17th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2013, Istanbul, Turkey, 10-11 September 2013

ASSESSMENT OF QT STEEL'S WELDED JOINT TOUGHNESS BASED ON REAL AND SIMULATED SPECIMENS

Doc. Dr. Ismar Hajro, Dipl.ing.
Faculty of Mechanical Engineering Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

Doc. Dr. Damir Hodžić, Dipl.ing.
Faculty of Mechanical Eng. Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

Univ. Assist. Mr Petar Tasić, Dipl.ing.
Faculty of Mechanical Eng. Sarajevo
Vilsonovo šetalište 9, Sarajevo
Bosnia and Herzegovina

ABSTRACT
Conventional assessment of welded joint impact toughness, as defined in relevant standards for welding procedure qualification is based on testing of real specimens taken from base metal, weld metal, and heat affected zone. Here particularly, testing of heat affected zone may become unreliable, mainly due to the welded joint configuration and placement of initial notch. In addition, from general welding metallurgy knowledge it is well known that most weakened microstructure of welded joint, e.g. within heat affected zone is coarse-grained zone where maximum temperatures reach around 1300°C. Thus, this paper presents results and comments of one combined approach, where real specimens where taken and impact tested from gas metal arc welded X-joint configuration. Additional specimens where acquired by mean of welding thermo-cycle simulation, characterised with similar cooling condition as for real joints, but with maximum temperature of 1300°C. Base metals were quenched and tempered low-alloyed structural steels. Finally, specimens from real welds shows acceptable level of impact toughness, which may be found as favourable for welding procedure qualification, while simulated specimens shows impact toughness undermatching as prescribed for base metal. This however should not disqualify welding procedure in conventional manner, but rather should be carefully taken into consideration.
Keywords: steel, welded joint, toughness

1. PREFACE
A conventional assessment of welded joint impact toughness is dominantly required to prove that corresponding welding procedure or technology provides joints with minimum required resistance to crack growth at minimum design temperature. In addition, when tested on instrumented Charpy pendulum, impact toughness or total absorbed impact energy, mostly represented as KV [J] may be divided on a crack initiation KV_i and crack propagation energy KV_p. Here, from a Fracture Mechanics point of view and particularly for welded joints which may contain various types of faults (mostly approximated as crack), an actual material crack resistance may not count with crack initiation energy KV_i. Therefore, structural materials should posses rather as higher as possible crack propagation energy KV_p, or generally higher resistance to crack growth. Of course, without neglecting rather complicated and demanding fracture mechanics parameters testing, e.g. testing of quasi-static toughness, such as fracture toughness K_c [MPam$^{0'5}$] or J-integral [J/m^2], an everyday engineering assessment of welded joint toughness still relay on impact toughness testing. In addition, impact toughness acceptance levels are clearly defined in reference design codes and materials standards.

As impact toughness specimens are characterised with initial V-shaped notch and approximate depth of 20% of specimen thickness, it is of crucial importance that notch tip, as well as remaining specimen ligament are positioned within a complete of zone of consideration (for testing). Therefore, while considering bevelled configuration of most butt welded joint, it may be a complicated task to sample a specimen which is reliable representative of heat-affected zone (HAZ). Here, due to the fact that sufficient volume, or rather plane where initial notch and remaining ligament of specimen are about to be sampled, sampling of specimens from base and weld metal are mostly reliable [1,2].
Further, from general welding metallurgy knowledge it is well known that most weakened microstructure of welded joint, e.g. within heat-affected zone is coarse-grained (CG-HAZ) zone where maximum temperatures reach around 1300°C. Here, CG-HAZ specimens may be only acquired by mean of welding thermo-cycle simulation characterised with similar cooling condition as for real joints, and with maximum temperature of cca. 1300°C [1,2,3,4].

2. EXPERIMENT

Two low-alloy quenched and tempered (QT) structural steels, S690QL and S890QL, were selected and gas-metal arc welded (GMAW). Butt welded joint on both steels were of X-joint configuration due to the selected base metal thickness of 30mm and 20mm, respectively. Beside other mechanical tests and corresponding specimens (which are not subject of this paper), all impact toughness specimens were taken perpendicular to joint axis (Fig. 1) [1,2].

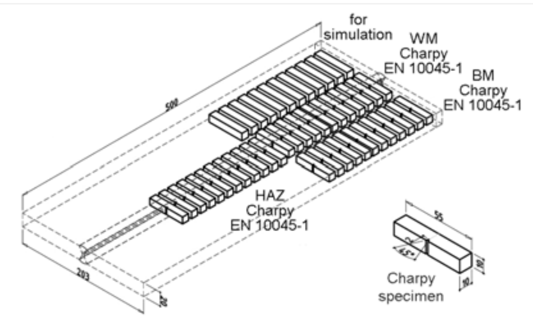


Figure 1. General appearance and position of specimens for impact toughness of base metal (BM), heat-affected zone (HAZ), weld metal (WM), and additional specimens for further simulation (CG-HAZ) [1]

Real welding condition were characterised with relatively rapid cooling, e.g. cooling time in range from 800°C to 500°C, $t_{8/5}$=6-7s. Both steels were preheated during welding at 200°C and 150°C, respectively. This was done in accordance to recommendation of respective steel manufacturer's recommendation and general recommendation from EN 1011-2 (recommended to be $t_{8/5}$=5-15s) [5,6].
Similarly to real welded joints cooling condition, a "simulated" specimens were acquired by thermo-cycle simulation on T_{max}=1300°C and $t_{8/5}$=6-8s (Fig. 2b). Here, input thermo-cycles (Fig. 2a) were calculated using "Thermocycle t85" application.
Simulations of "real" welding thermo-cycles were done on thermo-mechanical simulator "SmithWeld" (Fig. 2c).

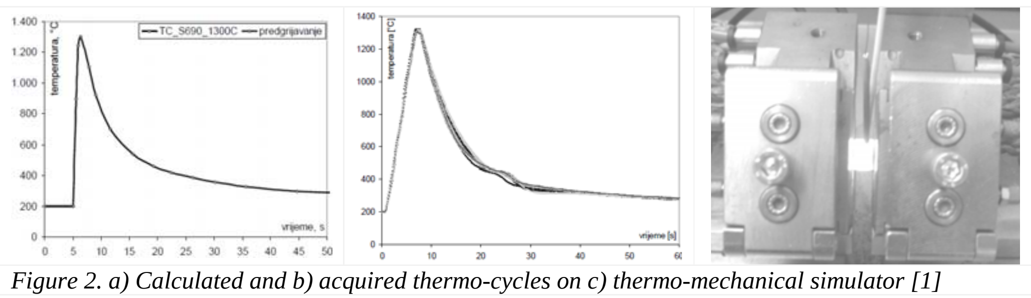


Figure 2. a) Calculated and b) acquired thermo-cycles on c) thermo-mechanical simulator [1]

Testing of impact toughness on real welded joint's specimens and simulated ones were done on instrumented Charpy pendulum. Primary testing results consist of resistance curves represented as impact force F [N] versus time [s], as well as curve which shows energy absorption KV [J] during test, e.g. time t [s]. On such resulting curves and close to maximum reached force F_{max}, a crack initiation energy KV_i can be acquired. A remaining energy from total absorbed energy KV, correspond to crack propagation energy KV_p (Fig. 3).

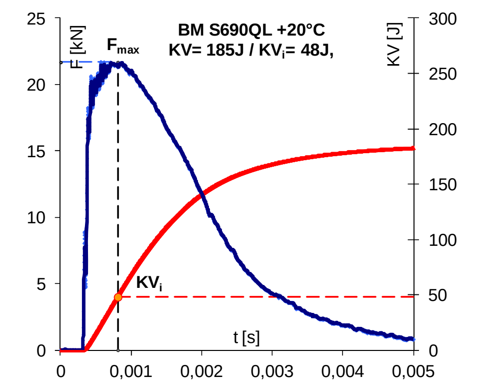


Figure 3. Typical resistance curves acquired on instrumented Charpy pendulum [1,2]

While minimum impact toughness of KV=40J on -40°C is prescribed for both base metals [7,8], the minimum testing temperature was down to -100°C, and -80°C respectively for selected steel's. Maximum testing temperature was room temperature, e.g. 20°C.

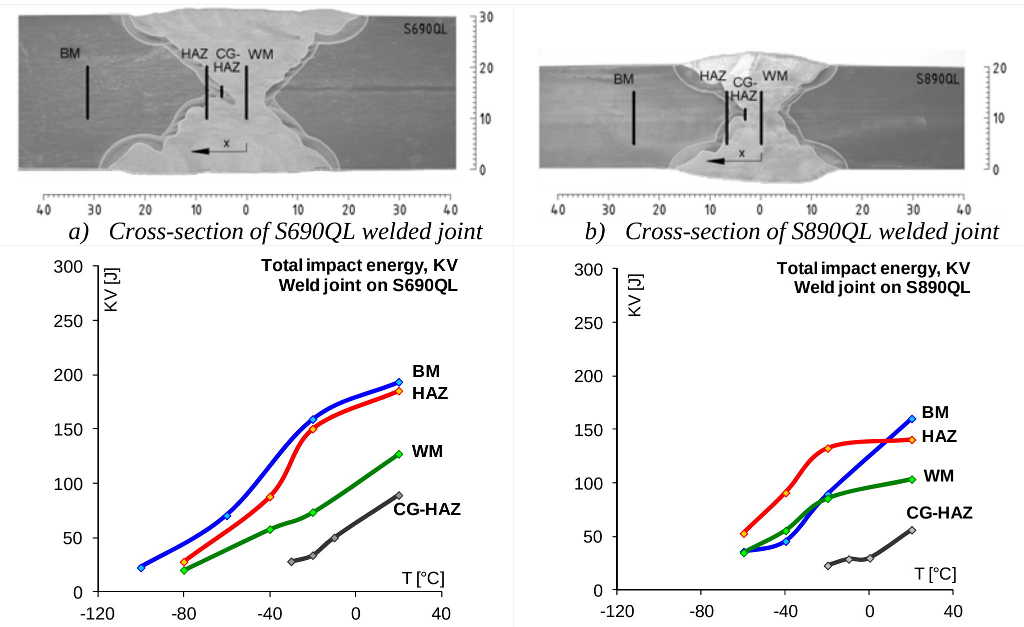
Scaled planes of initial notch and remaining specimen's ligament of BM, HAZ, CG-HAZ and WM on welded joint cross-section are shown on Fig. 4a and 4b, both with corresponding distribution of impact toughness, KV, versus testing temperature, T (Fig. 4c and 4d).

There, it could be clearly seen how sampling plane of so called "HAZ" specimens actually crosses unevenly trough X-shaped joint configuration and corresponding real HAZ.

Position of CG-HAZ, between real HAZ and WM on Fig. 4a and 4b is provided only for reference along perpendicular axis.

3. RESULTS AND DISCUSSION

Impact toughness of specimens taken from real welds, e.g. base (BM) and weld metal (WM), and heat affected zone (HAZ) are acceptable if we consider requirements set for base metal, T_{27J}<-40°C [1,7]. However, specimens obtained by simulation of welding thermo-cycles, e.g. representative of coarse-grained heat-affected zone, CG-HAZ, shows significant degradation of toughness [1,2].



a) Cross-section of S690QL welded joint

b) Cross-section of S890QL welded joint

c) Impact energy versus testing temperature on S690QL welded joint

d) Impact energy versus testing temperature on S890QL welded joint

Figure 4. Summarized results of impact toughness testing [1]

Brief visual examination (Fig 4a and 4b) show that this critical zone of welded joints is 0,3-0,7mm wide, on a base metal thickness in a range of 20-30mm.This fact does not mean that welded joints have to be rejected, but rather it should taken carefully into consideration [1].
From impact toughness testing on instrumented Charpy pendulum, it is observed that crack initiation energy, KV_i, stay relatively stable with temperature drop, e.g. in the range of 10-30J. Also, crack propagation energy, KV_p follows general decrease trend of total impact energy, KV, with testing temperature decrease [1].

4. REMARKS

Finally, specimens from real welds shows acceptable level of impact toughness, which may be found as favourable for welding procedure qualification, while simulated specimens shows impact toughness undermatching as prescribed for base metal.
Here, unreliable results of HAZ specimens should be carefully considered due to the butt welded joint groove configuration. This is rather a fact, and no so called "problem" which may be easily exceeded.
This however should not disqualify welding procedure in conventional manner, but rather should be carefully taken into consideration, particularly while considering that simulation of welding-thermo cycles is not a common and easily available engineering tool.

5. REFERENCES

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