A STUDY ON J-R CURVE BEHAVIOUR OF A COPPER NICKEL CHROMIUM ALLOY

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Results from an experimental programme to study size effects on the fracture properties of copper nickel chromium alloy are presented. The crack growth resistance is given in terms of the elastic-plastic fracture toughness parameter J. Results are compared from J-R curve tests on different sized compact tension specimens. It is shown that valid J-R curves are not obtained using the unloading compliance procedure. This is attributed to the extensive out of plane cracking observed for this alloy. An alternative procedure based on a key curve is described. In this approach an effective specimen thickness termed B_{eff} is defined related to the out of plane crack growth.

INTRODUCTION

Cast cupronickel is extensively used for marine fittings such as valves, pipes and various hollow sections, where resistance to general corrosion deterioration and impingement attack are important design requirements. In the as cast state the IN768 cupronickel alloy has tensile properties of UTS 480 MPa, proof stress 300 MPa and 18% elongation. The alloy exhibits appreciable plastic deformation prior to fracture and recourse must be made to elastic-plastic fracture mechanics to define toughness. For this type of material behaviour the toughness may be given by a critical value of J obtained experimentally from a crack growth resistance curve (J-R curve) (1,2). Provided certain restrictions are satisfied the resulting R-curve can also be regarded as a material property.

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TEST PROGRAMME

For the work reported here specimens were tested in broad agreement with the EGF recommended J-R curve procedure (2) using a computerised unloading compliance test system employing a data acquisition unit. The test programme consisted of room temperature, unloading compliance J-R curve tests on standard compact tension specimens of different sizes. Four specimen sizes were tested having nominal W dimensions of 100, 50, 40 and 26 mm. The specimens were all fatigue precracked to provide initial crack length to specimen width ratios (a_0/W) of approximately 0.6. All specimens tested had a thickness equal to half the width.

During the tests, load, and mouth opening displacement were continually measured. At the commencement of each test ten loadings and unloadings to 90% of the fatigue precracking load were performed and the average value of specimen compliance determined. Tests were undertaken in displacement control at a rate of 0.0025 mm/s. At each unloading station, corresponding to displacement intervals of 0.05 mm the specimen was unloaded to 85% of the load achieved. Before commencing the unloading sequence, to allow for specimen relaxation effects, the specimen was held at fixed displacement untill no load relaxation was observed during a 5 second measurement interval.

For each series of specimen sizes the unloading compliance tests were terminated at different amounts of mouth opening displacement to span the range of crack extension allowable for the particular specimen size. On completion of the tests the specimens were post fatigue cracked before being broken open. Both the initial fatigue crack length (a_0) and the stable crack growth (including stretch zone) were calculated using the weighted nine point average method.

The crack length at each unloading was estimated using the compliance relationship given in EGF P1-90 (2) and, in addition, the crack length was also calculated at each unloading station using the key curve method. The key curve method is described in by Jones and Davies (3) and assumes that the normalised load Pn is a power law function of the normalised plastic load point displacement Qp/W.

For all tests the J and Δa data were "validated" in accordance with the criteria given in EGF P1-90 (2). This validation establishes the extent of stable crack growth and the maximum J value that can be measured from the specimen to ensure that the J field is the controlling crack tip parameter. For each test an estimate of the initiation toughness termed $J_{0.2bl}$ was determined.

RESULTS AND DISCUSSION

A comparison of normalised load against normalised displacement data for the tests showed, apart from the W = 100 mm size specimens, significant scatter between the repeat tests. This could indicate that the data does not belong to the same set. Such an effect would occur if there existed significant material scatter. However, this is not considered to be the case in this instance and the observed variation is judged to be attributable to out of plane cracking of the fracture surface. This feature is particularly prominent for this alloy and presumably can be related to the material's large grain size. The consequence of such out of plane cracking is to effectively increase the B dimension of the test specimen. Measurement of the profile at the end of the fatigue precrack taken from sections through the specimen were compared with a B_{eff} defined from the average compliance determined during the initial loading/unloading cycles by assuming a fixed value of Young's modulus of 140000 MPa.

Average results of the B_{eff} values obtained are given in Table 1. As shown, there is no discernible trend with specimen size with the measured profile ratio being generally lower than the unloading compliance values.

TABLE 1 - Comparison of B_{eff} obtained from surface profile measurements and from unloading compliance

B mm	B_{eff} measured	$\frac{B_{eff}}{B}$	B_{eff} compliance	$\frac{B_{eff}}{B}$
50	58.80	1.18	56.91	1.14
25	28.66	1.15	33.23	1.33
20	22.71	1.14	26.70	1.34
13	14.70	1.13	14.81	1.14

The effect of employing the B_{eff} in the normalisation of load is to give a closer correspondence between the load/displacement data both for repeat tests and between the tests on the different size specimens.

A comparison between the J-R curves obtained using the unloading compliance analysis employing an E_{eff} and the key curve analysis using B_{eff} is given in Figure 1. As shown the unloading compliance analysis significantly underestimates the extent of stable crack extension. In comparison the key curve approach which, although calibrated to give agreement with the measured final crack length values, does also give a reasonable prediction of the initial crack length. A further consequence of employing a B_{eff} with the key curve approach is to decrease the calculated value of J.

Mean offset power law fits to the J-R curve data for each specimen size plotted up to the respective Δa max limit are compared in Figure 2 for the unloading compliance analysis and in Figure 3 for the key curve analysis. The J_{max} limits for each specimen size are also included in the figures.

As demonstrated from previous work by Jones and Gordon (4,5,6), the breakdown of J controlled crack growth is a gradual process and J-R curves do not show well defined separation points. Nevertheless, size independence in the J-R curves is normally seen within the accepted limit of 10% of the ligament. This is not seen for the tests reported here. It is clear that even within the region of J controlled crack growth there is disparity between the J-R curves. The agreement is closer between the curves for the key curve analysis where, apart from the smallest specimens, the curves could be considered coincident within material scatter. It is of note that the smallest specimen size J-R curve which has a noticeably steeper gradient than the larger specimens is limited by J_{max}. In comparison, for the unloading compliance technique where the J-R curves are significantly diverse, all specimens apart from the largest are controlled by J_{max}. However, as shown, neither figure indicates any systematic effect of specimen size on J-R curve behaviour.

Values of $J_{0.2bl}$ for each of the tests from both the unloading compliance and key curve analysis are given in Figure 4. The results from the unloading compliance analysis appear to indicate a trend of decreasing toughness with increasing specimen size. However, as shown, only three of the unloading compliance tests meet the validity criteria given in EGF P1-90. It is of particular note that the highest values are seen from the smallest specimens where the $J_{0.2bl}$ values exceed the J_{max} validity limit.

In comparison, the values of $J_{0.2bl}$ from the key curve analysis are in general lower than those from the unloading compliance analysis and a linear regression analysis of the key curve data gives a low dependence on specimen size with a mean toughness of 108 N/mm. This mean value compares favourably with the valid test results from the unloading compliance analysis.

REFERENCES

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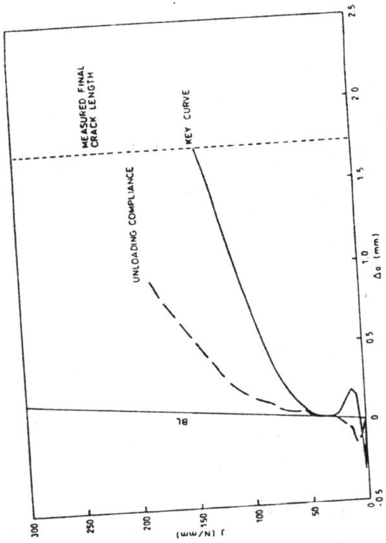

Figure 1 Unloading Compliance and Key Curve J-R Curve

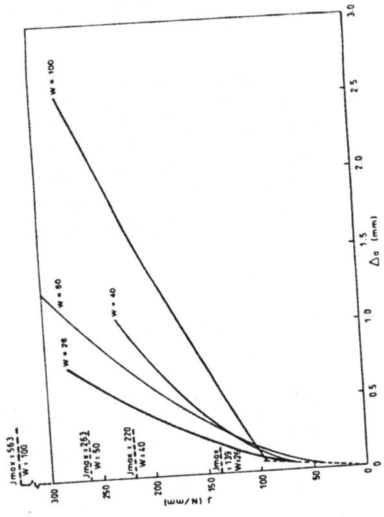

Figure 2 Effect of Specimen Size - Unloading Compliance Technique

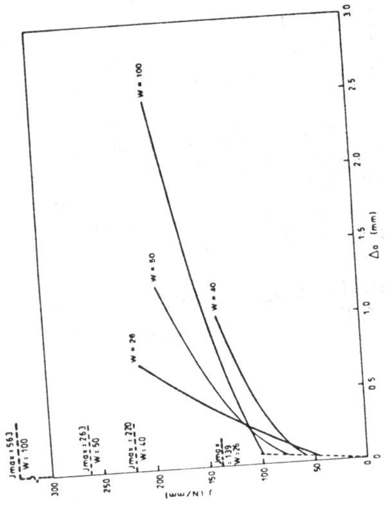

Figure 3 Effect of Specimen Size - Key Curve Technique

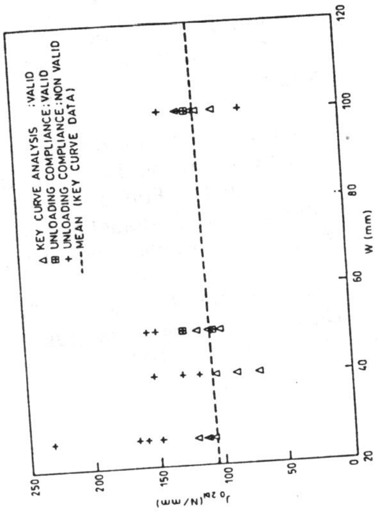

Figure 4 Effect of Specimen Size on Fracture Toughness