RELATIONSHIP BETWEEN STRETCH ZONE AND DYNAMIC FRACTURE TOUGHNESS

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ABSTRACT

On the fracture surfaces of precracked Charpy specimens of various steel grades, the stretch zones were determined by means of a scanning electron microscope, and coordinated with the results of the instrumented Charpy test. Dynamic values of fracture initiation toughness, σ_{di} or J_{di}, can be determined from the stretch zone height. The temperature dependence of the stretch zone permits a fracture initiation transition temperature T_i to be defined. Measuring the stretch zone on precracked Charpy specimens yields a better relationship between the micro-structural and topographical features of the crack tip behaviour and macroscopic dynamic fracture toughness parameters.

KEYWORDS

Precracked instrumented Charpy test; dynamic fracture toughness; stretch zone.

INTRODUCTION

The precracked instrumented Charpy test is a well-known method of determining dynamic fracture toughness parameters. The load-deflection or load-time curves of this test can be evaluated concerning the type of diagram by the LEFM, COD or J-integral concept. When fracture occurs prior to general yield, the value K_{pci} of dynamic initiation of unstable crack growth can be determined from the maximum load. However, in the case of elasto-plastic specimen deformation with limited or fully stable crack extension, monitoring for fracture initiation is difficult. One possible approach is to measure the stretch zone on the fracture surface.
The stretch zone is the characteristic feature of crack tip blunting which precedes actual crack extension (Fig. 1).

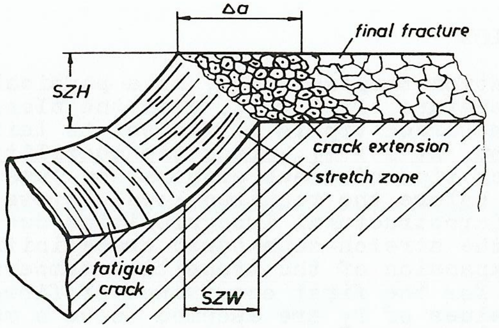

Fig. 1. Schematic representation of the stretch zone

Evidence of the stretch zone and correlations with fracture toughness parameters have been reported in several papers, e.g. Bayoumi and Bassim (1983), Blauel (1980), Hopkins and Jolley (1983), Krasovsky and Vainshtok (1981), Miyamoto, Kobayashi and Ohtsuka (1983), Provenzano and coworkers (1983). These studies provided a better understanding of the crack blunting and propagation process in the case of static loading. This contribution was prepared to outline the importance of the stretch zone to determining the dynamic fracture initiation parameters and defining a physically defined transition temperature.

EXPERIMENTAL

The steel grades investigated were a CrMoV pressure vessel steel (17CrMoV10) with various sulfur content, H52 and H 60 medium-strength steels with different grain size, a vacuum-melted steel containing 13 % Cr (UR-X5CrNi13), and a cold-tough cast steel (2001FL).
Using an instrumented impact pendulum, fatigue-cracked ISO-V specimens ($a/W = 0.5$) were tested at various temperatures and load-time diagrams recorded. Both stretch zone width (SZW) and stretch zone height (SZH) measurements were carried out by a scanning electron microscope of type JSM50-A, Blumenauer and Wagner (1980). On all the materials the stretch zones were well seen; however, the uniformity of stretch zone formation clearly varied with the degree of purity. In order to eliminate the influence of shear lips on the surface of notched-bar specimens, the stretch zone measurements were each started at 1 mm distance from the specimen edge so that, for each fracture surface, an 8 mm wide stretch zone formation was plotted from some 200 individual values.

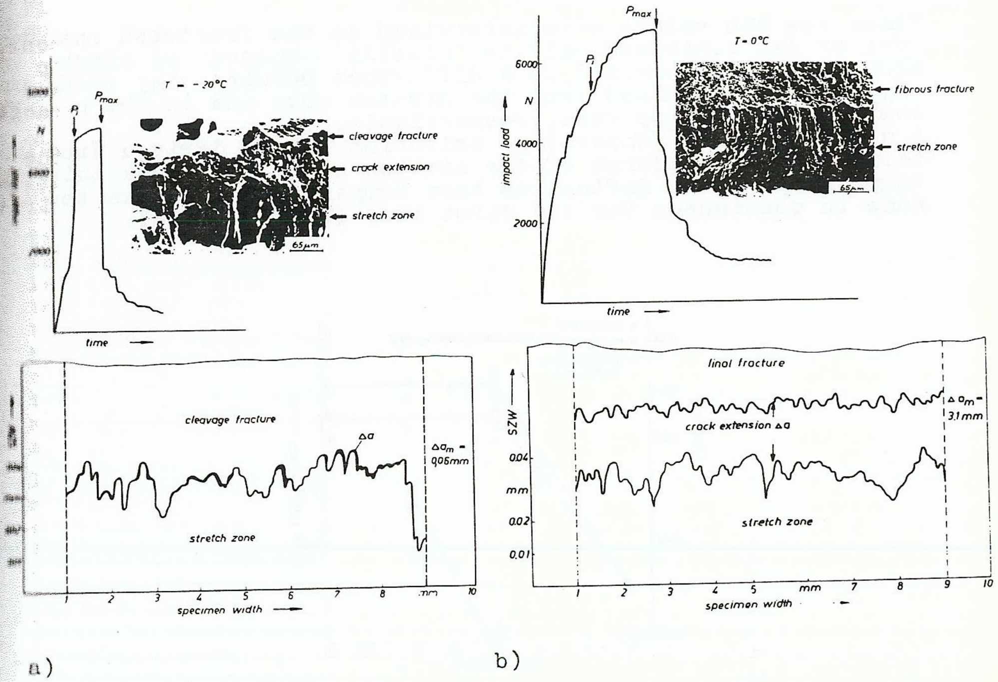

Fig. 2. Load-time diagram and stretch zone for CrMoV pressure vessel steel
a) Test temperature -20 °C
b) Test temperature 0 °C

RESULTS

Fig. 2 shows typical load-time diagrams for the CrMoV pressure vessel steel, along with plots of the stretch zone height and the pattern of SZW and stable crack growth. For lower temperatures only an interrupted stretch zone can be seen. The formation of a continuous stretch zone is manifested in a plateau of the load-time plot after the initiation load P_i. A sudden load drop after the maximum load P_{max} is characteristic of cleavage-induced unstable crack growth following the stretch zone formation. The gradual load drop corresponds to slow crack growth by dimple fracture. Thus, it is evident that the stretch zone reflects the phenomena in the process zone ahead of the crack tip. Consequently, the following correlation can be established with the dynamic parameters of fracture initiation:

$$\delta_{di} = 2 \cdot SZH \qquad (1)$$

$$J_{di} = m \cdot \sigma_{dF} \cdot \delta_{di}, \qquad (2)$$

where the constraint factor m can range from 1 to 3 and σ_{dF}

is the dynamic flow stress.

Since the SZH values were determined on the fractured specimens, σ_{di} or J_{di} contained only the plastic component of crack tip blunting. This resulted in a difference between σ_{di} (SZH) and σ_{di} (PCI) determined from the stretch zone and in the precracked instrumented Charpy test, respectively.
A new transition temperature criterion can be derived from the temperature dependence of the stretch zone. The crack initiation temperature T_i is defined as that temperature at which the stretch zone is continuous for the first time (Fig. 3 and 4).

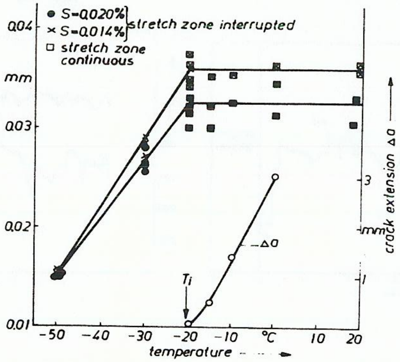

Fig. 3. Stretch zone and stable crack growth vs. temperature for CrMoV steel

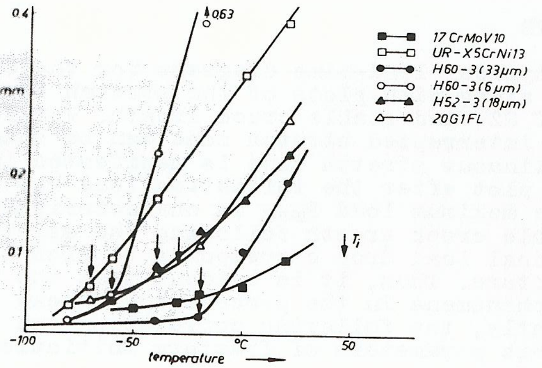

Fig. 4. Dynamic COD values vs. temperature for various materials

Fig. 3 also shows, that the SZW of the steel with the lower sulfur content is larger.

CONCLUSION

The crack initiation temperature T_i is a physically defined transition temperature. At $T < T_i$, even the elastic stress concentration at the crack tip is sufficient to initiate unstable crack propagation. At $T > T_i$, crack tip ductility entails blunting of the crack tip and crack propagation (unstable or stable) is possible not before the required local stress concentration is reached on microstructural irregularities due to an increase in load. Thus, the stretch-zone-based crack initiation temperature T_i is an expansion of the transition temperature T_F propose by Knott (1981) for the first occurrence of fibrous fracture observed. The values of T_i are assumed to be a material characteristic independent of specimen geometry, since the fracture mode on which its definition is based, i.e. stretch zone with subsequent cleavage, is the same in thick-walled components.

It may well be possible to make use of σ_{di} or J_{di} values determined at T_i, in estimating tolerable flaw sizes, e.g. by means of COD or J-integral design curves, as well as in failure analysis. The information contained in the stretch zone pattern, about the influence of the microstructure, predominantly that exerted by inclusions on fracture initiation, is essential to alloy design.

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