AN ANALOGY IN FRACTURE DYNAMICS: CRACKS AS OSCILLATORS

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Abstract

The incubation time fracture criterion (ITFC) is used to analytically investigate dynamic crack initiation under short pulse loads. Particular attention is paid to the phenomenon of delayed fracture – a fundamental fracture effect that can be observed in experiments with short pulse loads. The effect can be described in the following way: the material failure occurs after local stresses reached their maximum values, meaning that the fracture takes place at a drop stage of the local tearing stress, and thus delay is present. It is shown that the fracture delay effect manifests itself when minimal required critical loads are applied to the system. Such loads are called threshold loads being a key tool for experimental investigation of the dynamic fracture effects. It is found that the experimentally registered fracture delay can be clearly explained within the incubation time framework. The conditions for the fracture delay are found, threshold load parameters are evaluated and the corresponding analytical formulas are given. Additionally, a simple analogy based on a mass-spring model is discussed. Analytical formulas available for the oscillator model are used to find some non-obvious similarities between the crack instability under short pulse loads and the oscillator failure when analogous loads are applied: the dynamic fracture process in the crack vicinity appears to exhibit inertial behavior.

1. Introduction

Classic fracture criteria such Irwin's stress intensity factor (SIF) usually are not capable of describing and predicting the situation when fracture takes place after local stress fields have passed their maximum values, however this effect – the facture delay effect, as we call it – has been reported in literature. We show that the incubation time fracture criterion is able to process such complex cases when crack initiation due to short pressure pulses is considered. Moreover, it appears that dynamic fracture exhibits inertial behavior which is surprisingly similar to the behavior of a linear oscillator when its failure due to pulse loads is considered. Such analogy is based on the fact that the macroscopic dynamic fracture cannot be regarded as an instant event, since preparatory or incubation processes (e.g. growth and coalescence of microscopic voids and cracks) need to precede the macroscopic fracture event. We show that even one of simplest mechanical systems – the linear oscillator can be used to study the fracture delay effect, then we process some known experimental data on fracture initiation due to short pulse loads using the ITFC and then we construct analogies between the crack initiation and the linear oscillator failure. The fracture delay effect occurs when the system is underloaded meaning that threshold loads are applied. In this particular case of rectangular load pulses, the threshold load is the one with a minimum amplitude for a fixed duration which is sufficient to make the system fail. If the pulse amplitude is fixed minimal pulse duration is sought if threshold load is considered.

2. Results

The linear oscillator failure due to pulse loads has been studied with the following results:

a. Conditions for the fracture delay have been deduced and dependencies of critical pulse duration on critical pulse amplitude have been built showing that the threshold pulses should be studied in order to investigate the fracture delay effect. Parameters of these critical pulses belong to certain ranges depending on whether the facture delay is present or not, meaning that for a given pulse amplitude there is a range of critical pulse durations and vice versa.
b. An optimal load to cause the oscillator failure in terms of the load impulse (amplitude multiplied by duration) has been found for both zero delay and maximal delay cases (Fig. 1b).

The following results were obtained for the crack initiation studies using the ITFC:

a. Experiments on short pulse loading of cracks were processes using the ITFC. The load parameters causing the fracture delay were evaluated – the threshold load parameters were found. The constructed relations for the critical load pulses (e.g. *pulse duration* versus *crack initiation time* relation and *pulse impulse* versus *pulse amplitude* relation (Fig. 1)) resemble the corresponding dependencies for the linear oscillator.
b. Virtual oscillators with particular eigenfrequencies were associated with particular specimens from the processed experiments on the crack initiation. Full qualitative coincidence with the behavior of the crack is received and values of critical parameters similar to those shown in Fig.1 for the chosen frequencies are obtained.

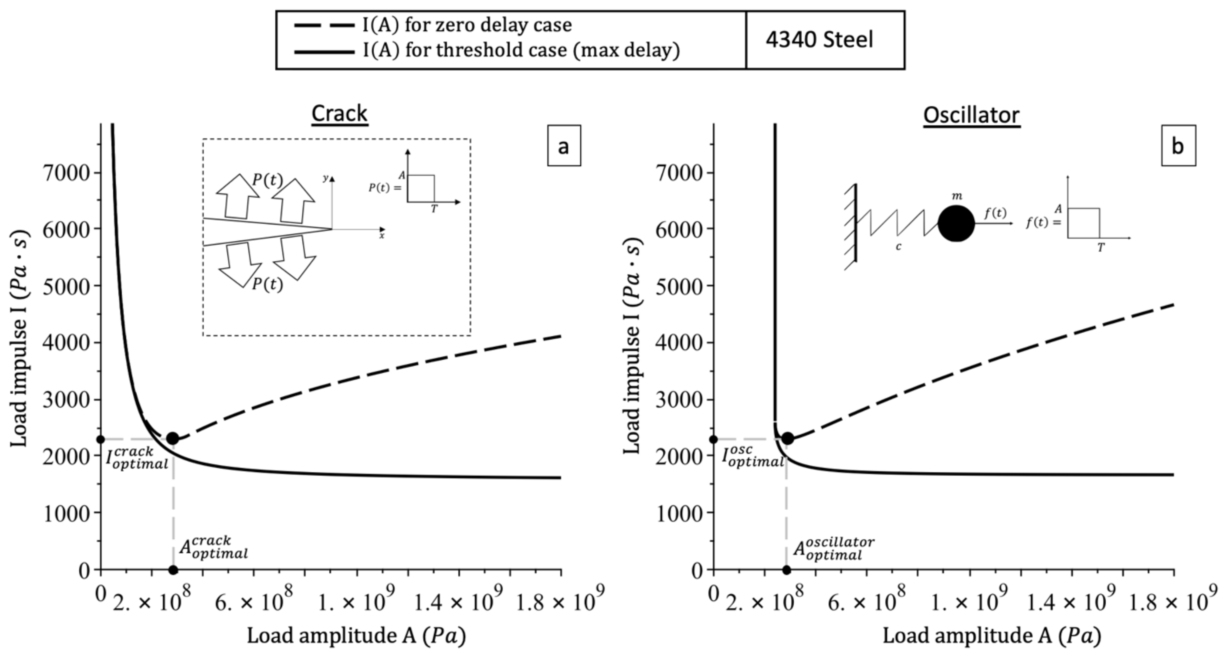

Fig.1 – Relations of load impulse on load amplitude for a crack in 4340 steel and for a calibrated oscillator. Minima of the zero delay curves for the both problems are indicated.

3. Conclusions

It has been shown that the incubation time fracture criterion can be used to study and predict the fracture delay effect as well as other special dynamic effects, which can take place when threshold pressure pulses are applied to the cracked sample and the system is not overloaded. Moreover, the dynamic fracture process appears to exhibit *inertial* behavior and the virtual oscillator with a particular eigenfrequency can be attributed to a specific crack initiation problem. We believe that the investigated analogy is fundamental for understanding the nature of the dynamic fracture process.

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