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IMPACT TOUGHNESS OF A516 Gr. 60 STEEL SIMULATED HEAT-AFFECTED-ZONE

UDARNA ŽILAVOST SIMULIRANE ZONE UTICAJA TOPLOTE ČELIKA 516 Gr. 60

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Keywords
- impact toughness
- A516 Gr. 60 steel
- simulated HAZ
- cooling time $t_{8/5}$

Abstract

The main focus of research presented here is the influence of cooling time $t_{8/5}$ on impact toughness of A516 Gr. 60 steel specimens. Experiments include simulation of heating and cooling during welding (thermal simulation) in order to achieve desired microstructures that would correspond to those obtained in actual welding. Specimens simulated in this manner are then subjected to impact testing, and obtained results are analysed in terms of total impact energy and its components in order to provide detailed insight into the behaviour of these specimens. By obtaining diagrams that show mutual dependence of force, time, energy and displacement (deflection), it is possible to determine how impact toughness is affected by cooling times. Hence, the research provides valuable input for the selection of welding parameters.

Ključne reči
- udarna žilavost
- čelik A156 Gr. 60
- simulirani ZUT
- vreme hlađenja $t_{8/5}$

Izvod

Glavni cilj ovde prikazanog istraživanja je bio da se ispita uticaj vremena hlađenja $t_{8/5}$ na udarnu žilavost epruveta od čelika A516 Gr. 60. Eksperimentalni deo ispitivanje je obuhvatio simulaciju procesa zagrevanja i hlađenja tokom zavarivanja (termičku simulaciju) kako bi se postigle mikrostrukture koje bi odgovarale stanju koje bi se dobilo u stvarnom zavarenom spoju. Ovako simulirane epruvete su potom ispitane na udar, i dobijeni rezultati za ukupnu udarnu energiju i njene komponente su dali detaljan uvid u ponašanje ovakvih epruveta. Pomoću dijagrama koji pokazuju međusobnu zavisnost vremena, sile, energije i pomeranja (ugiba), određen je uticaj različitih vremena hlađenja na udarnu žilavost. Stoga može da se zaključi da ovo istraživanje ima značajan doprinos pravilnom izboru parametara zavarivanja.

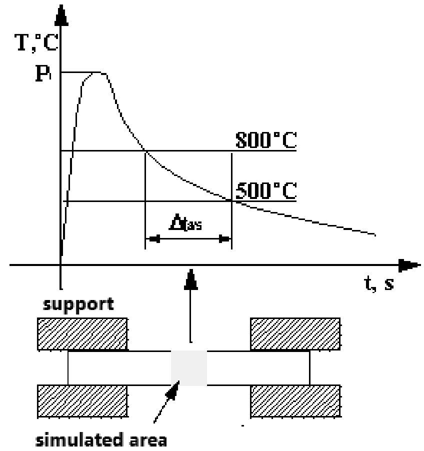
INTRODUCTION

Manufacture of complex and high-risk welded structures requires acceptability criteria (mainly related to defects) of a much higher level than usual practice /1, 2/. Due to high rates of heating and cooling, the whole welding process is unbalanced in the sense that all phase and structural changes take place under overheating or sub-cooling conditions, /3/. By introducing a new approach to welded structural design, it is possible to use a welding simulator to simulate the microstructure of the heat affected zone, to improve testing efficiency. Thermal simulation involves heating of specimens with maximal dimensions of 15×15×60 mm, until a specified temperature is reached, followed by programmed cooling, /4, 5/. Microstructure for different subzones of the HAZ is obtained in the midsection of the specimen, with width 10-12 mm. Test results obtained by these simulated trials are used as the base for selection of optimal welding technology, whereas welding parameter selection is assessed based on mechanical properties in exploitation.

SIMULATION OF THE HEAT AFFECTED ZONE

The welding simulator is a device that achieves controlled heating and cooling, resembling the processes that occur during actual welding. Schematic display of a welding simulation of the HAZ is given in Fig. 1. Data that are important

a)



b)

Figure 1. Schematic display of welded joint simulation (a), and the appearance of simulated specimens (b).

for a heat cycle during the heating simulation include maximal temperature and cooling time $\Delta t_{8/5}$, which represents the time it takes for the specimen to cool down from 800 °C to 500 °C, /4/.

The HAZ simulation procedure itself is performed using a state-of-the-art thermal cycle simulator 'SMIT-WELD', Fig. 2. This simulation uses specimens with a square cross-section of 11×11×55 mm. Prior to heating, a Cr-Ni-Cr thermocouple is welded to the specimen mid-section, which is then used to monitor the change in temperature during the simulation.

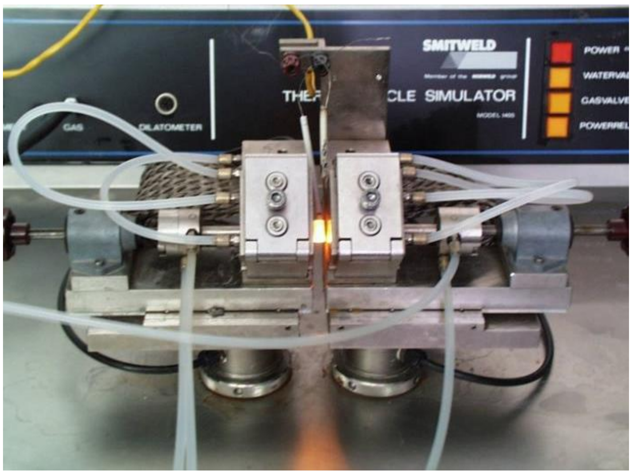


Figure 2. Thermal cycle simulator 'SMITWELD'.

Steel A516 Gr. 60 belongs to a group of high-quality low-alloyed carbon steels of medium strength. These steels are commonly welded with a cooling time range $\Delta t_{8/5}$ = 5-15 s, /6/.

Simulation of thermal conditions during welding is typically performed by applying thermal cycles to base material specimens in the following two ways:

- Single-pass influence, by applying a single cycle until the temperature of around 1350 °C (corresponding to the coarse-grain HAZ).
- Double-pass influence, by applying two cycles – the first one with temperature reaching around 1350 °C (in order to form CGHAZ), and the second one where temperature ranges between 700 and 1100 °C (in this way, the toughness of the output coarse-grained HAZ is transformed, fully or partially, which can either improve or degrade its quality).

As shown by previous experience, the best results for this group of steels are obtained when using the single-pass simulation of thermal conditions.

The heating rate is around 200 °C/s. Heating temperature is maintained at its maximum (T_p) for a total duration 3 to 5 s (so that the whole cross-section of the specimens would be thoroughly heated), and cooling time $\Delta t_{8/5}$ is varied from 5 s (Group 1) to 10 s (Group 2), and 15 s (Group 3). Thermally simulated specimens are used to make Charpy specimens for impact tests according to standard SRPS EN ISO 148-1:2017, /7/.

Schematic display of a thermal cycle for a single-pass HAZ, for specimen denoted as S-1-1C (Group 1), is shown in Fig. 3, whereas Figs. 4 and 5 include specimens S-2-1C (Group 2) and S-3-1C (Group 3), respectively.

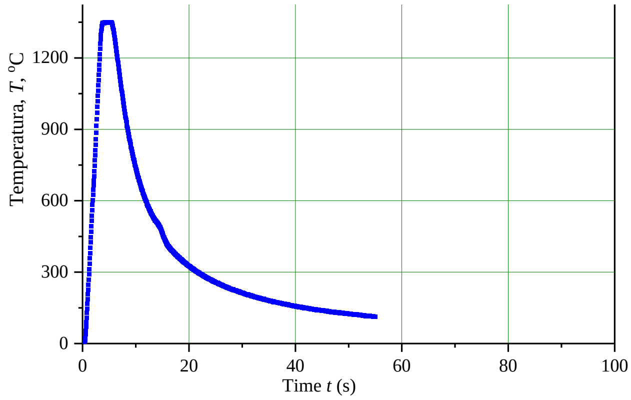


Figure 3. Thermal cycle for a single-pass HAZ, specimen S-1-1C.

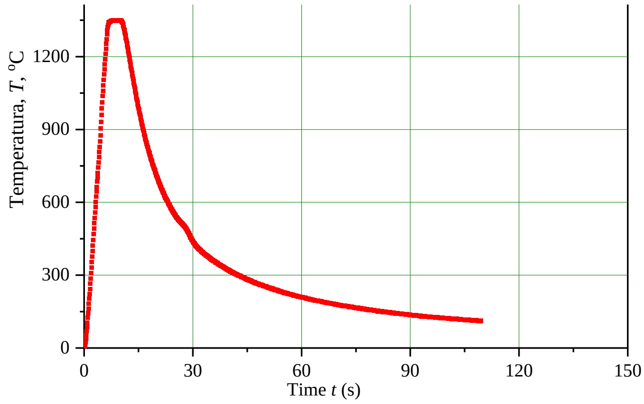


Figure 4. Thermal cycle for a single-pass HAZ, specimen S-2-1C.

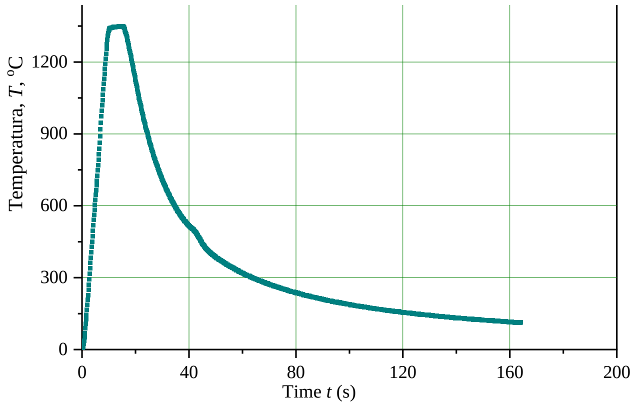


Figure 5. Thermal cycle for a single-pass HAZ, specimen S-3-1C.

Verification of HAZ simulation process is performed via impact tests of simulated specimens. These specimens (with dimensions of 11×11×55 mm) are machined to standard test sizes of 10×10×55 mm, including a V-2 notch. This is performed after completing the simulated thermal cycle of the HAZ. Test procedure and specimen geometry are defined according to standard SRPS EN ISO 148-1:2017, /7/. Tests are performed on a state-of-the-art instrumented Charpy pendulum 'AMSLER' 150/300 J. Results of these tests are shown in Table 1, at test temperature of -20 °C (suffix C in the specimen designation refers to this), for different cooling rates, as previously described.

Since these tests were performed using an instrumented Charpy pendulum, it was possible to assess the effect of impact (impulse) load on the impact properties of the specimens, along with assessing the plasticity of the tested material. Diagrams showing the dependences between force and time, as well as energy and time, and force and displacement are shown in Fig. 6 for specimen S-1-1C (Group 1), Fig. 7 for specimen S-2-1C (Group 2), and Fig. 8 for specimen S-3-1C (Group 3).

Table 1. Results of impact tests for different cooling rates $t_{8/5}$.

Specimen designation	Cooling times $\Delta t_{8/5}$ (s)	Total impact energy W_t (J)	Crack initiation energy W_i (J)	Crack propagation energy W_p (J)	Deflection s (mm)
S - 1 - 1C		102.7	81.2	21.5	8.9
S - 1 - 2C	5	94.7	77.3	17.4	8.3
S - 1 - 3C		93.1	65.9	27.2	8.6
S - 2 - 1C		55.9	50.6	5.3	4.2
S - 2 - 2C	10	48.6	40.4	8.2	4.0
S - 2 - 3C		51.6	45.7	5.9	3.9
S - 3 - 1C		30.2	23.7	6.5	2.1
S - 3 - 2C	15	35.4	27.4	8.0	2.4
S - 3 - 3C		28.3	22.1	6.2	1.9

Diagrams obtained in the previously described manner also enable a thorough analysis of the test results in terms of cooling time and its effects on total impact energy W_t and its components: crack initiation energy W_i and crack propagation energy W_p. As one can see in Table 1 and in Figs. 6-8, the total impact energy is significantly reduced with increased cooling time. The same holds for the crack initiation and propagation energy, except for the latter one in the case of 10 s and 15 s of cooling time, when the crack propagation energy has approximately the same value (6.5 J vs. 6.9 J). One can also notice that the crack initiation energy is a dominant component of the total impact energy, indicating strong material resistance to cracking, but weak resistance to crack propagation.

Additionally, the effect on deflection is analysed, since it represents a very important aspect of plasticity assessment. Dependence of these parameters on cooling time is shown in Figs. 9-11. The highest deflection, i.e., the highest ductility, is obtained for the shortest cooling time. This is in accordance with impact energy dependence on cooling time. To analyse and explain such behaviour, further investigation of the microstructures is needed.

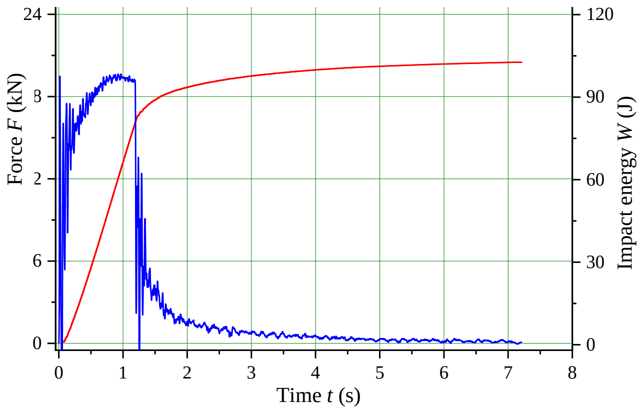


Figure 6. Diagram force, energy vs. time for specimen S-1-1C.

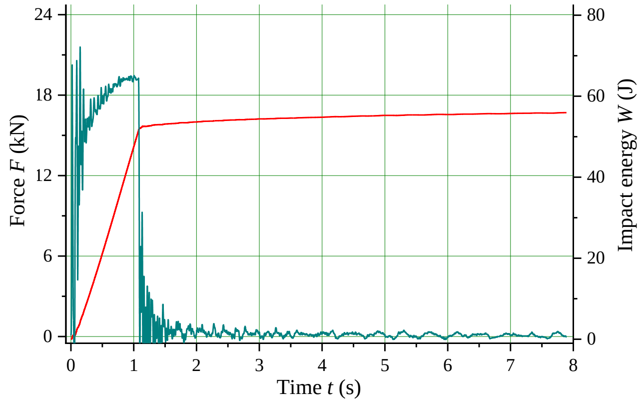


Figure 7. Diagram force, energy vs. time for specimen S-2-1C.

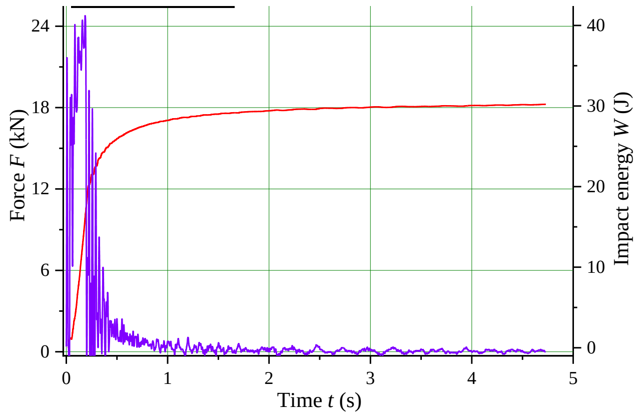


Figure 8. Diagram force, energy vs. time for specimen S-3-1C.

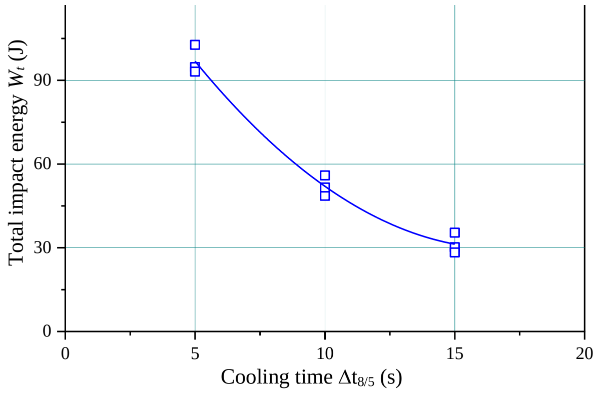


Figure 9. Dependence of W_t vs. $\Delta t_{8/5}$ at T = -20 °C.

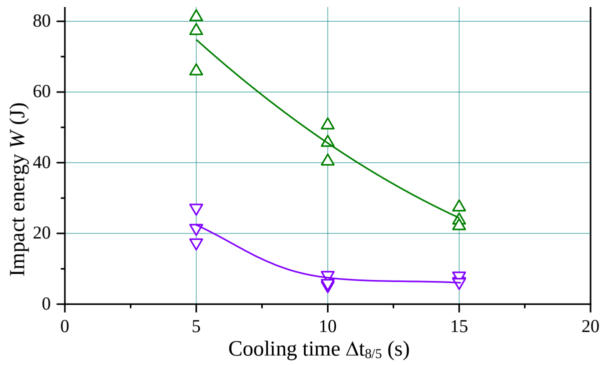


Figure 10. Dependence of W_i and W_p vs. $t_{8/5}$ at T = -20 °C.

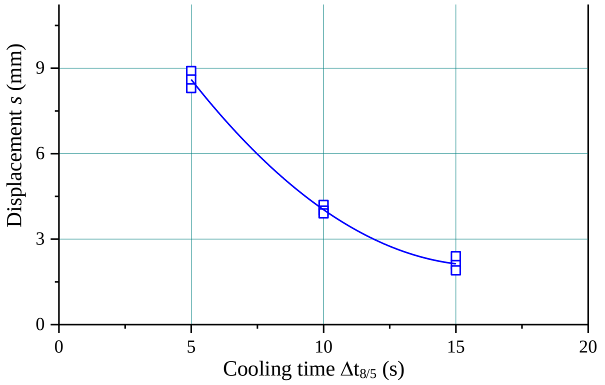


Figure 11. Dependence of displacement *s* vs. $\Delta t_{8/5}$ at T = -20 °C.

CONCLUSIONS

Based on the presented results, one can conclude the following:

- Impact energy and plasticity is significantly reduced with increasing cooling time.
- Further investigation of microstructures is needed to analyse and explain such a behaviour.

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