PROBABILISTIC ANALYSES OF YIELD STRENGTH AND TEMPERATURE EFFECTS ON THE DUCTILE CRACK GROWTH RESISTANCE OF HSLA STEELS

N. GUBELJAK*, J. LEGAT* and J. VOJVODIČ-GVARDJANČIČ**

In this paper the effects of three different supply conditions of HSLA steels on ductile crack growth resistance at room and T_{NDT} temperatures are shown.
The values of $J_{0.2BL}$ and J_C-integral were chosen as suitable parameters and treated by the lognormal distribution function for the determination of confidence intervals.
The results obtained show that HSLA steels with higher yield strength are more sensitive to the condition of the steel and to temperatures than lower-strength steels are.

INTRODUCTION

HSLA steels are used for manufacturing of engineering structures (pipes, pressure vessels, cranes, off-shore structures, etc.), where they are exposed to different environmental influences and processes of materials aging. Also, parts of the structure are deformed during installation. However, the mechanical properties of steels change during manufacturing and over the service life. The consequences of this are changes in the resistance of steels in relation to ductile crack growth. The problems become more complex at low temperatures (in the brittle fracture region) and where there is significant scatter of fracture toughness data.

The aim of this paper is to estimate the change of ductile crack growth resistance of HSLA steels in relation to different supply conditions of steels at room temperature and at T_{NDT} temperatures.

* Faculty of Technical Sciences, University of Maribor, SLOVENIA.
** Institute of Metal Structures, Ljubljana, SLOVENIA.

CHARACTERIZATION OF MATERIALS

The observation of yield strength and temperature effects on ductile crack growth resistance are made on two HSLA steels (designated NIOVAL 47 and C.0562) with the following chemical compositions, Tab.1:

TABLE 1- Chemical compositions (weight %) of steels.

Steel	C	Si	Mn	P	S	Cr
NIOVAL 47	0.19	0.42	1.49	0.013	0.005	0.13
C.0562	0.17	0.32	1.28	0.020	0.009	0.21
	Ni	Mo	Cu	Nb	V	Al
NIOVAL 47	0.10	0.04	-	0.050	0.07	0.087
CO562	0.23	0.05	0.35	0.030	-	0.045

Three different material conditions were observed:
a) HSLA steel in the normalized condition (as-delivered), designated "A",
b) aged state, after a 10% cool plastic deformation and heating at 250°C for 30 minutes, designated "B",
c) deformed state after a 10% cool plastic deformation, designated "C".

The longitudinal tensile specimens, drop weight test and compact tension (CT) specimens were cut from 20mm thickness plates. The mechanical properties were determined at room temperature and at T_{NDT} temperatures (determined by drop weight testing), by longitudinal testing, given in Tab. 2.

TABLE 2- Mechanical properties of NIOVAL 47 and C.0562 steels at room temperature and T_{NDT} temperatures.

Steel	Mark of Specimens	Yield Strength	Ultimate Tensile Strength	Elongation at Fracture	T_{NDT}	Yield Strength at T_{NDT}
		MPa	MPa	%	°C	MPa
NIOVAL 47	VA	442	610	13.7	-72	514
	VB	647	726	4.7	-104	780
	VC	627	684	4.5	-132	757
C.0562	CA	366	553	14.3	-92	475
	CB	586	656	4.8	-112	653
	CC	595	624	4.1	-120	675

The increasing strength of steels, associated with decreasing elongation at fracture is clearly seen in Tab. 2. Also, a further increase of yield strength with a decrease

of temperatures is obvious.
On the basis of the results obtained, (Tab. 2) it was decided that the testing would be carried out at room (+20°C) temperature and T_{NDT} temperatures (-72°C and -92°C) of both steels in the normalized condition.

DEFINITION OF THE PROBABILITY MODEL

The experimental data must be mathematically treated by a suitable model. The model should include the scatter of results and allow the determination of intervals for 99% reliability. The probability density function of the lognormal distribution law is used to detrmine the confidence level:

$$f(x) = \frac{1}{V_y \cdot \sqrt{2\pi}} \cdot e^{-\frac{(\ln(x)-\mu_y)^2}{2 \cdot V_y^2}} \qquad (1)$$

where V_y is variance and μ_y is the expected value determined according to the normal distribution law for $y=\ln(x)$.
Applying the mathematical theory (1) of probability, the reliability can be defined by:

$$R(x) = 1 - F(x) = 1 - \int_{x_{\inf}}^{x_{\sup}} f(x)dx \qquad (2)$$

With equation (2), it is possible to determine the limit values of confidence intervals by 99% reliability.

EXPERIMENTAL RESULTS

Experiments were done on 6 series of 15 standard (2) CT specimens. On the basis of the F-CMOD (Load versus Crack Mouth Opening Displacement) records, J-R resistance curves were determined, along at room temperature and with J_C values at T_{NDT} temperatures (where all specimens were fractured in a brittle manner).

For probabilistic analyses, the parameters $J_{0.2BL}$ (determined from J-Δa plots at room temperature see: Fig. 1) and J_C (determined from brittle fracture tests at T_{NDT}, Fig. 2) were used.

The widths of confidence intervals for R=99% (at room and T_{NDT} temperatures) were determined by applying equation (2), Tab. 3. To achieve a clearer interpretation, the results obtained are shown as plots of density functions, Fig. 3 and Fig. 4.

TABLE 3-Widths of intervals ($J_{0.2BL}$ and J_C) and expected values at room temperature and T_{NDT} temperatures for both steels.

Spec.	Toughness parameter $J_{0.2BL}$ [N/mm]			Toughness parameter J_C [N/mm]		
	left bound	expected value E	right bound	left bound	expected value E	right bound
VA	420.5	476.5	532.5	3.31	52.62	102.1
VB	209.4	231.6	253.8	1.23	20.44	40.1
VC	297.9	333.2	368.4	3.85	25.02	46.2
CA	305.3	335.5	365.6	87.09	196.39	305.7
CB	240.1	262.5	285.0	24.12	47.62	71.2
CC	247.7	282.3	316.9	24.65	65.4	106.1

DISCUSSION

The steels NIOVAL 47 (mark VA) and C.0562 (mark CA) in normalized condition have the highest resistance to ductile crack growth at room temperature, which is clearly shown in Fig. 3, 4 and in Tab. 3. The steel NIOVAL 47 (mark VA) has a greater resistance because its steel has a higher strength.

In deformed steels the toughness is lower than in normalized steels. This is true for both steels and temperatures. As well the influence of deformation in the resistance of aged steels, segregation causes the toughness of steel to be reduced.

As is evident in Fig. 3,4 and Tab. 3, the scatter of results is significant for normalized (as-delivered) steels, and lowest in aged steels. This is a result of the influences of numerous different microstructure parameters. The scatter decreases with deformation, particularly with aging, because the influence of one parameter dominates over other parameters as temperature is decreased.

CONCLUSION

HSLA steel with higher yield strength also has a higher resistance to ductile crack growth in the normalized (as-delivered) state at room temperatures. In the case of cold-deformed or aged of steels, the toughness of the steel with the higher yield strength could be lower than the toughness of the steel with a smaller yield strength, particularly at low temperatures.

At decreasing temperatures, the influence of microstructural factors decreases, which results in smaller scatter of experimental data.

SYMBOL USED

$J_{0.2BL}$ = engineering measure of initiation of crack growth (N/mm)

J_C = value of J-integral determined from brittle fracture test (N/mm)

T_{NDT} = temperature of brittle fracture determined by the drop weight test (°C)

REFERENCES

(1) Pavlic I., "Statistika teorija i primjena", Tehnicka knjiga Zagreb 1988.

(2) ASTM E1152, "Standard Test Method for Determining J-R Curves".

(3) ASTM E813, "Standard Test Method for J_{IC}, a Measure of Fracture Toughness", 1983.

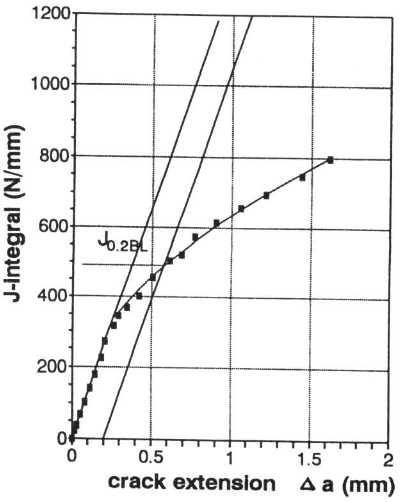

Figure 1 J-Δa resistance curve and the determination of $J_{0.2BL}$ value.

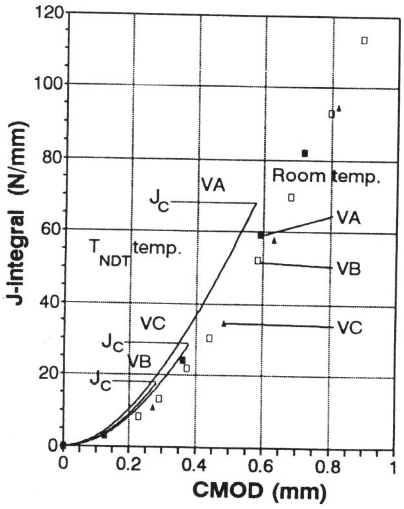

Figure 2 J-CMOD curves and J_C values at T_{NDT} temperatures.

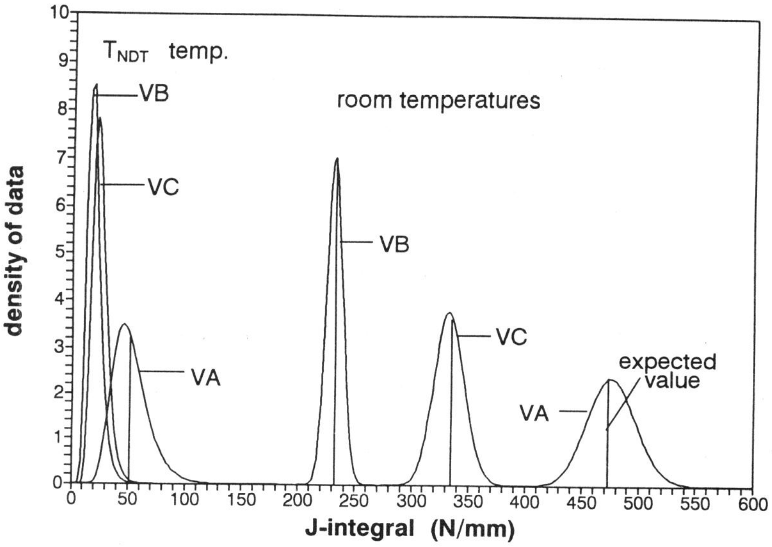

Figure 3 Probability distribution of toughness parameters at room and T_{NDT} temperatures for all states of steel NIOVAL 47.

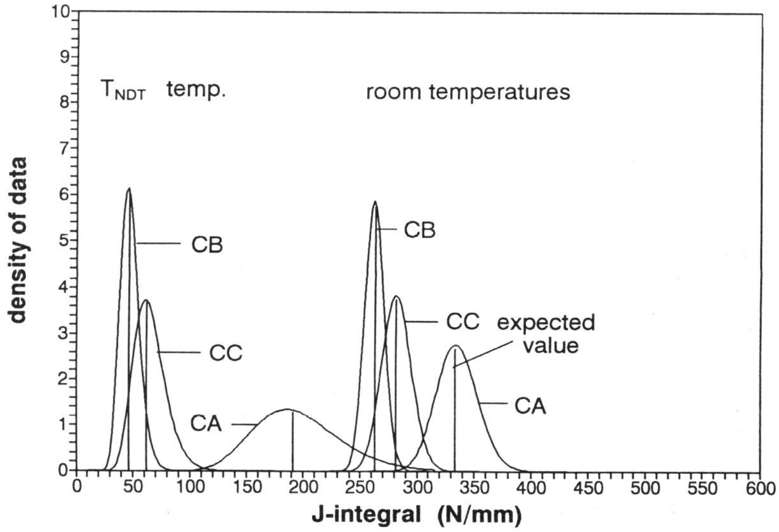

Figure 4 Probability distribution of toughness parameters at room and T_{NDT} temperatures for all states of steel C.0562.