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TESTING OF IMPACT PROPERTIES OF WELDED JOINTS BY NOTCHED AND PRECRACKED SPECIMENS

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Abstract

The application of high strength steel and its welded joint in structures, exposed to very high stresses can be accepted if the properties satisfy strong requirements. The benefits which can be obtained by increased strength must be additionally confirmed by sufficient resistance to brittle fracture, e.g. by the resistance to stress concentration. For that reason the data about impact V notch toughness and about crack behaviour in impact and in stable crack growth condition are required before final decision for the selection of high strength steel for manufacturing highly loaded welded structures. For that, the data of crack resistance for weld metal (WM) and the heat-affected-zone (HAZ) are also necessary. Applied techniques in this experiment enabled to evaluate separately notch and crack parameters of welded joint constituents (base metal - BM, WM and HAZ), important for the application of high strength steel [1-3].

1. Data for investigated steel and welded joints

The experiments had been performed with high strength steel NIONIKRAL-70 (NN70), corresponding to HY100 steel class. This steel is used for highly stressed welded structures, for pressure vessels and in shipbuilding, e.g. for submarines. Chemical composition, mechanical properties and Charpy V absorbed energy are shown in Tables 1 and 2, respectively.

Table 1 Chemical composition of tested material

C	Si	Mn	P	S	Cr	Ni	Mo	V	Al
0.1	0.2	0.23	0.009	0.018	1.24	3.1	0.29	0.05	0.08

Table 2 Mechanical properties of tested material

Yield stress $R_{p0,2}$, MPa	Tensile strength R_m, MPa	Elongation A, %	Impact energy, J		
			+20°C	-60°C	-100°C
735	807	19	240	115	85

Two plates of NIONIKRAL-70, 18 mm thick, had been prepared by edge machining for asymmetric 2/3 X welded joint (Fig. 1). Welding is performed in six passes, with 2 mm gap, using Tenacito – 80 electrode. The chemical composition and mechanical properties of the filler metal are shown in Tables 3 and 4, respectively.

Table 3 Chemical composition of all weld metal, %

Electrode	C	Mn	Si	Cr	Ni	Mo
Tenacito-80	0.06	1.65	0.3	0.55	2.0	0.35

Table 4 Mechanical properties of all weld metal

Electrode	**Yield stress $R_{p0,2}$, MPa**	**Tensile strength R_m, MPa**	**Elongation A, %**	**Impact energy, J**		
				+20°C	**-40°C**	**-60°C**
Tenacito-80	710-770	770-830	18-20	50-80		35-65

The specimens for impact Charpy test were cut and their V-notch located as presented in Fig. 1.

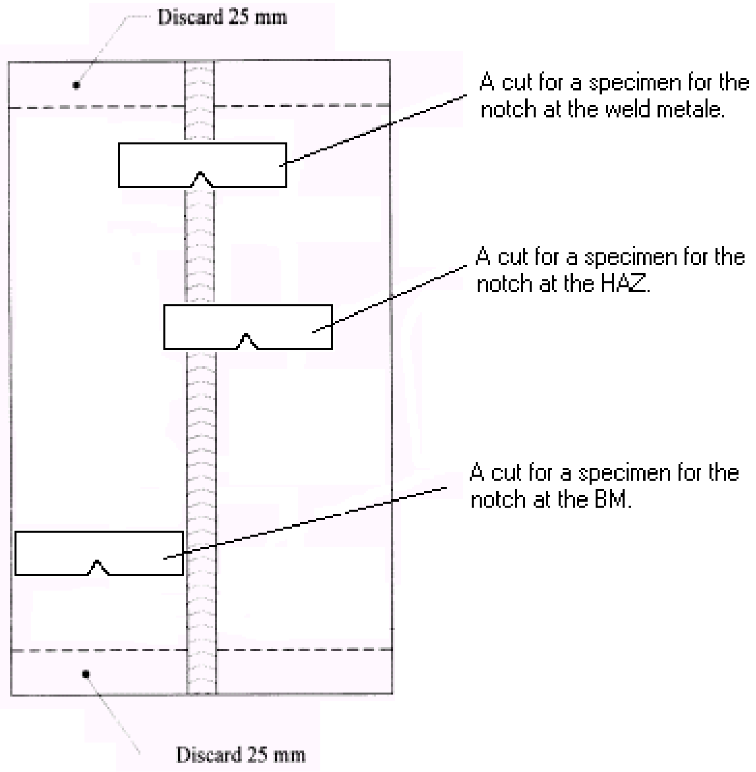


Fig. 1 Impact test specimens and V notch location

2. Impact testing of charpy v specimens and precracked specimens

Impact testing is performed at room temperature, according to EN 10045-1 [4] and EN ISO 90162013 [5], with Charpy specimens (Fig. 2), V notched in BM, WM and HAZ, on the instrumented Charpy pendulum SCHENCK TREBEL 150 J (Fig. 3).

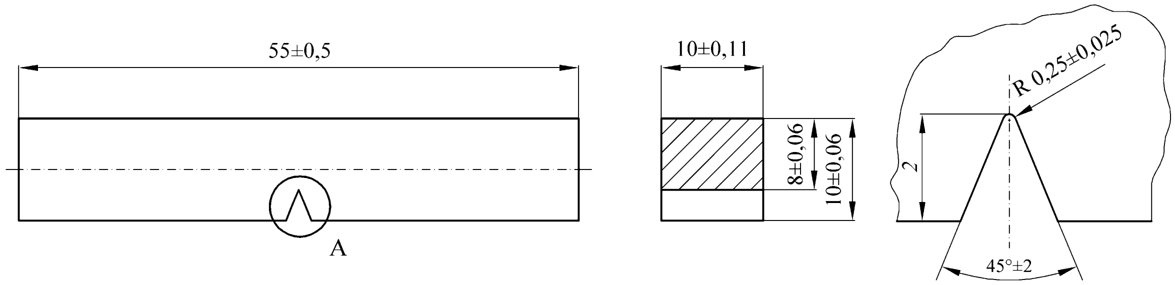


Fig. 2 Charpy V specimen

Two typical relationships, force vs. time, and energy vs. time obtained by instrumented impact testing, are presented in Fig. 4 for specimen BM-1, in Fig. 5 for specimen WM-1, and in Fig. 6 for specimen HAZ-1. Obtained results for total impact energy, for crack initiation and crack propagation, together with deflection values, are summarized in Table 5.

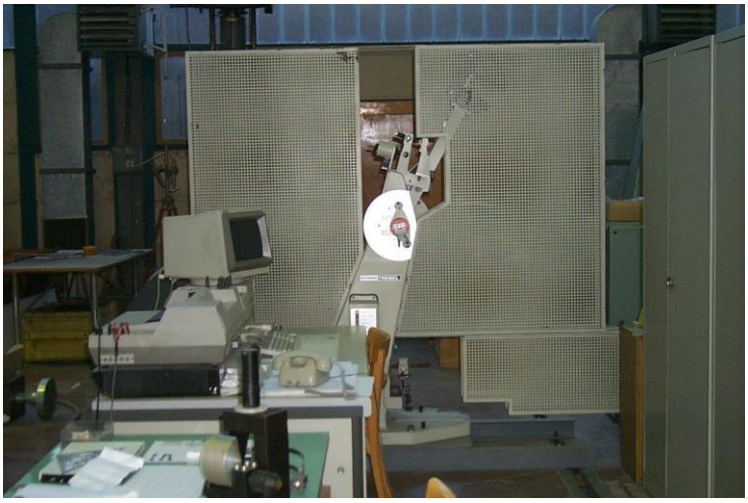
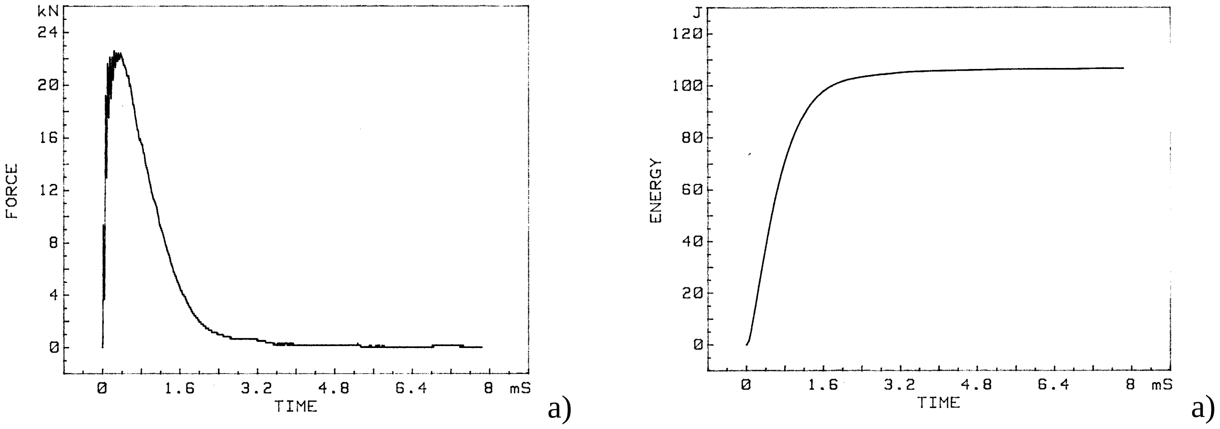


Fig. 3 Instrumented Charpy pendulum

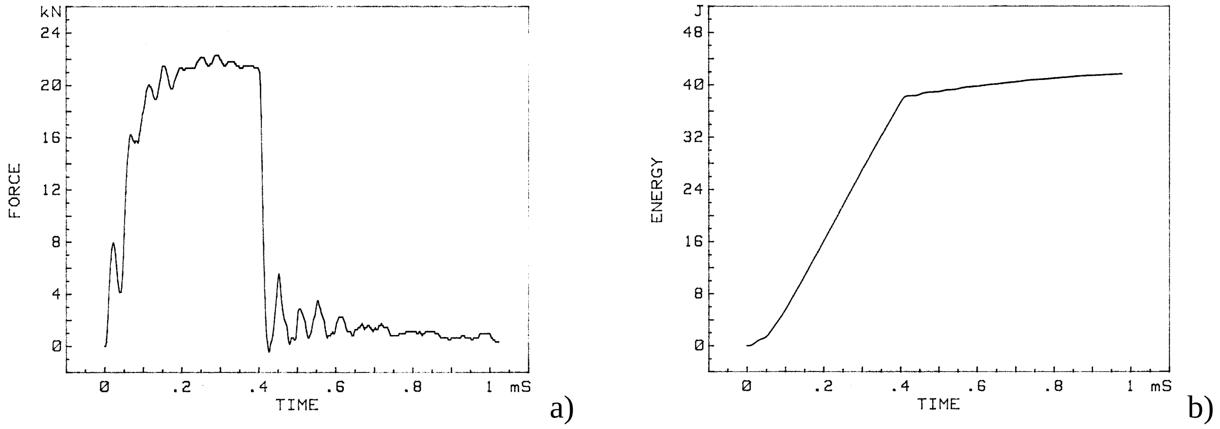
Table 5 Instrumented impact testing results of welded joint specimens

Specimen No.	**Total impact energy, E_u, J**	**Crack initiation energy, E_{in}, J**	**Crack propagation energy, E_{pr}, J**	**Deflection D_f, mm**
BM-1	107	41	66	18.1
BM-2	93	32	61	17.4
WM-1	46	38	8	2.1
WM-2	47	41	6	2.2
HAZ-1	74	42	32	14.2
HAZ-2	62	34	28	14.0



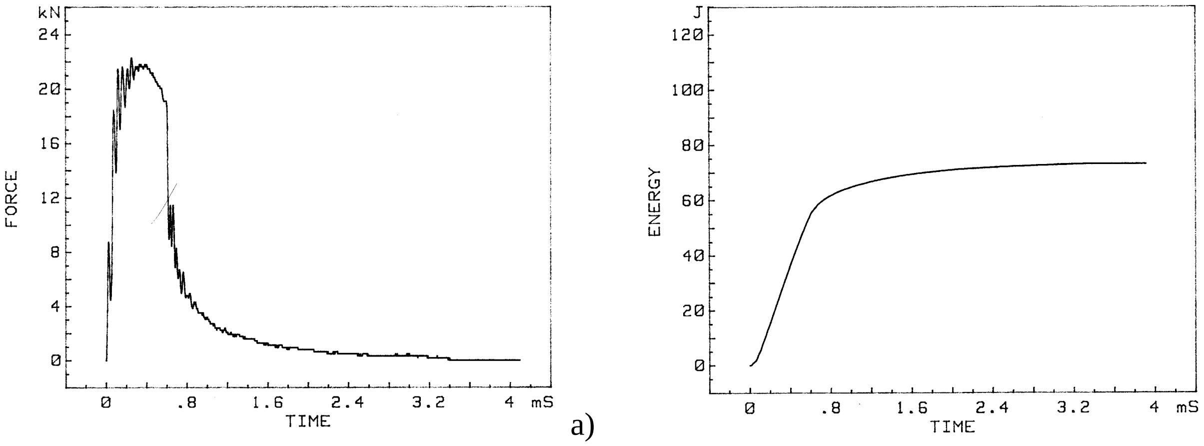
a) a)

Fig. 4 Relationships force vs. time (a), and energy vs. time (b) for base metal specimen BM-1



a) b)

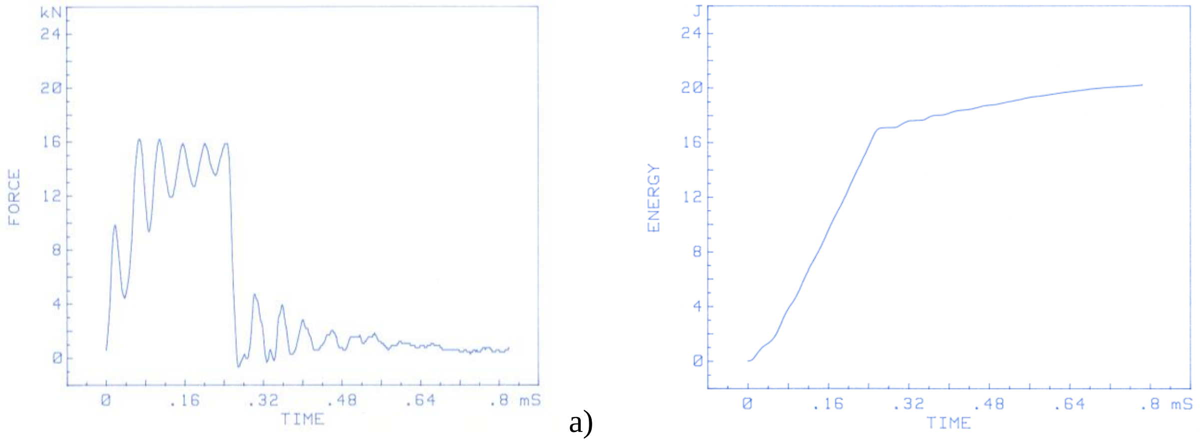
Fig. 5 Relationships force vs. time (a), and energy vs. time (b) for weld metal specimen WM-1



a) b)

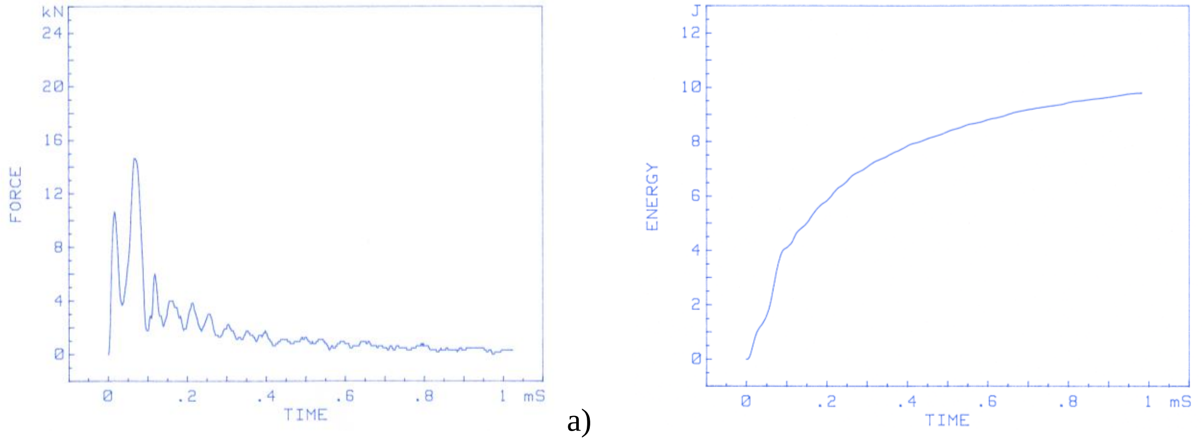
Fig. 6 Relationships force vs. time (a), and energy vs. time (b) for specimen HAZ-1

In addition to Charpy V specimens, specimens precracked in BM, WM and HAZ had been tested. Typical relationships, force vs. time, and energy vs. time obtained by instrumented impact testing for specimens with different crack length are presented in Fig. 7 for base metal BM-5, in Fig. 8 for specimen WM-5, and in Fig. 9 for specimen HAZ-5. The difference in specimens crack length is a consequence of fatigue precracking procedure applied to materials in BM, WM and HAZ of different microstructures, responding in different way. An average value of fatigue precrack length, measured after fracture, in 5 equidistant positions, represents crack length *a*.



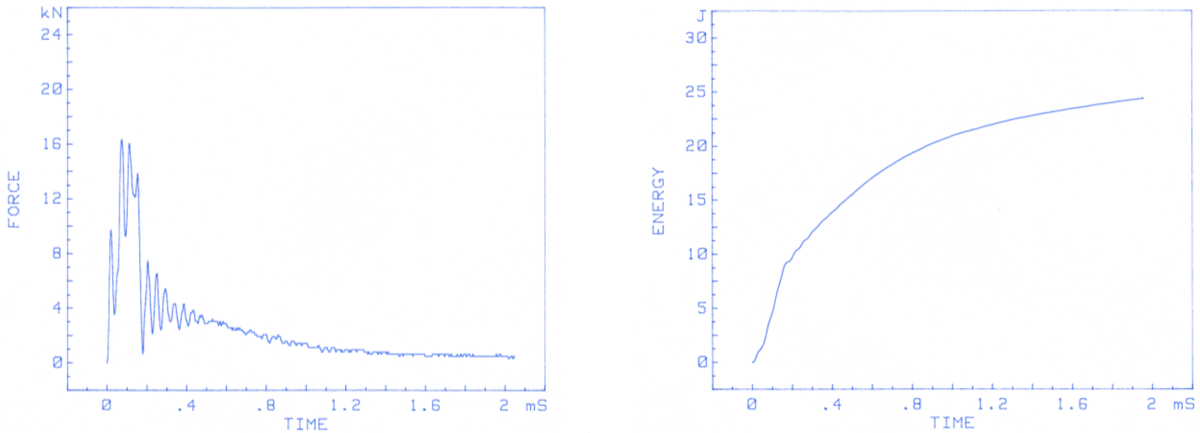
a) b)

Fig. 7 Relationships force vs. time (a), and energy vs. time (b) for specimen precracked in BM (BM-5), crack length *a* = 5.35 mm



a) b)

Fig. 8 Relationships force vs. time (a), and energy vs. time (b) for specimen precracked in WM (WM-5), crack length *a* = 4,37 mm



a) b)

Fig. 9 Relationships force vs. time (a), and energy vs. time (b) for specimen precracked in HAZ (HAZ-5), crack length *a* = 3,78 mm

Total impact energy, as an integral value in Charpy bend test, enables the comparison of different materials regarding their respond to impact load. Instrumented testing allows to separate the energies necessary for crack initiation and for crack propagation. It is possible, thanks to these data, to evaluate crack arrest properties of samples, in which some crack-like defect already exists. In addition, the capacity of material to be strained, e.g. by deflection in bend test, is also an important characteristic for material behaviour under loading.

Average crack length and corresponding absorbed impact energy KV, present a pair of values for KV vs. *a* plot, which initiates at notch depth (2 mm) and follows parabolic law, as presented in Fig. 10 through 12 for BM, WM and HAZ, respectively. It is now possible to determine crack susceptibility (CS) [6], defined as the ratio of KV value for Charpy V notch specimen (average value from Table 5) and KV1 value, corresponding to 1 mm crack extension (total crack length *a* = 3 mm), taken from Figs. 10 to 12 [6]

$$CS = \frac{KV}{KV1} \qquad (1)$$

Calculated values of crack sensitivity are tabulated in Table 6.

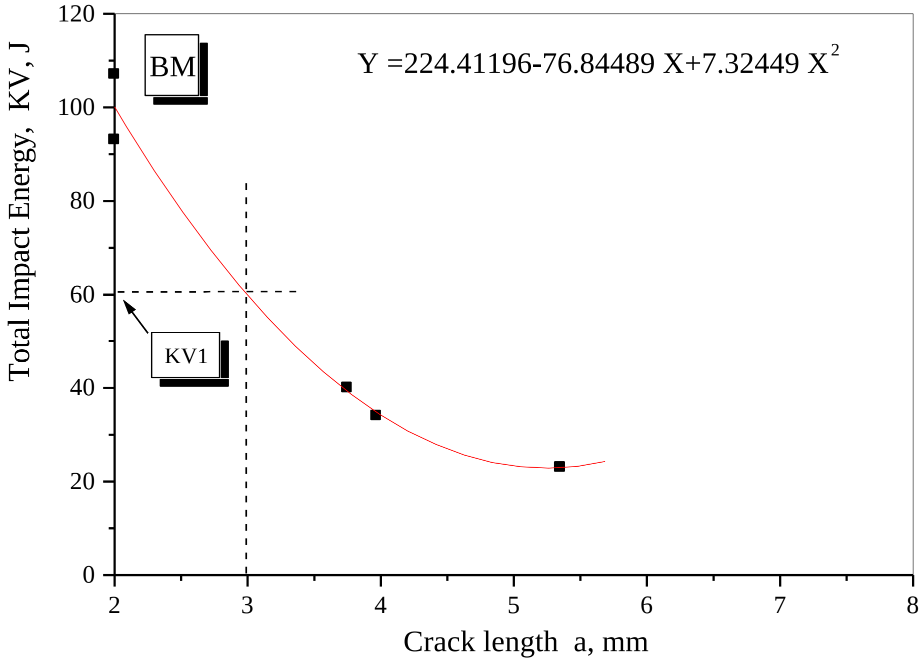


Fig. 10 Diagram impact energy KV vs. crack length *a* for base metal specimens

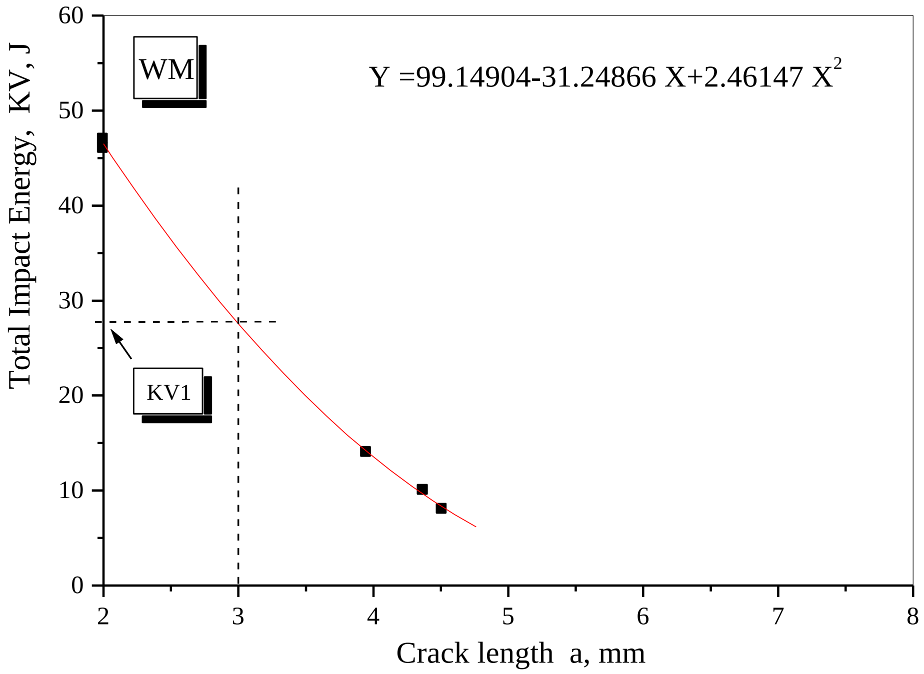


Fig. 11 Diagram impact energy KV vs. crack length *a* for weld metal specimens

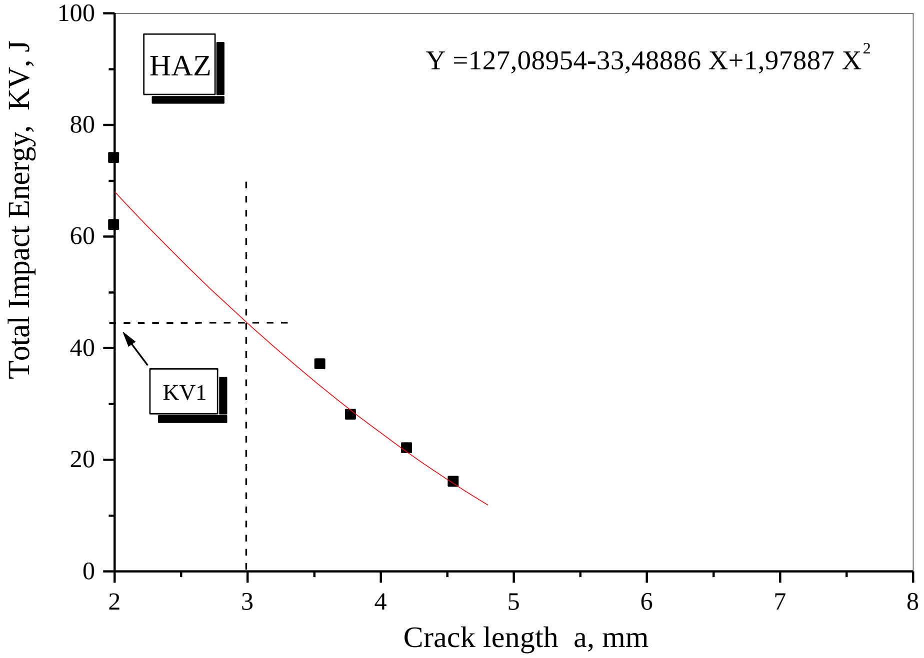


Fig. 12 Diagram impact energy KV vs. crack length *a* for HAZ specimens

Table 6 Crack sensitivity factors for base metal, weld metal and heat-affected-zone

	Notched specimen	**Cracked specimen**	**Crack sensitivity**
Specimen type	KV	KV1	KV/KV1
Base metal	100	60.5	1.65
Weld metal	47	38	1.24
Heat-affected-zone	68	48	1.42

3. Discussion

Performed experiments enable to consider separately and compare the behaviour under impact loading of welded joint constituents (BM, WM and HAZ) specimens, containing notch and crack.

The results in Table 5 reveal that the impact toughness of BM is satisfactory, at high level for this type of steel. The results obtained in HAZ are still satisfactory, but they are low for WM, where the part for crack propagation is probably critical. It is to notice that in all considered cases crack initiation energy level is almost of the same value, and the difference is due to crack propagation energy. Obtained results agree in general with data from material specification. The differences in HAZ behavior can be attributed to different microstructure in HAZ, and the question is in which microstructure region is notch tip positioned. Crack propagation energy of WM is higher in specification than that given in Table 5. Deflection values (Table 5) confirmed the poor impact behaviour of WM, and satisfactory behaviour of BM and HAZ.

The diagrams obtained under impact loading with precracked specimens (Figs. 7 through 9) for all three welded joint constituents present brittle behaviour. This can be explained by deep initial crack in BM crack length was a = 5,35 mm, in WM a = 4,37 mm and in HAZ a = 3,78 mm. In order to compare the benaviour of different regions, crack sensitivity is determined, based on plots drawn in Figs. 10 through 12. For crack length value of 1 mm, calculated crack sensitivity factor is 1.65 for BM, 1,24 for WM and 1.42 for HAZ. These relations can be accepted as offering proper description of relation between individual welded joint constituents behavior.

Having in mind that weld metal in this welded joint is a constituent of minimum crack resistance properties, expressed in impact toughness of notched as well as cracked specimens and in plane strain fracture toughness value, there is a space to consider how to improve welding technology parameters. This can be achieved by selection of other electrode or by adopting welding regime parameters, e.g. heat input.

4. Conclusion

The application of high strength steel and its welded joint in structures, exposed to high loads can be accepted if the properties satisfy strong requirements. The benefits which can be obtained by increased strength must be additionally confirmed by sufficient resistance to brittle fracture, e.g. by the resistance to stress concentration. For that reason the data about V notch impact toughness and crack behaviour in impact and in stable crack growth condition are required before final decision for the selection of high strength steel for manufacturing responsible welded structures.

Applied techniques in this experiment enabled the evaluation of parameters, important for the application of high strength steel welded joint. It is to underline that crack-like defects can be expected in welded joint due to nature of welding procedure, and the data about crack resistance of welded joint constituents are necessary for successful application of high strength steel.

5. References

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