CHINESE JOURNAL OF MECHANICAL ENGINEERING
Vol. 24, No. *, 2011

DOI: 10.3901/CJME.2011.**.***, available online at www.cjmenet.com; www.cjmenet.com.cn

Effect of Heat Input on the Microstructure and Mechanical Properties of 07MnCrMoVR Weld Joints

XU Lianghong*, ZHANG Jun, and CHEN Yanqing

Shougang Research Institute of Technology, Beijing 100043, China

Received on January 27, 2010; revised on November 23, 2010; accepted on December, 2010; published electronically on December, 2010

Abstract: As a new type of low cracking suscepbility high strength steel, 07MnCrMoVR steel has excellent weldability, with low carbon equivalent and cold cracking susceptibility coefficient. However, there are still some problems when this steel is on the outdoor actual welding condition, such as having some extend cold cracking suscepbility and embrittlement of heat affected zone. Currently, researching works for the welding of this steel mostly focus on the evaluation the weldability of it, only few works are concentrated in how the heat input affecting the embrittlement of HAZ. The goal of this research is to study the effect of heat input on the embrittlement of the heat affected zone so as to get the optimal welding heat input range for it. In this paper, 38 mm 07MnCrMoVR steel made by Shougang is welded by manual arc welding technology, and the effect of heat input on the microstructure and mechanical properties of weld joints is also investigated by use of optical microscope(OM), scanning electron microscope(SEM), mechanical properties testing machines and Viker hardness tester. The microstructure and fractography observation results and the mechanical properties testing results indicate that the 07MnCrMoVR steel made by Shougang has a wide adaptable range for heat input, and when the heat input is in the range of 15–42 kJ/cm, the toughness of the weld joints is well. With the increase of heat input, the impact toughness of weld zone and heat affected zone decrease, whereas the tensile strength of the weld joints does not change at all. The microstructure of the weld is acicular ferrite with small amount of proeutectoid ferrite, and with the increase of heat input, the ratio of proeutectoid ferrite and the amount of M-A constituent increase, as well as the grain size and the width of the bainite lath in coarsened grain heat affected zone. Fractography results show that with the increase of heat input, the number of dimples in impact fracture specimens decreases, and the cleavage patterns increase, inducing the fracture from ductility to embrittlement. This research provides a theory support for guiding the penstock constructor how to use 07MnCrMoVR steel in actual welding.

Key words: 07MnCrMoVR, heat input, microstructure, impact toughness, heat affected zone

1 Introduction*

As a low cracking suscepbility steel, 07MnCrMoVR steel is widely used in the construction of oil tanks, spherical tanks in petrochemical engineering, as well as the construction of penstock and spiral casing in power stations[1–4]. Especially, with the support of Chinese nation policies and the increasing demand of power capacity for power stations in these years, the 07MnCrMoVR steel is mainly used for the penstock. However, because the welding quality is very high for building the penstocks, and it is easy to give rise to cold cracking and embrittlement of the weld joints during the welding process, especially the embrittlement of weld joints has attracted more attention from constructors. Heat input is the main factor for affecting the embrittlement of weld joints, when the heat input is very high, the impact toughness of the weld joints is very low, but in order to improve the welding efficiency, the heat input is required to be high enough in actual engineering welding, so it is necessary to know the suitable range of the heat input for the 07MnCrMoVR steel made by Shou Steel.

A number of previous studies on 07MnCrMoVR steels have been directed toward evaluating the weldability of the 07MnCrMoVR steel, especially evaluating the hydrogen-induced cracking susceptibility of this steel[3–5]. For instance, XIAO, et al[3], proposed that the 07MnCrMoVR steel had low cold cracking suscepbility and excellent weldability. Subsequently, using the cold cracking test and heat affected zone(HAZ) peak hardness test techniques, YANG, et al[4], evaluated the weldability of the 07MnCrMoVR steel made by Wuyang Steel. In a few other investigations, there are observations primarily related to the effect of welding processes and welding materials on the mechanical properties of the weld joints[6–8].

In view of the aforementioned, it is felt that most of the studies only evaluate the weldability of 07MnCrMoVR steel, few investigate the effect of heat input on the embrittlement of the heat affected zone. This research program was carried out on the 38 mm thick plate

---

* Corresponding author. E-mail: xlh_smile@sohu.com

07MnCrMoVR steel made by Shougang. The heat input was varied in actual welding in order to study the effect on the microstructure and mechanical properties of the weld joints were also studied, so as to guide the penstock constructors how to use this steel in actual welding.

The present investigation has been aimed to address the effect of heat input on the mechanical properties and microstructure of the 07MnCrMoVR steel weld joints by using the shielded metal arc welding(SMAW) process with three different levels of heat input. The mechanical properties test has been carried out to show how the heat input effect on mechanical properties. In addition, microstructure and fractography observation tests were also done for reveal the effect of heat input on the microstructure of weld joints. Consequently, based on the results above, an optimal welding orange for this steel is put forward, followed by discussions and conclusions.

2 Materials and Experimental Procedure

2.1 Materials

38 mm thick plate of quenched and tempered steel 07MnCrMoVR made by Shougang which is usually used in construction of penstock was selected as the experimental subject. The plates are austenitised at 950 °C for 40 min and quenched in water followed by tempering at 620 °C for 0.5 h. The nominal chemical composition of this steel (mass fraction) is as follows: C $\leqslant$ 0.09, Si0.15–0.24, Mn1.2–1.6, S$\leqslant$0.010, P$\leqslant$0.025, Mo0.1–0.3, Cr0.1–0.3, V0.02–0.06, Ti0.013. And the mechanical properties of this steel are shown in Table 1. For manual arc welding, the high strength super low hydrogen electrode J607RH with a diameter of about 4 mm is used as welding material and the detail of the chemical compositions of deposited metal was C0.059, Si0.23, Mn1.4, S0.007, P0.011, Mo0.95, Ni0.29. Before actual welding, the welding electrodes are kept in oven at 350 ºC for 1.5 h, and then kept in dryer barrel at 100–150 ºC.

Table 1. Mechanical properties of 07MnMoVR steel

Yield strength $R_{\mathrm{eL}}/\mathrm{MPa}$	Tensile strength $R_{\mathrm{m}}/\mathrm{MPa}$	Elongation $A/\%$	−20 ºC impact absorbed energy $E_{\mathrm{a}}/\mathrm{J}$
580	665	22.5	203, 286, 284

2.2 Experimental procedure

Symmetrical X groove angles (30°) are cut in the quenched and tempered steel plates with no root face for a total 60° included angle between two plates. Manual arc welding is adopted in actual welding. In order to find a suitable heat input range, three different heat input levels are chosen, i.e., 16–21 kJ/cm, 19–24 kJ/cm and 35–42 kJ/cm. Details of the welding parameters are shown in Table 2. Before welding, the plates are preheated, the preheating temperature is was 100 ºC, and the interpass temperature is controlled between 100 ºC and 160 ºC.

The tensile specimens of 10 mm diameter are machined from the welded plates with the longitudinal axis of the specimens parallel to the rolling direction of the plates, and the tensile test is done on UH-F50A tensile equipment according to GB2651-2008. Standard Charpy samples of 10 mm×10 mm×55 mm dimensions with 2 mm V-notch are prepared according to ASTM E 23. Samples are cut in the transverse through thickness (T–T) direction, keeping the position of the notch in the weld centre, fusion line and respective HAZ 2 mm from fusion line. Impact test was conducted by a Zwick Charpy impact testing machine according to GB2650-89 at −20 °C. The hardness is measured in a Vicker's hardness tester by using a 10 kg load with a 10 s holding time, and an average hardness of 10 indented fields for a particular sample is reported.

Table 2. Welding parameters

Heat input $E/(\mathrm{kJ \cdot cm^{-1}})$	Type of passes	Weld current I/A	Weld voltage U/V	Weld speed $v/(\mathrm{mm \cdot min^{-1}})$
35–42	Root pass	130	24	150
	Middle pass	200–210	26–28	80–100
	Surface pass	200–210	26–28	80–100
19–24	Root pass	140–150	22–24	150
	Middle pass	170–180	26–28	125–135
	Surface pass	170–180	26–28	125–135
16–21	Root pass	130	23	150
	Middle pass	130–140	23–25	100–130
	Surface pass	130–140	23–25	100–130

Observation of transverse sections is carried out by using optical and scanning electron microscopy. The specimens are mechanically polished and etched with a 2% nital solution for observation of the microstructure by using an OLYMPUS Lext3100 optical microscope. Several etchants are used to reveal specific microstructures. For example, LePera's solution is used to reveal the M-A constituent, and in the photos the martensite is revealed as white areas, ferrite revealed as grey, and bainite revealed as black.

Fractography studies of the tested impact specimens are carried out in Hitachi S-3400N scanning electronic microscope(SEM).

3 Test Results and Analysis

3.1 Effect of heat input on joint mechanical properties

The tensile properties of the specimens obtained from the weld joints with three different heat input levels are shown in Table 3. The tensile test results show that the yield strength of the specimens with three different heat input levels are all above 490 MPa, as well as the tensile strength values are all above 610 MPa, which meet the hydroelectric standards. The effect of heat input on the tensile strength of the weld joints is also studied. The compared results show that heat input has little effect on the tensile properties. With the increase of heat input, the tensile strength of welding joint only increases little.

The fracture site of the specimens obtained from the weld joints with three different heat input levels all crack in HAZ, which means that HAZ is the weakest zone in the whole weld joint. The results of the hardness curves also prove this conclusion as shown in Fig. 1. It is apparent that most of the HAZ 10–15 mm distance from the weld centre has a lower hardness than the base metal (HV260), showing a soft zone in HAZ. It can be concluded that the width of the soft zone increases with the increase of heat input from the hardness curve with three different heat input levels. The softening cause is the recrystallization of HAZ under weld thermal cycle.

Table 3. Tensile properties of the weld joints with 3 different heat input levels

Heat input $E/(\mathrm{kJ \cdot cm^{-1}})$	Heat treatment	Yield strength $R_{\mathrm{eL}}/\mathrm{MPa}$	Tensile strength $R_{\mathrm{m}}/\mathrm{MPa}$	Elongation $A/\%$	Fracture site
35–42	As welded	570	667	12.7	HAZ
19–24	As welded	585	670	15.5	HAZ
	580 °C×1 h	580	660	15.0	HAZ
16–21	As welded	579	673	15.8	HAZ

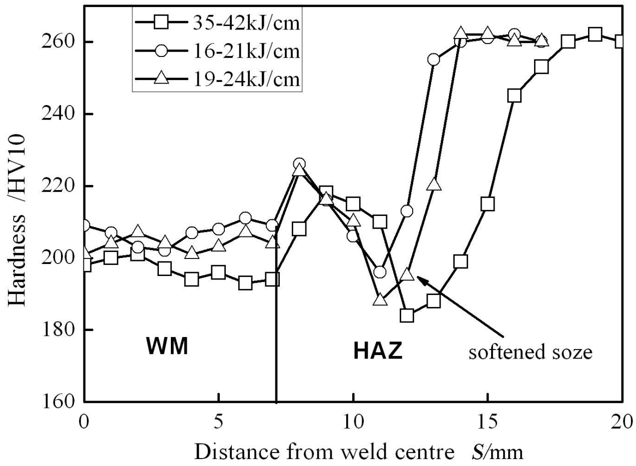


Fig. 1. Hardness curves of welding joints

In addition, in order to research the effect of stress relief heat treatment on the mechanical properties and microstructures of the welding joints, the mechanical properties of the specimens obtained from the weld joints which are post heat treated at 580 °C for 1 h have been measured. The details of the heat treatment parameters are as follows: the heating rate is 60 °C/h, the holding time is 1h, and the cooling rate is 50 °C/s. It can be concluded from the results given in Table 3 that the post weld heat treatment has little effect on tensile properties, and the properties decrease a little after holding 1 h at 580 °C, and the fracture also occurred in HAZ.

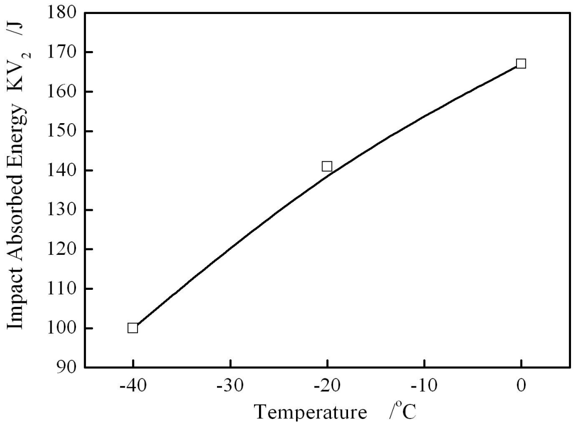
The Charpy-V notch impact toughness data obtained at −20 °C from the WM, Fusion line and HAZ regions of three weld joints welded with three heat inputs are presented in Table 4, in which the figure with underline shows the average value of the impact absorbed energy. It is clear that the impact toughness of every zone of the weld joints with three different heat input levels all satisfy the demand of 47 J at −20 °C, even when the heat input is in the range of 35–42 kJ/cm, the impact toughness of WM, Fusion line and HAZ are still respective 102 J, 110 J and 225 J, respectively, and with all the three heat input levels the impact toughness of HAZ were all higher than 200 J, showing no brittle phenomenon in HAZ of 07MnCrMoVR steel. This means that the 07MnCrMoVR steel made by Shougang has a wide heat input range for actual welding, and with the increase of heat input the −20 °C impact values of the weld, fusion line and HAZ only decrease a little, for example, the impact value of weld is only changed from 132 J to 102 J.

Table 4. Impact toughness of WM, fusion line and HAZ with three different heat input levels

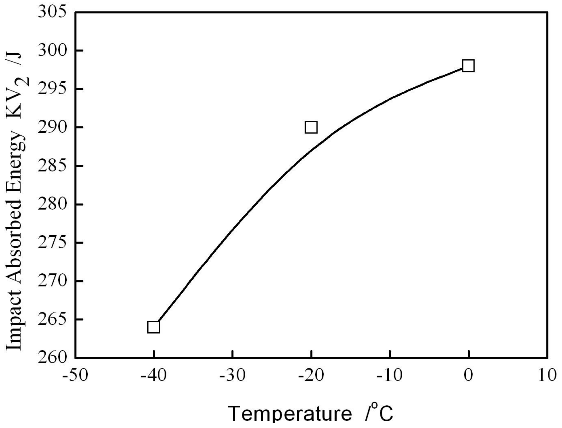
Heat input $E/(\mathrm{kJ \cdot cm^{-1}})$	Heat treatment	−20 °C impact absorbed energy E_{a} /J		
		Weld zone	Fusion line	HAZ
35–42	As-welded	110, 112, 85 102	85, 118, 88, 114, 146 110	257, 298, 120 225
19–24	As-welded	102,104,109 105	50, 155, 175, 149, 176 161	157, 268, 302 242
	580 °C×1 h	180,183,108 157	103, 143, 172, 179 149	227, 212, 219 219
16–21	As welded	131,139,126 132	44, 271, 277, 188, 153 206	287, 281, 299 289

Furthermore, the effect of a stress relief heat treatment on the toughness of the 07MnCrMoVR weld joints is also studied. The impact toughness of the weld joints with as welded condition and with tempering at 580 °C for 1 h are compared when the heat input is in the range of 19–24 kJ/cm. The compared results show that the stress relief heat treatment has little effect on the impact toughness, even after post heat treating at 580 °C for 1 h, the impact absorbed energy of the WM, fusion line and HAZ regions of the weld joints are still very high. This means that the reheating embrittlement susceptibility of this steel is low under the condition of the heat treatment temperature is at 580 °C.

The effect of impact temperature on the impact toughness has been researched, and the results are given in Fig. 2. The heat input adopted here is 19–24 kJ/cm. The results indicate that the impact toughness of each zone in the weld joints decreases with the decrease of impact temperature. However, the weld and HAZ still have high impact toughness even at −40 °C, which is much higher than 47 J specified in the hydroelectric industrial standard. It is clear that the ductile-to-brittle temperature of weld and HAZ are both below −40 °C, which means Shougang 07MnCrMoVR steel can be used in the manufacture of penstock working under low temperature condition.



(a) Weld zone

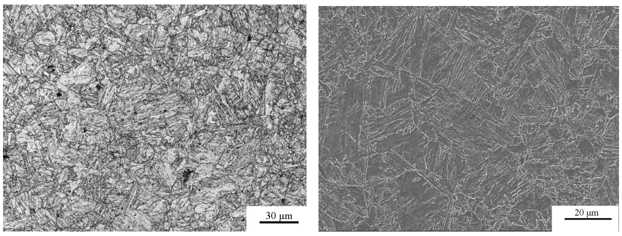


(b) HAZ

Fig. 2. KV2-T curves of weld zone and HAZ

3.2 Effect of heat input on the microstructure of the weld joints

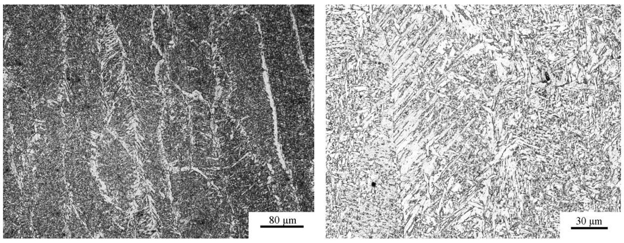
The microstructure of base metal is shown in Fig. 3. The observation results show that the base metal is consistent with a bainite microstructure, and the grain size measurements also indicate that the grain size of the bainite bind is also very small. Because of the small ferrite plate where the original austenite microstructure is refined, a refined bainite microstructure is gained, and then the strength and impact toughness of base metal are improved.



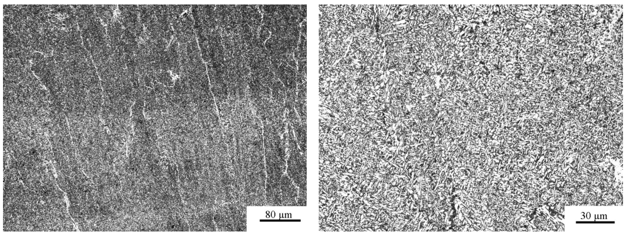
(a) OM　(b) SEM

Fig. 3. Photos of the base metal

The microstructure of the weld zone under different heat inputs are shown in Fig. 4. The microstructure of the welds under different heat inputs is consistent with acicular ferrite and the plate proeutectoid ferrite along the grain boundary. The impact toughness of the weld depends on the proportion of acicular ferrite and the plate proeutectoid ferrite. The crack is easy to initiate and propagate in proeutectoid ferrite, so when the proportion of proeutectoid ferrite is very high, the toughness of the weld will be deteriorated. The fined acicular ferrite is useful to improve the impact toughness of welds because the crossing distribution grain boundaries can impede the propagation of cracks. The microstructures produced at the heat input of 35–42 kJ/cm appear at this level of resolution to be acicular ferrite, the plate proeutectoid ferrite and some Widmanstaten sideplate ferrite structure, the Widmanstatten sideplate ferrite nucleates from the prior austenite grain boundaries. The lower heat input (16–21 kJ/cm) as shown in Fig. 4(b) produces fined acicular ferrite microstructure and little proeutectoid ferrite.



(a) 35–42 kJ/cm

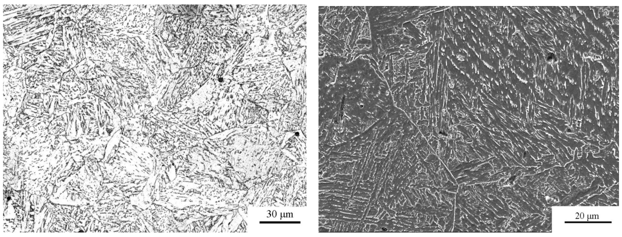


(b) 16–21kJ/cm

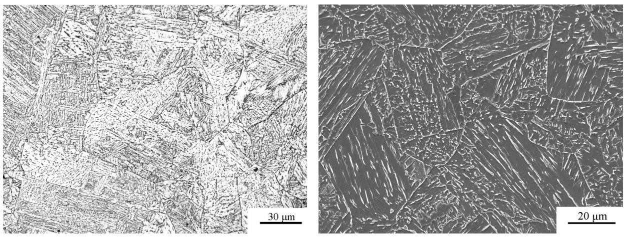
Fig. 4. Effect of the heat input on the microstructure of weld zone

Fig. 5 shows the effect of heat input on the microstructure of coarsened grain zone. The coarsening of original austenite grain and the formation of brittle microstructure are the main cause for the decrease of toughness in coarsened grain zone. It can be seen from Fig. 5 that the original austenite grain size increases with the increase of heat input. In addition, the size of lath bainite and the proportion of granular bainite in coarse grain zone also increase with the increase of heat input, which results in the decrease of toughness in coarsened grain zone under high heat input.

The formation of Martensite-Austenite(M-A) constituent is also the reason for the decrease of the impact toughness of coarsened grain zone[9–13]. The morphology of M-A constituent in coarsened grain zone under different heat inputs are shown in Fig. 6. When the heat input is very high, there is lots of M-A constituents, and the size of M-A constituent is also very big, as shown in Fig. 6(b). M-A constituent is a hard and brittle microstructure, and it is easy to occur on the crack site when deformed. It is well known that with the increase of the amount of M-A constituent as well as its size, the impact toughness of coarsened grain zone decreases, so the impact toughness is very low under high heat input.

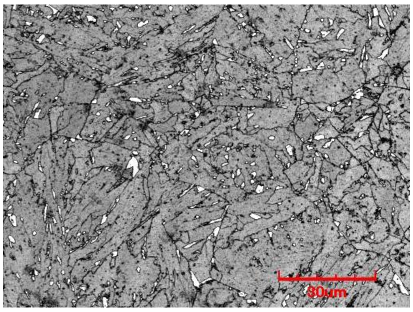


(a) 35–42 kJ/cm

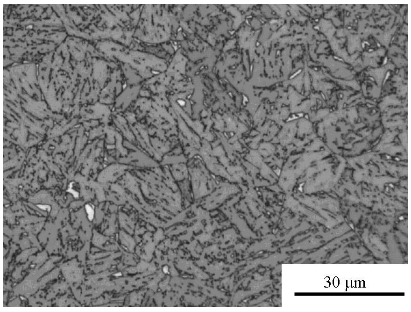


(b) 16–21 kJ/cm

Fig. 5. Effect of heat input on the microstructure of coarsened grain zone



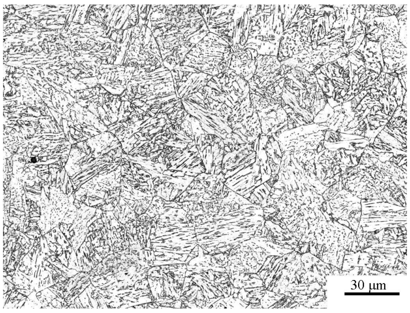
(a) 35–42 kJ/cm



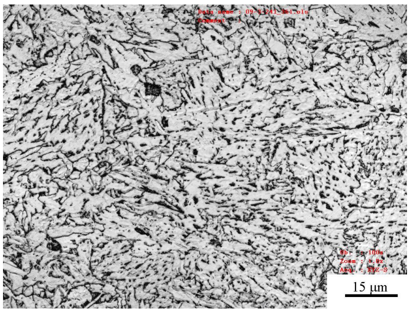
(b) 16–21 kJ/cm

Fig. 6. Effect of heat input on the morphology of the M-A constituent in coarsed grain zone (etched with Lepra reagent)

It is reported that the 07MnCrMoVR steel has some reheating embrittlement susceptibility, and the extent of reheating embrittlement depends on the reheating temperature. The cause for the reheating embrittlement phenomenon in coarsened grain zone still needs to be further researched. However, many researches indicate that the reheating embrittlement of the coarsened grain zone of 07MnCrMoVR steel is related to the elements Cr, Mo, and V elements in this steel[14–17]. These elements exist in the steel in the form of carbide, but with the effect of welding thermal cycle, especially when the peak temperature is higher than 1 300 °C, the carbide with Cr, Mo or V in the steel will be dissolved, and during the post heat treatment, these dissolved carbides will be precipitated at grain boundary, so as to strengthen the grain boundary and make the deformation concentrated in grain boundary. The microstructure as shown in Fig. 7 show that the carbide in coarsened grain zone has some clustering, but the clustering extent is not very serious, so after the post heat treatment, the impact toughness of CGHAZ has been decreased little, this means that the reheating embrittlement susceptibility of CGHAZ of 07MnCrMoVR weld joints at 580 °C is very low.



(a) As welded condition



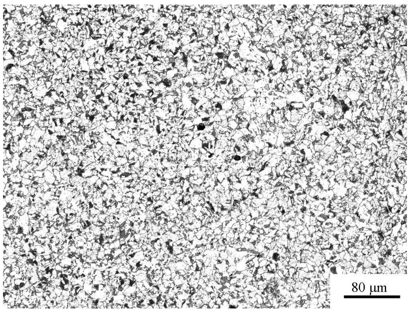
(b) 580 °C×1 h

Fig. 7. Effect of post heat treatment on the microstructure of coarsened grain zone

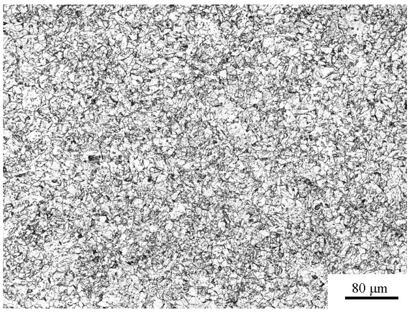
The effect of heat input on fine grain zone is given in Fig. 8. The microstructure of this zone is ferrite with some pearlite and bainite. When the heat input is high, pearlite transformation is easy because of the low cooling rate and long holding time at high temperature. Therefore, the pearlite content in fine grain zone and the ferrite grain size both increase under high heat input, and the bainite content decreases. Ferrite phase transition which causes the fine grain zone turned to the soft zone in welding joint lies in that the samples are easier to crack in this zone. In addition, because of the increase of ferrite grain size and the decrease of bainite content, the softening is more serious under high heat input.

3.3 Effect of heat input on the fractography of the impact specimens

The fractography of the weld is shown in Fig. 9. It can be seen from this figure that with the increase of the heat input, the plastic deformation extent decreases, and the proportion of the shear lip also decreases. The SEM observation results show that the fractography of the weld appear to be dimple mixed with quasi-cleavage character under low heat input, but when the heat input is high, the fractography of the weld appears to be cleavage character, and the cleavage plane is large. This is very fit for the high impact toughness of the weld under low heat input condition.

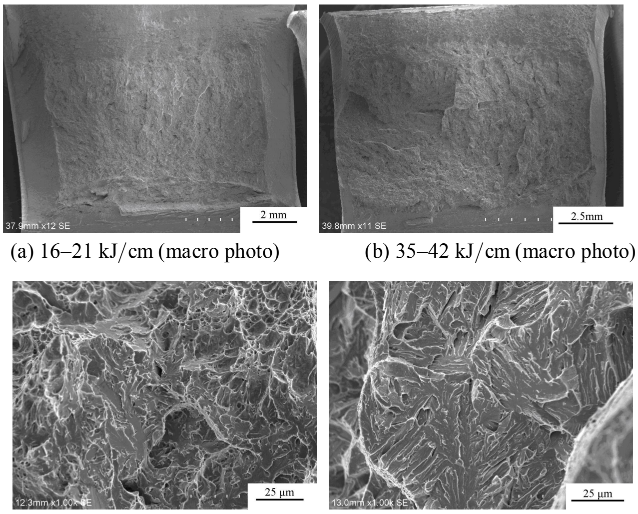


(a) 35–42 kJ/cm



(b) 16–21 kJ/cm

Fig. 8. Effect of heat input on the microstructure of fine grain zone

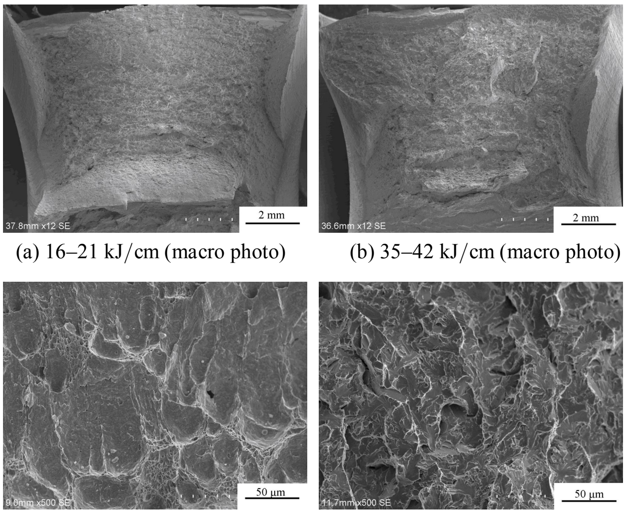


(a) 16–21 kJ/cm (macro photo)　(b) 35–42 kJ/cm (macro photo)

(c) 16–21 kJ/cm (micro photo)　(d) 35–42 kJ/cm (micro photo)

Fig. 9. Fractography of the weld zone

The fractography of the impact specimens of heat affected zone is shown in Fig. 10. It can be seen from this figure that the proportion of the shear lip decreases with the increase of heat input from the macrography results. The micro fractography results show that the impact fractures of the HAZ appear to be the dimple fracturing character, and with the increase of the heat input, the amount of the dimples decease, and the cleavage pattern increases. The fracture mode changes from the dimple ductile fracture to cleavage brittle fracture with the increase of heat input.



(a) 16–21 kJ/cm (macro photo)　(b) 35–42 kJ/cm (macro photo)

(c) 16–21 kJ/cm (micro photo)　(d) 35–42 kJ/cm (micro photo)

Fig. 10. Fractography of HAZ

6 Conclusions

(1) The 07MnCrMoVR steel made by Shougang has a wide adaptable range for heat input, and when the heat input is in the range of 15–42 kJ/cm, the −20 ºC impact toughness of the weld joints is above 47 J, and with the increase of heat input, the impact toughness of different zones in weld joints all decreases to some extent.

(2) There is a softened zone in the weld joints for the quenched and tempered 07MnCrMoVR steel, and the softened extent increases with the increase of heat input.

(3) The 07MnCrMoVR steel has low reheating embrittlement susceptibility when the heat temperature is at 580 ºC.

(4) The microstructure of the base metal is tempered bainite structure, and the weld is consistent with the acicular ferrite structure and the plate proeutectoid ferrite, and with the increase of heat input, the amount of proeutectoid ferrite increases. The CGHAZ produces the bainite microstructure, and both the primary austenite grain size and bainite binds in the grain increase with the increase of heat input. The fine grain zone is consistent with the ferrite and pearite microstructure, and the proportion of pearite is high when the heat input is high.

(5) The impact fractures of the HAZ appear to be the dimple fracturing character, and with the increase of the heat input, the amount of the dimples decease and the cleavage area increases. The fracture mode changes from the dimple ductile fracture to cleavage brittle fracture with the increase of heat input.

References

[1] TANG Yueying. The points of designing and selecting suitable materials of 2000m^3 spherical tanks[J]. *North China Petroleum Designing*, 2004, 20(2): 33–35. (in Chinese)

[2] DUAN Liming, WANG Fei, TIAN Yunfeng. The welding process for domestic 07MnCrMoVR high strength steel[J]. *Yun Nan Hydraulic Electric Power Generation*, 2005, 21(1): 69–72. (in Chinese)

[3] XIAO Kewei, HUANG Wei. Study of the weldability of ADB610 steel[J]. *Mechanical & Electrical Technique of Hydropower Station*, 2005, 28(4): 36–39. (in Chinese)

[4] YANG Xiujin, YANG Hailin, YAO Liandeng. Supper low carbon Bainitic Steel W DB620 and its W elding Performance[J]. *Materials for Mechanical Engineering*, 2003, 27(9): 42–45. (in Chinese)

[5] WANG Hui, BU Huaquan, FANG Wunong. Study on welding cold-sensible crack of NK-HITEN 610U2L steel[J]. *Petro Chemical Equipment*, 2006, 35(4): 13–16.

[6] WANG Qingfeng, WANG Yanan, SHANG Chengjia, et al. Study on weldability of low carbon bainitic steel with ultrafine microstructure[J]. *Iron and Steel*, 2006, 41(3): 77–80.

[7] ZHANG Lihong, CHEN Furong. Analysis of the low temperature impact toughness of 07MnNiCrMoVDR low temperature steel welding joints[J]. *Welding Transaction*, 2008, 29(6): 68–72.

[8] WU Qiang. *Research on the performance simulation of HAZ of 07MnNiCrMoVDR steel*[D]. Tianjin: Tianjin University, 2007.

[9] QIAN Bainian, TIAN Dewei, YANG Jingli. Studying of the local embrittlement of pipeline steel[J]. *Welding Pipe*, 1993, 6(6): 8–12. (in Chinese)

[10] LEE S, KIM B C, LEE D Y. Fracture mechanism in coarse grained HAZ of HSLA steel welds[J]. *Scripta Metallurgica*, 1989, 23(6): 995–1 000.

[11] JING Hongyang, HUO Lixing, ZHANG Yufeng. Effect of Niobium on morphology of martensite-austentite constituents in weld HAZ[J]. *Journal of China Welding Institute*, 1997, 18(1): 37–42. (in Chinese)

[12] JIA Kunning, GAO Cairu, DU Linxiu, et al. Effect of simulated welding thermal cycle on microstructure and properties of HAZ for micro-calcium steel[J]. *Research of Iron & Steel*, 2007, 35(2): 17–21. (in Chinese)

[13] QIAN Bainian, LI Jingli, SI Chongyao. Effect of C, Al, and Ti on the toughness of HAZ of HSLA steel[J]. *Chinese Journal of Materials Research*, 1995, 9(2): 119–124. (in Chinese)

[14] ZHAO Deshan, WANG Chunlin. Effect of heat treatment on the reheat cracking of 07MnCrMoVR steel spherical tank[J]. *Petrochemical Construction*, 2007, 29(5): 39–41.

[15] YAO Jin. The reheat cracking mechanism of HQ-80[J]. *Welding Transaction*, 2004, 25(6): 77–81. (in Chinese)

[16] YUAN Chao, QI Yihui, SUN Xiaofeng. The reheating embittlement of crack-free steel during post-welding heat treatment[J]. *Journal of Liaoning Institute of Technology*, 2001, 21(1): 4–7.

[17] ZHAO Shilu, LI You. Study of the reheating embrittlement of the heat affected zone of P460L1[J]. *Mechanical Design and Construction*, 2006, 43(2): 115–116.

Biographical notes

XU Lianghong, born in 1980, is currently an engineer in *Shougang Research Institute of Technology, China*. He received his PHD degree from *Centre Iron & Steel Research Institute, China*, in 2008. His research interests include weldability of high strength steel
Tel: +86-571-87953096; E-mail: xlh_smile@sohu.com

ZHANG Jun, born in 1973, is currently a senior engineer in *Shougang Research Institute of Technology, China*. He received his master degree on materials from *Baotou University, China*, in 1996.
E-mail: zhangjun@mail.shougang.com.cn

CHEN Yanqing, born in 1968, is currently a senior engineer in *Shougang Research Institute of Technology, China*. Her research interests include weldability of high strength steel
E-mail: chenyanqing@mail.shougang.com.cn