#507229 (26)

CRACK ARREST TOUGHNESS OF A SHIP STRUCTURAL STEEL

by

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ABSTRACT

Esquimalt Defence Research Detachment and Director Maritime Ship Support have initiated a project to develop procedures and then determine the crack arrest toughness of ship structural steels typical of those used in naval surface ships. In the project to date, a 16 mm thick 350 WT steel has been characterized in terms of its standard mechanical properties (CVN, DT etc.) in both the L-T and T-L orientations. Tests have been performed in the L-T orientation, using the procedure in ASTM Standard E1221 to determine Plane Strain Crack Arrest Toughness but with little success in meeting all of the validity requirements. Full thickness compact crack arrest tests with embrittled chevron notch were then tried using specimens machined in both L-T and T-L orientations, and resulted in improved success. However, further work is required to improve the success rate.

The crack arrest toughness results obtained in the project will be presented and attempts made to relate these to the steel's conventional toughness properties.

Outline

1. Background
2. Objective
3. Methodology of CCA Testing
4. Results
5. Conclusions and Recommendations

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Background

- **Test Material**
  - 15.5 mm thick CSA 350WT - controlled rolled microalloyed steel with high strength and toughness
- **Deck plating, shell plating, bulkheads and bottom walls i.e. major portion of the CPF hull girder**

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Objective

- **Measure the arrest toughness in the L-T and T-L orientations, using full thickness compact crack arrest (CCA) specimens.**
  - Dynamic effects are neglected and a static arrest toughness (K_a) of a short (~250 mm long) running crack is measured.

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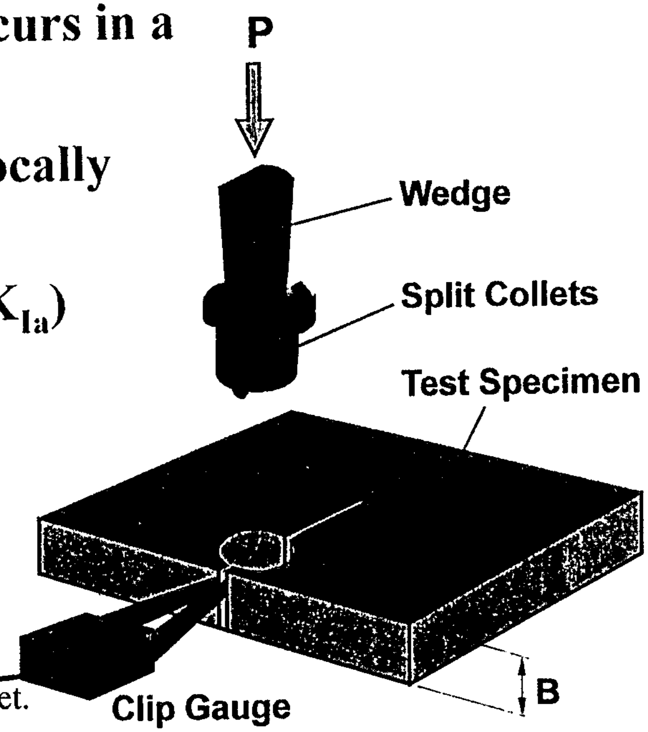
Methodology of CCA Testing

- Wedge loading - crack run occurs in a diminishing K field
- Inject a running crack from locally embrittled zone
- ASTM E1221 - Plane strain (K_{Ia}) imposed by two side grooves

$$K_a = [\delta_f E f(a/W)\ (B/B_N)] / W^{1/2}$$

where: E = Young's Modulus;
δ_f = CMOD at arrest; $f(a/W)$ = compliance function; W = distance from wedge load to back wall of specimen and a = crack length.

$K_a = K_{Ia}$ when conditions for plane strain are met.



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Methodology of CCA testing (cont)

- **<u>Modified ASTM E1221 Specimen Design</u>**

  Full Thickness (without side grooves)

  - Largest in-plane dimensions specified: (W/B) ratio of 8
  - Anticipated difficulty in obtaining a valid plane strain (K_{Ia}) due to high toughness and small thickness

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Methodology of CCA Testing (cont)

- <u>Non-plane Strain CCA Specimen Design</u> **Crosley & Ripling**

$$W \geq 2.83\,(K_v / \sigma_y)^2$$

Where: K_v = is the "anticipated" crack arrest toughness - typically the minimum required for quality control purposes; σ_y = yield strength.

As test temperature is raised in-plane dimensions (W) increase - no limit for specimen size.

Validity requirements less stringent than ASTM - no check for plane strain.

Specified CMOD limits within which the run-arrest event should occur

- lower limit is based on a minimum crack length (0.5W)
- upper limit is based on a maximum crack length (0.8W)
- if arrest length is below or above these values a lower bound or upper bound estimate of K_a is realized.

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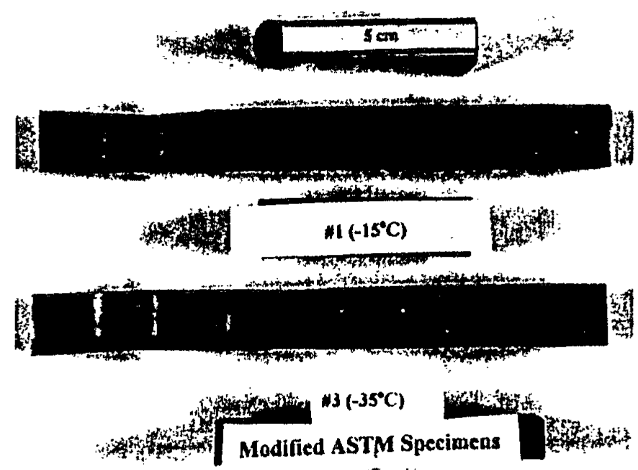
Typical Results

Modified ASTM E1221 Specimen

- Crack starter: brittle weld bead
- To get a run-arrest event of significance, loading was continued beyond the maximum limit allowed by the standard.
- Fractures displayed two stage propagation
- The significant event occurred at the 2nd stage - initiation from the tough HAZ associated with the deposition of the brittle weld bead.
- All test results did not meet validity criterion.
- Inferences:
  a) high stress intensity factor (K_0) for initiation in the second stage
  b) specimen size limitations (W/B = 8).



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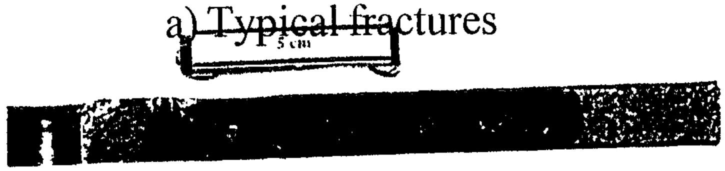
Typical Results (cont.)

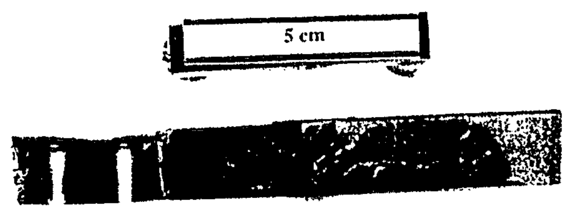
- **<u>Non-plane Strain Specimen</u>**
  - Crack starter: strain age embrittled chevron notch
  - More successful in initiating a run-arrest event within the CMOD limits.
  - **L-T Orientation**

    a) Typical fractures



#2 (W - 175mm), (30°C)

Chevron Notched Specimens



#6 (W = 100mm), (-45°C)

Chevron Notched Specimens

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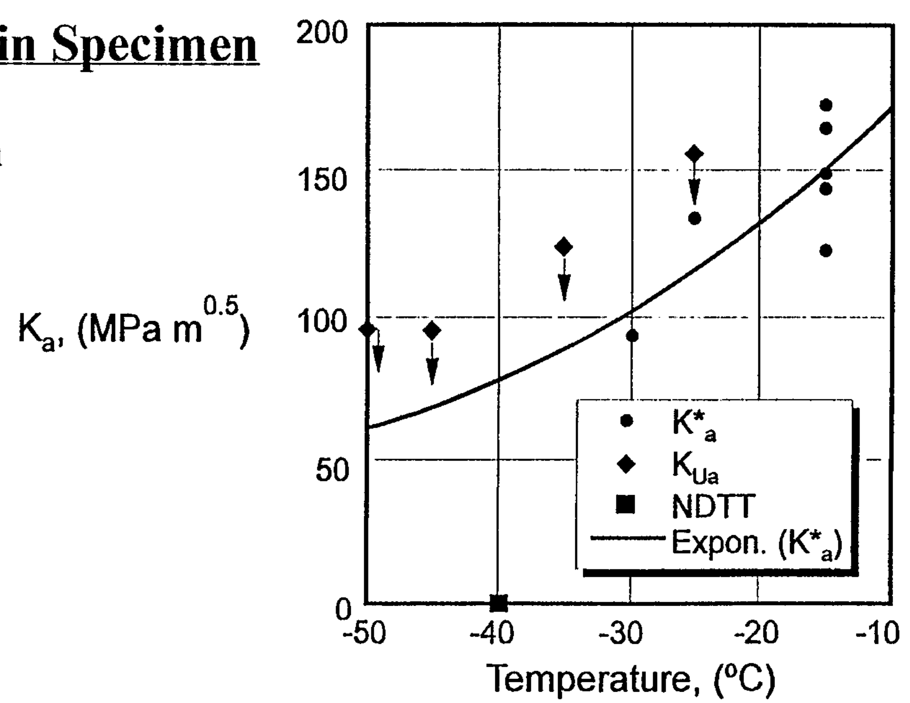
Results (cont.)

- **Non-plane Strain Specimen**

  L-T Orientation

  b) Results



Crack Arrest Toughness vs Temperature
L-T Specimens

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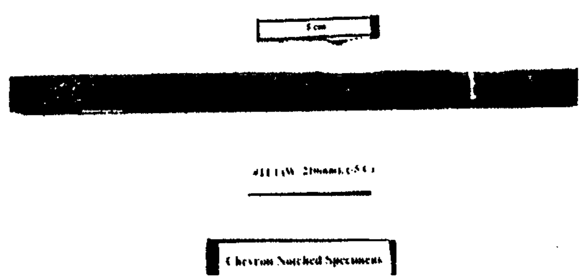
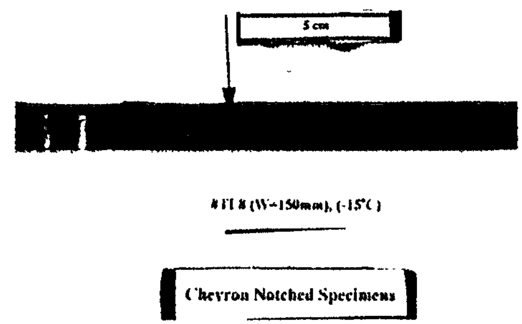
Typical Results (cont.)

- **<u>Non-plane Strain Specimen</u>**
  - **T-L Orientation**

    a) Typical fractures displaying the 3 types of behaviour





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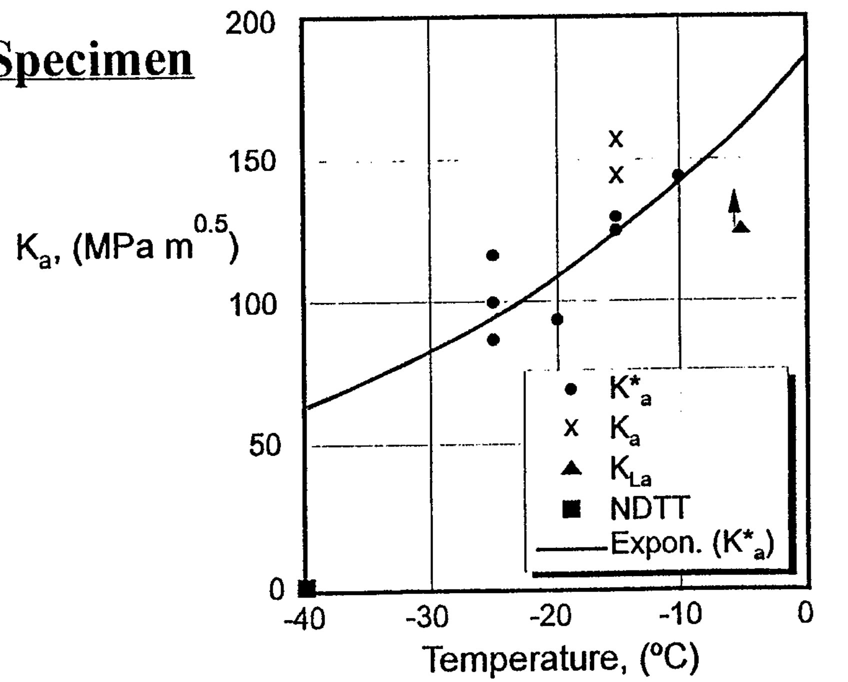
Results (cont.)

- **Non-plane Strain Specimen**

T-L Orientation

b) Results



Crack Arrest Toughness vs Temperature
T-L Specimens

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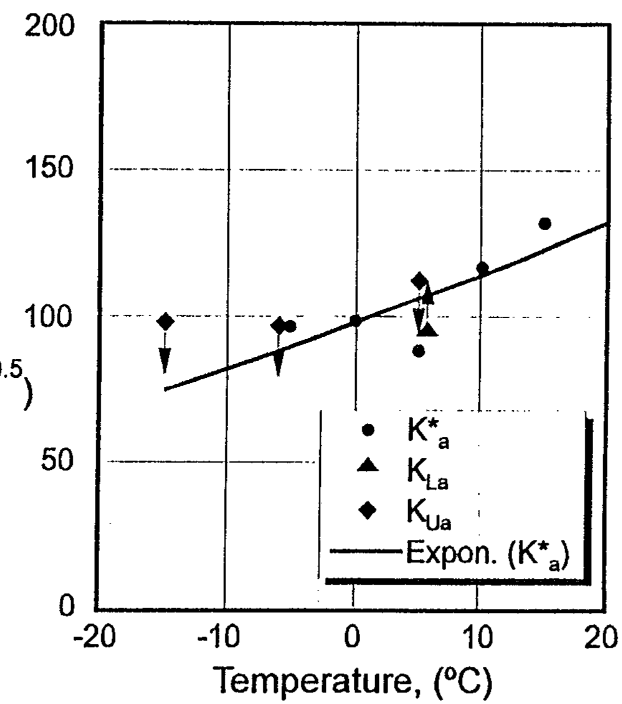
Results (cont.)

- **Non-plane Strain Specimen**
  - L-T Orientation



Crack Arrest Toughness vs Temperature
CGHAZ

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Conclusions

- **Modified (full thickness) ASTM E 1221 is not suitable -high toughness and small thickness of marine structural plate - anticipated.**
  - a) size limitation (W/B) ≤ 8
  - b) failure of the crack starter - brittle weld bead

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Conclusions

- **Non-plane strain full thickness CCA specimens were more successful for this plate.**
  - a) no size limitation; in-plane dimensions increase with anticipated increase in K_a with temperature
  - b) more successful crack starter - strain age embrittled

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Recommendation

- Study of different degrees of embrittlement of the crack starter - initial findings

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