Summary

The papers in this symposium volume review selected developments in the American Society for Testing and Materials (ASTM) fracture mechanics test method standardization from the viewpoint of recent activities of the ASTM Subcommittee E24.01 on Fracture Mechanics Test Methods. These papers may be divided into two general categories: (1) application of elastic mechanics to the direct measurement of values that have been proposed to quantitatively characterize the fracture resistance of metallic materials, and (2) the development of tests using small specimens (screening tests) which can provide a ranking of materials in terms of their fracture toughness and whose results can be correlated with quantitative measures of fracture toughness. Included in this latter category is the surface crack specimen which has found direct application in fracture control programs as a means for simulating the effect of flaw geometries sometimes encountered in service.

In addition to the technical papers, this volume also contains copies of the following ASTM standards: (1) E 399-74 Method of Test for Plane-Strain Fracture Toughness of Metallic Materials, (2) E 338-68 (1973) Standard Method of Sharp-Notch Tension Testing of High-Strength Sheet Materials, (3) E 602-76T Tentative Method of Test for Sharp-Notch Tension Testing with Cylindrical Specimens, and (4) E 561-76T Tentative Recommended Practice for R-Curve determination. The symposium papers contain information that will serve as a basis for modification of these standards and for the development of new standards in fracture toughness testing.

Direct Measurements of Fracture Toughness

Included under this heading is information relating to modifications of the ASTM E 399-74 Method of Test for Plane-Strain Fracture Toughness of Metallic Materials, the development of a J_{Ic} test method, and to the formulation of the ASTM E 561-76T Tentative Recommended Practice for R-Curve Determination. These standards attempt to provide a quantitative measure of the crack propagation resistance that can be used to evaluate the loading carrying capacity of structures in terms of some characteristic measure of fracture toughness.

E 399 K_{Ic} *Test Method*

The ASTM E 399 K_{Ic} Test Method has been in existence for over six years, and during that time a considerable amount of experience has been gained from its use in the metal production and fabrication industries. This experience is reviewed in the paper by Kaufman who is presently Chairman of E-24. While the data presented relate to aluminum alloys, the problems discussed are common to the application of ASTM Method E 399-74 in the steel and titanium industries. A frequently heard complaint against ASTM Method E 399-74 concerns its numerous validity criteria (14 in all), and the degree of sophistication needed in the instrumentation. These problems are reviewed by Kaufman with the object of examining the possibility of reducing the cost and complexity of the test method.

Specifically, he points up that while the P_{max}/P_Q limit of 1.10 helps to ensure the constancy of K_{Ic} with variation of W/B or specimen size, "good data" are sometimes rejected by this limitation. He proposes that the limitation on P_{max}/P_Q be a function of the W/B ratio and suggests a "calibration relation." Data for the influence of precracking K level on the subsequently measured K_{Ic} values are presented for several unidentified aluminum alloys. These data indicate that this limitation might be increased from the present value of 0.60 K_{Ic} to 0.80 K_{Ic}. Kaufman points up that the requirements on fatigue crack front straightness are sometimes impossible to meet because of variation in the metal properties through the thickness of the specimen. He presents data for paired specimens of unidentified aluminum alloys with one specimen of each pair meeting and one failing the crack straightness requirements. The results are shown as a function of "crack front curvature" where this value represents the maximum percent difference between the middle three crack length measurements on a given specimen. On the basis of these results, there seems to be no systematic trend of K_{Ic} values with increasing curvature up to about 20 percent.

In a discussion to Kaufman's paper, Jones and Brown advance the argument that ASTM Method E 399-74 should be considered as a reference test method applicable to a wide variety of materials even though this formulation can lead to inefficiencies in application to specific materials. For example, they point up that the variation of K_{Ic} with W/B observed for tougher materials could be eliminated by restricting the W/B ratio to two. This restriction would also eliminate the need to provide "calibration relations" between P_{max}/P_Q and W/B as shown in Fig. 4.[1] In the opinion of these discussers, ASTM Method E 399-74 should not be elaborated with special relief procedures designed to broaden its

[1] Unless otherwise noted, figure, equation, and reference numbers refer to those in the author's paper.

applicability to specific material conditions. Rather, such procedures should be incorporated in the appropriate ASTM standards relating to material specifications. However, they point up that a change in the crack front straightness requirements should be made because the present requirements based on crack length permit increasing curvature at the center of the thickness as W/B increases from one to four. This effect can be substantially reduced by basing the requirements on the thickness rather than the crack length.

Several years ago Kendall and Hussian (Ref *2*) suggested the use of a C-shaped specimen for determining the fracture toughness of tubular stock where the crack plane was normal to the tangential direction of the tube. Applications include the testing of gun barrel forgings or heavy walled tubing. The ASTM E24.01.01 Task Group on E 399-74 is in the process of incorporating the C-shaped specimen into that test method. The papers by Underwood and Kendall and by Gross and Srawley give stress intensity factor calibrations for the specimen. In addition, Underwood and Kendall present some essential features of a K_{Ic} test method using two designs of the C-shaped specimen and discuss the application of this type of specimen to J_{Ic} tests and to fatigue crack growth rate determinations. Both papers report the results of K calibrations obtained using boundary value collocation techniques. These are expressed in terms of the dimensionless stress intensity factor $KBW^{1/2}/P$ as a function of the radius ratio (R_0/R_1), the relative crack length (a/W), and the loading hole position in relation to the crack mouth (X/W) (for example, see Gross and Srawley, Fig. 2). The results reported by Gross and Srawley apply to both internal and external cracks and are formulated in such a way that K values for a wide range of specimen geometries can be obtained by superposition of solutions for two special cases, one for net section tension and the other for net section bending. The K calibrations reported by Underwood and Kendall agree well with those of Gross and Srawley for the range of specimen geometries that will be incorporated into ASTM Method E 399-74.

An expression for the dimensionless stress intensity factor is given by Underwood and Kendall (Eq 1) in terms of a/W, X/W, and r_2/r_1 (R_0/R_1 of Gross and Srawley). It should be noted that while this expression is stated to apply over the entire range of radius ratios between one and infinity, it is probably not appropriate for very large values of this ratio. The limiting case is a disk specimen (radius ratio of infinity), and Eq 1 would apply only if the crack tip extended beyond the center of the disk by some undetermined amount. It would seem better to treat the disk specimen by a separate analysis, and this has been recently done by Gross.[2] In this analysis, the definition of crack length and specimen width

[2]Gross, B., "Analysis of a Cracked Circular Disk Subjected to a Couple and a Force," NASA TM 73692, National Aeronautics and Space Administration, Washington, D.C., 1977.

are consistent with those used for the compact specimen which is obviously a close relative of the disk specimen.

J_{Ic} *Testing*

Landes and Begley provide a thorough review of the J-integral concept as it relates to development of a fracture criterion for situations where the amount of crack-tip plasticity is well beyond that permitting the application of linear elastic mechanics (that is, K_{Ic} testing). They discuss the essential features of a proposed J_{Ic} test method being considered by ASTM E24.01.09 and some of the problems that have been encountered during its evolution. It is evident from their review that a considerable amount of research must be completed before we have a J_{Ic} test method that can give fracture toughness values having the precision and breadth of application that now characterize K_{Ic}.

The authors point up that in the case of plastic behavior where deformation is not reversible (as compared with linear or nonlinear elastic), J loses significance as a crack driving force since it is no longer a measure of energy available at the crack tip for crack extension. The justification for using J as a fracture criterion lies in its interpretation as a crack-tip stress-strain field intensity parameter based on an analysis (Refs *10, 11*) which assumes power law hardening. The hypothesis is that J provides an adequate description of the plastic zone surrounding an intensely deformed fracture process zone. Providing this zone is sufficiently small in comparison with the plastic zone and the planar dimensions of the specimen, crack initiation should take place at a critical value of J independent of the geometry. This concept leads to the need for size requirements for J_{Ic} tests. At the present time these have not been well established. The following guidelines are suggested by Landes and Begley: $b,a,B > \alpha\ J_{Ic}/\sigma_{flow}$ where, a is the crack length, b the uncracked ligament, and B the specimen thickness. The requirement on B is necessary to ensure that plane-strain fracture conditions are maintained. The coefficient α may have values between 25 and 50 depending on the material. The average of the tensile ultimate and the 0.2 percent offset yield strength is taken as σ_{flow}.

The presently accepted method of obtaining J from a specimen where the uncracked ligament is subjected to bending makes use of Eq 10 which represents a situation where the crack is sufficiently deep that plastic deformation is confined entirely to the ligament and the total displacements are essentially equal to those due to the crack. This represents a limiting case that may or may not be approached by the actual specimen behavior. However, determinations of J in J_{Ic} testing are based generally on the total displacement of the specimen load point. Attempts to explore the implications of this procedure have involved analyses of the ASTM Method E 399-74 bend and compact specimens (Refs *18, 19, 20*). For the bend specimen (Ref *18*), it has been shown that the coefficient 2 in Eq 10 applies to rigid perfectly plastic behavior (where crack and total displacements are equal) at all values of a/W and to the total displacements for linear elastic behavior at a/W values above 0.5. The observation that the same coefficient applies to these two extremes of material behavior lends confidence to the use of this coefficient for the ASTM Method E 399-74 three-point bend specimen geometry. An analysis of the compact specimen (Ref *20*) leads to a modification of Eq 10 which indicates that the use of Eq 10 with a coefficient of two for the ASTM Method E 399-74 compact specimen could underestimate substantially the value of J. The same analysis indicates that the use of total displacements for the compact specimen will not lead to significant errors at a/W values greater than 0.45.

The proposed J_{Ic} test method focuses attention on the onset of crack extension as determined from a J_I resistance curve. This curve represents the trend of data on a plot of J_I versus crack extension. The data are generated from tests on several specimens loaded to progressively higher values of displacement and then unloaded and broken open to determine the amount of crack extension that had occurred. Following unloading, the crack advance is marked by heat tinting or some other suitable procedure. The J_I value at the unloading load is computed using the appropriate expression for J. If everything goes right, the points will define a curve which is nearly linear at small crack advances. This curve is then extrapolated to the "blunting line" (see Fig. 4) and the J_I value at the intersection taken as J_{Ic}. Experience has shown that this method of determining J_{Ic} while providing a direct measurement of crack extension, in some cases, leads to uncertain values due to scatter in the data which establish the J_I resistance curve. Landes and Begley discuss other methods of obtaining J_{Ic} including sensing of crack extension from measurements of compliance, electric potential, and ultrasonics. These methods have the potential of permitting the determination of J_{Ic} from a single specimen, however, as yet there is insufficient experience with them to permit a meaningful comparison with the multiple specimen technique of the proposed test method. Landes and Begley recommend the compact specimen of ASTM Method E 399-74 for J_{Ic} tests with a modification that permits the clip gage to sense the displacement on a line connecting the loading pin centers. However, as the specimen deforms this measurement does not represent the true load point displacement. Calculations show that the errors can become significant for specimens close to the size requirements.[3]

[3] Donald, K., "Rotational Effects on Compact Specimens," presented at ASTM E24.01.09 Task Group Meeting, 24 March 1977, Norfolk, Va.

Landes and Begley caution against using the maximum load from a test on a single specimen to calculate J_{Ic}. While it is possible that under some circumstances the maximum load values agree with those determined by the proposed test method, such agreement is fortuitous. In many cases, large differences are encountered (for example, Fig. 15) with the maximum load values being higher than the J_{Ic} values determined according to the proposed test method.

It is probably too early to clearly define various applications of J. However, Landes and Begley mention several, including the characterization of fracture originating from a blunt notch, the description of crack extension under corrosive conditions, the correlation of fatigue crack growth rates, the determination of the load carrying capacity of a structure containing a defect surrounded by a well-developed plastic region, and the determination of K_{Ic} by conversion of J_{Ic}. In addition, they discuss a modification of the J-integral for application to crack-growth rate correlations under high-temperature steady-state creep conditions. For all of these applications, considerable additional data will be required to permit a judgment of their practical value. An application which is illustrated by experimental data in the author's paper is the conversion of J_{Ic} to K_{Ic}. Here the practical value lies in the considerable reduction in specimen size that would be, in theory, realized for very tough materials. However, this conversion is complicated by the fact that different measurement points are used in the J_{Ic} than in the K_{Ic} test procedure. Thus, J_{Ic} relates to the onset of crack extension while K_{Ic} relates to 2 percent "effective" crack extension. Depending on the steepness of the J_I resistance curve, the K_{Ic} determined by conversion of J_{Ic} may underestimate substantially the value of K_{Ic} determined directly. This is illustrated in Fig. 12 and also in a paper by Underwood.[4] Attempts to "correct" for this difference by computing J_{Ic} at 2 percent crack extension from the resistance curve are complicated by the fact that the K_{Ic} measurement point does not represent necessarily an actual crack extension of 2 percent but rather a change in the crack mouth displacement that would correspond to 2 percent crack extension under ideally elastic conditions. In reality, a portion of this change in crack mouth displacement can be due to plastic flow at the crack tip. Therefore, in some cases a conversion based on a J_{Ic} value taken at 2 percent actual crack extension may overestimate K_{Ic}.

Landes and Begley mention areas which they consider important for future study. These may be summarized as follows: (1) better definition of the J_{Ic} test specimen size requirements; (2) comparison of J_{Ic} results from different types of specimens; (3) the use of J in an instability

[4]Underwood, J. H., "J_{Ic} Test Results from Two Steels," *Cracks and Fracture, ASTM STP 601*, American Society for Testing and Materials, 1976, pp. 312–329.

analysis of structures; and (4) means of reducing the conservatism in J_{Ic} values as they apply to actual structural behavior. Added to these might be studies directed toward developing a consistent measuring point for J_{Ic} and K_{Ic} tests and the further development of single specimen methods of measuring J_{Ic}.

Crack Growth Resistance Curves in Terms of K

ASTM E 561-76T Tentative Recommended Practice for R-Curve Determination requires the determination of an "effective crack length" equal to the initial crack length plus the directly measured (or physical) crack growth plus a plastic zone adjustment ($r_y = \pi/2\ K^2/\sigma_{ys}^2$). The effective crack length may be alternatively determined from displacement measurements on the specimen and the use of a compliance calibration relation which gives the dimensionless displacement in terms of the relative crack length a/W. Three specimen types are incorporated into the recommended practice; center cracked tension (CCT), compact tension (CS), and crack line wedge loaded (CLWL). The paper by McCabe and Sha presents compliance calibrations for these three types of specimens determined by both analytical and experimental techniques.

The authors reproduce displacement results for each of the specimen types obtained by Newman using boundary value collocation (Ref *10*). These results apply to measurements at the centerline of the CCT specimen over several gage lengths and to measurements on the crack line at four locations for the CT and CLWL specimens. Compliance calibrations based on these results include all the information necessary to reduce the displacement measurements specified by the tentative recommended practice to effective crack lengths. The authors compare these analytical results with experimental compliance measurements for the CT and CLWL specimens and find excellent agreement. For the CCT specimen, a limited number of finite element results obtained by the authors are presented and shown to be in good agreement with the boundary value collocation information. Experimental compliance measurements for the CCT specimen obtained by the authors for a single gage length over a range of a/W values between 0.05 and 0.6 are compared with finite element results and with an expression proposed by Estis and Liebowitz (Ref *12*). The agreement appears to be satisfactory among these three compliance calibrations for the CCT specimen.

The information in the paper by McCabe and Sha has been used in a revision of the Proposed Recommended Practice for R-Curve Determination to produce the ASTM E 561-76T Tentative Practice. The major changes were concerned with corrections to the compliance calibration Tables for the CS and CLWL specimens and the use of Eq 2 in Section 10 in place of a less accurate expression in the Proposed Recommended Practice.

Screening Tests

There has been increasing interest in the development of so called screening tests which could provide rapid and relatively inexpensive indexes of fracture toughness. A review of the applications of such tests and of the various types that have been proposed is available in a recent NMAB Report.[5] The ASTM E-24 Committee on Fracture Testing of Metals is responding to the need for such tests through the activities of task groups charged with the responsibility of developing test methods for three types of specimens, namely, a plate tension specimen, a sharply notched cylinder, and a precracked Charpy. It should be noted that the ASTM standards now contain two test methods for fracture toughness screening tests. One is the ASTM Method E 338-68(1973) for Sharp-Notch Tension Testing of High-Strength Sheet Materials, and the other is a Proposed Method for ⅝ in. (16 mm) Dynamic Tear Test of Metallic Materials. The former is limited to sheet less than 1/4 in. (6.4 mm) thick and the latter requires a relatively large amount of material. It is not anticipated that the new test methods will supplant these established methods but rather supplement them.

Plate Tension

The paper by Shannon et al reports data from an investigation intended to optimize the design of a plate tension specimen (DENC specimen) having double edge notches with one notch being fatigue cracked. Minimum length dimensions were determined by photoelastic studies and by tests on maraging steel at several strength levels. A systematic investigation was made of the influence of specimen width and thickness for a variety of high-strength alloys having well-established ASTM Method E 399-74 K_{Ic} values. The results from plate specimens are presented as ratios of the nominal crack strength to the 0.2 percent offset tensile yield strength (σ_c/σ_{ty}) as a function of the specimen thickness or width. As might be expected, increasing thickness continuously lowers the ratios for the toughest alloys and has no influence on the brittlest material conditions. Behavior between these extremes is noticed for alloys of intermediate toughness. The influence of increasing width is to reduce the crack strength ratio with the low toughness alloys following the inverse square root relationship with crack length. The influence of specimen width and thickness on the crack strength ratio are interrelated in that the thickness effect for the tougher alloys appears to be reduced as the width decreases.

[5] "Rapid Inexpensive Tests for Determining Fracture Toughness," NMAB Report 328, National Materials Advisory Board, The National Research Council, Washington, D.C.

Based on ordinal ratings, the results show that the correlation between crack strength ratio and K_{Ic} improves as the DENC specimen width to thickness ratio decreases. This is probably explained by the fact that plastic zone development at maximum load is reduced as the width decreases or the thickness increases. Satisfactory correlations were obtained using DENC specimens having a width of 1 in. and a thickness of ½ in.

The DENC specimens were provided with crack mouth displacement gages so that K_Q values could be obtained from each test. The influence of crack length and thickness on K_Q was in agreement with that previously reported (Ref *2*). However, while the largest specimens appeared to satisfy all the requirements of ASTM Method E 399-74, the K_Q values were about 10 percent lower than the corresponding K_{Ic} values. This effect is possibly due to a slightly unsymmetrical stress field in the DENC specimen.

Sharply Notched Cylinder

ASTM E 602-76T Tentative Method for Sharp-Notch Tension Testing with Cylindrical Specimens specifies two sizes of notched cylinders (½ in., 13 mm and 1$\frac{1}{16}$ in., 27 mm diameter) having notches with a maximum root radius of 0.0007 in. (0.018 mm) which remove 50 percent of the cross-sectional area. The sharp-notch strength (nominal strength at maximum load) is the single quantity determined from the test. The ratio of the sharp notch strength to the 0.2 percent tensile yield strength designated as the notch yield ratio (σ_{NTS}/σ_{YS} or NYR) is used as an index of K_{Ic}. It is well known that eccentricity of loading can give rise to bending stresses which will reduce the notch strength and that if these vary from test to test the result will be a contribution to the scatter. The method therefore specifies an upper limit on the percent bending (determined using a special verification specimen) of 10 percent. The paper on the sharply notched cylindrical tension specimen is divided into two parts; Part I by Jones et al describes the influence of fundamental testing variables on the sharp notch strength of several high-strength aluminum alloys, and Part II by Bucci et al describes the statistical analysis of correlations between the notch-yield strength ratio (NYR) and K_{Ic} for various lots of 2124-T851 aluminum alloy plate.

The investigation of fundamental testing variables included the effect of variations in the notch root radius and eccentricity of loading on the notch strength. In addition, the influence of specimen diameter on the notch yield ratio was investigated for a wide range of K_{Ic} values. The results show that variations in notch root radius and eccentricity of loading within the range permitted by ASTM E 602-76T can contribute significantly to the scatter observed in relations between the σ_{NTS}/σ_{YS} and K_{Ic}. The authors suggest that the tentative test method be revised to reduce these effects. Thus, it is proposed to decrease the root radius limit to 0.0005 in. (0.013 mm) and the bending permitted to 5 percent.

As might be expected, the notch yield ratio loses sensitivity to changes in K_{Ic} for sufficiently tough metal conditions. The upper limit of useful sensitivity decreases with decreasing specimen diameter. On the basis of the results obtained by Jones et al, it is doubtful that the ½ in. (13 mm) diameter specimen will provide a useful index of K_{Ic} for the new high toughness aluminum alloys. However, it does appear that the upper limit of 1.3 placed on the notch yield ratio by the test method is overly conservative and could be increased to 1.5 without loss of useful sensitivity of the ratio to changes in K_{Ic}.

The aluminum industry has gained experience in the use of the sharply notched cylindrical specimen for material lot release when minimum values of K_{Ic} are specified. The paper by Bucci et al gives examples of how this specimen is used in a quality assurance program. Results are presented for 90 lots of 2124-T851 plate of different thicknesses tested using ASTM Method E 399-74 bend and compact specimens to obtain valid K_{Ic} values and using the 1$\frac{1}{16}$ in. (27 mm) diameter notch specimen of E 602-76T to obtain corresponding NYR values. In most cases, K_{Ic} was determined for three crack orientations (S-L, T-L, and L-T). A multiple least squares linear regression analysis was made of these data which included the variables of plate thickness, 0.2 percent offset tensile yield strength, crack orientation, notch strength, NYR, and K_{Ic}. The results of this analysis show that only crack orientation and plate thickness are significant in affecting a correlation between NYR and K_{Ic}. The orientation effect was further studied and the suggestion made that the T-L orientation would be suitable as a control for the other orientations.

The authors refine their regression model using special statistical techniques to determine tolerance limits that could be used in establishing a lower bound on the relation between K_{Ic} and NYR useful for setting values of the notch yield ratio corresponding to minimum acceptable values of K_{Ic}. They further show that a quality assurance plan based on the notch yield ratio could effect a considerable cost savings as compared with one based on direct determination of K_{Ic}.

Precracked Charpy Specimens

Charpy V-notch specimens precracked before testing have been employed by various investigators for several years in the evaluation of the "fracture toughness" of high-strength alloys. Both slow bend and impact tests have been used in these evaluations. Originally, some investigators thought that K_{Ic} or "K_c" values could be directly derived from the results of these tests. However, it is now generally accepted that while this is not possible, useful correlations may exist between K_{Ic} and the results of precracked Charpy tests. ASTM E24.03 Subcommittee on Dynamic Testing has established task groups having the responsibility of drafting test methods for precracked Charpy slow bend and impact tests. As part of this activity, a statistically designed large test program is underway to assess the influence of notch preparation and precracking variables on the results obtained from precracked Charpy tests. This program includes several alloys and involves both slow bend and impact tests.

While the results of this program may prove ultimately to be quite useful, it was thought desirable to proceed as rapidly as possible in standardization of the slow-bend precracked Charpy test using appropriate information from ASTM Method E 399-74 as a guide in specimen preparation. The two papers by Succop et al present information that will be helpful in this standardization process.

The first of these two papers (Succop, Bubsey, Jones, and Brown) is concerned with determination of fracture work per unit of original uncracked area ($\bar{W}/A$) from precracked Charpy specimens. The authors point up that if the load point deflection could be accurately measured to the end of the fracturing process, $\bar{W}$ would represent the total fracture work. However, in practice problems can arise because of extraneous deflections which contaminate the measured displacements, and because, except for very brittle metal conditions, there is no way of unambiguously determining the end of the fracturing process from the test record. Thus, the value of $\bar{W}$ can depend on the method of sensing deflection and the method of record analysis. The authors suggest some ways to solve these problems based on analysis of load-deflection records from a number of materials having a wide range of K_{Ic} values.

Precracked Charpy specimens ¼ in. (6.4 mm) thick were cut from broken K_{Ic} specimens of two steels heat treated to a wide range of strength levels, from several high-strength aluminum alloys and from a titanium alloy. These specimens were prepared and tested in accordance with the specifications of ASTM Method E 399-74. Load-deflection records were obtained from measurements of the tensile machine loading screw rotation and directly from the specimen deflection. Elastic moduli computed from selected load-deflection records were compared with the average of the tension and compression moduli. These comparisons showed that records obtained from screw rotation contained large extraneous deflections arising primarily from elastic strains in the tensile machine. On the other hand, moduli computed from direct measurement of specimen deflection agreed with the average of the tension and compression moduli within 10 percent. The authors show that, by truncating the load-deflection record beyond maximum load at a deflection corresponding to 10 percent of maximum load, the effects of the extraneous deflections on the $\bar{W}/A$ values is greatly reduced. A simplified method of determining $\bar{W}$ is presented that does not involve graphical integration of test record but which can be used only if the specimen deflection is measured directly.

A statistical analysis is presented of the relations between the crack size factor K_{Ic}^2/σ_{YS}^2 and $\bar{W}E/A\sigma_{ys}^2$ for each alloy investigated. The results are shown on log-log plots in terms of "calibration lines" which could be used to predict K_{Ic} from the precracked Charpy data. These plots also contain the correlation coefficient and the 95 percent confidence bands. On the basis of this analysis, the authors conclude that useful relations between $\bar{W}/A$ and K_{Ic} can be obtained for some materials; however, the degree of confidence with which K_{Ic} can be predicted from $\bar{W}/A$ will vary depending on the alloy conditions incorporated in the correlation. It is suggested that the best correlations will be obtained from tests on a single alloy having a relatively simple aging or tempering reaction and where a single crack orientation is involved.

The second paper (Succop and Brown) explores the possibility of using the nominal strength, σ_N, of the precracked Charpy specimen (based on the maximum load and initial uncracked area) in formulation of correlations with K_{Ic}. This analysis involved the same specimens as were used to determine the $\bar{W}/A$ values just discussed. Data were plotted as dimensionless ratios, σ_N^2/σ_{ut}^2 versus K_{Ic}^2/σ_{ut}^2W, on log-log coordinates. Here W is the specimen width. The ultimate strength, σ_{ut}, was selected rather than the yield strength in order to better use the Green and Hundy limit load in computing an upper bound for the data. Thus, for sufficiently tough metal conditions, the nominal strength will be determined not by fracture but by plastic instability in the ligament. The data on these plots fall surprisingly close to the elastic relation between σ_N and K_{Ic} (for example, Fig. 6), but for the toughest metal conditions gradually deviate from this line to approach a nearly constant value at the Green and Hundy limit. The authors believe this way of plotting the data helps to establish the useful range of correlation between the Charpy strength ratios and K_{Ic}. Calibration lines were determined by a linear regression analysis. Correlation coefficients and 95 percent confidence bands were established for each plot. The results of this analysis were essentially the same as the one based on $\bar{W}/A$ values providing the toughness range of the correlations was restricted to avoid the loss in sensitivity of σ_N to changes in K_{Ic} at high toughness levels.

The authors conclude that strength ratios from precracked Charpy specimens can provide useful correlations with K_{Ic} for some materials and that the use of strength ratios rather than $\bar{W}/A$ values greatly simplifies the test procedure and reduces the cost. The previously mentioned NMAB Report on Rapid Inexpensive Tests for Determining Fracture Toughness recommends that a precracked Charpy test to provide strength ratios be standardized. The ASTM E24.03.03 Task Group has this as their first priority.

Surface Crack Specimens

The paper by Orange is a report of the ASTM E24.01.05 Task Group on the Surface Crack Specimen. It provides the background information necessary to draft a recommended practice for testing of surface crack specimens. These specimens have been widely used to determine the influence of "service type" flaws on the residual strength of metallic alloys. They are not specimens suitable for determination of K_{Ic} values although they are sometimes used for this purpose. A basic problem in obtaining quantitative measures of fracture toughness from the surface crack specimen is the lack of a generally accepted stress analysis that would permit the determination of stress intensity factors for a range of crack shapes, depths, and specimen widths. Obtaining the necessary information involves the solution of an extremely difficult problem in three dimensional elasticity. Detailed interpretation of surface crack data is hampered by the fact that measurements of change in visible crack length during a test do not provide direct information on concurrent changes in shape or depth. Attempts to use crack mouth opening measurements to obtain such information are complicated by the absence of an elastic solution for crack mouth displacement as a function of elliptical crack size and shape.

In spite of these difficulties, the author points up that the surface crack specimen can indeed furnish valuable information concerning the fracture behavior of metallic alloys providing the specimen is thought as modeling a flaw in an actual or intended structure. Thus, the thickness of the specimen should be the same as that of the structure at the point where the flaw is assumed to exist and the test section should be wide and long enough that infinite plate conditions are closely approached. On the basis of experience, the specimen width should exceed 5 times the surface crack length, and the test section length should be at least twice the specimen width. The author points up that the control of crack size and shape during fatigue cracking is an art and that considerable experience may be required before cracks of some desired shape and size can be produced. At present, there is no information from surface crack tests that would serve as a guide regarding the maximum stress intensity to be used in producing the fatigue crack nor regarding the minimum extension of the fatigue crack beyond the starter notch. It is suggested that the requirements of ASTM Method E 399-74 concerning fatigue cracking be followed when possible. It is recommended that a record be obtained of crack mouth displacement versus load for each test. This record can furnish qualitative information regarding the initiation of crack extension and the presence of large amounts of crack-tip plasticity.

No specific method of data analysis is recommended. A plot of gross fracture stress (residual strength) versus some measure of crack size is a direct way of displaying the results. In most cases, the parameter a/ϕ^2 is as good a measure of crack size as are more elaborate parameters which attempt to correct for plasticity. It is most important to report pertinent information concerning the material tested, the specimen design, and all details of specimen preparation and testing procedure.

While there are still many gaps in our understanding of the surface crack specimen, it would be most helpful to those using this specimen type to have the benefit of guidelines contained in a recommended practice. Based on presently available information, it should be possible to produce a document that would be helpful in reducing the scatter often observed in surface crack data and increasing the general utility of information obtained from surface crack specimen tests.

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