THE EFFECT OF CRACK BLUNTING IN LIQUID METAL ENVIRONMENTS ON $K_{IEAC}$ DETERMINED BY THE RISING LOAD TEST

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(Received 13 March 1996)

$K_{IEAC}$ is the threshold stress intensity below which environmentally assisted crack growth does not occur. This parameter is equivalent to $K_{ISCC}$ for stress corrosion cracking, or $K_{ILME}$ for crack growth in molten metal environments. Two techniques frequently employed in the determination of $K_{IEAC}$ are the constant load and constant displacement tests. Although these tests have been used extensively in the past [1], they require substantially long testing times before reliable $K_{IEAC}$ values can be obtained. By using environments significantly more aggressive than those encountered in practice, the testing times can be reduced. However, this approach introduces considerable difficulties and uncertainties in the interpretation of data.

In order to overcome the limitations of the constant load and constant displacement tests, McIntyre and Priest [2] proposed the use of an accelerated testing method, now commonly referred to as the rising load $K_{ISCC}$ test. This technique is essentially identical to the procedure used for $K_{IC}$ fracture toughness testing [3], except that slower loading rates are used. A monotonically increasing load is applied to a pre-cracked fracture mechanics type specimen exposed to the environment of interest. The stress intensity for crack initiation is calculated from the initiation load, as determined from the point of deviation from the linear load–displacement record, and the corresponding crack length (Fig. 1). This stress intensity value is assumed to be equivalent to $K_{IEAC}$.

![Fig. 1. Schematic of the rising load $K_{ISCC}$ test method [11].](image-url)
The rising load $K_{IEAC}$ test has been used successfully on a number of material–environment combinations [4–9]. The technique has also been shown to be applicable under elastic–plastic fracture mechanics conditions [6–9]. A further advantage is that both $K_{IEAC}$ and crack growth rate data can be determined from a single test.

A current limitation to the use of the rising load $K_{IEAC}$ technique is the determination of the loading rate necessary to obtain reliable and accurate values of $K_{IEAC}$. Hirano et al. [5] and Mayville et al. [10] have shown that $K_{IEAC}$ varies with loading rate or the rate of increase of stress intensity ($dK/dt$). As $dK/dt$ decreases, $K_{IEAC}$ decreases, and at low $dK/dt$ values $K_{IEAC}$ becomes constant (Fig. 2). Furthermore, it appears that at very low values of $dK/dt$ the apparent $K_{IEAC}$ may again increase [10]. This is shown schematically with a dotted line in Fig. 2. Mayville et al. [11] have proposed a procedure to determine the required loading rate base from crack growth data in inert environments and in the environment of interest, the latter being obtained by alternative test procedures.

The increase in apparent $K_{IEAC}$ at low loading rates has been attributed to the formation of a protective film at the crack tip [10]. Under conditions of low loading rates, the rate of film formation (e.g. oxidation) can exceed the rate of crack growth and thus lead to the formation of a protective layer which essentially shields the crack tip from the environment. The formation of such a protective film at the crack tip under stress corrosion conditions has been well documented [12].

Wheeler et al. [13] have reported similar results in the case of crack growth in the aluminium–molten mercury system. By changing the loading conditions from fixed displacement to fixed or increasing load, a decelerating crack (under fixed displacement) was changed to an accelerating crack (under fixed or increasing load). If the stress intensity, and hence crack growth rate, at which the loading conditions were changed was high, the crack would accelerate under fixed or increasing load conditions. However, if the change in loading conditions was made at lower stress intensities, and therefore at lower crack growth rates, the crack would initially accelerate, but would then decelerate and eventually arrest. This behaviour is shown schematically in Fig. 3. Wheeler et al. [13] showed that these observations were due to crack tip oxidation effects which compete with the crack growth process. At low crack growth rates, crack tip oxidation is sufficiently rapid to suppress crack growth. At higher crack growth rates, however, insufficient time is available for oxidation to take place, and, therefore, crack growth dominates.

A further cause for the increase in the apparent $K_{IEAC}$ at very low loading rates which has not been addressed to date is the occurrence of crack blunting at low crack growth rates in certain material–environment systems. The present authors have carried out extensive crack growth...
growth tests on 63/37 brass in a molten gallium environment where liquid metal induced embrittlement of the solid metal occurs. Fatigue tests performed under various conditions of load ratio, cyclic frequency, load wave form and temperature have shown that at low crack growth rates, or where the crack tip is exposed to the liquid metal for long periods, dissolution of the solid metal into the liquid metal takes place at the crack tip [14, 15]. This results in blunting of the crack tip, which, in turn, leads to an increase in the apparent stress intensity required for subsequent crack initiation. Preliminary rising load $K_{IEAC}$ tests performed on the same material–environment system suggest that blunting also occurs under monotonically loading conditions, provided the loading rate is sufficiently slow [16].

It should be noted that crack tip blunting due to the dissolution of the solid metal into the liquid environment has also been observed in environments other than molten metals. Radon et al. [17] have shown that crack blunting occurs in mild steel tested in aqueous sodium chloride solutions at low crack growth rates. Similar results were reported by Austen et al. [18] for martensitic steels tested in acidified water and acidified aqueous sodium chloride solutions.

The Technical Committee 10 (“Environmentally Assisted Cracking”) of the European Structural Integrity Society (ESIS) has recently prepared a document entitled *Recommendations for Stress Corrosion Testing using Pre-cracked Specimens* (ESIS P4-92D), in which an attempt is made to specify a test procedure based on the rising load $K_{ISC}$ test [19]. It is hoped that such a procedure will allow the determination of both $K_{IEAC}$ and crack growth data within an acceptable period. The question remains, however, as to the selection of an appropriate loading rate. In this regard, cognisance should be taken of the exact processes (e.g. oxidation, dissolution, etc.) taking place at the crack tip, since these could significantly affect the validity and reliability of results.

REFERENCES