TESTING OF PLASTIC DEFORMATION AND CRACK PROPAGATION BY THE ELECTRICAL POTENTIAL METHOD

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Results obtained by AC electrical potential measurements made on tensile and 1CT specimens are summarized. The results show that the AC potential changes are in good correlation with the deformation process and can be used to determine the yield point at tensile tests. From the minimum of the AC potential curves obtained at fracture mechanics tests the onset of crack propagation can be identified and the following potential increasing can be used to estimate the crack length.

INTRODUCTION

At the measurements presented here the AC method was used and a special instrument has been developed. Due to the applied frequency the skin depth /δ/ was relatively small /0.35 .. 0.8 mm/ to the sizes of the specimens, which has the consequence that not only the real but also the imaginary part /i.e. the reactance of the self inductance/ must be taken for calculating the impedance of the specimens. In case of cylindrical rod /like the used tensile specimens/ the real and imaginary part of the impedance relative to the DC resistance /R_0/ are:

$$\frac{R}{R_0} \approx \frac{\omega L}{R_0} \approx \frac{r}{2\delta} \qquad /1/$$

where $R_0 = \frac{1}{\gamma} \cdot \frac{l}{A}$ /2/ and $\delta = \frac{1}{\sqrt{\pi \cdot f \cdot \gamma \cdot \mu}}$ /3/

Thus the impedance /Z/ of the tensile specimen can be calculated as:

$$|Z| = \frac{1}{\sqrt{2\pi}} \cdot \frac{l}{r} \sqrt{f} \cdot \sqrt{\frac{\mu}{\gamma}} \qquad /4/$$

where R: real part of the impedance;
$\omega = 2\pi f$; f: frequency of the AC source;
L: self inductance;
l: length, r: radius, A: cross-section of the rod;
γ: electrical conductivity; μ: magnetic permeability

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TEST RESULTS

The tensile specimens /r=5 mm, l=10r/ were made of the steel used at VVER 440 type reactor pressure vessels. /$\bar{R}_{p0.2}$ =400 MPa, $\bar{R}_{m}$ =560 MPa, A_5 =25 %/
Fig 1 shows the typical potential and force curves against the strain. Four Zones can be distinguished: in Zone I the impedance drops because of the reversible inverse magnetostrictive phenomenon /Villari-effect/. In Zone II the elastic-plastic deformation is taking place: the impedance goes through a minimum and after this follows the irreversible Zone III which belongs to the uniform deformation. here the impedance begins to increase approximately linearly. Reaching the F_m, ε_m point, a sharp increasing of the impedance is taking place: this Zone IV belongs to the reduction of area. Fig 2 shows the correlation between the relative potential difference and the relative strain at uniform deformation and at reduction of area.

The 1CT specimens were made of the same material. Here also four Zones can be distinguished. In Zone I the impedance of the specimen increases due to the fact that the faces of the fatigue crack are going to separate. In Zone II which still belongs to the elastic deformation, the Villary effect causes an impedance decreasing. At the onset of plastic yielding the curve deviates from linearity: it goes through a minimum /Zone III/ and afterwards the impedance increases due to the crack growth /Zone IV/. On Fig 4 the correlation between the average crack length obtained by eye and the crack length estimated by electrical potential method can be seen.

CONCLUSIONS

The results of the AC electrical potential measurements are in good correlation with the various deformation processes occuring at tensile tests. The yield point can be determined on the basis of this correlation which might be benificial at extreme temperatures.

At fracture mechanics tests the second inflection point indicates the onset of the crack propagation and the following potential difference increasing is the result of the crack propagation.
Calibrating curves are needed to estimate the crack length directly from the potential differences.
Furthermore the velocity of the crack propagation can be determined from the velocity of the potential changes.

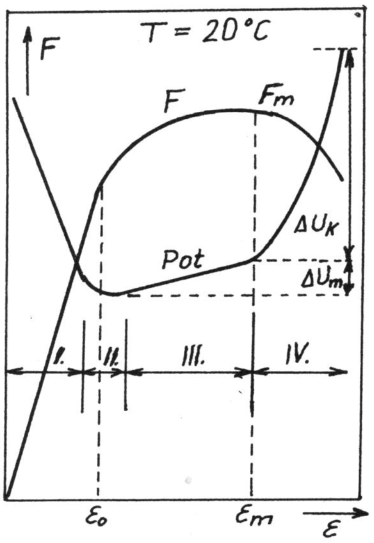

Fig 1. Potential and force against strain.

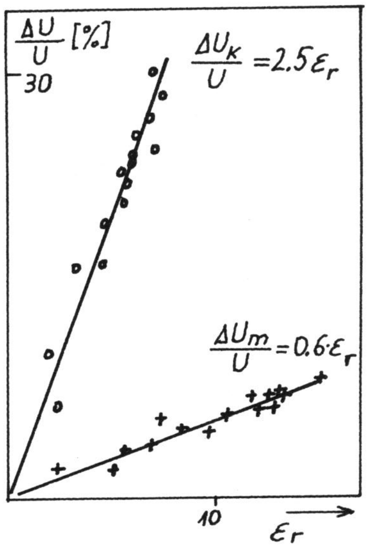

Fig 2. Relative potential changes at tensile tests.

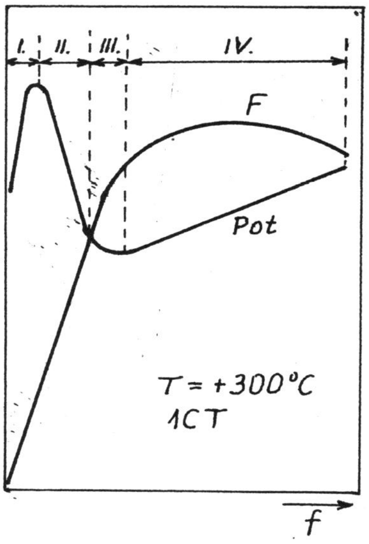

Fig 3. Potential and force against displacement.

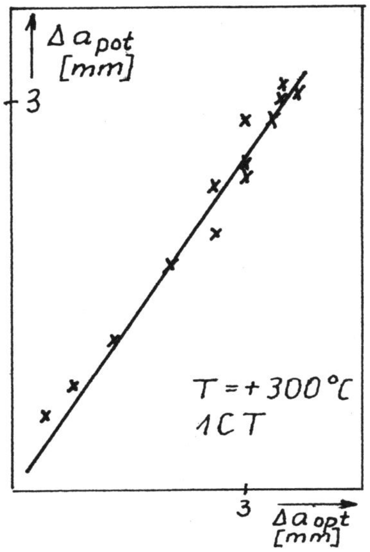

Fig 4. Correlation between optical and electrical results