Image Cover Sheet

CLASSIFICATION	SYSTEM NUMBER 510313
UNCLASSIFIED	

TITLE

APPLICATION OF J AND CTOD ESTIMATION FORMULAS TO NAVAL CONSTRUCTION STEELS

System Number:

Patron Number:

Requester:

Notes: Paper #8 contained in Parent Sysnum #510305

DSIS Use only:

Deliver to: DK

 #510313 (8)

APPLICATION OF J AND CTOD ESTIMATION FORMULAS TO NAVAL CONSTRUCTION STEELS

Jack Morrison and Zhenhua Zhai
Defence Research Establishment Pacific

K.J. KarisAllen
Defence Research Establishment Atlantic

INTRODUCTION

Over the past two decades standardized experimental procedures for laboratory elastic-plastic toughness determination using J_{Ic}, J-R Curves, and Crack Tip Opening Displacement have all been developed and widely employed (e.g. ASTM Standards E813, E1152, and E1290, and British Standard BS 5762). These standards include the most commonly used specimen types, namely compact and three point bend geometries. Depending on the parameter being measured, for example J, there may be a requirement for measurement during the test of both specimen crack mouth opening and load-line displacement. If required, compact fracture specimens can fairly easily be modified to make the two suitably coincident. When single edge notched bend specimens are employed, however, the required instrumentation tends to become more complex, and in the case of small specimens, difficult to accommodate. It would therefore be useful if estimates of J and CTOD could be made from either mouth opening or load line displacement. At the same time estimation formulas applicable to wider ranges of crack length would also be useful, particularly for evaluating specimens containing shorter cracks than are currently permitted in the standard procedures (1, 2). Recently Kirk and Dodds (3) provided a series of estimation formulas allowing for both J and CTOD calculation from either load-load-line displacement, or load-crack mouth opening, based on a finite element analysis. This paper describes an investigation of how well these formulas apply to three point bend specimen fracture tests on both 25 mm HSLA80 steel plate and the fusion zone of a 50 mm Q1(N) steel weldment .

In general the estimation formulas show excellent agreement.

SUMMARY

The following summary provides additional comments on the pages which follow.

Page 4. CTOD Estimation Formulas. Refer to reference (3) for nomenclature. Equation (1) is from the ASTM procedure E1290, using CMOD. Equation (2) uses the area under the load-CMOD curve. Equation (3) uses the area under the load-load line displacement curve. Note that the elastic first term is the same in each case. The η values are tabulated in reference (3) as a function of a/W and work hardening coefficients derived from tensile tests using a Ramberg-Osgood fit.

Page 5. J estimation formulas. These relationships corresponding to equations (2) and (3). Equation (5) is the formula found in the standards

HSLA80

Pages 8 and 9. Typical load-CMOD and load-LLD curves for the HSLA80 plate using unloading compliance for crack length determination. Specimens were 25x50 mm with a/W=0.5.

Page 10. Effect of rate and temperature on the onset of unstable fracture. The estimation formulas were applied to specimens which cleaved only after maximum load.

Page 11. Comparison of CTOD formulas for HSLA80. Some error is expected at high Δa because the formulas do not correct for crack extension.

Page 12. Comparison of J formulas for HSLA80.

Q1(N) WELD

Pages 13 and 14. Typical load-CMOD and load-LPD curves. In this case LPD was determined indirectly using machine displacement and known machine compliance. The test was carried out at -5°C with a displacement rate of 2 mm/s.

Pages 15 and 16. Comparison of CTOD and J estimation formulas for Q1(N) weld. Note the very large final crack extension. Over the first 2 mm of crack extension the agreement is reasonably good, and even at long crack lengths and after encountering instabilities, the area base calculations are in excellent agreement.

OUTLINE

- Introduction

- J and CTOD Estimation formulas

- Materials
  - chemical composition
  - tensile properties
  - impact properties

- Test Procedures
  - tensile
  - fracture toughness

- Results
  - load-displacement curves
  - temperature/rate sensitivity of HSLA80 steel
  - variation of toughness with crack length in Q1(N) weld

  - CTOD and J R-curves from estimation formulas

  - Conclusions

J ESTIMATION FORMULAS

4. Using the area under the load-crack mouth opening displacement curve:

$$J = \frac{K^2(1-\upsilon^2)}{E} + \frac{\eta_{J\text{-}C} A_{pl}(CMOD)}{Bb} \qquad (4)$$

5. Using the area under the load-load line displacement curve:

$$J = \frac{K^2(1-\upsilon^2)}{E} + \frac{\eta_{pl} A_{pl}(LLD)}{Bb} \qquad (5)$$

CTOD ESTIMATION FORMULAS

1. Using the plastic component of crack mouth opening displacement:

$$\mathrm{CTOD} = \frac{K^2(1-\upsilon^2)}{m\sigma_f E} + \frac{r_{pl} b \,\mathrm{CMOD}_{pl}}{r_{pl} b + a} \qquad (1)$$

2. Using the area under the load-crack mouth opening displacement curve:

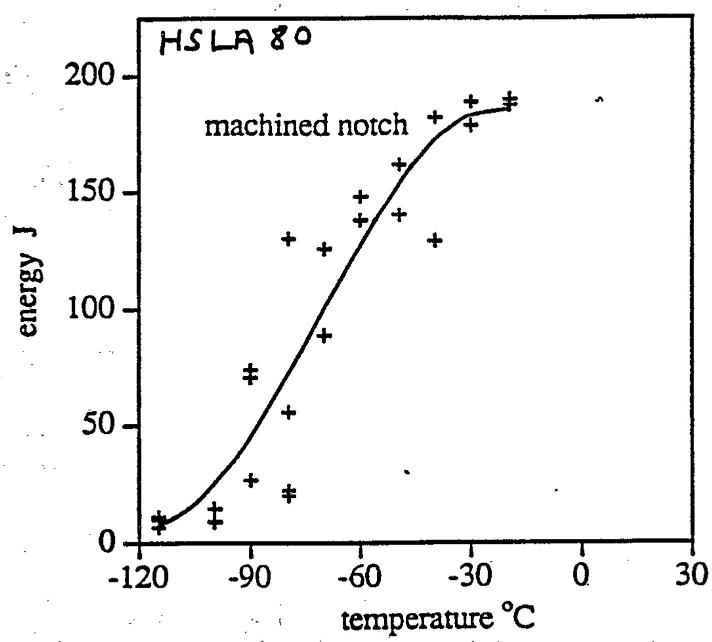
$$\mathrm{CTOD} = \frac{K^2(1-\upsilon^2)}{m\sigma_f E} + \frac{\eta_{C\text{-}C} A_{pl}(\mathrm{CMOD})}{Bb\sigma_f} \qquad (2)$$

3. Using the area under the load-load line displacement curve:

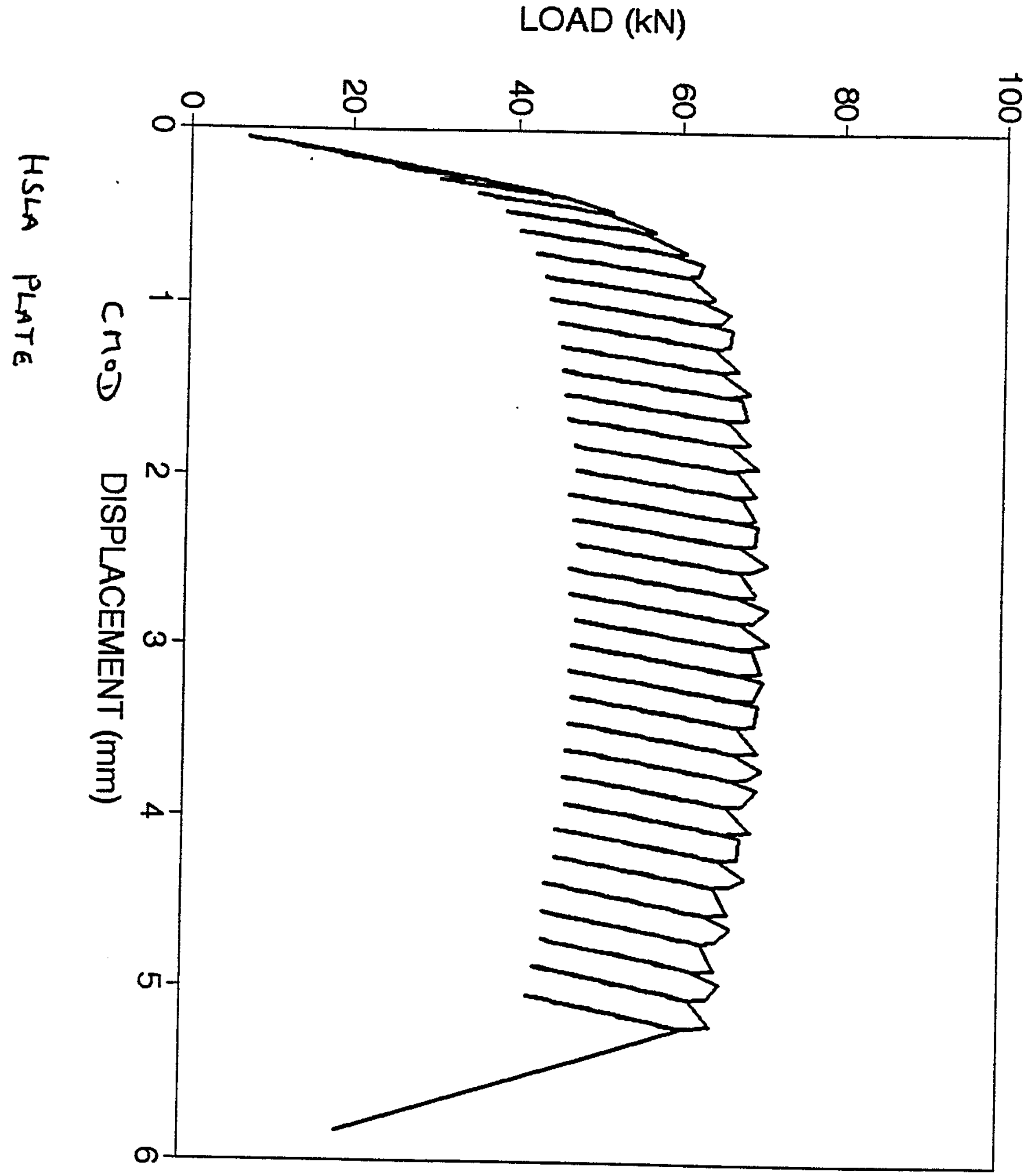
$$\mathrm{CTOD} = \frac{K^2(1-\upsilon^2)}{m\sigma_f E} + \frac{\eta_{C\text{-}L} A_{pl}(\mathrm{LLD})}{Bb\sigma} \qquad (3)$$

Chemical composition wt %.

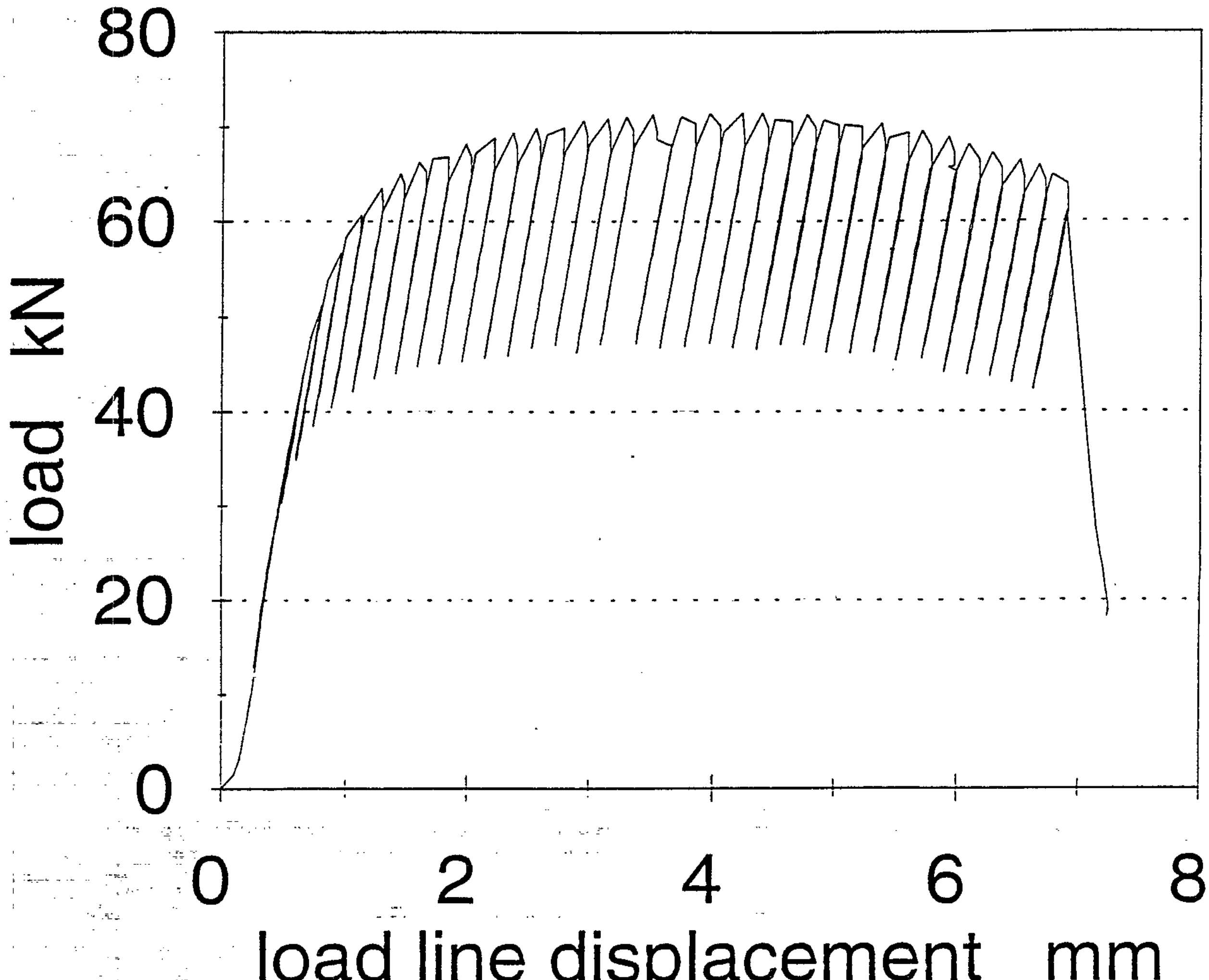
	HSLA plate	Q1(N) plate	sample Q1(N) weld	Q(1)N HAZ
C	0.06	0.15	0.06	0.14
Mn	0.61	0.38	1.42	0.38
Si	0.30	0.26	0.55	0.43
Ni	0.81	2.77	1.83	2.86
Cr	0.74	1.41	0.13	1.43
Cu	1.01	0.02	0.01	0.02
Mo	0.22	0.4	0.04	0.41
V	-	-	0.02	-
Ti	-	0.005	0.06	0.04
Co	-	-	0.02	0.01
S	0.006	0.007	0.009	0.008
P	0.02	0.03	0.03	0.03
Al	0.07	0.1	0.03	0.1

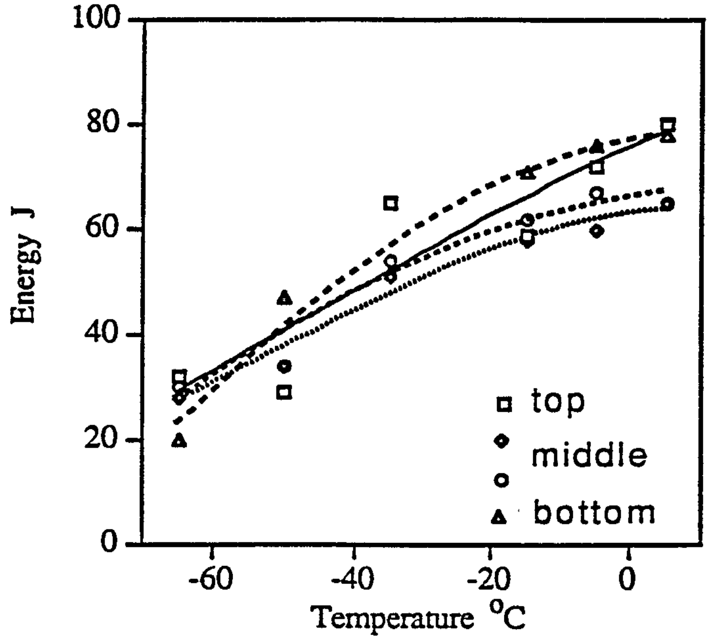


Charpy transition curve

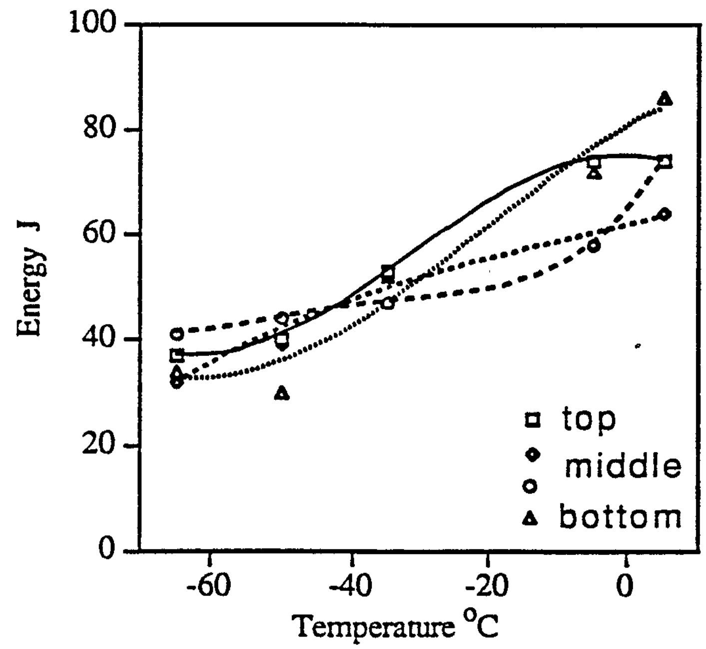

LOAD (kN)
0
20
40
60
80
100
0
1
2
3
4
5
6
CMOD DISPLACEMENT (mm)
HSLA PLATE

sample 4 - 0.2 mm/sec, -20 C



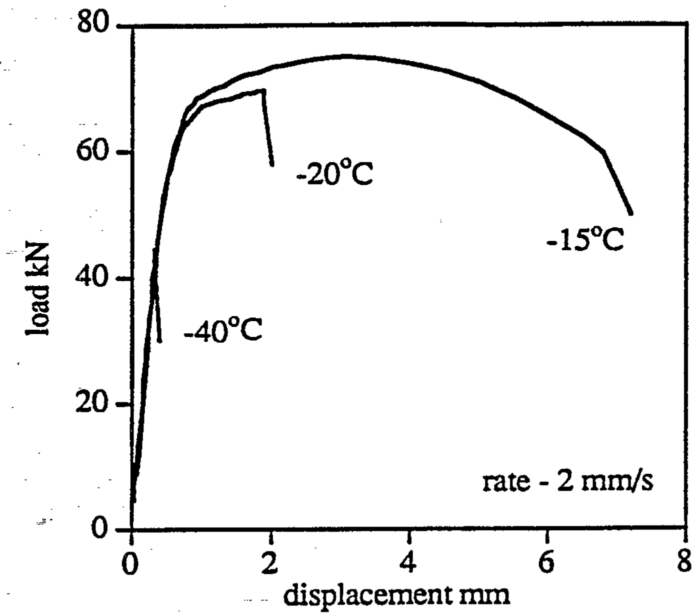


T-S orientation

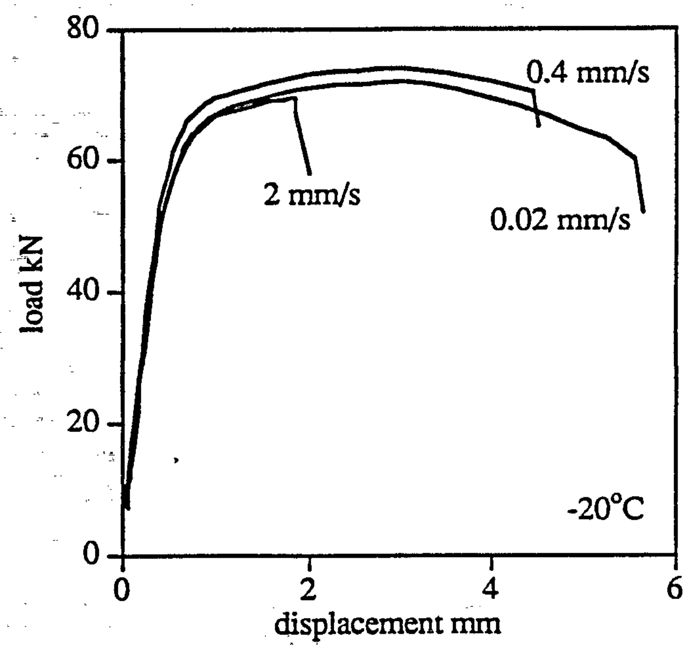


T-L orientation

Charpy impact test results for Q1(N) steel weld

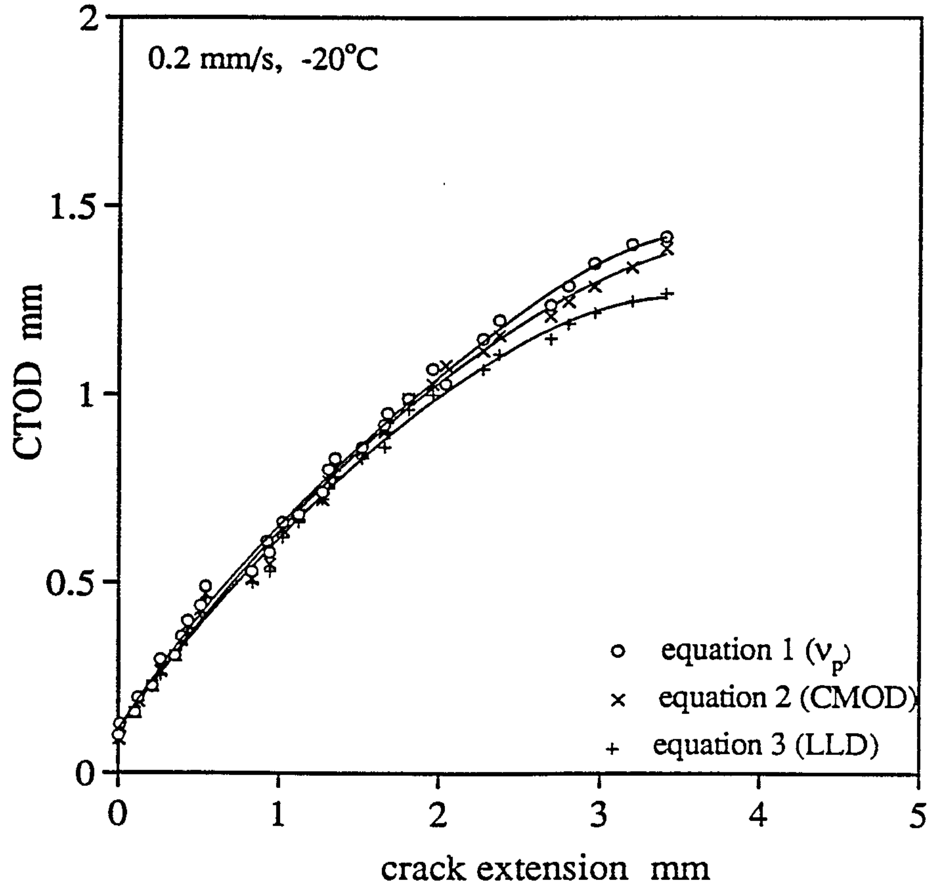


Effect of temperature

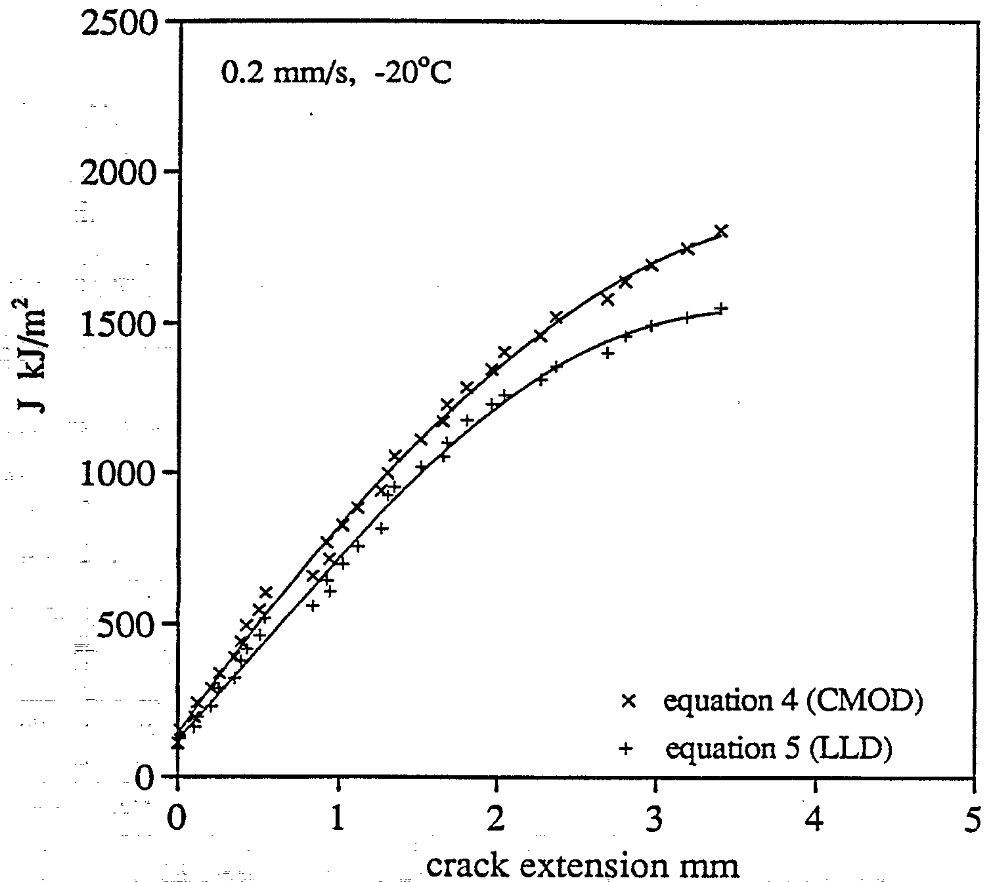


Effect of displacement rate

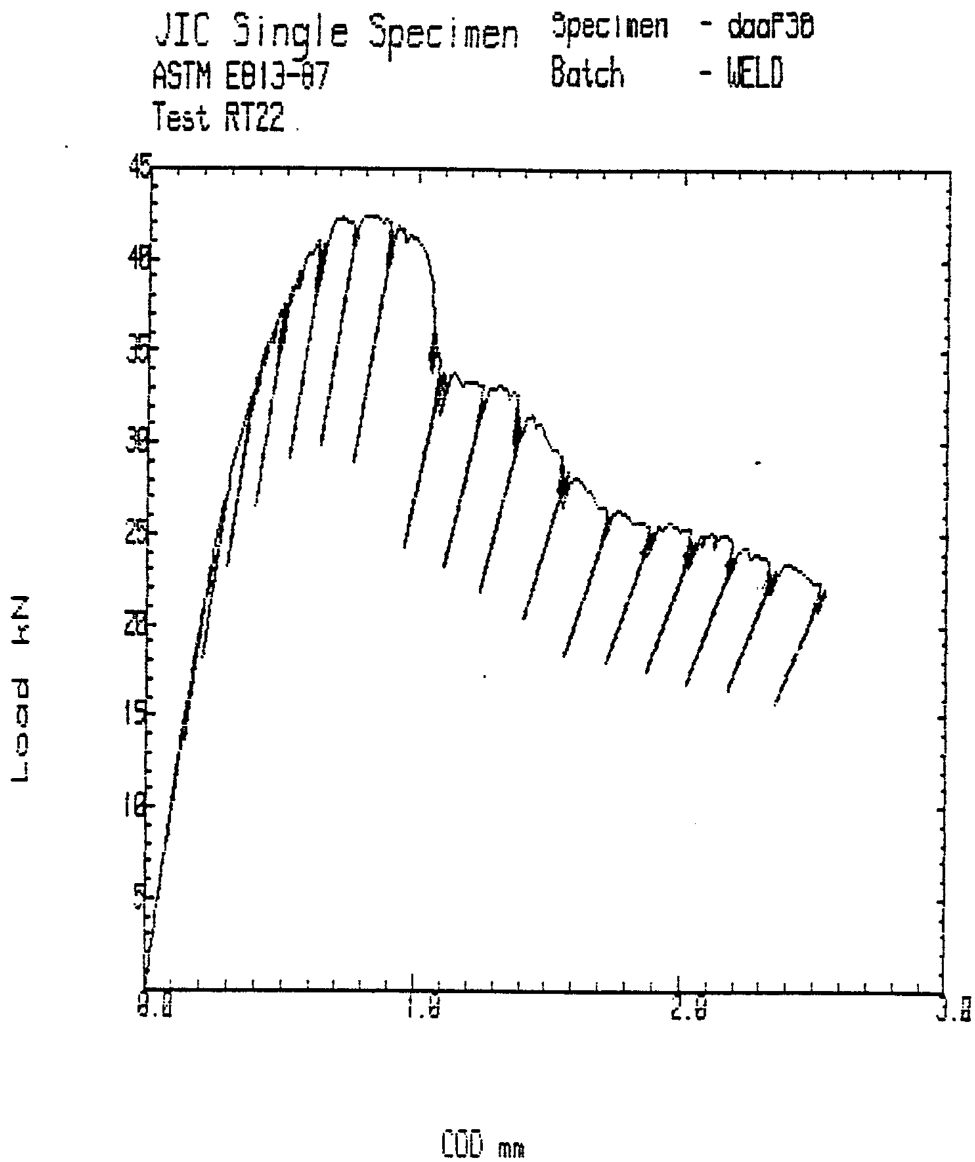
Load-displacement curves for HSLA steel

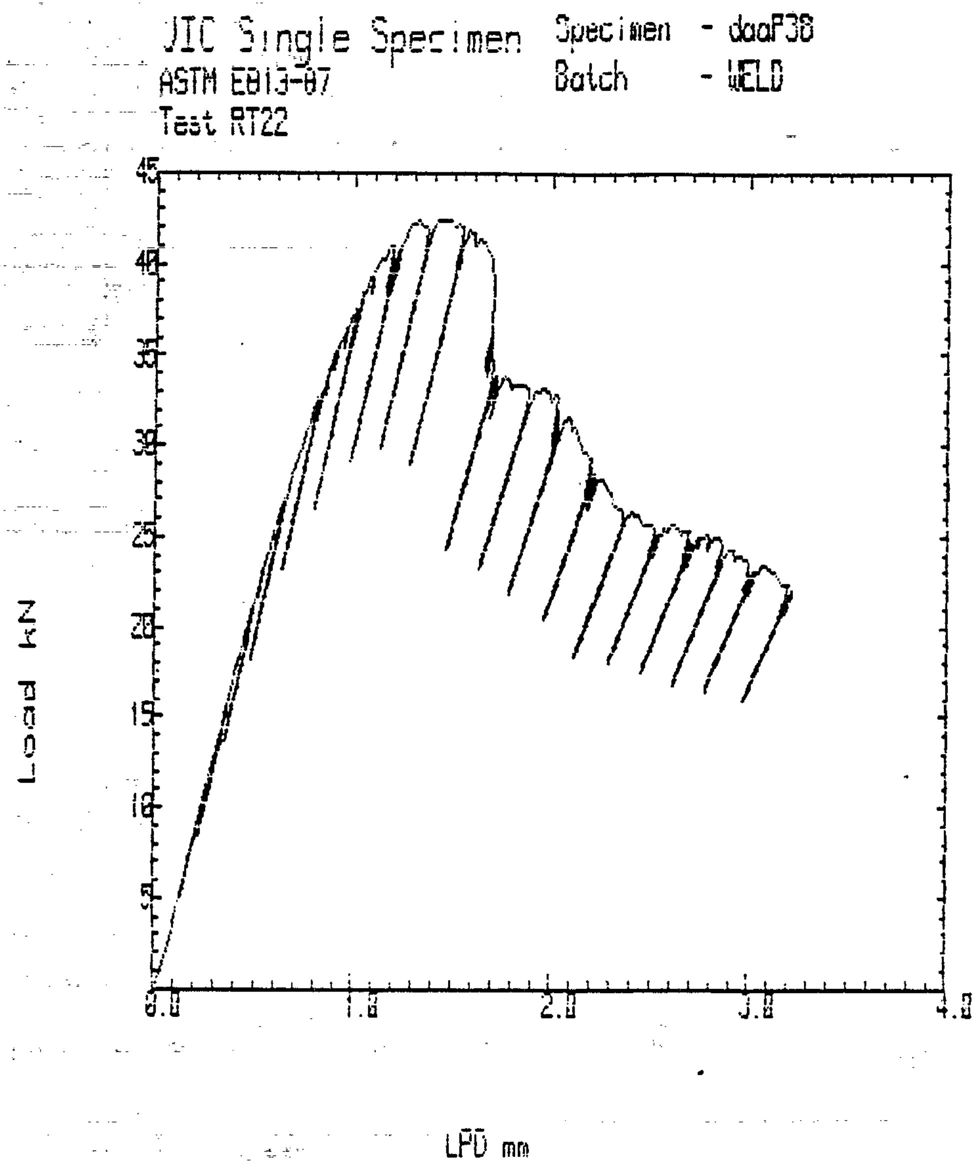


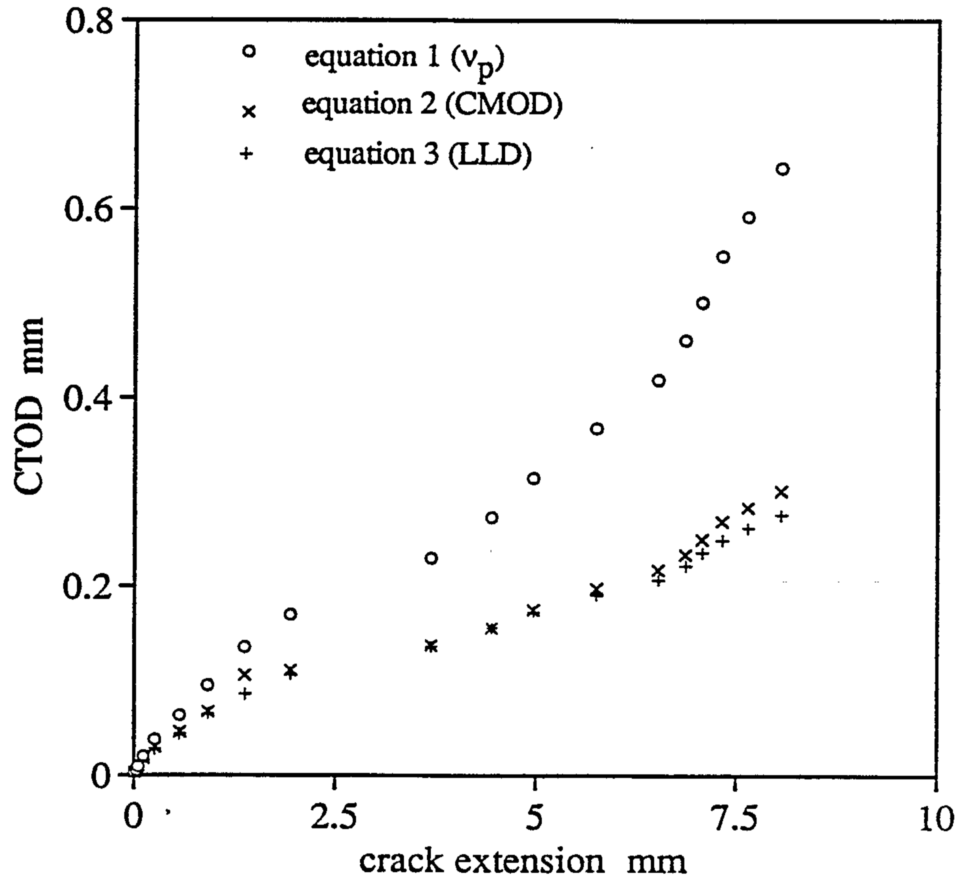
HSLA-80 CTOD Comparisons



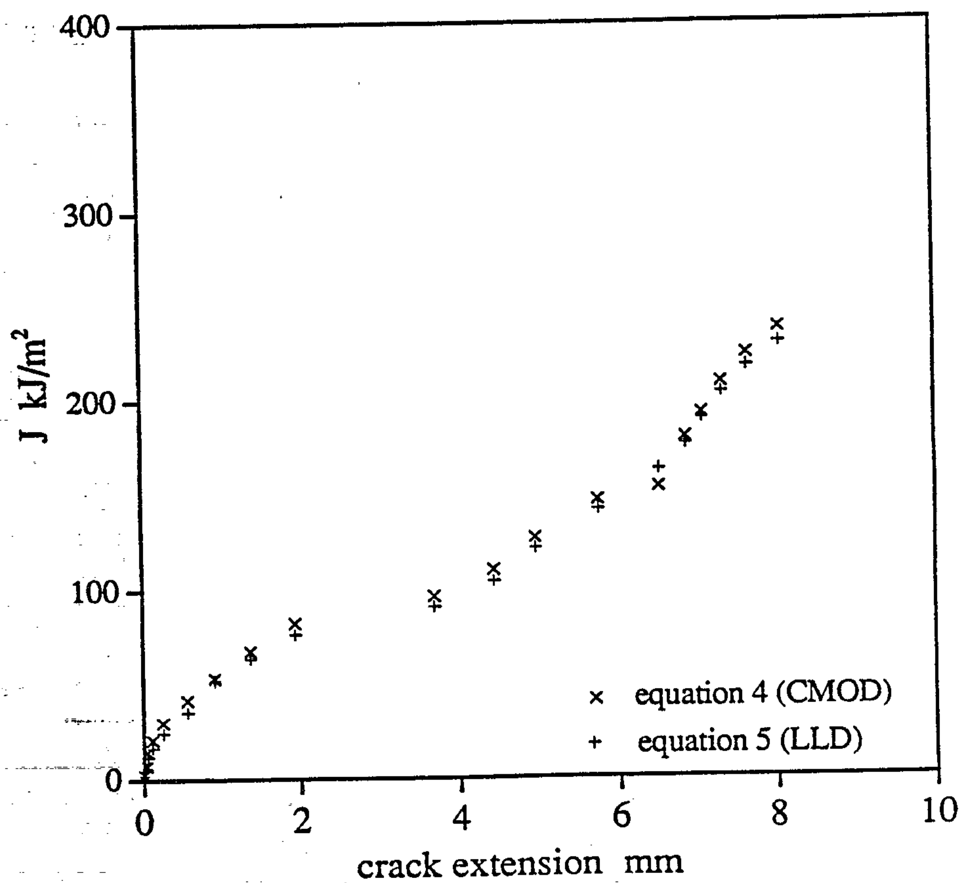
HSLA-80 J Comparisons


JIC Single Specimen
ASTM E813-87
Test RT22
Specimen - daaF30
Batch - WELD
45
40
35
30
25
20
15
10
5
0.0
1.0
2.0
3.0
Load kN
COD mm


JIC Single Specimen
ASTM E813-87
Test RT22
Specimen - daaP38
Batch - WELD
Load kN
LPD mm
0.0
1.0
2.0
3.0
4.0
45
40



Q1(N) Weld CTOD Comparisons



Q1(N) Weld J Comparisons