimens prepared in welding simulator

Results and discussion

Microstructure was observed by the light microscope LEICA at magnification of 100×. The microstructure consists of small laths martensite, as shown in Figure 7 and Figure 8. Photographs of the specimens under light microscope reveal that the average size of fine crystal grains was 11µm, while the average size of coarse crystal grains was 200 µm.

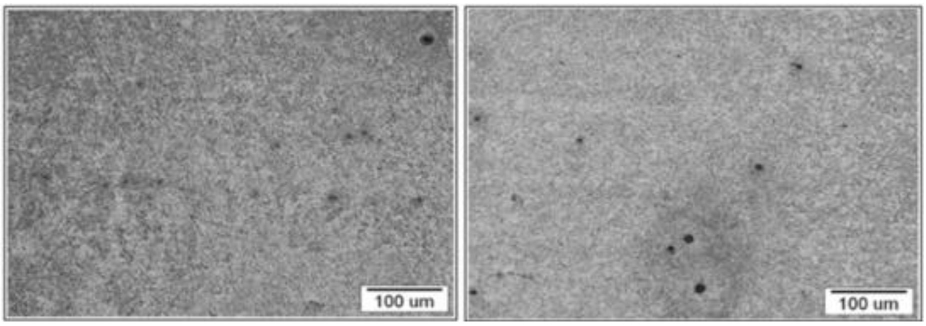

Figure 7. Microstructure of FG HAZ material; light microscope 100 ×, preparation in laboratory furnace and welding simulator

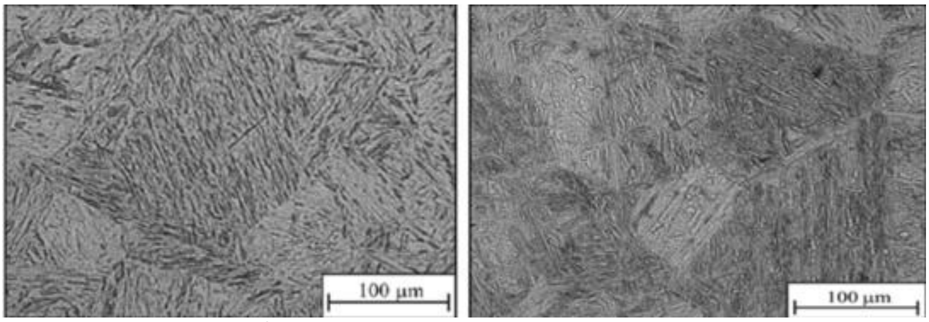

Figure 8. Microstructure of CG HAZ material; light microscope 100 ×, preparation in welding simulator and laboratory furnace

Hardness measurement

Vickers hardness of FG HAZ and CG HAZ was measured by using load of 98.1 N on instrumented Zwick machine. Hardness of FG HAZ was 380 HV10 and 455 HV10 of CG HAZ. Results are shown in Figure 9, presenting measurements of the Vickers hardness.

It was not possible to measure the tensile strength and a yield stress by mechanical testing, because simulated HAZ region was too small. They were calculated approximately from the hardness by applying equations from the BS 7448-2 [3] and equations proposed by Pavlina and Tyne [4], but in such cases error occurs up to 10%. Equations 1 and 2 refer to the BSI standard and equations 3 and 4 were proposed by Pavlina and Tyne:

$$R_{p0.2} = 3.8 \cdot HV - 221 \quad (1)$$

$$R_m = 3.15 \cdot HV + 93 \quad (2)$$

$$R_{p0.2} = 2.876 \cdot HV - 90.7 \quad (3)$$

$$R_m = 3.734 \cdot HV - 99.8 \quad (4)$$

(HV is the Vickers hardness number)

The yield stress and the tensile stress are presented in Table 3.

Table 3 Yield stress and tensile strength FG HAZ, CG HAZ and base material

Material	$R_{p0.2}$ / MPa	R_m / MPa
FG HAZ	1223 (1)	1290 (1)
	1002 (2)	1319 (2)
CG HAZ	1271 (1)	1526 (1)
	1218 (2)	1599 (2)
Steel 17CrNiMo7	474 (1)	761 (1)
	519 (2)	692 (2)

(1) BSI 7448-2 standard (equations 3 and 4)

(2) proposed by Pavlina and Tyne (equations 5 and 6)

After preformation of Charpy Instrumented test diagrams were plotted and comparison of the room-temperature load-time curves of the FG HAZ and CG HAZ microstructures is prepared. Remarkable difference in toughness is obvious.

Conclusion

Welding simulator and laboratory furnace make possible simulation and preparation of the fine and coarse grain specimens with same microstructure as it is in heat affected zone of the welded joint.
Average size of crystal grains of FG HAZ microstructure prepared by welding simulator and laboratory furnace was 11 µm, while the size of crystal grains of CG HAZ microstructure was 200 µm.
The FG HAZ microstructure hardness was 380 HV10, while CG HAZ microstructure hardness was 455 HV10.
Impact toughness of the CG-HAZ was 101J, whiles impact toughness was 58J which was approximately half of the impact toughness of CG-HAZ.

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