Assessment of crack arrest behaviour in modern structural steels

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1. Motivation

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 will 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 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.

2. Procedure

The ability of a material to arrest a crack is usually described in one of two ways: stress intensity factor (K_{IA}) or crack arrest temperature (CAT).

- K_{IA} is the critical stress intensity factor for fracture mode I crack arrest, above which a fast-running crack is arrested, and is calculated using the standards.
- The CAT is the minimum temperature at which the material arrests a crack.
  - The CAT approach often employs Robertson tests, ESSO tests, Charpy tests or drop weight tests.
  - These are generally simple pass/fail crack propagation tests which are carried out at different temperatures to find the nil ductility transition temperature (NDTT) and the CAT, and can be empirically related to large-scale specimens

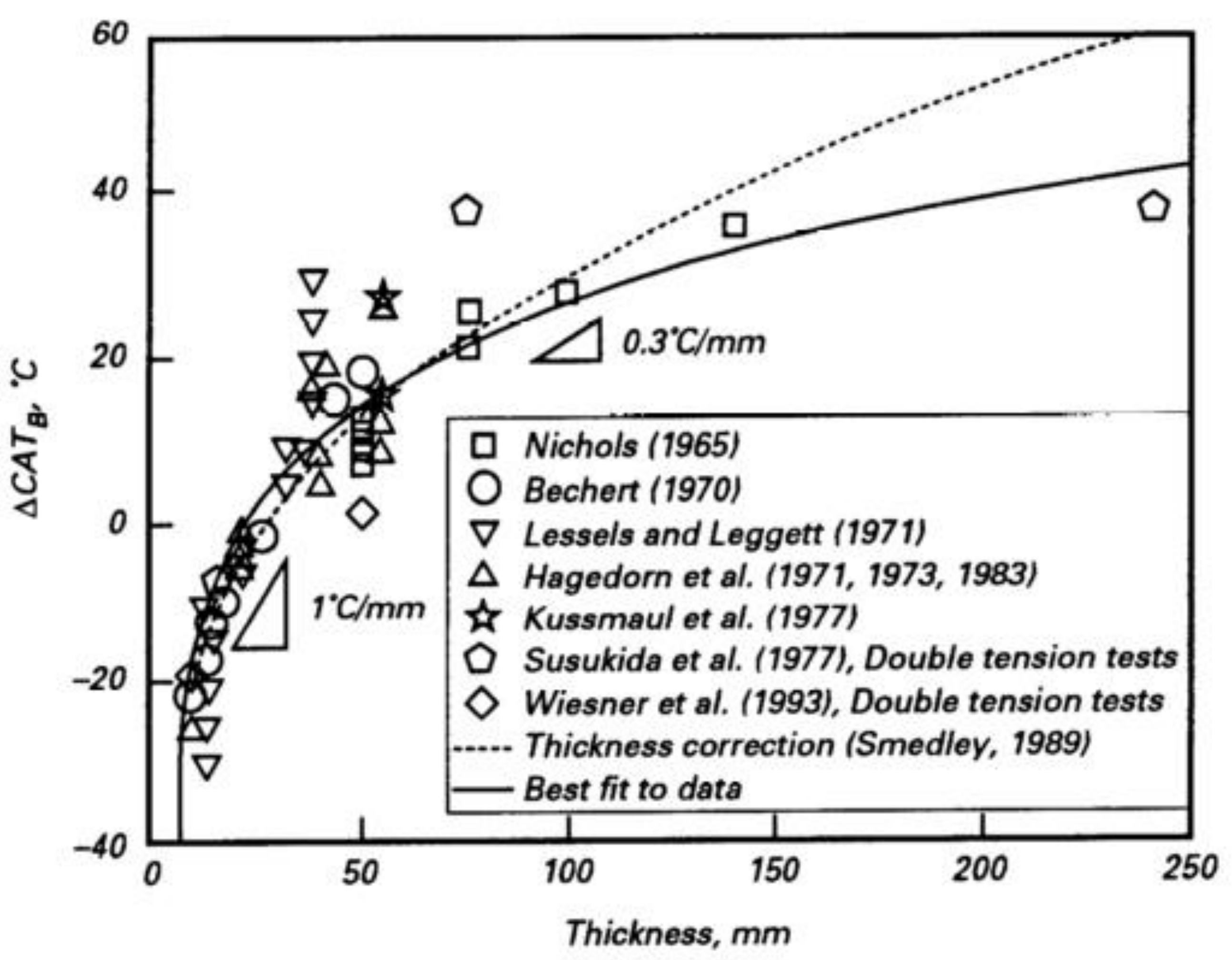

Figure 1. Change in CAT compared to that of a plate with 25mm thickness. A large amount of scatter is shown in samples above 50mm thickness. (Wiesner, 1995)

3. Empirical Equations

There are a multitude of empirical relations which have been derived for different tests under different conditions. Whilst this is adequate for validation, the mechanism of arrest is not fully understood which means that these are not applicable to the new, tougher materials, thicker sections, and current loading conditions.

CAT = NDTT + 10

CAT = DWTT 50% FATT

CAT = 120J CVN + 60

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

CAT = NDTT +30

CAT = NDTT +40

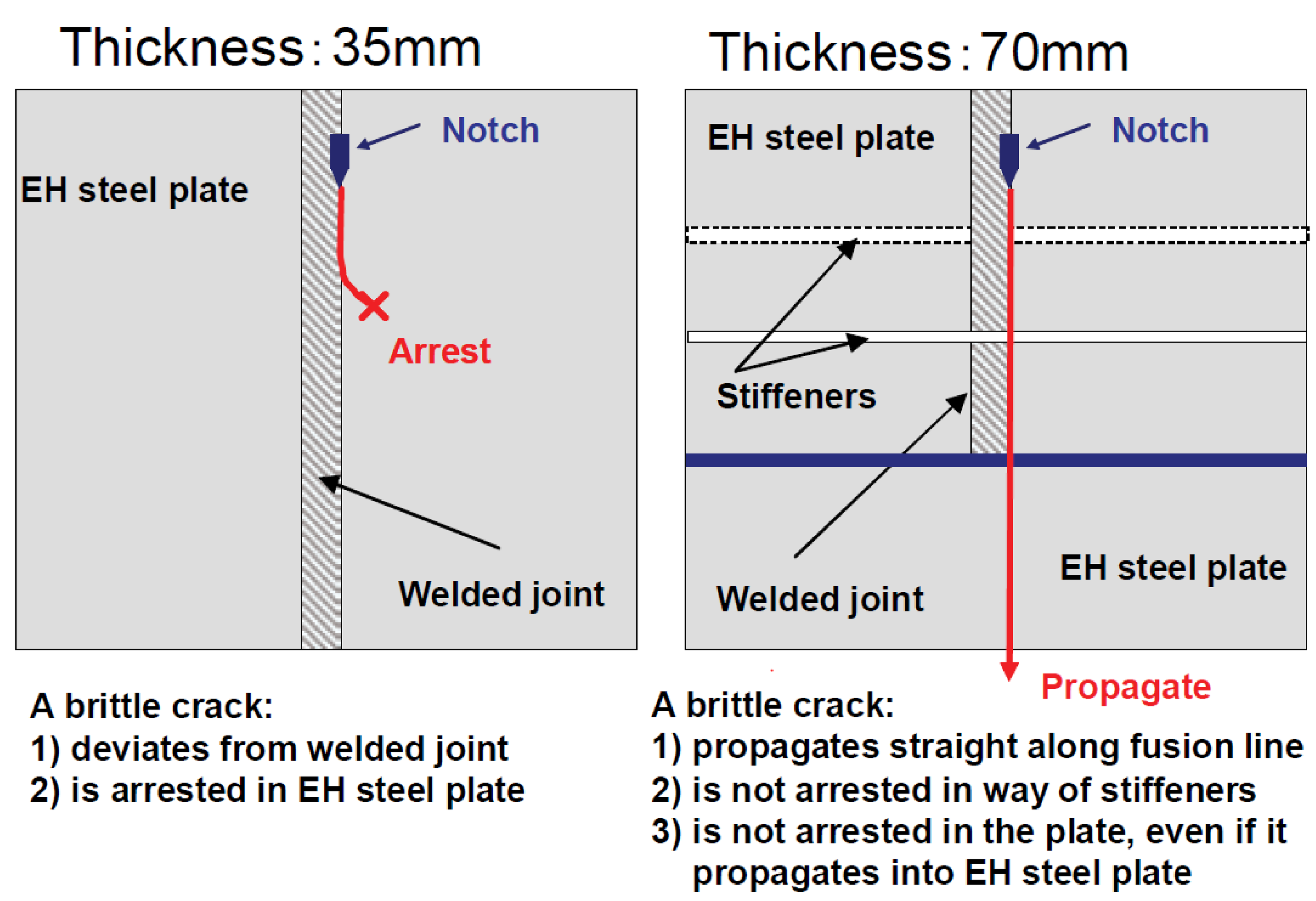

Figure 2. Effect of increased plate thickness of crack arrest behaviour in EH shipbuilding structural steels. (Sugimoto, 2010)

4. Thickness Effects

The crack arrest behavior of small samples is adequately understood, however:

- The increasing tonnage of container ships leads to a necessity in using thicker hulls of higher strength steels,
- This has an adverse effect on both their fracture toughness and crack arrestability.

This can be shown in figure 2 where, even with added stiffeners, the crack is not arrested in the thicker plate of steel.

As the thickness of the steel increases, the empirical relationships between the small scale Charpy tests (which are favored in the industry) and the NDTT starts to break down, which causes additional issues with material characterization.

5. Conclusions & Future Work

Whilst the empirical relationships between small and large scale tests were valid for previous material specifications, a deeper understanding of the mechanism governing crack arrest is needed in order for it to be a futureproof approach to preventing fracture. New test procedures may need to be developed in order for appropriate certification of materials and vessels to be possible. Additionally, current test procedures need to be optimized for this purpose to ensure compliance with one another and more confidence in results.

References: K. Sugimoto, "Thickness effect on brittle crack arrest toughness value (Kca)-6,", 2010. and C. Wisener, "A Review of Crack arrest tests, models and applications," 1995.