

# The Use of the Potential Drop Method for Crack Growth Studies in Ceramics

## A Short Applications Note

Measuring crack growth in metals by the potential drop method has been employed for many years in research and the procedure is now widely accepted as a routine materials testing tool. The ASTM organisation has recently published a standard that covers the application of the technique to metals testing. No mention is, however, made of the use of potential drop in the measurement of crack growth in ceramics. This important area is the subject of this note.

Ceramics, although at first unlikely candidates for stable crack propagation, can exhibit crack growth under fatigue conditions. The most difficult aspect of fatigue crack growth in ceramics is the initiation stage. This can take as long as several days in certain ceramic systems. It is during the initiation stage that most premature specimen failures occur.

Once a crack has been initiated, measurement of the growth rate is usually performed by optical methods, whereby a travelling microscope is used to follow the progress of the crack and measurements are made against a calibrated scale. The brittle nature of ceramics places a serious limitation on the degree of crack opening displacement that is observed in a specimen under test. This does little to assist the optical measurement of crack length which relies upon crack opening to generate a noticeable optical contrast.

The optical method also suffers from the need for an operator to collect data at regular intervals. This can lead to logistical problems as well as missed data. Electrical methods such as those reliant upon strain gauges offer unattended and continuous monitoring of defect propagation and are therefore to be preferred. The potential drop technique falls into this category but suffers from the requirement that the specimen be electrically conducting.

Although some ceramics exhibit conduction at elevated temperatures, most testing is performed at room temperature. More significantly, the structure and mechanical properties of ceramics can be dramatically altered by changing their thermal history. Thus intrinsic conduction is not the answer.

A simple but effective method of electrically measuring crack growth is to bond or evaporate a pattern of metal

strips onto the side of the ceramic specimen. Changes in the electrical resistance of the pattern occur as the crack grows and progressively severs the strips in succession. This arrangement is shown schematically below in Fig 1.

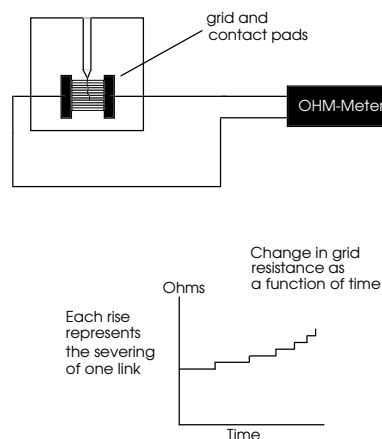


Fig 1. Use of a bonded metal grid to monitor crack propagation.

By monitoring the resistance of the metal pattern using a suitable Ohmmeter, the progress of the crack can be followed. The one major deficiency of this method is the poor resolution achievable. The ultimate resolution is determined by the number of links in the grid. It is therefore difficult to obtain resolutions below fractions of a millimetre.

By depositing a metallic layer rather than a grid, the resolution limitation is removed, and the emphasis shifts to the resolution of the measuring instrument used to record the resistance data. The resistance of a continuous metallic layer will be dependent upon the metal's resistivity and the thickness of the layer.

However, it is likely that a milliohmmeter will have to be employed in order to measure the resistance.

Once the user has graduated to using a metallic layer, many advantages in terms of resolution and noise reduction can be gained by employing a dedicated potential drop instrument rather than an Ohmmeter to monitor crack length. DC potential drop (DCPD) can be simply thought of as a means of measuring specimen resistance. A direct current is passed through the specimen and the corresponding voltage drop across a particular area on the specimen is measured. The direct current flows through the bulk of the specimen.

The AC potential drop method (ACPD) employs a high frequency alternating current and therefore measures specimen impedance. A phenomenon known as the skin effect confines the alternating current to the surface regions of the specimen. The skin depth characterises the current distribution and is the order of a few millimetres for ferritic materials at commonly employed AC frequencies.

ACPD is generally accepted as being more sensitive to crack growth than the DCPD technique. This is in part due to the skin effect which acts to both maximise the signals from surface breaking defects and also imparts a linear signal response with respect to the crack depth.

Detection and amplification of the small voltages generated by the passage of the supply current also benefits from AC techniques such as phase sensitive detection. This dramatically reduces noise and thereby increases the sensitivity to changes in crack length.

The DC technique suffers from the effect of thermoelectric EMFs which are

generated at the point where the specimen and leads are connected. These can be of the same order of magnitude as the voltages generated at the crack site. Whilst nominally of constant magnitude, any slight temperature variation or gradient between contact points can easily mask the potential drop changes that are being sought.

DCPD instruments have improved markedly in order to counter the sensitivity criticism. Techniques such as dual channel operation, whereby a reference channel is simultaneously used to normalise the active channel, remove the effect of thermal variations in the DCPD itself. Such variations are caused by changes in the specimen's resistivity with temperature.

More significantly, the advent of the interrupted DCPD technique, whereby the excitation current is supplied in regular pulses, has led to the elimination of thermoelectric EMF problems. Measurements of the DCPD are made during and after a current pulse. Subtraction of these values removes any thermoelectric EMFs and yields the true DCPD.

A metallic layer deposited on the surface of a ceramic can be regarded as a very thin metal specimen for the purpose of PD measurements. In this respect ACPD loses the benefit of the skin effect since the skin depth is invariably greater than the layer thickness. Hence, both AC and DC potential drop methods offer similar performance in terms of resolution for such thin layers.

The choice of which method to use then largely depends upon personal preference, although the AC technique is far better at following rapid crack propagation and registering transient responses. For mechanical tests lasting hours or days, both techniques are suitable.

A schematic of a typical test set-up is shown in Fig 2.

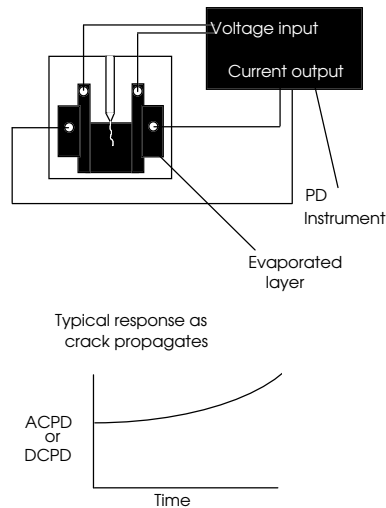


Fig.2 Using the potential drop technique to monitor crack propagation

For an accurate result, the metallic layer must be in intimate contact with the ceramic surface. This is most readily achieved by evaporating the metal onto the specimen. Gold coating instruments are widely used in most electron microscope laboratories and these offer a quick route to layer deposition. The area of interest should be masked and the coating conditions should be optimised to give a uniform, adherent gold layer of approximately a micron in thickness. If other evaporation sources are available, then the use of a higher resistivity material such as a nickel-chromium alloy may give better results.

Connection of the current supply and voltage pick-up leads can be problematic. It is difficult to contact to such a thin coating without damaging it, but users should experiment with sprung contacts (with area rather than point contact) and conductive paints or pastes.

The use of solders can also be considered as a means of achieving contact but good results are only likely if a solder paste is first applied and heated gently. Too high a temperature can cause the evaporated layer to diffuse into the ceramic surface and disappear almost completely!

Ultra-sonic ball bonding is another possibility but the equipment for this is usually only found in semiconductor processing laboratories. Some of these methods are schematically illustrated below in Fig 3.

Any contacts are likely to be delicate and fragile. Consequently, precautions should be taken to anchor wires and leads to prevent undue strain from being transmitted to the contact points during a fatigue test.

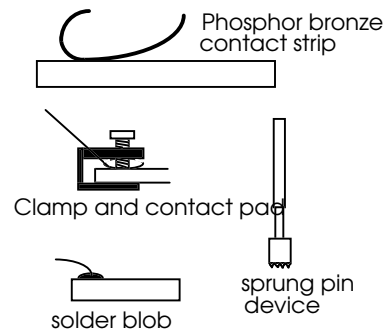


Fig 3. Suggested methods of achieving specimen contact.

The one major disadvantage of detecting and following crack growth in ceramics by using a conductive surface layer is the fact that what occurs on the surface is nearly always different from what is happening inside a specimen. In other words the crack profile can significantly alter the user's appreciation of the results. If possible, steps should be taken to ascertain the significance of this fact before a firm conclusion is reached on the basis of surface growth. This caution applies to both optical and potential drop methods.

By careful work, the use of the potential drop method in conjunction with a metallic layer is capable of monitoring crack propagation in ceramics to sensitivities below 10 microns. This together with the obvious advantage of continuous, unattended measurement, offers the ceramicist new opportunities for crack initiation and propagation studies.

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