APPLICABILITY OF MAGNETIC AND ELECTRIC EMISSION TECHNIQUES FOR DETECTING CRACK INITIATION IN IMPACT TESTS

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The capability of the magnetic and electric emission effects to determine the onset of crack propagation in various materials is investigated. Magnetic signals can be observed only with ferromagnetic materials (i.e., steel). Brittle and ductile fracture onset can be determined as well. Almost all the materials under test exhibited electric signals. Their interpretation, however, differs with the material. In metals yield effects are described by electric signals but not fracture events. Plastic materials generally emit electric signals when breaking. Only one material of apolar molecule structure did not show any signal with the fracture event.

INTRODUCTION

In fracture mechanics determining the instant of crack initiation is the basic task for the measurement of critical material parameters. Two newly found field emission methods are considered to be capable to render this task in particular also with impact tests. These easy to apply techniques are the magnetic and the electric emisson method (1, 2, 3). This paper investigates their applicability for the study of fracture processes in instrumented Charpy tests.

The principle of the magnetic measurement technique (1, 2) is demonstrated in Fig.1.a. Two physical phenomena contribute to the magnetic emission signal: (a) mechanically induced Barkhausen signals appear when the internal magnetic structure changes during loading, and (b) a propagating crack causes the internal magnetic field to emerge from the solid into the gap between the two crack surfaces, thereby changing the external magnetic field.

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These field variations can be observed locally by a magnetic transducer which basically consists of a coil. The transducer's output voltage is the *magnetic emission (ME)* signal. This appears to be proportional to the derivative of the magnetic field (MF).

The principle of the electric emission technique is shown in Fig.1.b. The sensor of an electric transducer is a capacitor. Any variation of the electric field at the location of the capacitor gives rise for a voltage signal which is named *electric emission (EE)*. The physical phenomena which can cause variations of the electric field may be different from material to material. Molecule deformations or charge separations during a fracture process are examples.

Experiments described in the following have been carried out with Charpy impactors.

EXPERIMENTS AND RESULTS

Charpy experiments were performed with different steels, aluminium, and different plastic materials. The experiments were performed on 300 J Charpy machines with metal samples and on a 4 J Charpy machine with plastic samples. V-notched and pre-cracked samples have been used. The histories of force (F), magnetic emission (ME) and electric emission (EE) have been registered. The measured data are handled by a spreadsheet procedure. From these experiments typical results are selected and presented here as examples for ferromagnetic and other metals and non-metals, for stable and unstable fracture events.

Fig.2. shows force, ME, and EE signals of a brittle behaving V-notched steel specimen (900A railway steel). Small-amplitude magnetic signals appear just at the beginning of the impact event and continue during the deformation phase as a consequence of energy-caused variations in the magnetic domain structure. Unstable crack propagation indicated by a force drop is accompanied by a sharp peak of the magnetic signal according to a rapid crack jump.

Stable crack initiation can usually not be determined directly from ME signals. This is demonstrated by an experiment using a ductile behaving pre-cracked steel specimen (BS4360-50E), see Fig.3. For these applications a method was developed (4) which uses the integrated ME signal, i.e., the magnetic field history, MF(t), eq.1:

$$\mathrm{MF}(t) = \int_{\tau=0}^{t} \mathrm{ME}(\tau)\, d\tau \quad \text{...} (1)$$

It was observed that ME signals originated by crack propagation can be distinguished from those originated by Barkhausen noise in the field curve by a change of the slope.

This is demonstrated in Fig.4. A continuous increase of the field can be seen from the beginning of the impact event with increasing force. The rupture event is indicated by a discontinuity in the slope of the field curve. This becomes even more obvious when being compared with a field curve of a low-blow experiment with no crack extension (Fig.5.). In both cases first the MF curve is continuously increasing. After the elastic part of the load curve a stabilisation can be seen. The magnetic field starts to change again if crack propagation occurs.

Electric signals in this case are connected to plastic deformations of the test piece. Beginning of yielding can be seen more clearly on the mathematically smoothed, low velocity force curve (Fig.6.). In this figure one also can see that the first higher amplitude electric signal coincides well with the onset of yielding in the notch root.

A series of plastic materials was investigated in order to compare the emitted electric signals. Some basic characteristics - which may have an effect on the obtained signals - of these materials are listed in Table 1 (5, 6).

TABLE 1 - Some characteristics of the investigated plastic materials

Material	HDPE	PVC	PA6.6	Araldit B
Structure	semi crystalline	amorphous	semi crystalline	thermoset
Molecule type	apolar	polar	polar	polar
Dielectric constant	2,3-2,5 As/Vm	3,5 As/Vm	8 As/Vm	3,5-5 As/Vm
Fracture type	brittle fracture after some plastic def.	brittle	brittle/ductile depending on the additions	brittle

Fig.7. shows the obtained result for HDPE which exhibits an apolar molecule structure and a small dielectric constant. There was no electric emission signal obtained during unstable crack propagation. Other investigated polymers with a polar molecule structure and higher dielectric constants showed large EE signals correlated to brittle fracture. This is demonstrated in Fig.8. with PVC as an example.

CONCLUSIONS

From these results is concluded:

1. With ferromagnetic steels unstable fracture is indicated by a strong magnetic signal. With ductile behaving steels, due to a very slow and indistinct onset of stable crack propagation the magnetic emission signal usually does not show clearly the beginning of that event. It was, however,

possible to determine this instant from a change of the slope of the magnetic field history which is the integrated emission signal.

2. The electric emission signals of all investigated metals indicate yielding effects. Fracture events are not shown by these signals.

3. With the investigated plastic materials of polar molecule structure unstable crack initiation was accompanied by a distinct change in the electric emission signal. Fracture events of a plastic materials of apolar molecule structure are not shown by electric signals.

SYMBOLS USED

ε = dielectric constant, As/Vm

EE = voltage signal of the electric emission probe, V

F = force, N

ME(t) = voltage signal of the magnetic emission probe, V

MF(t) = magnetic field, Vs

t, τ = time, s

v = impact velocity, m/s

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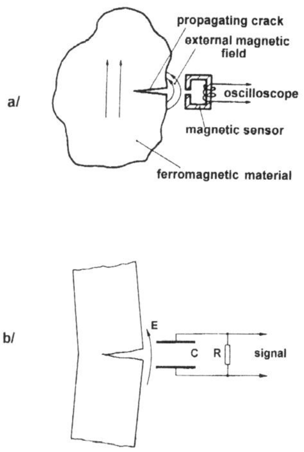

Figure 1.The principle of the a/ magnetic and b/ electric emission technique

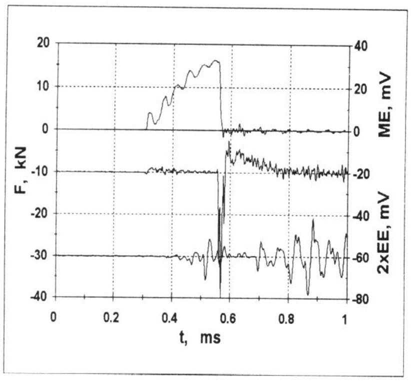

Figure 2. Force, ME and EE signals of V-notched steel sample (v=2 m/s)

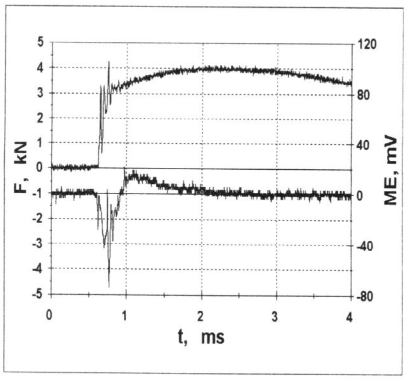

Figure 3. Force and ME signals of pre-cracked steel sample (v=1,57 m/s)

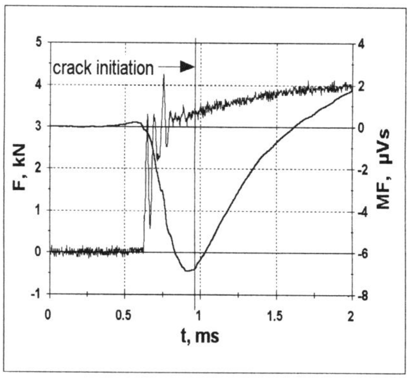

Figure 4. Force and MF signals of pre-cracked steel sample (v=1,57 m/s)

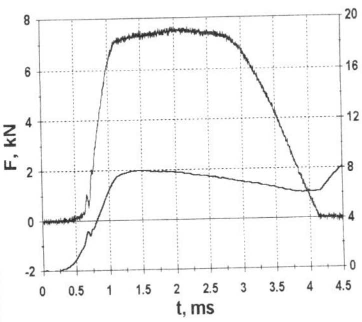

Figure 5. Force and MF signals of pre-cracked steel sample (v=0,8 m/s)

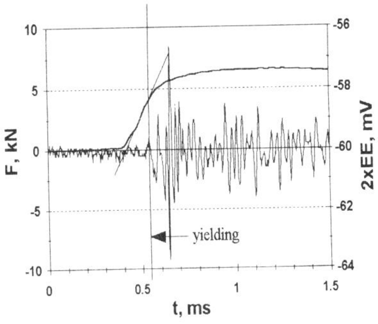

Figure 6. Force and EE diagrams of pre-cracked steel sample (v=1,4 m/s)

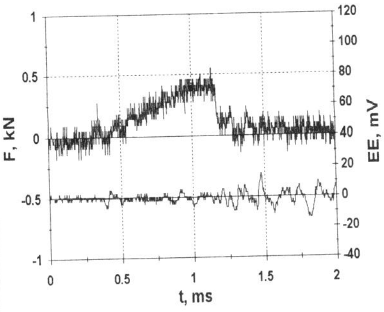

Figure 7.Force and EE signals of V-notched HDPE sample (v=1,5 m/s)

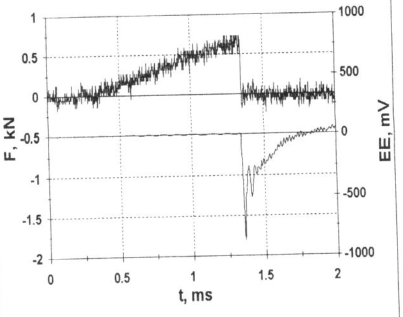

Figure 8. Force and EE signals of V-notched HDPE sample (v=1,09 m/s)