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# Fracture Control for Surface Ships

by

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## ABSTRACT

Determining susceptibility of structural steels and weldments to transgranular cleavage instabilities is of primary importance in the safe design of any structure. Gaining acceptance during the Liberty Ship failures during the Second World War, the Charpy V-notch test (ASTM E23) has since dominated material transition curve testing in the nuclear, pipeline, pressure vessel, shipping and offshore industries. Acceptance has been in part derived from the inexpensive and simplistic nature of the test. It was recognized early on that there were a number of serious problems associated with the interpretation of the data realized from such a test. Of these perhaps the most significant was the fact that because of the notch detail and small size of the specimen, the transition curve obtained may not reflect actual structural performance of the material. Debate on the magnitude of the transition curve shift still continues (especially with the increasing use of thermo-mechanically controlled rolled steels).

DREA has been developing alternative testing procedures which provide directly transferable, structurally relevant temperature transition data. These tests will be described with respect to their applicability to fracture control issues of CF surface ships.

# SUMMARY

**Why Qualify Minimum Notch Toughness Levels for Surface Ship Structural Steels and Weldments?**

**What Small Scale Specimen Geometry Should be Utilized to Generate Notch Toughness Information?**

**What Test Parameters Accurately Describe the Fracture Characteristics of Structural Steels and Weldments?**

# MATERIAL FAILURE MECHANISMS

**Plastic Collapse (flow stress)**

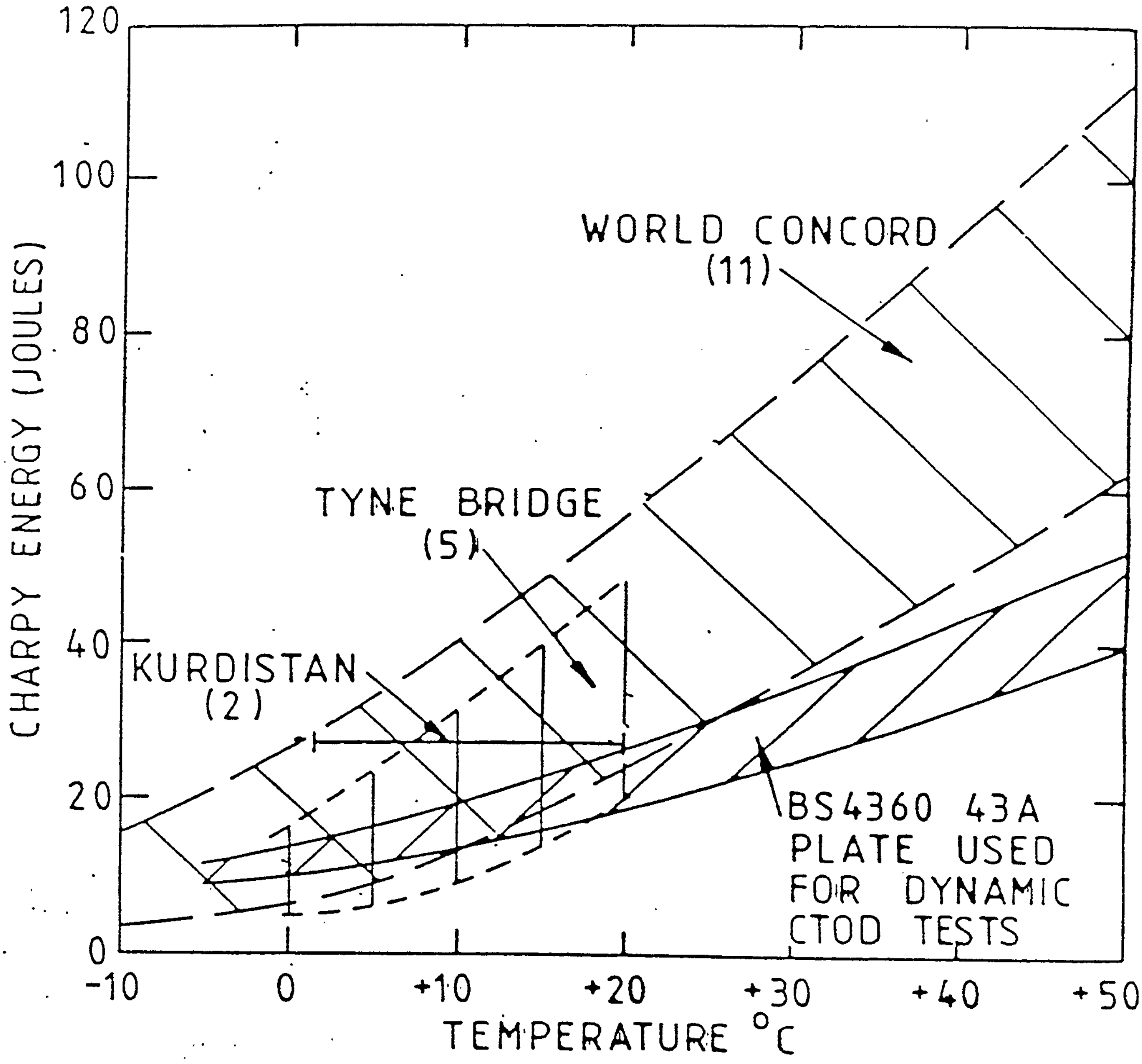
**Fracture (over the service life of a ship cracking will occur)**

- **a) Ductile Tearing**
- **b) Brittle Crack Propagation**

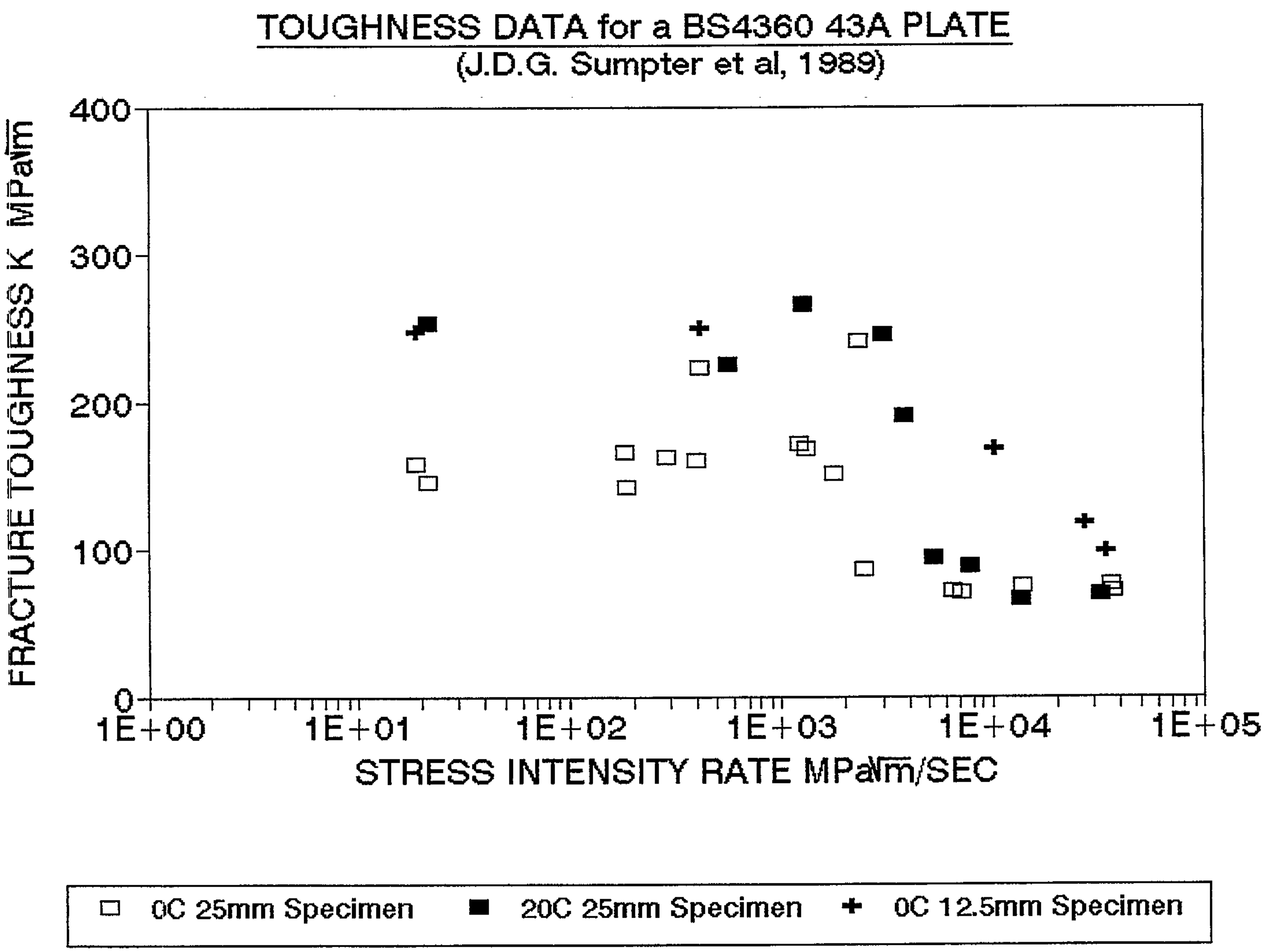
**Important Variables**

- **a) Temperature**
- **b) Loading Rate**
- **c) Constraint Effects**

**Classification Societies (Loyds, ABS) Allow the Use of Structural Steel Components Which Have No Minimum Material Notch Toughness Requirements**




(J.D.G. Sumpter et al, 1989)


TOUGHNESS DATA for a BS4360 43A PLATE
(J.D.G. Sumpter et al, 1989)
FRACTURE TOUGHNESS K MPa√m
400
300
200
100
0
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
STRESS INTENSITY RATE MPa√m/SEC
0C 25mm Specimen
20C 25mm Specimen
0C 12.5mm Specimen

## SOURCES OF DYNAMIC LOADING

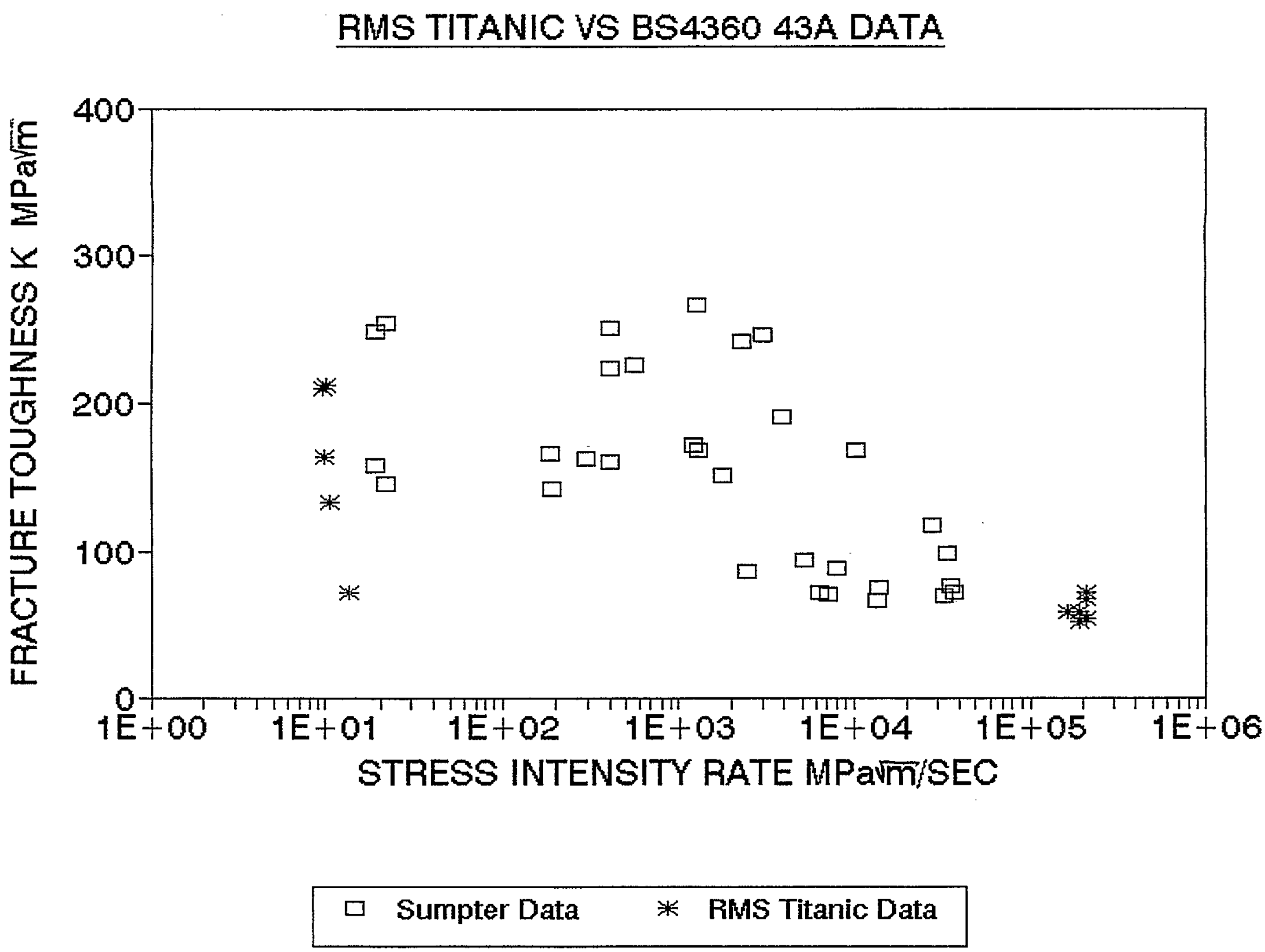
Slamming (global stress, intermediate rate)

Side Shell Impact (local stress, high rate)

Collision (local & global stresses, high rate)

Grounding (local & global stresses, high rate)

Weapons (local & global stresses, high rate)


RMS TITANIC VS BS4360 43A DATA
FRACTURE TOUGHNESS K MPa√m
400
300
200
100
0
1E+00
1E+01
1E+02
1E+03
1E+04
1E+05
1E+06
STRESS INTENSITY RATE MPa√m/SEC
Sumpter Data
RMS Titanic Data

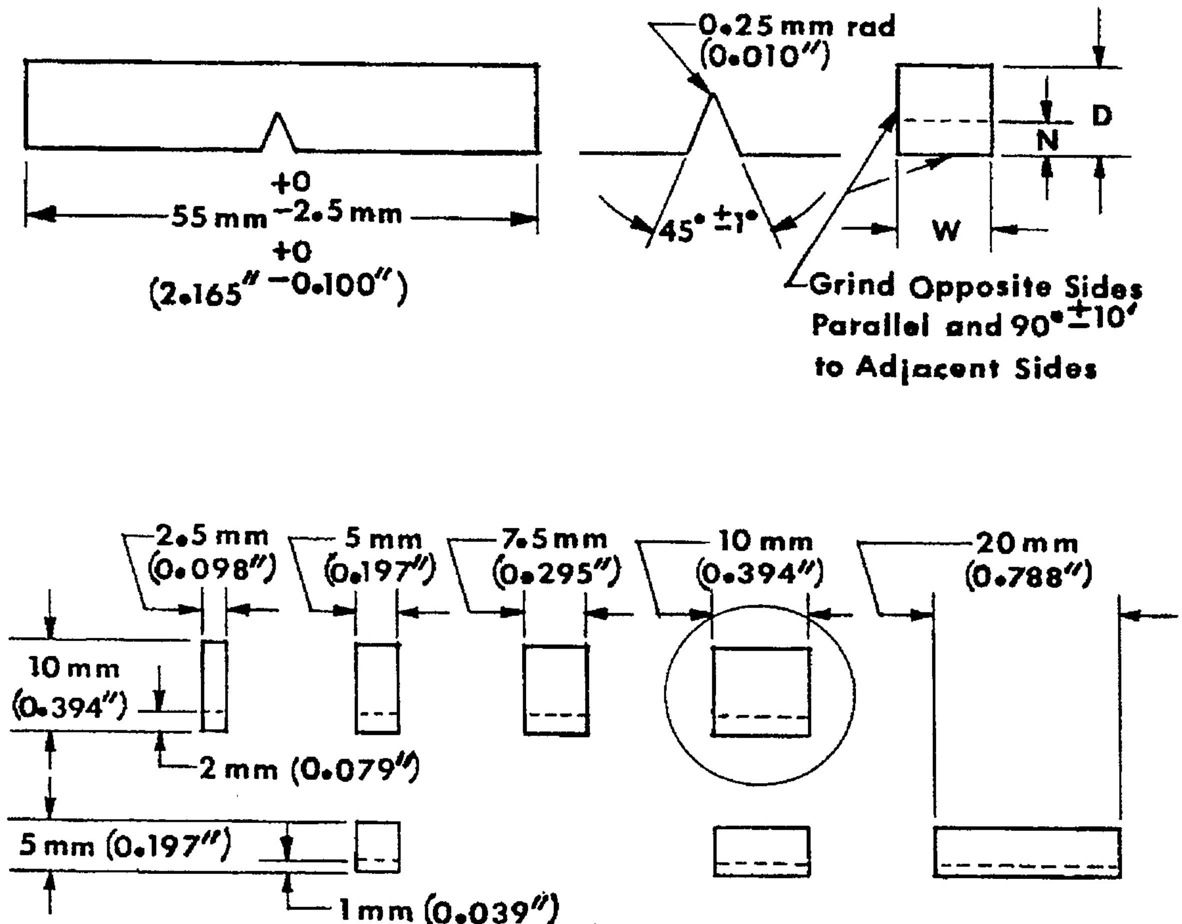
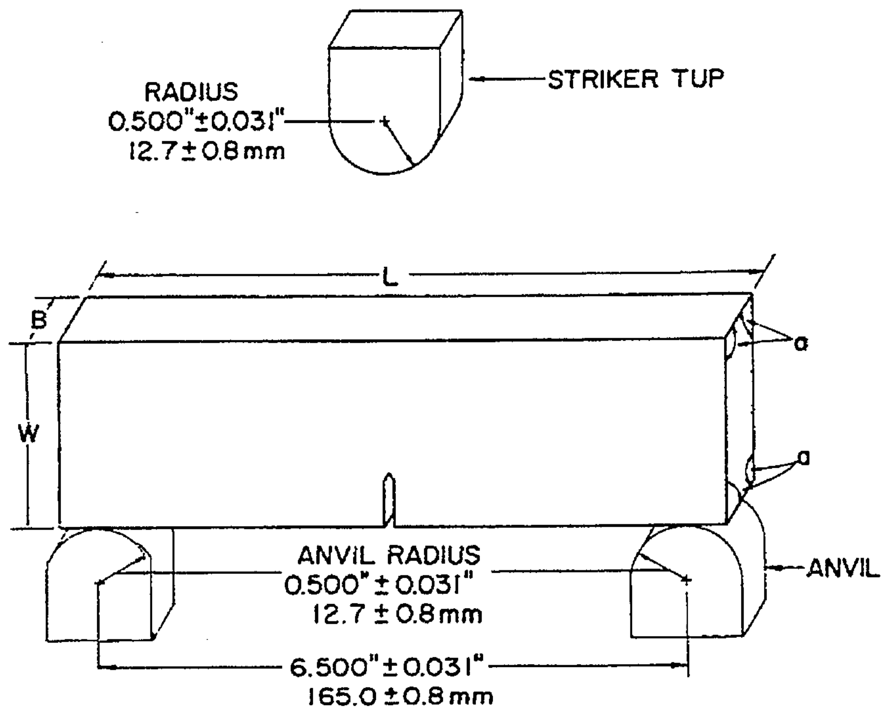



**Figure 3** - ASTM E-23 Charpy V-notch impact specimen



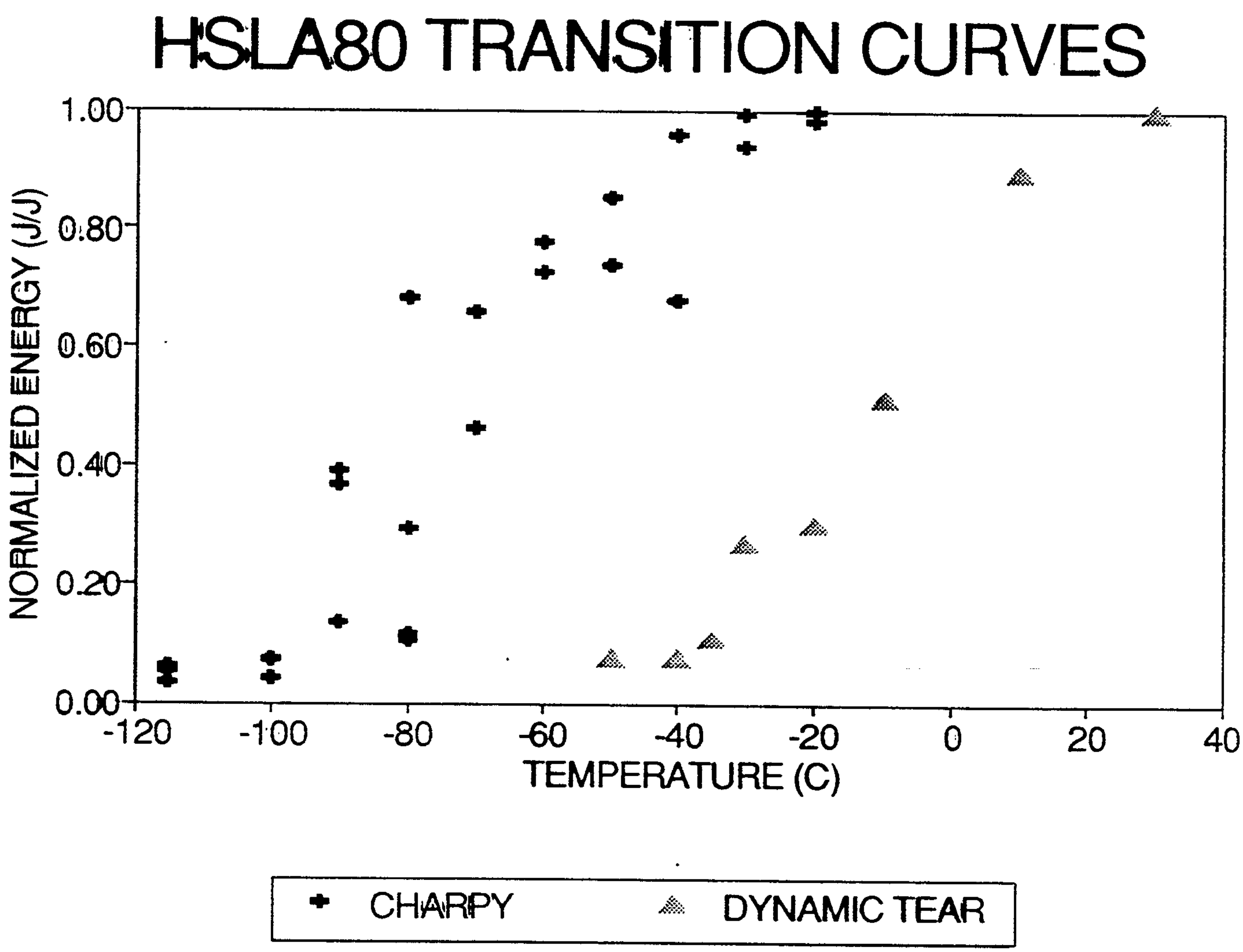

Dimensions and Tolerance for Specimen Blank

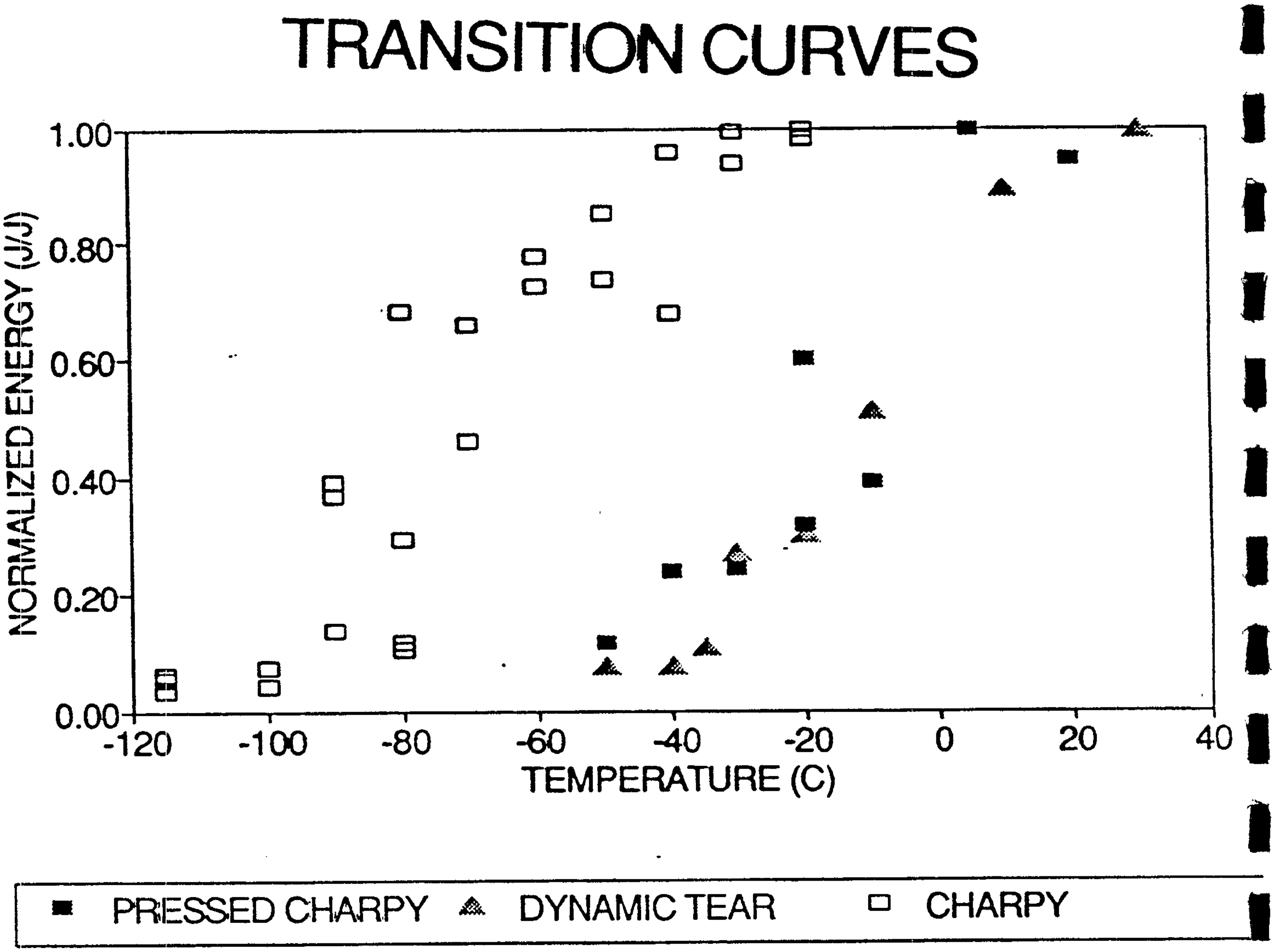
| Parameter | Units | Dimension | Tolerance |
|---|---|---|---|
| Length, *L* | in. | 7.125 | ±0.125 |
| | mm | 181 | ±3 |
| Width, *W* | in. | 1.60 | ±0.10 |
| | mm | 41 | ±2 |
| Thickness, *B* | in. | 0.625 | ±0.035 |
| | mm | 16 | ±1 |
| Angularity, α | deg | 90 | ±1 |

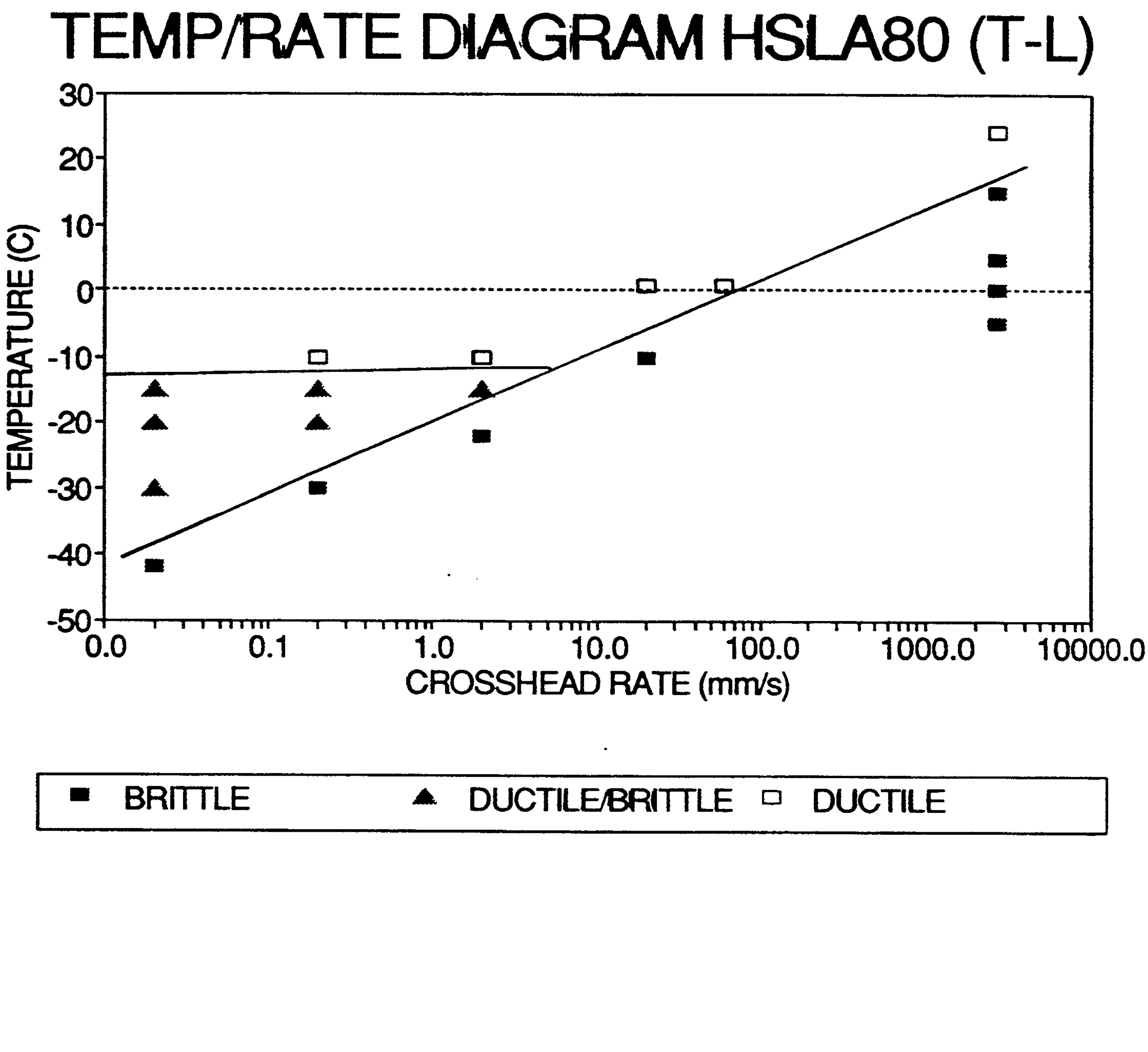
NOTE—See 9.1 for specimens less than ⅝-in. (16 mm) thick.

**FIG. 1 Dynamic Tear Test Specimen, Anvil Supports, and Striker**

**Figure 4** - ASTM E604 dynamic tear impact specimen.


HSLA80 TRANSITION CURVES
NORMALIZED ENERGY (J/J)
1.00
0.80
0.60
0.40
0.20
0.00
-120
-100
-80
-60
-40
-20
0
20
40
TEMPERATURE (C)
CHARPY
DYNAMIC TEAR


TRANSITION CURVES
NORMALIZED ENERGY (J/J)
1.00
0.80
0.60
0.40
0.20
0.00
-120
-100
-80
-60
-40
-20
0
20
40
TEMPERATURE (C)
PRESSED CHARPY
DYNAMIC TEAR
CHARPY


TEMP/RATE DIAGRAM HSLA80 (T-L)
TEMPERATURE (C)
30
20
10
0
-10
-20
-30
-40
-50
0.0
0.1
1.0
10.0
100.0
1000.0
10000.0
CROSSHEAD RATE (mm/s)
BRITTLE
DUCTILE/BRITTLE
DUCTILE

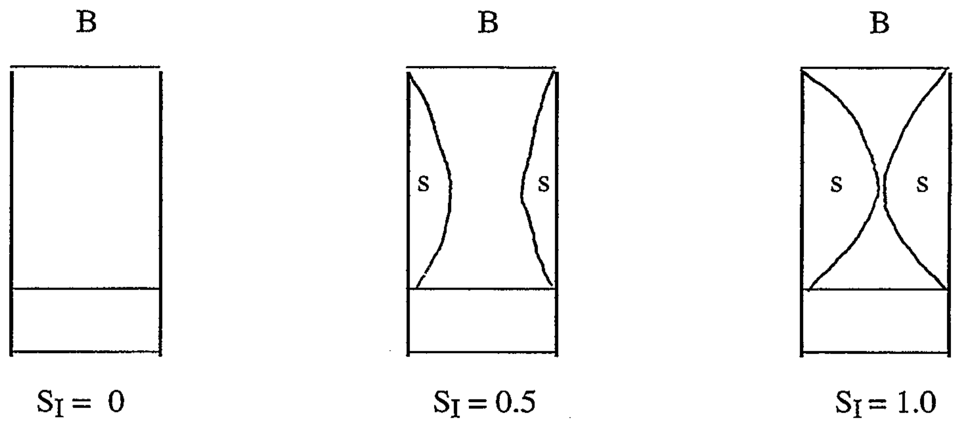



Fig. 1. Typical morphologies for dynamic tear impact samples (shear index is measured at the point of the closest contact between the two shear lips: $S_I = 2s/B$).

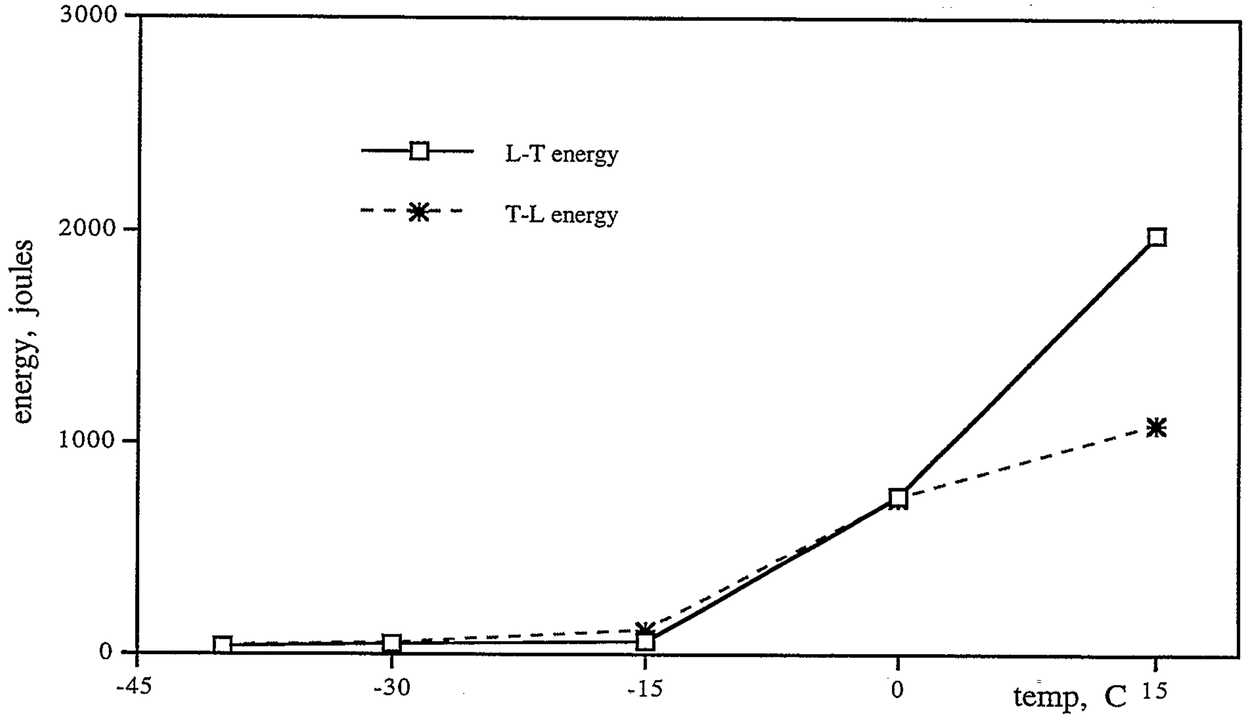



Figure 1a: Dynamic tear energy for 15 mm 350 WT steel.

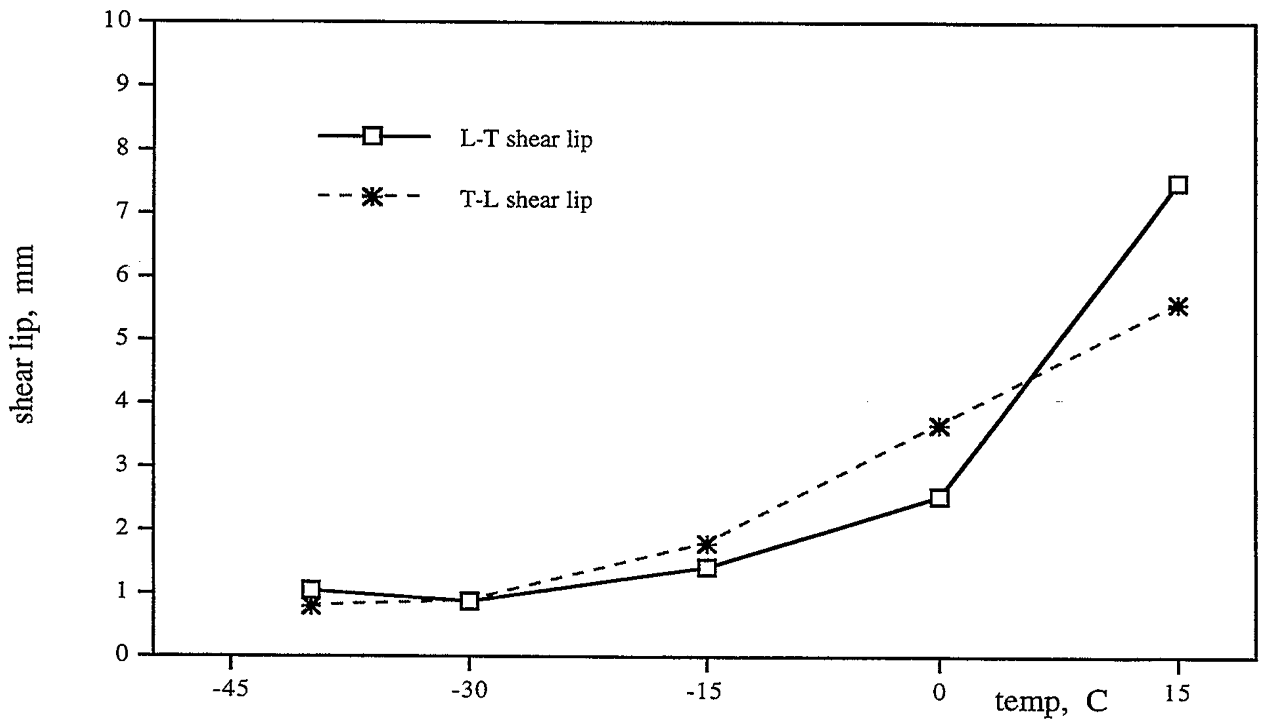



Figure 1b: Shear lip transition curves for 15 mm 350 WT steel.

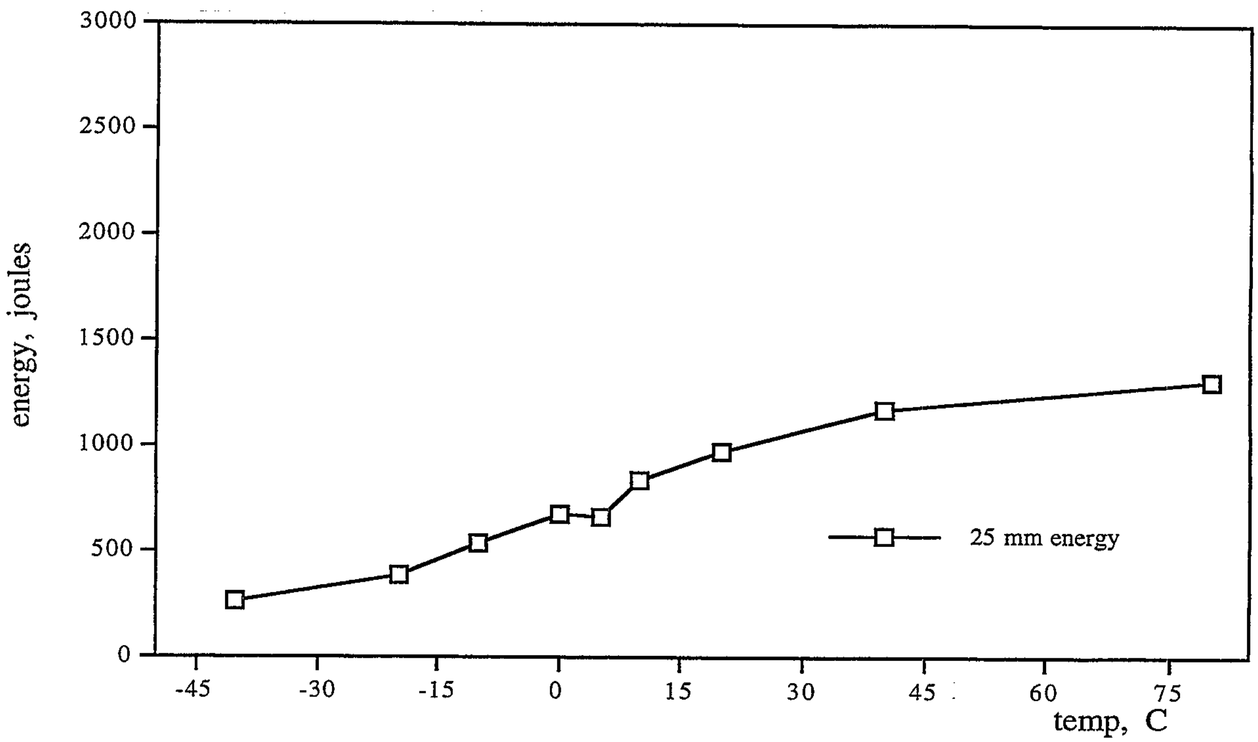



Figure 2a: UK produced marginal toughness GMAW weldment (2-4 kJ/ mm). Marginal toughness was intentionally produced for TTCP Op Ass.

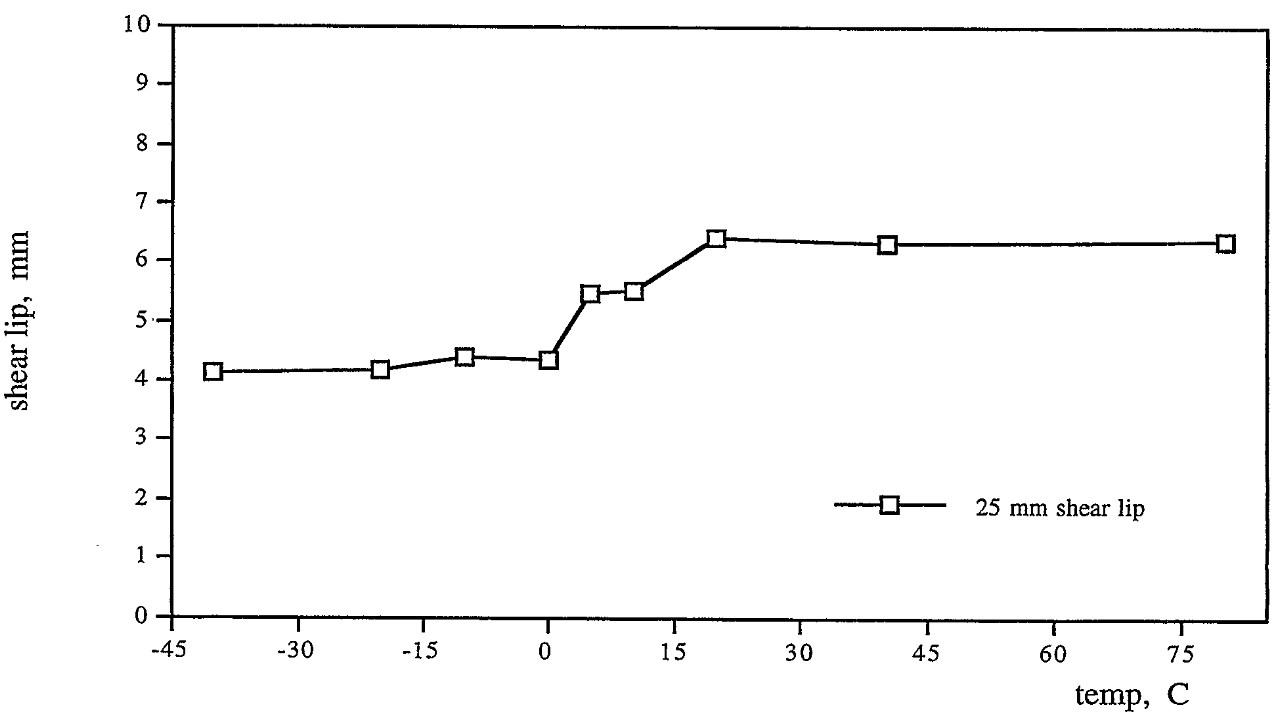



Figure 2b: UK produced marginal toughness GMAW weldment (2-4 kJ/mm). Marginal toughness was intentionally produced for TTCP Op Ass.

## CONCLUSIONS

In conclusion, by not specifying minimum notch toughness requirements for steel and weldments we've ignored fracture as a possible failure mechanism in the design process.

Investigations into surface ships which have suffered structural failure indicate that the absence of notch tough steel leaves these structures susceptible to failure under dynamic loading.

The Dynamic Tear specimen geometry and procedure provides transition temperature information which is directly transferable when predicting structural response.

Transition curves generated using the shear lip measurement procedure outlined correlates well to transition curves developed from fracture energy measurements.