ASSESSMENT OF PERFORMANCE BY MONITORING IN-SERVICE CHANGES IN MATERIALS PROPERTIES

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Condition assessment of high energy components is dependent on accurate knowledge of critical material properties. The ability to remove small samples from these components in an effectively non-destructive manner offers major advantages for these assessments. A research programme involving the high-sensitivity testing of miniature disc specimens is described. This study has established that results are reproducible and in good agreement with data measured using standard test techniques.

INTRODUCTION

The safe operation of a wide range of components and structures must be assured. In general, design approaches include appropriate margins of safety so that provided construction methods comply with appropriate specifications, satisfactory short-term operation is achieved. There are presently major economic incentives to extend the operating lifetime of large-scale plant. Thus there is increasing demand for reliability assessments to be performed on existing installations. These assessments are required to evaluate the current level of damage and then to estimate the expected period of safe operation for selected service conditions. Typically, this estimation of future performance requires calculation of the rate of future damage accumulation and knowledge of an appropriate failure criterion. Most programmes of this type are based on conservative assessment of overall damage state followed by non-destructive testing of locations identified as "high-risk". The details of this assessment will depend on the structure being evaluated. In general approaches necessitate calculation of component stress or stress range and application of this information to appropriate materials data (1). Analytical techniques have advanced to the situation where accurate stress analysis can be performed for most structures. Difficulty in quantitative assessment of damage then occurs because of uncertainty in materials data. Laboratory test programmes have shown that materials data sets must usually be described by a

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mean line with a scatter-band. In many cases the variation in properties between the limits of the scatter approaches an order of magnitude. Furthermore, even when component specific materials properties are available for new material, operation at elevated temperature can modify particular properties, ie the materials properties of a component change during service (eg 2). In these situations evaluation of structural integrity must be based on accurate knowledge of actual material properties. Recently versatile equipment has been developed which allows button shaped samples of material to be taken from service components in a virtually non-destructive manner (3). The present paper describes application of the sampling technique to plant components and the laboratory test techniques developed to measure properties using miniature disc samples.

MATERIAL SAMPLING

Measurement of component specific properties has been limited since traditional methods of material removal necessitate good access in the location to be sampled, and require post-sampling repair to restore the material removed. In general, repair procedures involve welding and the associated thermal cycles can be deleterious to further operation. In extreme situations major cracks have been reported directly as a result of repair welding (eg 4). The removal of the button-shaped samples of material has been achieved using a 50mm diameter hemispherical cutter which is spun about its axis of symmetry and rotated about an orthogonal axis through the material being sampled, Figure 1. The set-up of the Surface Sampling system (SSAM) and the cutting operation are controllable. Thus, samples up to about 25mm in diameter and 6mm in thickness can be removed without mechanical deformation or thermal degradation of the material. To date samples have been removed from a wide range of components, Table 1. Laboratory analysis has been used to characterize defects, identify damage mechanisms and provide semi-quantitative assessment of condition. This type of information offers major advantages for accurate assessment. The development of small sample testing techniques then has the potential for additional benefit through effectively "non-destructive" measurement of critical properties.

TABLE 1 - Examples of Component Assessments performed using SSAM

Industry/Component	Application
Petrochemical Industry	
Pressure Vessels	Evaluation of Graphitization, Creep Damage, Hydrogen-induced cracking
Electric Utility - Fossil Fuelled	
Piping, Valves, Casings, Headers	Evaluation of macro-defects and micro-damage due to creep fatigue and graphitization
Rotors	Evaluation of near-bore defects and samples for determination of properties
Electric Utility - Nuclear Fuelled	
Reactor Vessels	Evaluation of samples required to support safety case for continued operation

MINIATURE SAMPLE TESTING

A range of miniature sample testing techniques has been suggested (eg 5, 6). Of these methods, ball punch testing of disc samples offers the potential for producing representative results from the button-shaped samples removed by the sampling system. These samples, Figure 2a, can be easily machined to disc form with diameters up to about 10mm and thicknesses up to around 2mm. An example of a typical testpiece is shown in Figure 2b. The disc-shaped specimens are supported around their periphery and subjected to a ram load at the centre.

In the present work, samples were tested at a selected displacement rate in the range 0.05 to 0.001mm/s and the test load monitored. Data were developed to a specific displacement limit or to failure as required, Figure 2c. The material selected was $\frac{1}{4}Cr\frac{1}{2}Mo\frac{1}{4}V$ ferritic steel typical of that used in high energy pipework. Standard tensile testing of this material gave a yield strength and ultimate tensile strength of approximately 400 and 550 MPa respectively with an elongation to rupture of 33%. Disc samples were prepared with a diameter of 9.5mm and thicknesses in the range 0.18mm to 1mm. In all cases, the required thickness was attained by hand grinding to 1200 grit using a purpose built jig. This jig ensured that the samples achieved the necessary thickness with parallel faces. The thickness was measured using a digital micrometer with an accuracy of ±0.005mm.

A matrix of 40 tests was carried out with ball sizes of 2mm, 3.2mm and 4mm. The majority of tests were conducted with a lower die containing a hole of 6mm diameter. Selected tests were performed where the hole in the lower die was 4mm in diameter. Typical load displacement curves are shown in Figure 3. For a given set of conditions, the load increased linearly to a yield region, increased further due to post yield work hardening to an ultimate yield position. The results obtained were reproducible with repeat testing exhibiting less than 10% scatter. The effect of friction between the punch and disc was examined by conducting experiments with degreased samples and on specimens lubricated with petroleum jelly or teflon powder. Results given in Table 2 indicate that a marginal decrease in load was observed for the samples lubricated with teflon powder. .All subsequent tests were performed using this lubricant. No significant effect of loading rate was detected, Table 2, and a loading rate of 0.05mm/s was used for the majority of tests.

The effects of changing ball diameter and disc thickness on yield load and ultimate load are shown in Figure 4. For a given specimen thickness increasing the ball diameter resulted in an increase in maximum load and an increase in displacement. However, ball size had little effect on the measured yield load. Similarly, as the thickness of the disc testpiece was increased the measured load increased. For each ball size used there was an approximately linear relationship between the yield load, maximum load and specimen thickness.

TABLE 2 - The effect of lubrication and displacement rate on load/displacement data for 1mm thick samples

Lubrication	Displacement Rate, mm/s	Yield Load, kN	Ultimate Load, kN	Maximum Displacement, mm
Degreased	0.05	0.66	5.28	3.23
Petroleum Jelly	0.05	0.79	5.53	3.46
Teflon Powder	0.05	0.66	4.94	3.55
Teflon Powder	0.001	0.65	4.87	3.23

DISCUSSION

The present programme has shown that for $\frac{1}{2}Cr\frac{1}{2}Mo\frac{1}{4}V$ ferritic steel ball punch testing of discs provides reproducible data which show sensible trends with specimen thickness and ball size. Qualitatively the observed behaviour is rational since, as ball size and/or specimen thickness increase for ductile material of the type considered here, the volume of material in contact with the ball must increase. Thus, methods to relate the load measured in a disc test with tensile data should be based on contact area and disc thickness, t. A relationship of this form has been suggested (7) as

$$\text{Stress} = \frac{KL}{\alpha d t} \qquad (1)$$

where K is a constant
L is the measured load in a disc test
d is the ball diameter
and α is the contact angle between the ball and the disc.

Application of this relationship is critically dependent on accurate knowledge of the contact angle. A range of tests was therefore interrupted prior to failure. These samples were metallographically prepared to give an accurate cross-section through the centre of the disc. The contact angle at the maximum load position appeared to be approximately 30°. Using this value in equation 1 suggests that ultimate tensile stress estimates from the disc test programme are in the range 500 to 600 MPa. Clearly these values are in good agreement with standard data.

The present work demonstrates that the technology exists to remove small samples of material from plant components and measure meaningful material properties from a laboratory programme on miniature samples. Whilst, for room temperature properties displacement rate appears to have no significant effect on load-displacement data, factors such as friction between the ball and disc, and ratio of ball diameter to die hole diameter exhibited some effect on results. The simple relationships suggested to relate disc test results with those produced by standard test methods, eg equation 1, do not include these factors. The present work is being expended to quantify these effects. Furthermore, a programme of detailed finite element analysis is in progress to provide a comprehensive understanding of the distributions of stress and strain developed during disc testing.

CONCLUDING REMARKS

The reliability of a wide range of components operating in industrial plant depends on accurate condition assessment. In many situations the greatest difficulty in making such an assessment arises due to uncertainty in specific material properties. The capability of removing samples of material from plant in an effectively "non-destructive" manner offers a significant advantage to accurate assessment. Techniques of laboratory testing of miniature samples then provide the potential for quantitative measurement of critical properties. The present work shows that, provided testing is performed with high sensitivity, accurate data can be reliably produced at room temperature. Testing to extend the experimental base is underway and it is anticipated that miniature disc testing procedures will be established for a wide range of deformation and fracture mechanisms.

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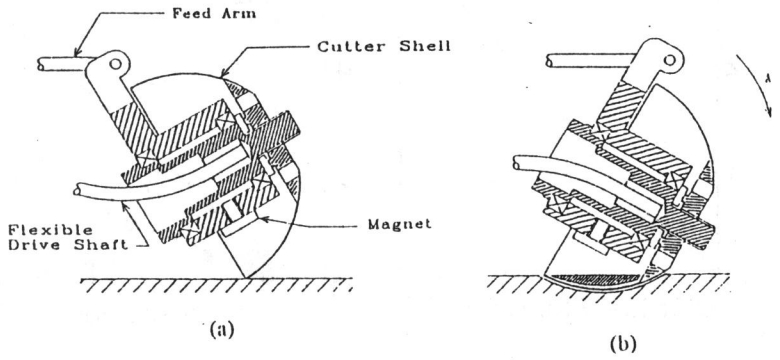

Figure 1. Schematic representation of removal of component samples

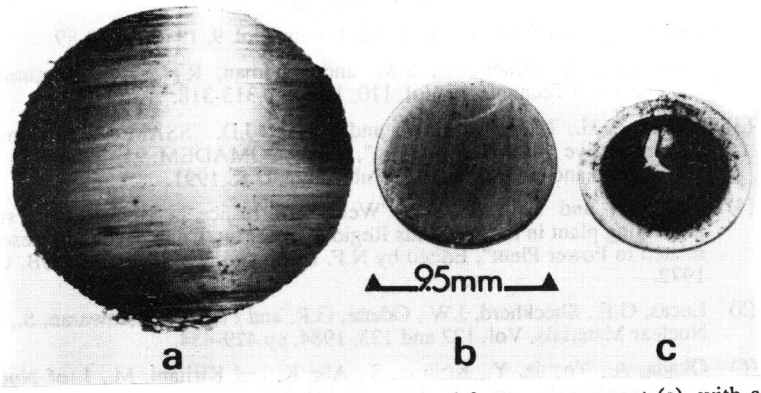

Figure 2. Typical button shaped sample removed from a component (a), with a disc testpiece shown before (b) and after testing (c)

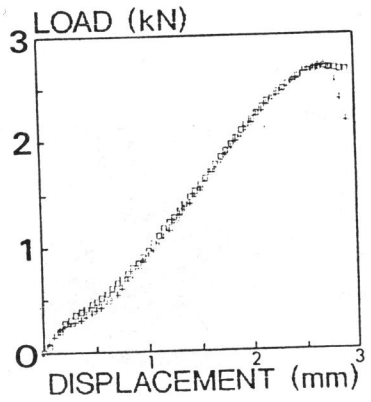

Figure 3. Typical load displacement curves for disc samples of ¼Cr½Mo¼V ferritic steel

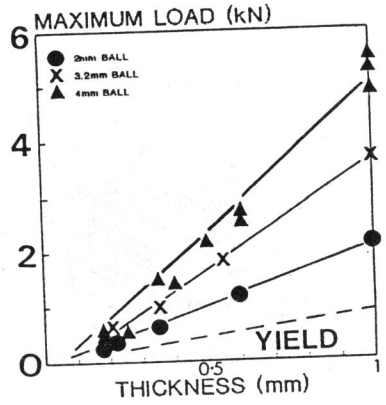

Figure 4. Variation of maximum test load with ball diameter and disc thickness for tests performed on ¼Cr½Mo¼V ferritic steel