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The influence of heat input on the toughness and fracture mechanism of surface weld metal

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Abstract

Surface welding is a way to extend the exploitation life of damaged parts and constructions and the heat input has a major influence on the weldment properties. In this paper is shown the influence of the heat input on the toughness and the fracture mechanism of the surface welded joint. Surface welding of high carbon steel with self shielded wire was conducted with three different heat inputs (6kJ/cm, 10 kJ/cm and 16 kJ/cm). Total impact energy, crack initiation and crack propagation energy were estimated at room temperature, -20ºC and -40ºC. Fracture analysis of fractured surfaces was also conducted and it has been found that increasing of heat input leads to an increase of share of transgranular brittle fracture, what is in complete accordance with the obtained energy values. Based on all obtained results, the optimum value of heat input for welding procedure applied was defined.

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Keywords: Heat input; Fracture mechanism; Toughness; Surface welding

1. Introduction

Surface welding is a way to extend the exploitation life of damaged parts and constructions and the heat input has a major influence on the weldment properties. The dependence of the mechanical properties on the welding conditions was studied, but the effect of heat input has been studied insufficiently by M.Pirinen et al. (2015). The most important characteristic of heat input is that it governs the cooling rates in welds and thereby affects the microstructure of the weld metal. At surface welding, heat input affects on the mixture degree, as relevant parameter

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of weld quality. Mixture degree increases with higher heat inputs, which results in different microstructures of obtained layers, and in different toughness values. When different welding heat inputs were used, the layers experienced different thermal cycles, and different microstructures were formed. Increasing the welding heat input restrained the formation of martensite and promoted the transformation of martensite to bainite by H. Dong et al. (2014). The hardness of the weld metal decreased when increasing the welding heat input. As fatigue cracks normally initiate around the bead, a higher hardness for weld metal and HAZ can prevent the initiation of fatigue cracks. Experimental studies have shown that fatigue life was increased when increasing the welding heat input by C.H.Suh et al. (2011). Therefore, the control of heat input is very important in arc welding in terms of quality control. The weld metal toughness of surface welded joint is the result of complex influence of many factors: type of filler material, heat input, mixture degree of base metal and filler material, post heat treatment with next layer, because each subsequent pass alters the structure in regions of the previous pass that are heated by O.Popovic (2006) and O.Popovic et al. (2012). The change in toughness is also significantly influenced by the weld bead size. As the bead size increases, which corresponds to a higher heat input, the notch toughness tends to decrease. In multiple-pass welds, a portion of the previous weld pass is refined, and the toughness improved, as the heat from each pass tempers the weld metal below it. If the beads are smaller, more grain refinement occurs, resulting in better notch toughness.

Nomenclature

Q	welding heat input
I	welding current
U	welding voltage
V	welding speed
E_t	total impact energy
E_{in}	crack initiation energy
E_{pr}	crack propagation energy
T	temperature

2. Experimental procedure

The surface welding of the testing plates was perfomed with self-shielded wire as the filler material (OK Tubrodur 15.43). Chemical composition and mechanical properties of base metal and filler material are given in Table 1 and Table 2. Since the CE-equivalent was 0.64, the calculated preheating temperature was of 230°C, and the controlled interpass temperature was of 250°C. Surface welding was conducted with three different heat inputs. The welding heat input (Q) was calculated with the formula: $Q=60\eta IU/V$, where I, U, V and η are the welding current, welding voltage, welding speed and arc efficiency, respectively. Values of heat input during welding, with corresponding sample designations and welding parameters, are given in Table 3. Surface welding was perfomed in three layers (samples 1 and 2), except for sample 3, where the required thickness of the weld (10 mm) was obtained in two layers, due the high heat input. Specimens for further investigation were prepared from weld metal of surface welded samples. Impact testing is performed according to EN 10045-1, i.e ASTM E23-95, with Charpy specimens, V notched in WM, on the instrumented machine SCHENCK TREBEL 150 J. Specimens were cut and tested at 20°C, -20°C and -40°C. Than the fractured surfaces were examined with a scanning electron microscope (SEM) Jeol JSM-6610 LV, with the acceleration voltage of electrons of 20kV and magnification of 1000x.

Table 1. Chemical composition and mechanical properties of base metal

Chemical composition, %							Tensile strength
C	Si	Mn	P	S	Cu	Al	R_m (N/mm^2)
0.52	0.39	1.06	0.042	0.038	0.01	0.006	680-830

Table 2. Chemical composition and mechanical properties of filler material

d, mm	Chemical composition							Hardness
	C	Si	Mn	Cr	Mo	Ni	Al	HRC
1.6	0.15	<0.5	1.1	1.0	0.5	2.3	1.6	30-40

Table 3. Sample designation and welding parameters

Sample no.	Welding current (A)	Voltage (V)	Welding speed (cm/s)	Heat input (J/cm)
1	180	28	47	6 440
2	235	30	40	10 520
3	280	30	31.8	15 850

3. Results and discussion

Instrumented Charpy pendulum enables separation of total impact energy (E_t) to crack initiation energy (E_{in}) and crack propagation energy (E_{pr}). Impact testing results at all testing temperatures and for all samples are given in Fig.1. At room temperature, the total impact energy is the highest for the lowest heat input (6.4 kJ/cm), and is equal 32 J. With an increase of heat input, impact energy decreases and is equal 21 J for 15.9 kJ/cm. The crack propagation energy, E_{pr}, is very low (4-12 J) and in all cases is lower than crack initiation energy, E_{in}. At -20^{0}C, the lowest total impact energy is obtained for the highest heat input (18 J), while the highest impact energy has sample with the lowest heat input (25 J). Crack initiation energy is equal to 15-19 J. At -40^{o}C, the differences between samples are minimal (15-17 J), and proportion of crack propagation energy at this temperature is negligible. Due the unsensitivity of crack initiation energy to temperature decrease, these joints have satisfactory and safe exploatation up to -40^{0}C.

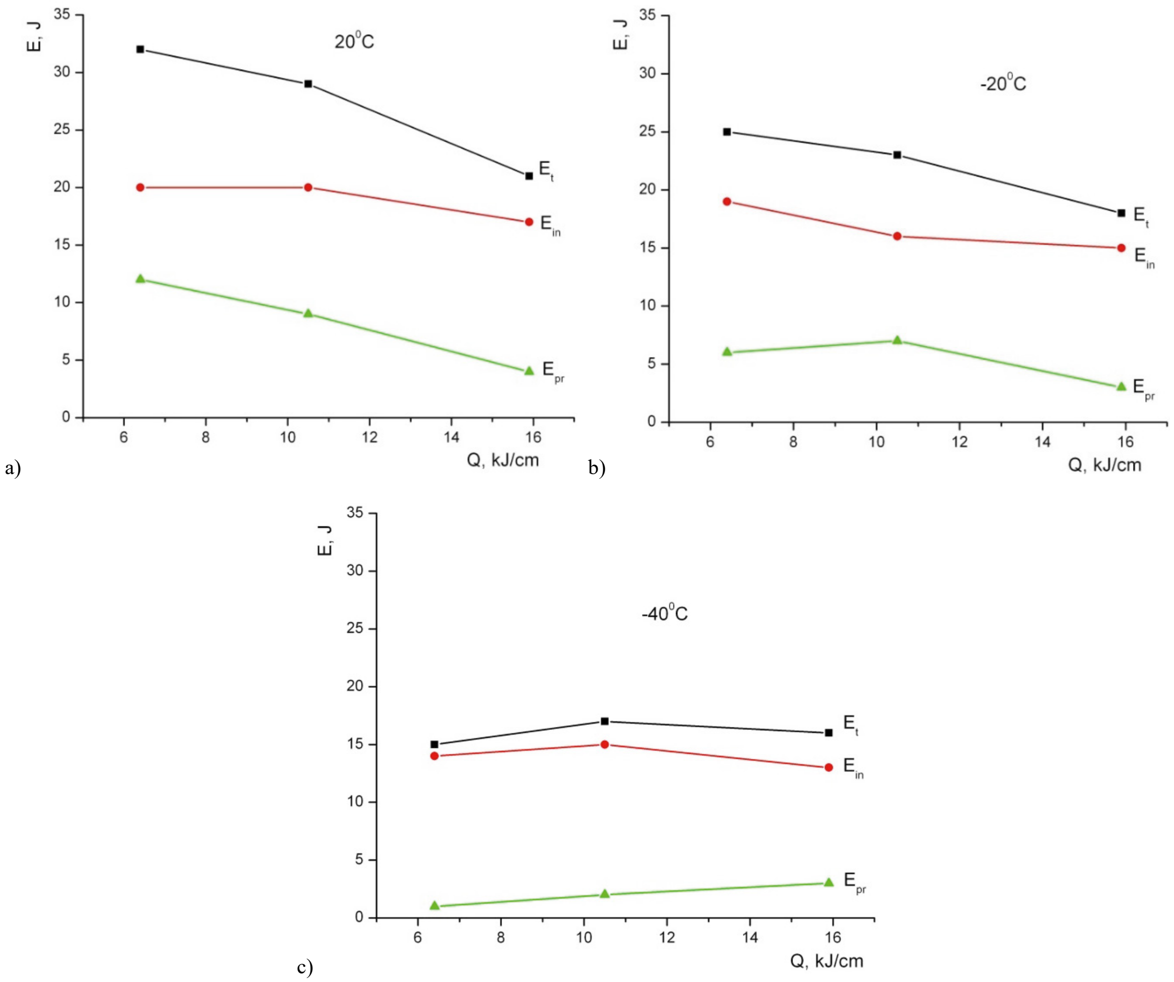
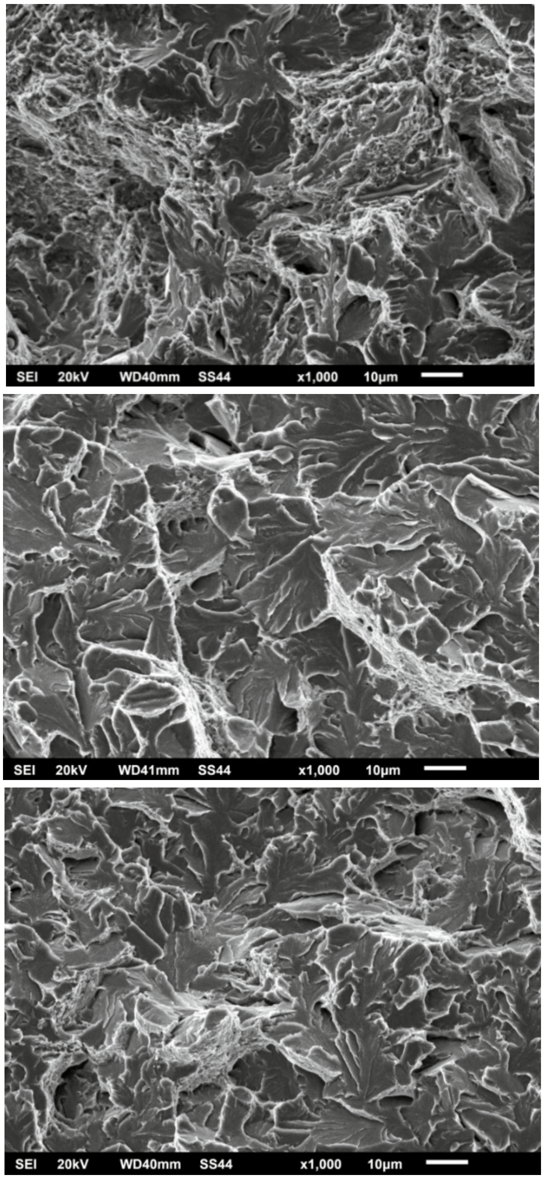


Fig.1. Dependence total impact energy, crack initiation energy and crack propagation energy vs. heat input at: a) 20^{o}C; b) -20^{o}C; c) -40^{o}C

By analysing the impact energy values of all samples, a change of toughness in continuity is observed, with no marked drop of toughness. Since the crack initiation energy is higher than crack propagation energy at all tested temperatures, that is the reason for the absence of significant decrease of toughness.

Fractographic investigation of the Charpy specimens at room temperature of all three samples indicates the clearly distinguished several zones. In the zone of stable crack growth, which is located directly below the notch, ductile transgranular fracture is dominant. The size of this zone is different, and the highest is in the sample 1. By transition to unstable growth, comes to change in fracture mechanism, so a small amount of brittle transgranular fracture by cleavage in certain planes appears. Furthermore, the proportion of brittle component increases to the final stage of fracture where transgranular brittle fracture becomes dominant. Fig.2 shows the typical fractography from the central zone of fracture in all three samples. It is noted that an increase of heat input leads to increasing the share of transgranular brittle fracture, what is in complete accordance with the obtained energy values.



a) b) c)

Fig.2. Fractography of Charpy specimens from the central zone of fracture at room temperature:
a) sample 1 (6.4 kJ/cm); b) sample 2 (10.5 kJ/cm); c) sample 3 (15.9 kJ/cm)

4. Conclusion

On the base of obtained experimental results and their analysis, the following is concluded:

- The experimental investigation of surface welded joints with different heat inputs has shown, as expected, significant differences on their performance in terms of mechanical properties. The heat input energy is very important parameter that affects the microstructure and weld quality.
- The experiment was conducted with the energies that are selected on the basis of the literature recommendations for welding similar steels. Notwithstanding the significant differences, each of the selected heat inputs provides satisfactory properties and safe exploitation.
- Comparing the samples surfaced with different heat inputs, noted that the toughness decreases with heat input increase, and in terms of toughness optimal heat input is in the lower range of values for applied welding procedure. But, with a temperature decrease, the differences are lower, and the optimal value of heat input is shifted to higher values. Therefore, it is very important to define the working conditions of welded structures.
- Fractographic investigation of the Charpy specimens at room temperature has shown that in all samples, ductile transgranular fracture is dominant with different amounts of transgranular brittle fracture. An increase of heat input leads to increasing the share of transgranular brittle fracture, what is in complete accordance with the obtained energy values.
- Based on the above, taking into account the toughness at room and low temperatures, resistance to crack growth and fractographic analysis, it can be concluded that the value of about 10kJ/cm is optimal for the welding procedure applied.

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