Using Small Scale Mechanical Tests to Predict the Crack Arrest Properties of Modern Structural Steels

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1. Background

Most structural integrity procedures aim to reduce the chance of fracture initiation.

An alternative approach uses the concept of crack arrest. In this approach, it is assumed that:

- a crack may initiate in a region of local stress intensity or embrittlement;
- the material is designed with a toughness high enough to arrest the crack outside these regions;
- the crack is prevented from lengthy, catastrophic, growth.

This is additionally important in welded structures where local welding imperfections and embrittlement can cause failure if the crack is not arrested in the bulk material.

Figure 1: result of a brittle crack's failure to arrest in a pipeline can cause catastrophic failure.

2. Research Problem

There are a multitude of empirical relations which relate small scale test results to structural behavior. These are preferred to structural tests because they are cheap and simple.

CAT = NDTT + 10

$$K_{IA} = 30 + 70\exp\left(\frac{\mathrm{T} - \mathrm{T}_{4kN} - 12.3}{52.63}\right)$$

CAT = DWTT 50% FATT

$$CAT = [NDTT + 10] + \left[\frac{\ln(\sigma)}{0.046} - 105\right] + [153(B-5)^{13} - 190]$$

CAT = 120J CVN + 60

CAT = NDTT +40

$$K_{IA} = 49.957 + 16.878\, exp0.028738(T - NDTT)$$

However, these relationships are valid only for specific materials under specific conditions. They are not applicable to modern structures with:

- Tougher materials,
- Thicker sections,
- Harsher loading conditions.

These relationships need to be verified for a range of modern steels to determine their applicability and drive standards. In the present study the mechanical properties of five structural steels were investigated through a range of small scale test methods.

3. Results

- Industry prefers Charpy test because it is cheap and standardised.
- Upper shelf Charpy energy is taken to indicate arrestibility.
- However there is no correlation (figure 2).
- NDTT indicates the onset of brittle behaviour.
- However for these steels, the NDTT lies on the upper shelf of the Charpy transition curve (figure 3). i.e. ductile region.
- However, there is good correlation between the 27J temperature (onset of lower shelf) and the NDTT (figure 4).
- Even for the steels where the NDTT lies on the upper shelf.

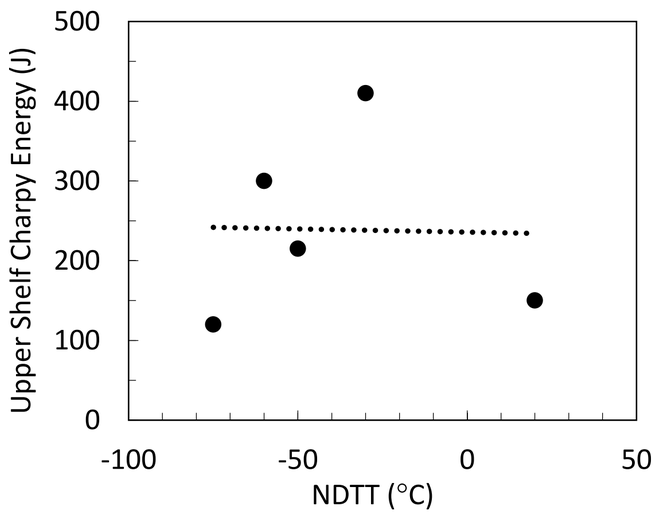

Figure 2: initiation fracture toughness from Charpy tests vs crack arrest toughness from Pellini tests (NDTT)

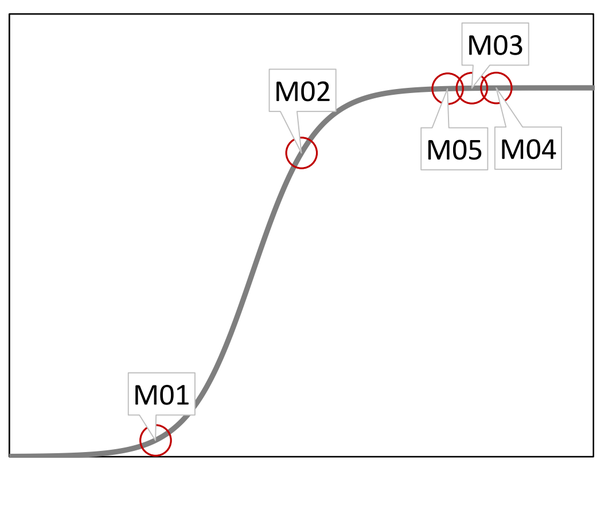

Figure 3: schematic representing where the NDTT lies on the Charpy curve for each material.

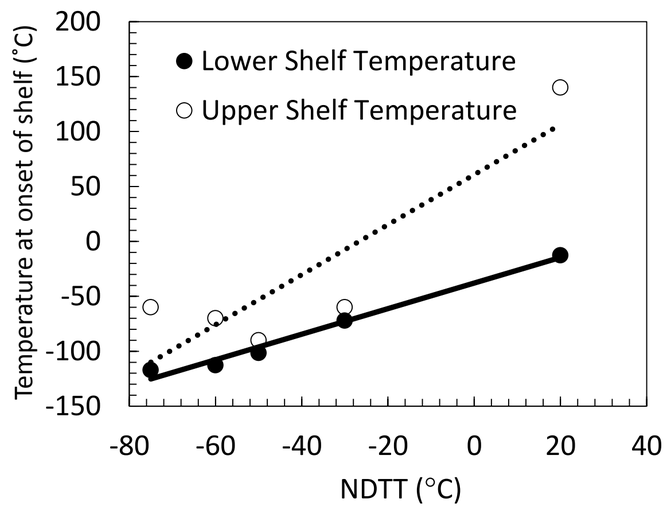

Figure 4: temperature of the onset of the shelf (upper/lower) vs NDTT

4. Conclusions & Future Work

- Simple Charpy tests cannot predict arrest properties, but the lower shelf may indicate arrestibility.
- Need to relate these results to large scale properties.
- Industry needs to move on from Charpy testing to a fracture mechanics test i.e. NDTT.
- Limited to small scale tests within the scope of this PhD (no wide plate tests) – aim to partner with University of Tokyo or Chinese steelmakers to provide wide plate results for comparison

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