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The Effect of Input Energy on Toughness of Weld Metal Made by Gas Metal Arc Welding of Microalloyed Steel

Impact toughness of weld metals of two hot rolled microalloyed steels, welded by gas shielded metal arc process, has been evaluated by using the instrumented Charpy pendulum. Previously determined optimum gas mixture ($Ar+5\%CO_2+0.9\%O_2$) *was used with different energy inputs to determine its effect on weld metal toughness at different testing temperatures. For both steels the optimum energy input has been determined, providing maximum crack propagation energy due to presence of acicular ferrite, as a dominant microstructure.*

Keywords: *microalloyed steels, energy input, total impact energy, crack initiation energy, crack propagation energy*

1. INTRODUCTION

Welding by metal arc process with mixture of shielded gases has been increasingly popular in recent years. For welding of microalloyed steels mixtures of argon (Ar), carbon-dioxide (CO_2), and/or oxygen (O_2) are often used. A compound of gas mixture significantly affects weldment properties, especially weld metal toughness. Previously determined optimum gas mixture (Ar + 5% CO_2 + 0.9% O_2) [1] is used with different energy inputs, to determine its effect on weld metal toughness at different testing temperatures. The energy input is generally very important parameter which affects significantly mechanical properties of a weldment, and specifically for microalloyed steels which are well known for their sensitivity to energy input level. The property most affected by energy input is the toughness and thus the investigation will be focussed on it.

2. EXPERIMENTAL PROCEDURE

Two microalloyed steels (hot rolled plates) were used for welding, one alloyed with Nb (denoted as N steel) of thickness 11 mm, and the other one alloyed with Nb, V and Ti (denoted by T steel) of thickness 7.2 mm. The composition and properties for both steels and filler material are given in tab. 1 and 2, respectively.

The filler material was commercially available wire VAC 60 Ni (produced by 'Jesenice', Slovenia), ∅1.2 mm, with composition and properties shown in Tab. 1 and 2, respectively. Preheating has not been applied, since the C equivalent was CE = 0.2 (steel N), and CE = 0.34 (steel T), [1]. In the previously performed investigation the optimum gas mixture (Ar + 5% CO_2 + 0.9% O_2) was determined [1] and used for welding by the gas metal arc process. The energy input is calculated by:

$$Q = \frac{60UI}{w}\,\eta\cdot 10^{-3}\ , \qquad (1)$$

where Q is the energy input [kJ/cm], U arc voltage [V], I current intensity [A], w welding speed [cm/min], and η effective coefficient, taken as 0,70 for MIG/MAG [2].

The input energy was 5, 7 and 12 kJ/cm for steel N, and 4, 7 and 10 kJ/cm for steel T.

For both steels the coupon plates with V grooves were welded and used for testing, Fig. 1. The specimens for weld metal toughness testing were cut out, with dimensions in accordance with standard ASTM E23-89, which allows reduced thickness B: 55×10×9 mm for steel N, 55×10×6 mm for steel T, Fig. 2. The standard 2 mm deep V notch was machined along 10 mm dimension, Fig. 2. Since the instrumented Charpy testing has not been standardized yet, experimentally verified recommendations, prescribed by ESIS [3], have be used instead. Testing has been done at the room temperature, -40°C and -55°C.

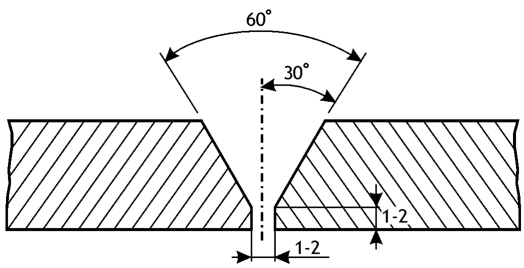

Figure 1. "V" groove.

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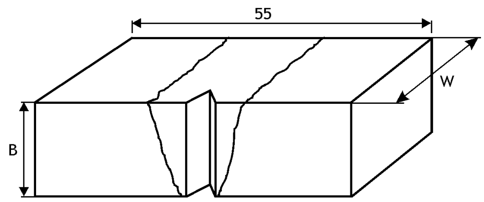

Figure 2. Charpy specimens with "V" notch in weld metal.

During the instrumented Charpy testing the following diagrams can be obtained: force (F) - time (τ); energy (E) - time (τ); force (F) - displacement (D_f). These diagrams provide additional informations about material behaviour and failure mechanism.

Typical diagram force (F) - displacement (D_f) obtained by the instrumented Charpy pendulum is show in Fig. 3, while the schematic procedure of energy separation is shown in Fig 4.

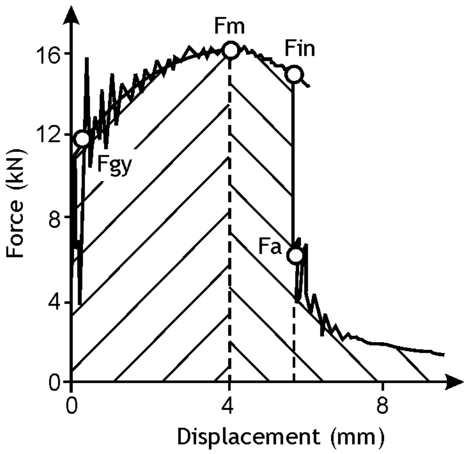

Figure 3. Typical diagram force-displacement obtained on instrumented Charpy pendulum [3].

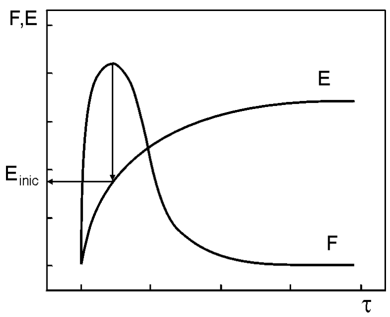

Figure 4. Schematic separation of total impact energy into crack initation and propagation energies

The impact toughness testing has been significantly improved after introduction of instrumented Charpy pendulum, i.e. after an application of oscilloscope, what enabled separation of total impact energy into crack initiation and crack propagation energy:

$$E_u = E_{inc} + E_{lom}\,, \tag{2}$$

where E_u stands for the total impact energy, E_{inc} for the crack initiation energy, and E_{lom} for the crack propagation energy. Even if two materials exhibit the same toughness value, i.e. the total impact energy, their behavior can be different from point of view of crack initiation and propagation. For example, although the total impact energy overcomes the critical value, the initiation energy may be dominant, leaving only small contribution for propagation energy. In that case, the value of total energy itself is not enough to guarantee avoidance of catastrophic fracture [3]. Therefore, if crack already exists, what can not be precluded when considering welded joints [4], the critical toughness value should take into account only crack propagation energy. One should notice different literature data on the critical toughness value, from 28 J [5-7], to 35 J [2] and 40 J [8], specifically for microalloyed steels.

3. RESULTS AND DISCUSSION

Results of toughness testing at different temperatures are shown in Fig. 5-7. The energies obtained are scaled to the standard thickness of 10 mm.

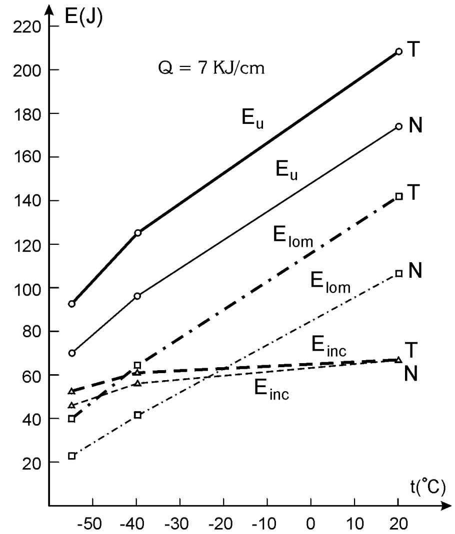

Figure 5. Impact energy vs. temperature.

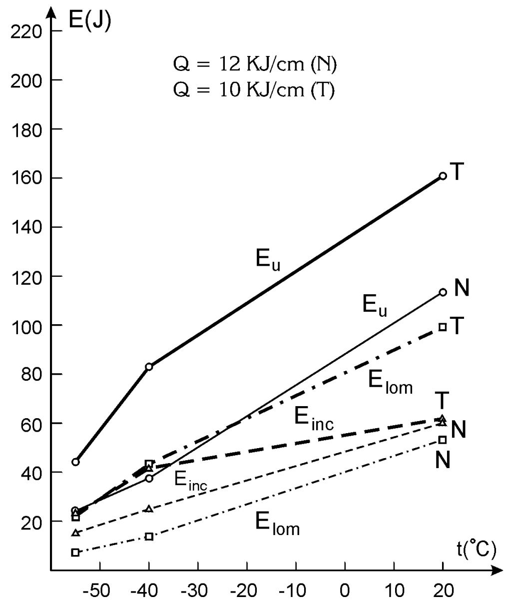

Figure 6. Impact energy vs. temperature.

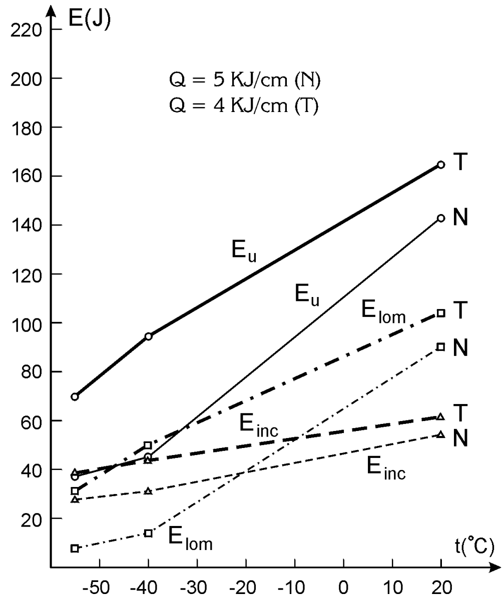

Figure 7. Impact energy vs. temperature.

From these results one can see that the total impact energy, E_u, as well as the crack initiation, E_{inc}, and crack propagation energies, E_{lom}, are higher for steel T in all cases. With reduced temperature both E_u and E_{lom} significantly reduce, while the effect on E_{inc} is much smaller. The reduction of E_{lom} is more expressed for steel N than for steel T.

At room temperature, E_u is the highest for weld metal made with energy input 7 kJ/cm (Fig. 5), being 174 J for steel N and 208 J for steel T. Both increase and decrease of energy input reduces the impact energy, Fig. 6 and 7. The initiation energy E_{inc} for both steel is almost the same and does not show any significant influence of the energy input, while the propogation energy E_{lom} depends on the energy input in the way similar to total energy, E_u. The propogation energy is higher than the initiation energy in all cases, except for steel N welded by energy input 12 kJ/cm, when it is slightly smaller.

The total impact energy E_u, at –40 °C, has also the highest values for welde metals made with the enrgy input 7 kJ/cm, being 97 J for steel N and 125 J for steel T. To some extent the initiation energy follows the behaviour of total energy, whereas the propagation energy is completely similar. Contrary to room temperature testing the initiation energy is higher than the propagation energy for all three energy input levels in the case of steel N, whereas the oposite holds for steel T.

With further temperature reduction all enbergy values reduce. So, at –55 °C, the total energy is 70 J for steel N, and 93 J for steel T. In all cases E_{inc} is higher than E_{lom} for both steels.

In order to explain the obained results a microstructural investigation has been performed, as shown in more details in [1]. Here only one characteristic micrograph is show, Fig. 8, indicating clearly the acicular ferrite as a dominant microstructure in the weld metals obtained by the optimum energy input. The beneficial effect of acicular ferrite has been known for some time, [4-8], and the basic aim of [1] was to investigate this effect and to establish the optimum gas mixture and energy input for typical microalloyed steels. The investigation presented here has proved the beneficial role of acicular ferrite.

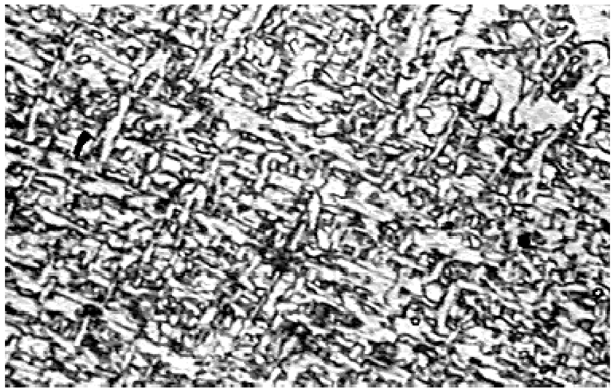

Figure 8. Typical weld metal microstructure with dominant acicular ferrite

4. CONCLUSIONS

Based on the analysis of experimental results, the following conclusions can be derived:

– The impact energy for both steels depends significantly on the energy input. One can recommend 7 kJ/cm as the optimal energy input for both steels. Both smaller and higher energy inputs are detrimental for toughness. The effect is more pronounced with higher enrgy input, e.g. crack propagation energy for steel N, welded with 12 kJ/cm, is smaller than crack initiation energy already at room temperature.
– Steel N has sufficient toughness at -40 °C only with the optimum energy input and in any case is not recommended at –55 °C. Steel T has significantly better toughness, since its toughness is sufficient at –40 °C in all cases and even at –55 °C it can be used with the optimum energy input
– Microstructural examinations have shown the the amount of acicular ferrrite in weld metal is proportional with its toughness.

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УТИЦАЈ УНЕТЕ ЕНЕРГИЈЕ НА ЖИЛАВОСТ МЕТАЛА ШАВА ДОБИЈЕНОГ ЕЛЕКТРОЛУЧНИМ ЗАВАРИВАЊЕМ МИКРОЛЕГИРАНИХ ЧЕЛИКА У ЗАШТИТИ МЕШАВИНЕ ГАСОВА

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Инструментираним арпијевим клатно је испитана ударна жилавост метала шава два ваљана микролегирана челика, заварена електролучно у заштити мешавине гасова. Претходно одређена оптимална мешавина гасова ($Ar+5\%CO_2+0.9\%O_2$) је коришћена са различитим вредностима унете енергије да би се одредио њен утицај на жилавост метала шава на различитим температурама. Оптималне вредности унете енергије су одређене за оба челика, које су давале највећу енергију раста прслине у присуству ацикуларног ферита, као доминантне микроструктуре.

Table 1. Composition of the base and filler metals.

Steel	elements, mass %											
	C	Si	Mn	P	S	Cu	Al	Nb	Ti	Cr	Ni	V
N	0.07	0.15	0.66	0.016	0.010	0.13	0.092	0.077	-	0.042	0.036	-
T	0.056	0.32	1.28	0.012	0.005	0.031	0.049	0.045	0.02	-	-	0.054
VAC 60 Ni	0.08-0.1	-	1.4-1.6	P+S<0.025		-	-	-	-	-	1-1.2	-

Table 2. Mechanical properties of the base and filler metals.

	R_e, [N/mm^2]	R_m, [N/mm^2]	A_5, [%]	KV(-20°C), [J]
Steel N	448-456	543-551	33-34	129-156
Steel T	510-537	571-595	37-42	152-197
VAC 60 Ni	440-510	560-630	22-30	80-125; 30-35 (-40^{0}C)

R_e, R_m, A_5 – measured along the rolling direction, KV – measured normal to the rolling direction