Thermal approach for evaluating the heat dissipated at the crack tip

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Abstract. This paper deals with the use of an experimental thermographic approach for determining the crack growth of a martensitic AISI 410 stainless steel, by measuring the heat dissipated ahead of the crack tip.
The relation between crack growth and the heat dissipated in the material is similar to the Paris Law model, and then the proposed approach could represent a useful tool to determine the crack propagation in rapid way.

Introduction

The use of Infrared Thermography can support the fracture mechanics and fatigue tests in order to determine the heat sources during the test. In the present paper, the investigation by means of thermal methods, involves the assessment of dissipative heat sources [1],[2] related to plastic phenomena occurring in the material.
Different authors [3-7] proposed the determination of dissipative phenomena by measuring energetic contribution from the material undergoing fracture mechanics test. In particular, performed experimental tests in order to evaluate from temperature measurements the specific heat energy per cycle averaged in a small volume surrounding the crack tip. However, this procedure found limitations for those cases in which temperature changes related to dissipative phenomena, are low [8-9] in value (in case of short cracks).
In this work, the crack growth is determined by measuring the second order component of thermographic signal that are directly correlated with the energy dissipated at the crack tip.
Three CT specimens of martensitic AISI 410 steel, were tested according ASTM E 647-00 and the monitoring of crack tip growth was performed continuously by means of a cooled IR camera. Thermal data were processed in the time domain in order to extract the heat source related to the heat dissipated at the crack tip. Then a simple method was used for estimate the heat energy dissipated per cycle. A similar Paris Law model was obtained between the crack growth and the heat dissipated per cycle.

Methods and setup

Figure 1 shows the experimental set-up adopted for tests. A cooled IR detector has been used in order to acquire thermographic sequences with a spatial resolution of 0,0067 mm/pixel.
A suitable mathematical algorithm allows for estimating the temperature variations related to the presence of an energy E_d rising two times per cycle. In particular, the thermographic signal can be represented by:

$$T(t) = T_0 + bt + \frac{T_d}{9\pi^2}\cos(2\omega t) \qquad (..)$$

The first part of the model is related to the signal variation of total temperature, which determines the mean temperature increment per cycle, while the term related to the dissipative temperature variation is the last.
The heat dissipated for cycle can be obtained as:

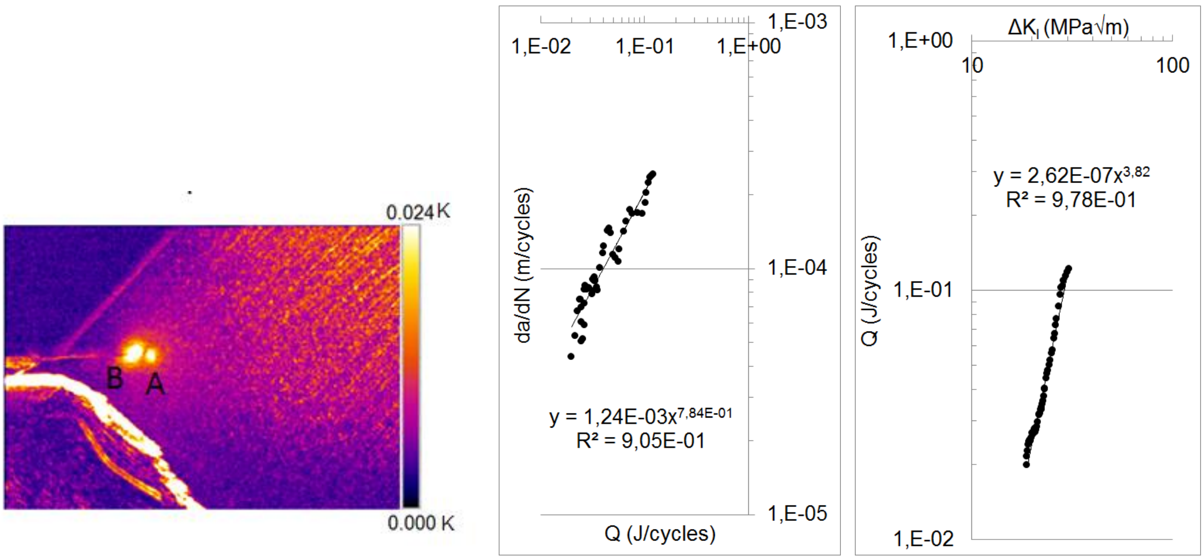
$$Q = E_d V_p = \rho c_p T_d V_p \qquad (\ldots)$$

where V_p has been obtained by considering the Irwin [10] model.

Figure. 1 setup and machines

Results

In Figure 2 is shown the plastic area (*A*) while the bigger area (*B*) represents the crack closure effect. The area *A* has been taken into account for evaluating the heat dissipated *Q*. A linear dependence of *Q* from ΔK_I and the crack growth rate has been found by considering a double logarithmic scale.



(a) (b) (c)

Figure 2 results (a) map of the amplitude T_2 (b) relation between da/dN and energy dissipated Q(c) relation between energy dissipated Q and ΔK_I.

Conclusions

In this paper, a new method to approach the study of the fracture mechanics behaviour of material is showed. In particular, it is possible to demonstrate that by measuring the dissipative component of temperature variations (T_d) the crack growth is easily achievable by-passing the more difficult experimental way to determine it. Clearly, it results in a less time consuming tests.

Finally, it has been demonstrated that the relation between heat dissipated per cycle *Q* and ΔK_I can be described by power equation which exponent is roughly similar to the one which describes the relation between *da/dN* and ΔK_I.

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