Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 18 (2019) 903–907

Structural Integrity
Procedia

www.elsevier.com/locate/procedia

25th International Conference on Fracture and Structural Integrity

Relation between impact and fracture toughness of A-387 Gr. B welded joint

Ivica Čamagić[a], Aleksandar Sedmak[b,*], Simon A. Sedmak[c], Zijah Burzić[d]

[a]*Faculty of Technical Sciences, 7 Kneza Miloša Street, K. Mitrovica, Serbia*
[b] *Faculty of Mechanical Engineering, 16 Kraljice Marije Street, Belgrade, Serbia*
[c] *Innovation Center of the Faculty of Mechanical Engineering, 16 Kraljice Marije Street, Belgrade, Serbia*
[d]*Military Institute of Techniques, 1 Ratka Resanovića Street, Belgrade, Serbia*

Abstract

The influence of temperature on impact and fracture toughness values in different regions of a welded joint is analysed for low-alloyed Cr-Mo steel A-387 Gr. B, designed for high temperature applications. Standard Charpy specimens were tested on instrumented pendulum to separate total impact energy into energy for initiation and propagation energy for base metal (BM), weld metal (WM) and heat-affected-zone (HAZ). Standard three point bending (3BP) specimens with crack tip located at different regions of a joint (BM, WM, HAZ), were used for fracture toughness testing. Experiments were performed both at the room temperature and at design working temperature, 540^0 C, which is the focus of this paper, to evaluate temperature effect on both notch and crack resistance for all different regions in a welded joint. Moreover, the relation between crack initiation energy and fracture toughness is established, purely on empirical base.

Peer-review under responsibility of the Gruppo Italiano Frattura (IGF) ExCo.

Keywords: welded joint; crack; impact toughness, crack initiation energy, crack propagation energy, fracture toughness.

1. Introduction

Standard ASTM E399 [1] for determining the fracture toughness under plain strain, $K_{Ic,}$ enables the process of linear elastic fracture mechanics application to real structures, if its stress state and stress intensity factor is known. Since plastic strain area around a crack tip is not negligible for most structural steels and welded joints, direct determining of the K_{Ic} is practically impossible, and its application to real conditions is limited. Instead, indirect measurement via J_{Ic}, can be used, including different regions in welded joints, parent material (PM), weld metal (WM) and heat affected zone (HAZ), [2,3].

---

* Corresponding author.
E-mail address: aleksandarsedmak@gmail.com

2452-3216 © 2019 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the Gruppo Italiano Frattura (IGF) ExCo.
10.1016/j.prostr.2019.08.241

Another useful material property is impact toughness, as measured by Charpy pendulum, especially after introduction of instrumentation which enabled separation of energy into the energy for crack initiation and energy for propagation, [4], as shown in Fig. 1.

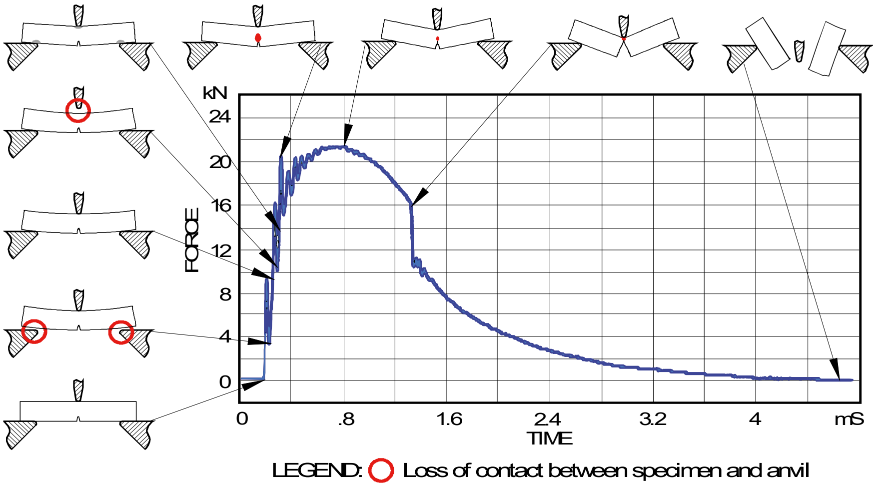


Figure 1. Load-time history for an instrumented Charpy test, [4]

One should notice that for the same total absorbed energy completely different behavior of material regarding crack initiation and propagation can be recorded, as shown in Fig 2. For the same absorbed energy material requires higher load in case (a) than in case (b), but the fracture time is greater in case (b) than in case (a). Material (a) is convenient for impact loading (e.g. an armor protection), material (b) for pressurized equipment (e.g. pressure vessel). Also, for the same load level crack initiation/propagation energy ratio can be quite different, e.g. 20:80 in case (c) and 80:20 in case (d).

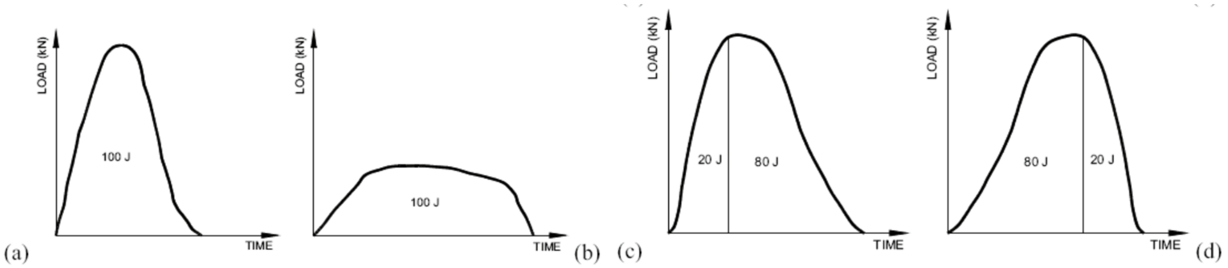


Fig. 2. Different load-time diagrammes for the same absorbed energy of 4 different steels

Although testing of fracture and impact toughness are completely different (static vs. dynamic load, crack vs. notch), there have been attempts to correlate impact and fracture toughness [5]. One may speculate that effects of load and crack/notch counteract, thus producing empirical correlation. This might be even more "interesting" phenomenon if one considers separated energies. Although at the first glance crack propagation energy is more likely to be in correlation with fracture toughness, it is actually crack initiation energy, which correlates better, as will be shown in this paper. One should also notice that there has been a trend toward using standard Charpy specimens which are pre-cracked by the introduction of a fatigue crack at the tip of the V notch for testing in the instrumented Charpy test to measure dynamic fracture toughness values, K_{Id}, [4].

The parent material investigated here was steel A-387 Gr. B with thickness of 102 mm. Chemical composition and mechanical properties of the PM and all relevant welding data is given elsewhere, [2].

2. Determination of plane strain fracture toughness, K_{Ic}

For determining K_{Ic} at the temperature of 540°C, modified CT specimens were used, [2]. Fracture toughness, K_{Ic}, determined indirectly using critical J-integral, J_{Ic}, by using elastic-plastic fracture mechanics, as defined by standard

ASTM E1820 [6], i.e. by monitoring crack propagation under plastic conditions. The European Structural Integrity Society (ESIS) then worked on improving of this standard [7], as used here to determine the fitted regression line.

Experiments were performed by testing a single specimen via successive partial unloading, using specimens with fatigue cracks in PM, WM and HAZ. Based on the obtained data, a J-Δa curves and regression lines are drawn to evaluate the critical value of J-integral, J_{Ic}. as well as the critical stress intensity factor (fracture toughness), K_{Ic}, using the following relation:

$$K_{Ic} = \sqrt{\frac{J_{Ic} \cdot E}{1-\nu^2}}$$

Typical F-δ and J-Δa diagrams for specimens taken out of the parent material, tested at room temperature and the elevated temperature of 540°C, as well as the calculated values of critical stress intensity factor are shown elsewhere, [8]. It is important to note that the elasticity module value for elevated temperature was used (cca 160 GPa for 540°C). As an example, the F-δ and J-Δa diagrammes for the specimen with a notch in the WM are shown in Fig. 3 for specimen tested at 540°C.

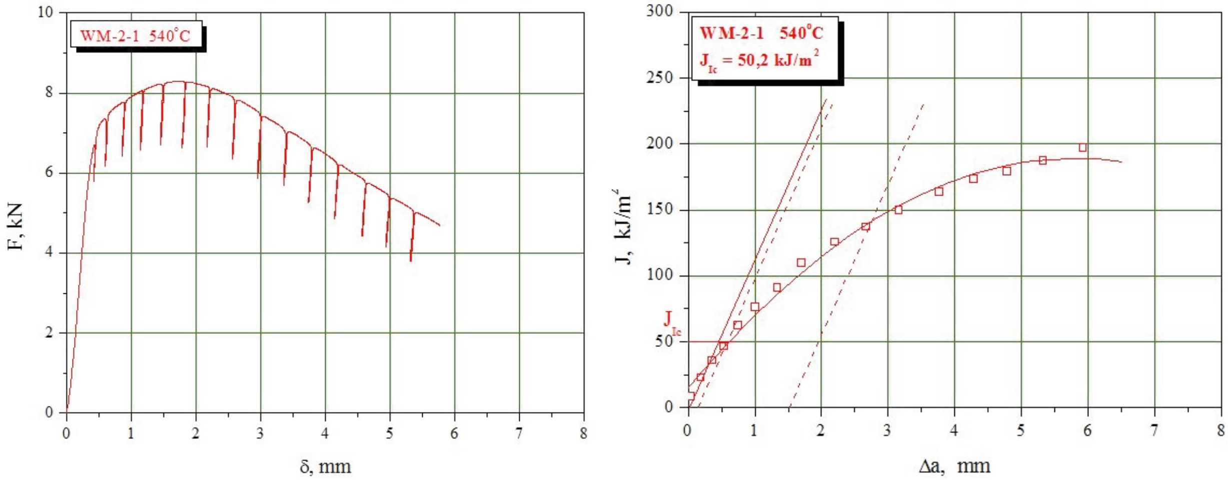


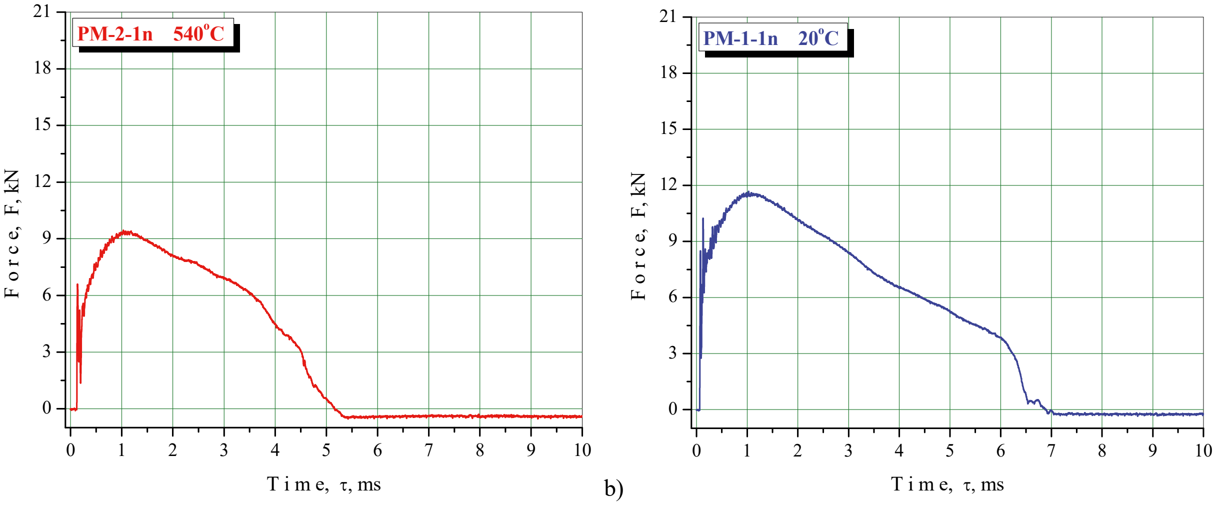
Figure 3. F-δ (left) and J-Δa (right) diagrams for specimen WM-2-1

3. Impact toughness testing

Impact toughness has been tested using Charpy instrumented pendulum as described in more details, including presentation of all results, in [9]. Here only average values of total energy, A_t, energy for crack initiation, A_i, and energy for crack propagation, A_p, are given for all cases of interest, together with the results for K_{Ic}, to allow simpler comparison of these two different sets of results, Table 1. One should notice that ratio K_{Ic}/A_i has no physical meaning, so its units are not relevant and thus not shown. As an example, energy vs. time record is given in Fig. 4.

Table 1. Impact toughness testing results, combined with fracture toughness

	A_t, J	A_p, J	A_i, J	K_{Ic}, MPa√m	K_{Ic}/A_i^*
New BM 20°C	210	48	162	118	2.5
New BM 540°C	140	40	100	88	2.2
Old BM 20°C	96	46	50	100	2.2
Old BM 540°C	78	32	46	64	2.0
New WM 20°C	190	60	130	131	2.2
New WM 540°C	136	40	96	94	2.3
New HAZ 20°C	185	45	140	101	2.2
New HAZ 540°C	135	45	90	78	1.7
Old HAZ 20°C	90	42	48	93	2.2
Old HAZ 540°C	75	30	45	61	2.0



a) b)

Figure 4. Force vs. time curves for PM tested at a) 540°C, b) 20°C

4. Discussion

The basic focus of this paper is relation between impact and fracture toughness. Toward this end, total impact energy, as well crack initiation and crack propagation energies, are compared with the fracture toughness to check if there is any correlation between them. According to the data presented here and in other papers, it was shown that the energy for crack initiation is almost in linear correlation with fracture toughness, with ratio of K_{Ic}/A_i in the range of (1.7-2.5), with an average value of 2.15 and most data in the range of 7% (2.0-2.3). This is of course purely empirical finding with no pretention to make any kind of law or universal relation. It is simply an observation on obviously existing relation between fracture toughness and energy for crack initiation, which need further investigation and analysis.

5. Conclusions

Based on presented results, one can conclude that the energy for crack initiation is in practically linear correlation with fracture toughness, with average ratio of K_{Ic}/A_i being 2.15 (+15% -20%) with the most data in the range of just 7% (2.0-2.3). This is of course purely empirical finding with no pretention to make any kind of law or universal relation. Further investigation and analysis is needed to find out if such a correlation exist also in other cases.

6. Acknowledgements

Parts of this research were supported by the Ministry of Sciences and Technology of Republic of Serbia through Mathematical Institute SANU Belgrade Grant OI 174001 Dynamics of hybrid systems with complex structures. Mechanics of materials and Faculty of Technical Sciences University of Pristina, residing in Kosovska Mitrovica.

References

[1] ASTM E399-89, Standard Test Method for Plane-Strain Fracture Toughness of Metallic Materials, Annual Book of ASTM Standards, Vol. 03.01. p. 522. 1986.
[2] Ivica Camagic, Simon A. Sedmak, Aleksandar Sedmak, Zijah Burzic, Mihajlo Arandjelovic, The impact of the temperature and exploitation time on the tensile properties and plain strain fracture toughness, K_{Ic} in characteristic areas of welded joint, Frattura ed Integrita Strutturale, ISSN 1971-8993, No. 46, Vol. 12, (October 2018), pp. 371-382, DOI: 10.3221/IGF-ESIS.46.34, https://www.fracturae.com/index.php/fis/issue/view/299.
[3] Ivica Čamagić, Simon Sedmak, Aleksandar Sedmak, Zijah Burzić, Aleksandar Todić, Impact of Temperature and Exploitation Time on Plane Strain Fracture Toughness, K_{Ic}, in a Welded Joint, STRUCTURAL INTEGRITY AND LIFE, ISSN 1451-3749) (printed edition), EISSN 1820-7863 (Online), Vol. 17, No. 3, 2017, pp. 239–244, http://divk.inovacionicentar.rs/ivk/ivk17/239-IVK3-2017-IC-SAS-AS-ZB-AT.pdf.
[4] V. Grabulov, Z. Burzić, D. Momčilović, Significance of mechanical testing for structural integrity, Proc. of IFMASS 9, TMF, Belgrade, 2008, p. 105-120,available online on http://www.structuralintegrity.eu/Schools/IFMASS9/files/assets/basic-html/page-1.html

[5] B. Senčić, S. Solić, V. Leskovšek, Fracture toughness–Charpy impact test–Rockwell hardness regression based model for 51CrV4 spring steel, Materials Science and Technology October 2014, 30(12):1500-1505
BS 7448-Part 1, Fracture mechanics toughness tests-Method for determination of K_{Ic} critical CTOD and critical J values of metallic materials, BSI, 1991.
[6] ASTM E 1820-99a, Standard Test Method for Measurement of Fracture Toughness, Annual Book of ASTM Standards, Vol. 03.01, 1999.
[7] "ESIS Procedure for Determining the Fracture Behavior of Materials", European Structural Integrity Society ESIS P2-92, 1992.
[8] Ivica Čamagić, Investigation of the effects of exploitation conditions on the structural life and integrity assessment of pressure vessels for high temperatures (in Serbian), doctoral thesis, Faculty of Technical Sciences, Kosovska Mitrovica, 2013
[9] Ivica Čamagić, Srđan Jović, Mladen Radojković, Simon Sedmak, Aleksandar Sedmak, Zijah Burzić, Cristian Delamarian, Influence of temperature and exploitation period on the behaviour of a welded joint subjected to impact loading, Structural Integrity and Life Vol. 16, No 3 (2016), pp. 179–185