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Comparison of Fracture Toughness Test Procedures for Aluminum Alloys

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CONTENTS

ABSTRACT

The Dynamic Tear (DT) test provides a sensitive and quantitative measure of the fracture toughness of aluminum alloys. The test permits the measurement of fracture propagation energy across the toughness spectrum for metals which are definable by linear elastic analyses to those requiring gross plastic strains for fracture. The linear elastic fracture mechanics parameter K_{Ic} provides a relationship between critical flaw size and stress level at which crack instability will occur. Unlike the DT test, the K_{Ic} toughness test cannot be used for fracture under conditions of elastic-plastic or gross plastic strain.

A correlation has been developed between the DT test and the K_{Ic} parameter for aluminum alloys. The relationship may also be expressed in terms of β_{Ic}-DT and $\mathcal{G}_{Ic}$-DT. The K_{Ic} values were determined with several specimen types, and a comparison of the values for different specimens was obtained.

The correspondence between K_{Ic} and DT serves several purposes. It provides a frame of reference for DT values obtained from frangible metals that fracture under linear elastic conditions. Accordingly, it permits use of the inexpensive DT test to approximate the flaw size-stress instability conditions which otherwise must be determined by the more expensive K_{Ic} test.

Another important aspect of the relationship between DT and K_{Ic} is that through extrapolation, the correlation which exists in the linear elastic region can be extended into the elastic-plastic region. The loss of a plane-strain stress state requires calculation of approximate K_c values from the extrapolated K_{Ic} values. Thus, it is possible to use the DT test to estimate the critical flaw size at crack instability for metals in which fracture occurs under an elastic-plastic strain field. Because of the relatively large flaws involved for this condition, the approximation is adequate for most engineering purposes.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases is continuing.

AUTHORIZATION

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COMPARISON OF FRACTURE TOUGHNESS TEST PROCEDURES FOR ALUMINUM ALLOYS

INTRODUCTION

The fracture toughness of a material is characterized by its resistance to initial crack extension and crack propagation in the presence of a flaw. Depending on the type of fracture toughness test, the measured quantity may be a stress intensity parameter with an inherent usefulness or it may acquire value through a correlation with criteria derived from structural performance.

The Charpy-V (C_v) test is an example of a test which requires a background of service experience or correlation with other structural tests before it may be effectively employed. Although a C_v energy value has a relative worth when compared with C_v values from different materials, it becomes far more significant when the value is suitably indexed by the described correlations. The Dynamic Tear (DT) test may also be used through correlations; in its first use the significance of DT energy values was established by failure conditions of prototype structural elements. These elements represented large plates containing flaws which were loaded by explosion techniques to failure — elastic or plastic. However, for DT specimens which represent the full thickness of the plate, the test accurately defines the limiting fracture mode which is characteristic of the metal for that specimen thickness.

Linear elastic fracture mechanics provides a method for defining the critical flaw size at which unstable crack movement occurs. When a plane-strain stress state exists in the crack tip region, the K_{Ic} value may be determined experimentally. Fracture mechanics theory provides for the calculation of the critical flaw size or the critical nominal stress for fracture from values of K_{Ic} which are considered material constants. Plane-strain fracture mechanics procedures cannot be applied to metals in which crack instability occurs concomitant with large plastic zones (elastic-plastic case) or with gross plastic strains.

The K_{Ic} test method is a relatively complicated procedure which is not amenable to general engineering usage: the specimen preparation is costly, and the interpretation of test results requires experienced personnel. If a correlation existed between the engineering tests, such as C_v or DT, and the K_{Ic} parameter, the significance of the engineering tests would be enhanced. Their energy values could be translated into K_{Ic} terms, and fracture mechanics analytical procedures may then be used in a two-step process. For fracture toughness levels which are outside of the plane-strain state, extrapolations and other independent procedures for the definition of fracture resistance are required.

DYNAMIC TEAR TEST

High-strength aluminum alloys have widespread application in thick sections primarily due to their favorable strength-to-weight ratio. Previous measurements of the fracture toughness of these alloys had been primarily limited to circular sharp-notch tensile tests and fracture mechanics test procedures due to the relative insensitivity of the C_v to discriminate among alloys (1). When the DT test was applied to aluminum alloys, it was found that it could distinguish between the fracture toughness of the alloys to a much finer degree than either the C_v or the circular notch tensile test.

The DT test is designed to provide a sensitive and quantitative measure of the energy required to propagate a moving crack under conditions of the characteristic fracture mode of the metal (Fig. 1). A major requirement of the test for this purpose is the simulation of a sharp, natural crack for the initiation of the fracture. This feature is obtained by introducing into the DT specimen an embrittled electron beam (EB) weld which serves as a crack initiator. The EB weld is embrittled by the diffusion of a phosphor bronze alloy through the test specimen to provide a 1.75-in.-long, through-thickness brittle weld which acts as a crack starter. When the specimen is impact loaded, the embrittled weld is fractured and thus provides a sharp crack which propagates into the test metal. In alloys possessing high fracture toughness, the crack moves through the test material with the development of large plastic zones or slant fracture, and a high propagation energy is measured. Brittle materials offer far less resistance to the movement

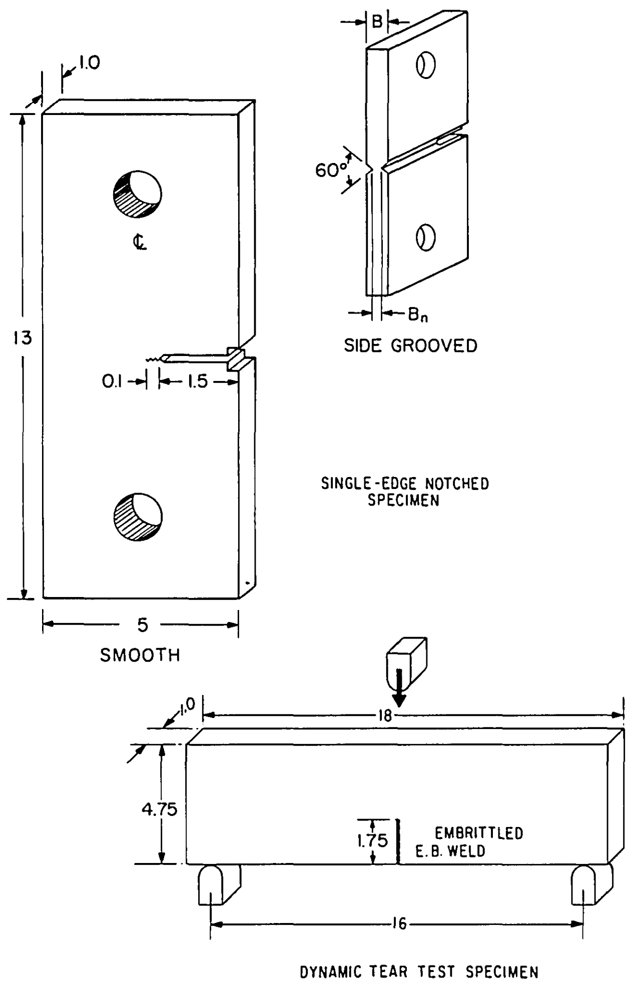

Fig. 1 - Smooth and side-grooved single-edge-notched (SEN) tension specimens used to measure K_{Ic} and the DT test specimen. All dimensions are in inches.

of the crack, because the resulting conditions of a flat break represent plane strain and very small plastic zones.

The DT test has several features which contribute to its importance as an engineering fracture toughness test (1). The test permits full-thickness plate specimens to be used and thereby integrates any variation in toughness from the center to the surface of the plate. Second, the energy to fracture the embrittled weld and thus initiate a crack is a very small portion of the total fracture energy for all but the most brittle alloys. This provides for a specific measurement of the energy required to propagate the crack through the specimen.

A highly significant attribute of the DT test is that it may be considered a "limit-severity" test, a factor especially important for metals which are sensitive to strain rate effects. The effective crack toughness of many rate-sensitive metals decreases to a lower limit as the crack velocity increases. The impingement of a high-velocity crack on the test material provides a measure of material toughness under the most severe conditions that the metal may experience in service. This circumstance is analogous to a pop-in of an embrittled area ahead of a crack embedded in a structure. For metals, such as aluminum, which are relatively insensitive to strain rate, the brittle crack simply serves the purpose of providing a condition of limiting crack tip acuity.

FRACTURE MECHANICS TESTS

The plane-strain fracture toughness (K_{Ic}) data on which the correlations have been based were obtained with both the single-edge-notched (SEN) tension and notch-bend (NB) specimens. The specimens were nominally 1 in. thick and represented the full thickness of the plate from which they were cut. Each specimen was fatigued at a low stress to cause a crack of approximately 0.10 in. to form at the tip of the edge notch.

The SEN specimen in Fig. 1 was modeled after the specimen designed by Sullivan (2), and the experimental compliance calibration of Ref. 2 was applied to calculate K_{Ic}. Although the calibration is independent of absolute specimen dimensions, care was taken to keep the ratio of the distance between loading pin centers to the specimen width similar to the specimen calibrated in Ref. 2. A mathematical stress analysis has been developed by Gross (3) which provides essentially the same K_{Ic} value as does the experimental compliance calibration for the crack-length-to-width ratios used in these tests.

Both three- and four-point-loaded NB specimens were employed to determine K_{Ic} values. The four-point-loaded specimen (Fig. 2) has the advantage of reducing the influence of the shearing stress on the strain energy release rate $\mathcal{G}$. (The shearing stress is zero within the minor span.) The stress intensity factor for the three- and four-loaded NB specimens was calculated using the boundary collocation K calibrations reported in Ref. 4. The three-point-loaded NB specimen, not shown in Fig. 2, had dimensions of 1 by 2 by 9 (thickness by width (depth) by length) in.

A NB specimen with a square cross section was also used to obtain K_{Ic} values for several alloys (Fig. 2). The width dimension of this specimen is one-half that of the NB, while the nominal thickness is similar to the NB. The K_{Ic} results for this square notch bend (SNB) specimen were employed as part of a K_{Ic} test comparison program reported later in this report and were not included in the development of the correlations. The formula used to determine K_{Ic} for the SNB (5) does not include an appropriate plasticity correction which was added to the uncorrected K_{Ic} value. The SNB specimen of Fig. 2 was used for the three- and four-point load application.

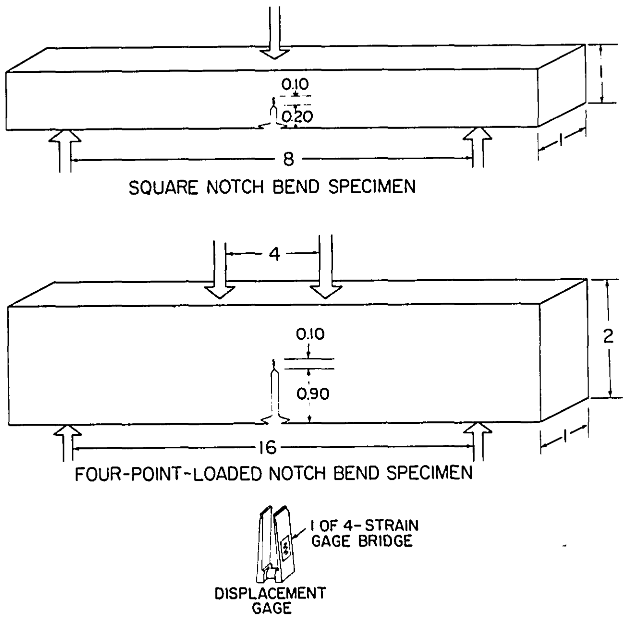

Fig. 2 - Dimensions of the three-point-loaded square notch bend (SNB) specimen, the four-point-loaded NB specimen, and a sketch of the beam displacement gage used to detect initial crack instability

Some of the SEN, NB, and SNB specimens were sidegrooved to a depth of 5% of the thickness on each side of the fracture plane (Fig. 1). Previous work has indicated that the side grooves accentuate the displacement at crack instability on the load-displacement record (6). The grooves contain an included angle of 60 degrees and a notch-root radius of 0.002 in.; the calculation to determine K_{Ic} for side-grooved specimens is reported in the Appendix.

An X-Y recorder was used to draw the load-displacement graph for each K_{Ic} specimen. When initial deviation from linearity occurred at or very near maximum load, this load value was used to calculate K_{Ic}; otherwise, the load at the lowest, distinct instability was chosen for the calculation. A beam displacement gage instrumented with a four-strain-gage bridge was used to detect initial crack extension (Fig. 2).

TEST RESULTS AND DISCUSSION

The aluminum alloys which were used in the fracture toughness test correlation study represented two alloy systems: 2xxx (Al-Cu) and 7xxx (Al-Zn-Mg). The temper notation T indicates the alloy was thermally strengthened, followed by an aging treatment and/or mechanical work (7). The plates, nominally 1 in. thick, arrived in the mill-heat-treated condition and underwent no further heat treatment. The mechanical properties are recorded in Table 1; these values represent room-temperature properties, as do the K_{Ic} values, except where otherwise noted.

Table 1
Mechanical Property Data

Alloy	Alloy Number	Fracture Direction	Tension Test Data				C_v Energy at 30° F (ft-lb)	DT Energy at 30° F (ft-lb)
			0.2% YS (ksi)	UTS (ksi)	Elongation in 2 in. (%)	RA (%)		
2020-T651	A-6	WR	76.3	80.4	2.0	2.0	—	79
2024-T4	A-2	RW	48.1	72.4	17.5	22.1	10	490
2024-T351	A-10	WR	43.9	65.8	17.0	19.5	7	206
2219-T87	A-9	RW	57.9	72.0	—	—	5	207
	A-9	WR	55.2	72.0	—	—	5	207
2219-T851	A-15	RW	59.3	73.4	10.0	22.7	5	380
	A-15	WR	58.4	74.3	9.4	19.6	5	208
7075-T6	A-5	RW	78.5	90.0	—	—	5	110
	A-5	WR	77.8	88.2	11.0	14.4	4	102
7075-T7351	A-14	RW	66.7	76.6	12.2	26.8	6	249
	A-14	WR	64.9	75.5	11.8	23.3	4	146
7079-T6	A-13	WR	74.9	85.4	—	—	2	82
7106-T63	A-17	WR	52.5	60.8	13.9	40.0	8	424

The plane-strain fracture toughness data are presented in Table 2. Only those aluminum alloys in which it was felt that fracture mechanics might apply were chosen for this investigation. For several alloys, K_{Ic} data have been obtained with both SEN and NB specimens. A plastic zone correction* was applied to the K_{Ic} numbers; the corrected values appear in the right-hand column of Table 2, and these values are used in Figs. 3 through 7. The ASTM designation procedure is used to describe the fracture orientation (8).

Relationship Between Plane-Strain Fracture Toughness and Yield Strength

The K_{Ic} data are plotted against 0.2% offset yield strength (YS) in Fig. 3. Each datum point represents an average value of the K_{Ic} results for a particular alloy and temper. Solid and open symbols identify the fracture orientation. The number of specimens tested for each alloys and the range of K_{Ic} values are recorded in Table 2. A solid line has been drawn connecting those WR datum points which exhibit the highest average K_{Ic} values for a given YS. The line has been designated the K_{Ic}-Optimum Material Trend Line (OMTL), and it indicates the upper limit of fracture toughness for any specified strength level for the alloys investigated. The broken portion of the line represents the region in which K_{Ic} values did not meet the requirements of the recommended practice suggested by ASTM Committee E-24.

$*r_y = \frac{1}{6\pi}\left(\frac{K_I}{\sigma_{ys}}\right)^2$

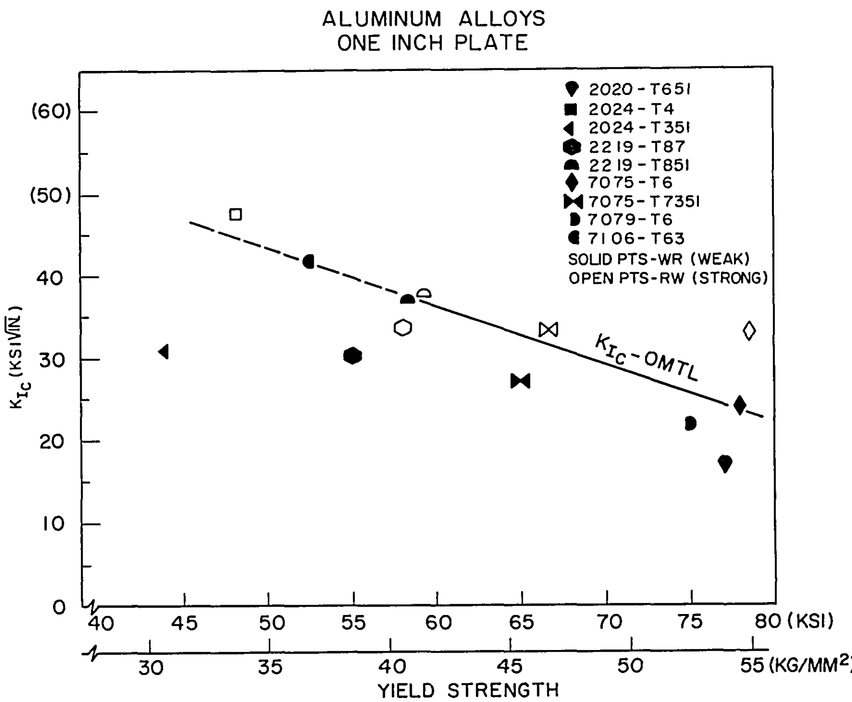

Fig. 3 - K_{Ic} plotted against yield strength for aluminum alloys at various levels of toughness

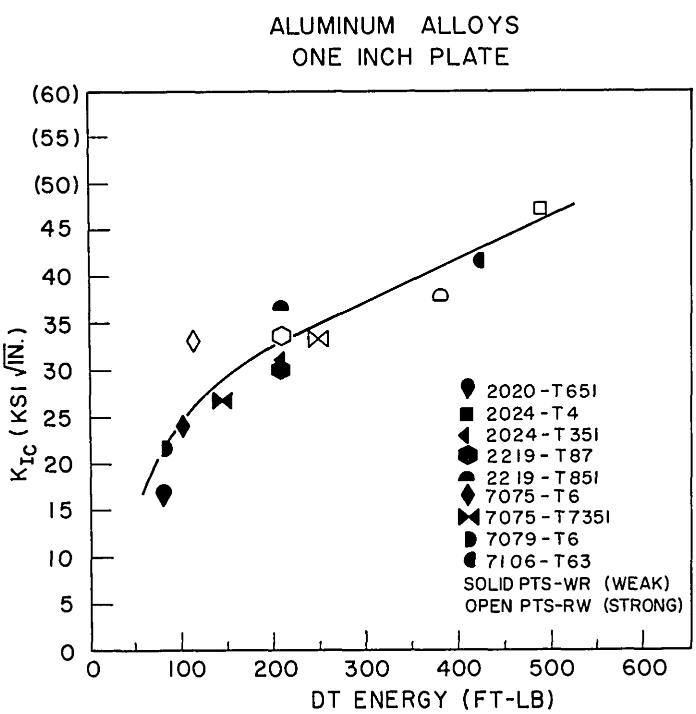

Fig. 4 - The correlation of K_{Ic} with DT test energy

Table 2
Plane-Strain Fracture Toughness Data

Alloy	Alloy Number	Fracture Direction	YS (ksi)	Specimen Type	Number of Specimens	K_{Ic}* Range (ksi $\sqrt{in.}$)	Av. K_{Ic}* (ksi $\sqrt{in.}$)	Av. β_{Ic}	Young's Modulus (psi $\times 10^6$)	Av. $\mathcal{G}_{Ic}$ (in.-lb/in.^{2})	Av. Nominal Fracture-Stress-to-Yield-Stress Ratio	K_{Ic} (ksi $\sqrt{in.}$)
2020-T651	A-6	WR	76.3	SEN	1	16.4	16.4	0.033	11.1	25	0.18	16.5
2024-T4	A-2	RW	48.1	SEN	3	45.1–46.8	45.8	0.903	10.6	212	0.81	47.4
2024-T351	A-10	WR	43.9	SEN	4	30.2–30.7	30.5	0.474	10.6	91	0.67	31.0
2219-T87	A-9	RW	57.9	SEN	2	31.6–34.4	33.0	0.315	10.4	107	0.47	33.3
	A-9	WR	55.2	SEN	2	29.3–30.4	29.9	0.286	10.4	87	0.45	30.1
2219-T851	A-15	RW	59.3	SEN	4	34.9–37.2	36.0	0.381	10.4	129	0.58	36.6
				NB-3†	3	35.1–40.8	38.3	0.432	10.4	146	0.84	38.9
	A-15	WR	58.4	SEN	8	32.4–37.8	37.3	0.423	10.4	139	0.55	38.0
				NB-4	4	35.2–35.9	35.5	0.381	10.4	125	0.68	36.1
7075-T6	A-5	RW	78.5	SEN	6	31.6–33.5	32.9	0.178	10.4	105	0.40	33.1
	A-5	WR	77.8	SEN	1	23.9	23.9	0.095	10.4	56	0.28	24.0
7075-T7351	A-14	RW	66.7	SEN	4	30.3–33.4	32.5	0.247	10.4	107	0.49	33.3
	A-14	WR	64.9	SEN	4	23.4–26.8	26.7	0.172	10.4	70	0.36	27.0
				NB-4	4	25.1–27.2	26.1	0.144	10.4	67	0.50	26.4
7079-T6	A-13	WR	74.9	SEN	1	21.7	21.7	0.082	10.4	45	0.27	21.7
7106-T63	A-17	WR	52.5	SEN	3	40.3–41.6	40.8	0.622	10.3	169	0.71	41.7

*Uncorrected K_{Ic} values.
†NB-3, NB-4: NB specimens, three-point or four-point loaded.

Correlation of K_{Ic} and DT

The DT energy is correlated with the K_{Ic} fracture toughness for aluminum alloys in Fig. 4. The comparison ranges from K_{Ic} values of 16 to 47 ksi $\sqrt{in.}$, while the DT energy values vary between 79 and 490 ft-lb. A linear relationship is evidenced between 200 and 490 ft-lb; below 200 ft-lb the K_{Ic} values decrease rapidly. The significance of this decrease will be discussed in a later portion of this report. The average fracture stress of the K_{Ic} specimens for most of the alloys was less than 0.70 YS, and none exceeded 0.84 YS.

Relationship of DT Energy to β_{Ic} and $\mathcal{G}_{Ic}$

The DT energy is compared to β_{Ic} in Fig. 5. The K_{Ic} values is incorporated in β_{Ic}, which in turn is proportional to the plastic zone radius for 1-in.-thick material. The β_{Ic} parameter is plotted against DT, since both the resistance of a material to initial crack instability (K_{Ic} test) and the resistance to crack propagation (DT test) are functions of the plastic zone size. The β_{Ic} value of 0.40 corresponds to the upper limit of toughness in terms of β which is advised by the recommended practice of the ASTM Committee E-24 for 1-in.-thick material. It may be seen from Fig. 5 that most of the alloys fall below this limit. References 6 and 9 indicate that higher values of β may be attained in specific instances without invalidating the K_{Ic} value.

The critical strain energy release rate $\mathcal{G}_{Ic}$ is plotted against DT energy divided by nominal fracture area (excluding the brittle weld) in Fig. 6. This curve permits a comparison to be made between the two parameters for identical units of measure (in.-lb/in.^{2}). The values of Young's Modulus E used in the computation of $\mathcal{G}_{Ic}$ ($\mathcal{G}_{Ic} = (K_{Ic})^2/E$) are tabulated in Table 2.

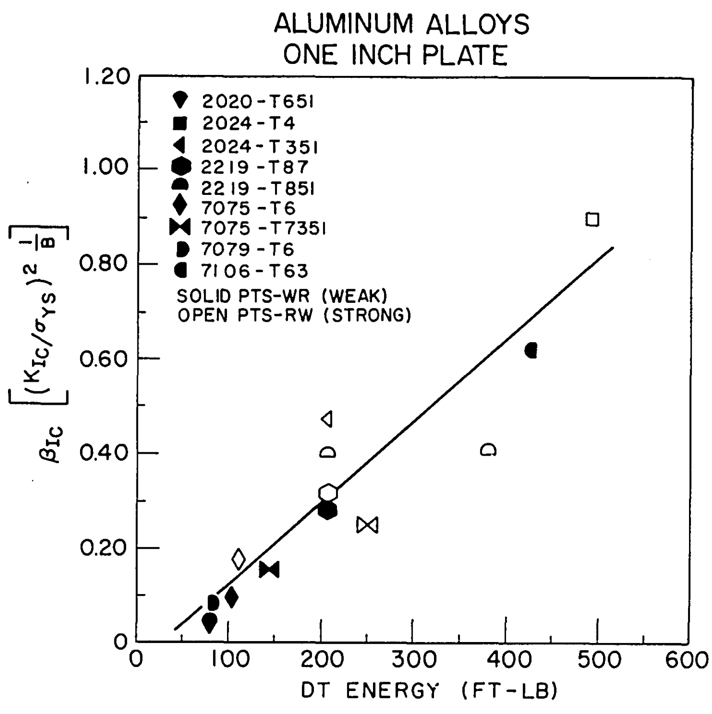

Fig. 5 - A comparison of β_{Ic} with DT test energy

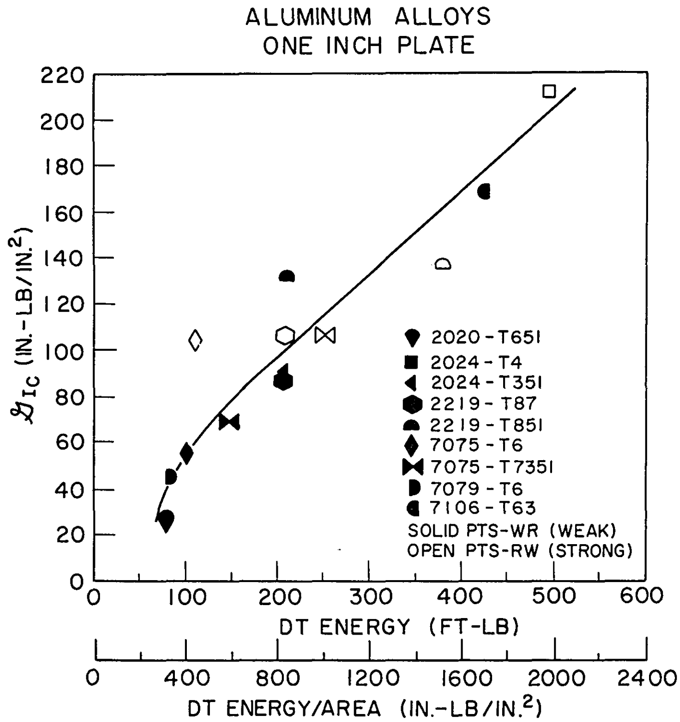

Fig. 6 - The strain energy release rate $\mathcal{G}_{Ic}$ plotted against DT test energy divided by the nominal area of the fracture plane

Relationship Between K_{Ic} and C_v

A plot of K_{Ic} versus C_v is provided in Fig. 7. Although a relationship is indicated between the K_{Ic} and C_v parameters, it is obvious that both the K_{Ic} test and the DT test are far more sensitive in discerning small variations in toughness. The total C_v range is only 8 ft-lb wide, and a change of 1 or 2 ft-lb on several alloys would cause an inordinate increase in the scatter.

Comparison of K_{Ic} Tests

The results from three types of specimens employed to determine K_{Ic} values are compared in Table 3. The specimens were used to measure values for the aluminum alloys 2024-T4, 2219-T851, and 7075-T7351. Several preliminary conclusions may be drawn from the table:

1. The K_{Ic} values from SEN tension specimens are essentially the same as those manifested by the NB specimens. The study included both three- and four-point loading of the NB specimen.

2. The SNB specimen, with its cross-sectional area one-half that of the NB specimen, appears to effectively measure K_{Ic} only when the fracture-stress-to-yield-stress ratio approximates or is less than unity. In Table 3 when the ratio was 1.10 or less for the SNB specimen, the K_{Ic} value was in close agreement with values measured by the

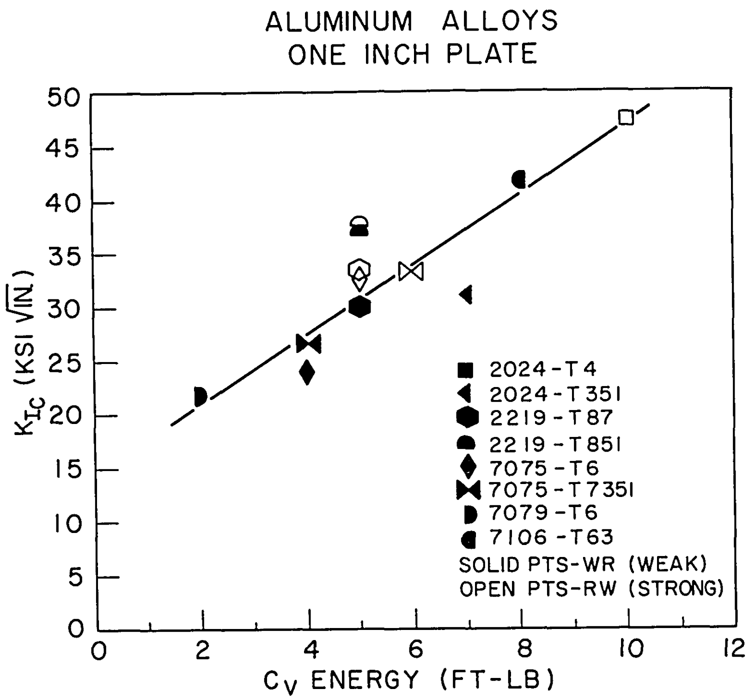

Fig. 7 - K_{Ic} versus C_v notched impact energy at 30°F

Table 3
Specimen Comparison of K_{Ic} Data

Alloy	Fracture Direction	Specimen Type*	Number of Specimens	K_{Ic}† Range (ksi $\sqrt{in.}$)	K_{Ic} (ksi $\sqrt{in.}$)	Av. Nominal Fracture-Stress-to-Yield-Stress Ratio
2024-T4	RW	SEN	3	45.1–46.8	47.4	0.81
	RW	SNB-3	3	36.8–37.2	42.0	1.91
2219-T851	RW	SEN	4	34.9–37.2	36.6	0.58
	RW	NB-3	3	35.1–40.8	38.9	0.84
	RW	SNB-3	2	35.1–36.2	37.7	1.10
	RW	SNB-4	2	34.2–34.3	36.4	1.06
	WR	SEN	8	32.4–37.8	38.0	0.55
	WR	NB-4	4	35.2–35.9	36.1	0.68
	WR	SNB-3	2	28.7–29.2	30.1	1.29
7075-T7351	WR	SEN	4	23.4–26.8	27.0	0.36
	WR	NB-4	4	25.1–27.2	26.4	0.50
	WR	SNB-3	2	25.4–26.3	26.6	0.76
	WR	SNB-4	2	25.1	26.1	0.62

*NB-3, NB-4: Notch bend specimen, three-point or four-point loaded.
SNB-3, SNB-4: Square notch bend specimen, three-point or four-point loaded. The nominal thickness and width dimensions are 1 in.; the span length is 8 in.; and the crack length is 0.2 to 0.4 of the width.
†Uncorrected K_{Ic} values.

SEN or NB specimens. However, when the ratio was 1.29 or greater, the SNB specimen underestimated the K_{Ic} by 11 to 19%.

3. Similar K_{Ic} values were obtained with the SNB specimen for both three-point and four-point loading.

4. The smaller cross section of the SNB specimen produces a higher fracture stress to cause the onset of K_{Ic} instability than is produced in either the SEN or the NB specimen for the same alloy. This results in a higher fracture-stress-to-yield-stress ratio and effectively decreases the measuring capacity of the SNB specimen.

Factors Which May Influence the Correlations

There are several elements which might affect the accuracy of the correlations. Since K_{Ic} is influenced by the strain rate, the high rate of applied strain in the DT test may cause the specimen to fracture with a lower apparent toughness than would be expected if the strain rates of the two tests were similar. However, since aluminum alloys are relatively insensitive to strain rate effects, this problem should not be applicable.

An energy loss is inherent in the fracture of the brittle crack-starting weld. Although the loss is small, it might be a significant portion of the energy recorded by the most brittle DT specimens. The loss of a linear relationship in Figs. 4 and 6 at low DT energy values may be due to the influence of the embrittled weld which limits the sensitivity of the DT test in this highly frangible region. It would further be expected that this factor should cause the curves in which DT energy is plotted to intersect the abscissa at a point offset from the origin rather than at the origin. This is demonstrated in Figs. 5 and 6 and may also be indicated in Fig. 4.

A third and perhaps most important point is that as the crack tears through the DT specimen, it may initially be governed by a plane-strain state of stresses, but in the tougher alloys it will propagate primarily under a mixed mode stress state. The mixed mode is probably caused by the lateral expansion of the crack at the same time that it moves forward. The lateral movement would effectively decrease the constraint around the crack tip and cause the stress intensity factor to rise once plane-strain conditions no longer exist. Hence, the plastic zone size would increase in the region of mixed mode; this would eventually produce surface relaxation manifested by shear lips. Therefore, it is expected that the energy measured in the DT test would, for tough alloys, represent mixed mode or plane stress, while the stress intensity factor determined in the K_{Ic} test would measure plane-strain conditions. However, this difference in stress state between the two tests has not resulted in a change in the slope of the K_{Ic}-DT and $\mathcal{G}_{Ic}$-DT relationships at higher DT energy values.

CONCLUSIONS

An engineering fracture toughness test may be considered as a test which characterizes crack toughness under a given set of conditions in a straightforward and uncomplicated manner. The conditions may include temperature, notch acuity, and a specific degree of mechanical restraint in the specimen. The product of the engineering fracture toughness test is a value which intrinsically has limited use, but when placed in a proper frame of reference it may facilitate the evaluation of metals and provide guidelines to their effective application. An example of this approach is a correlation between the engineering test and potential design criteria such as the critical flaw size-stress level relationship. The translation of the DT test results into a flaw size-stress level criteria has been the purpose of this report.

A high degree of correlation exists between the plane-strain stress intensity factor K_{Ic} and DT energy values for aluminum alloys. The relationship between these tests may be expressed in terms of β_{Ic}-DT and $\mathcal{G}_{Ic}$-DT. A less sensitive association has been demonstrated between K_{Ic} and C_v.

The correlation serves several functions. It provides a frame of reference for the DT test in a region in which no previous correlation had been established for the DT energy values. Second, it permits the use of the simple and less expensive DT test to predict K_{Ic} values related to a DT energy value. From the K_{Ic} values, a relationship can be established between a critical flaw size and the stress at which the flaw will undergo initial extension.

Perhaps the most important aspect of the correlation is that through extrapolation of the K_{Ic}-DT correspondence, prediction can be made of the critical flaw size and stress relationship even when the metal is well within the elastic-plastic region. By transforming the extrapolated K_{Ic} value obtained from the DT test to an approximate K_c value through the use of an appropriate equation suggested by Irwin (10), a flaw size can be estimated at which crack extension will initiate for a given level of stress. Thus, through the use of the K_{Ic}-DT correlation, the DT test can be employed to estimate the flaw size at which a crack becomes unstable for metals which manifest elastic-plastic behavior.

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Appendix

CALCULATION OF K_{Ic} WHEN SIDE GROOVES ARE EMPLOYED

The stress intensity factor for the SEN specimens was computed according to the experimental compliance calibration of Ref. 2, while the boundary collocation formula of Ref. 3 was used to calculate K_{Ic} for the NB specimens. The nominal stress intensity factor for both specimen types was determined by neglecting the presence of the side grooves; i.e., the thickness of the fracture plane was assumed to be equal to the thickness of the ungrooved specimen B. In terms of the strain energy release rate, it is evident that the strain energy is working on only that thickness of plate which comprises the fracture plane B_n. Therefore, a thickness correction must be made:

$$\mathcal{G}_{nom}\left(\frac{B}{B_n}\right) = \mathcal{G}_{Ic}, \tag{1}$$

where $\mathcal{G}_{nom}$ is the nominal value of $\mathcal{G}$ calculated with the assumption that the side grooves were not present. The correction in terms of the stress intensity factor is given by

$$K_{nom}\left(\frac{B}{B_n}\right)^{1/2} = K_{Ic}\ . \tag{2}$$

For reasons described in Ref. 6 the thickness correction mentioned above is more complicated; the exponent is actually greater than 1/2 but less than 1. However, as it would be impractical to determine the specific exponent for each alloy, the exponent of 1/2 was used throughout this report to compute K_{Ic}. By employing shallow side grooves, the error is kept small and will tend to cause the stress intensity factor to be slightly conservative.

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13. ABSTRACT

The Dynamic Tear (DT) test provides a sensitive and quantitative measure of the fracture toughness of aluminum alloys. The test permits the measurement of fracture propagation energy across the toughness spectrum for metals which are definable by linear elastic analyses to those requiring gross plastic strains for fracture. The linear elastic fracture mechanics parameter K_{Ic} provides a relationship between critical flaw size and stress level at which crack instability will occur. Unlike the DT test, the K_{Ic} toughness test cannot be used for fracture under conditions of elastic-plastic or gross plastic strain.

A correlation has been developed between the DT test and the K_{Ic} parameter for aluminum alloys. The relationship may also be expressed in terms of β_{Ic}-DT and $\mathcal{G}_{Ic}$-DT. The K_{Ic} values were determined with several specimen types, and a comparison of the values for different specimens was obtained.

The correspondence between K_{Ic} and DT serves several purposes. It provides a frame of reference for DT values obtained from frangible metals that fracture under linear elastic conditions. Accordingly, it permits use of the inexpensive DT test to approximate the flaw size-stress instability conditions which otherwise must be determined by the more expensive K_{Ic} test.

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Another important aspect of the relationship between DT and K_{Ic} is that through extrapolation, the correlation which exists in the linear elastic region can be extended into the elastic-plastic region. The loss of a plane-strain stress state requires calculation of approximate K_c values from the extrapolated K_{Ic} values. Thus, it is possible to use the DT test to estimate the critical flaw size at crack instability for metals in which fracture occurs under an elastic-plastic strain field. Because of the relatively large flaws involved for this condition, the approximation is adequate for most engineering purposes.