INVESTIGATION INTO THE USE OF MINIATURE SPECIMENS FOR THE DETERMINATION OF K_{IC} AND K_{ISCC} VALUES

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This paper reports the method of fatigue precracking, test technique (K_{IC}, K_{ISCC}) and analysis employed for a circumferentially cracked round specimen (CCR) of 8mm diameter. A comparison with the results obtained from the larger, CT-type specimen is also provided.
K_{IC} determination was performed for 2xxx- and 7xxx-series aluminium alloys, and for TA11 (Ti-6Al-4V) titanium alloy, these being widely used in the aerospace industry.
K_{ISCC} values were obtained for 2xxx and 7xxx series aluminium alloys in a substitute seawater solution (ASTM D 1141).

INTRODUCTION

Measurement of appropriate data such as plane strain fracture toughness (K_{IC}) often poses problems because of restrictions in the amount of relevant material available for testing. This is especially true with materials extracted from in-service components, forgings, castings or newly developed materials with a limited thickness.

The standard specimens associated with the current test methods, ASTM and European Standards, are costly to produce. The precracking process must be tightly controlled and this can be a costly and time consuming affair.

This investigation attempts to establish the viability of employing simple and inexpensive miniature specimens in order to generate plane strain fracture toughness data. If successful, it was felt, the design and test method could also be used to estimate K_{ISCC} (Stress corrosion cracking stress intensity threshold).

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TEST SPECIMENS AND MATERIALS

Two different specimen geometries were used in this investigation.

Standard proportional compact tension (CT) specimens were manufactured in order to obtain plane strain fracture toughness in accordance with BS 7448 : Part 1 : 1991. Tensile specimens were extracted to obtain tensile properties. The results of these tests are detailed in Table 1.

The miniature specimens were circumferentially cracked round type (CCR). A fatigue precrack was started from a circumferential notch by applying fatigue loading in single point bending mode under rotation. The compliance functions for a circumferential crack in a round bar are available (1). Figure 1 shows the miniature specimens.

All specimens were extracted from adjacent locations, and the crack plane in the CT and CCR specimens was identical. at the mid-thickness of the material.

To date, this investigation has utilised four materials; three aluminium alloys and one titanium alloy. The details are presented in Table 1.

TEST METHODS AND RESULTS

The fracture toughness tests on compact tension specimens were carried out in accordance with BS 7448 : Part 1 : 1991 at ambient temperature and humidity. The results for all materials are presented in Table 1.

The fatigue precracking of the miniature specimens was carried out using a modified rotating bend machine shown in Figure 2. The depth of the fatigue precrack was controlled by monitoring the applied load. A load reduction of between 5% to 8% was found to produce a CONCENTRIC fatigue precrack of suitable depth, ie. 1.5mm to 2.0mm, for all four materials. The initial load was dependent on the material under investigation.

The fracture toughness tests on miniature specimens were carried out under displacement control at a rate of 0.4mm/minute. During the test, axial load versus specimen displacement was recorded.

At the end of the test crack length a_o was calculated by taking the average of 8 equally spaced radial measurements.

The place strain fracture toughness K_{IC} was calculated using

$$K_{IC} = \frac{(4P)}{(\pi D^2)} \sqrt{\pi \bar{a} F} \qquad (1)$$

where

P	=	Maximum load
D	=	Specimen diameter
$\bar{a}$	=	Plastic zone corrected crack length
	=	$a_o + r$
a_o	=	Physical crack length
r	=	Plastic zone
	=	$(1/(6\pi))\,(K_{IC}/\sigma y)^2$
σy	=	0.2% Proof stress
F	=	$1.25/(1-(2a/D)^{1.47})^{2.4}$

The results for all materials are presented in Table 2.

The environment chosen for stress corrosion cracking test was a simulated seawater solution (ASTM D1141, without heavy element). The solution was circulated through the test chamber from an aerated reservoir via a peristaltic pump. The chamber construction allowed monitoring of solution temperature, pH and the electropotential being developed at the notch.

Each specimen was housed in specially produced insulating ceramic grips in order to ensure that there would be no stray current flow through the test piece. An inert sealant was also applied at the specimen grip interface, to isolate the stainless steel threaded insert.

The specimens were preloaded, within the environment, to 0.5kN, and this load was maintained for 24 hours to allow development of a 'micro climate' in the notch/precrack region. At the end of this period the control programme resumed loading, at a fixed extension rate. The extension rate selected was 0.03μm/minute. The initial trials indicated that this should allow acceptable results while avoiding excessive duration. Following testing, specimen was cleaned in nitric acid and crack length was measured as described before. The value of K_{ISCC} was determined using equation 1 where P is the crack initiation load. The results are presented in Table 2.

Fracture surface of tested specimens are shown in Figures 3 and 4.

DISCUSSION AND CONCLUSION

Comparison of results of K_{IC} from Table 1 (Compact Tension Specimens) and Table 2 (Miniature Specimens) shows the miniature specimens can be used to obtain valid K_{IC} results. Further testing will be required to generate a sufficiently large number of results to carry out a statistical analysis. Similar conclusions can be drawn regarding K_{ISCC} results.

The geometric requirements for the specimen also need investigating to ensure that the test results will yield plane strain fracture toughness values, with different materials, specimen diameter and length.

REFERENCES

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TABLE 1 **Mechanical Properties**

Results of BAe/MET Tests except where indicated

Material (orientation)	0.2% Proof Stress (MPa)	Ultimate Stress (MPa)	Elongation %	K_{IC} * (MPa√m)	K_{ISCC} (MPa√m)
2024 T351 (S-L)	333	406	5.0	26-29	5-8 (Ref 2)
7010 T651 (S-L)	430	588	4.7	20	4-8 (Ref 3)
7010 T7651 (S-L)	470	518	3.8	22-23	
TA-11 Forged (T-L)	885	945	1.8	55-66	

* CT specimens, Test Method BS 7448.

TABLE 2 **Miniature Test Piece Results**

Material (orientation)	Specimen Ident.	Crack Depth (Average, mm)	Load, * (kN)	K_{IC} (MPa√m)	K_{ISCC} (MPa√m)
2024 T351 (S-L)	359	1.560	8.970	25.54	
	360	1.691	7.315	23.00	
	361	1.268	10.130	23.68	
	362	1.939	6.161	23.47	
	363	1.525	9.049	24.94	
	364	1.565	8.098	23.12	
	332	2.05	2.40		8.74
	333	2.05	2.25		7.35
	334	2.05	2.53		8.10
	503	1.95	2.057		7.67
	530	1.88	2.025		6.09
	532	1.86	2.014		5.90
7010 T651 (S-L)	396**	2.233	3.388	13.61	
	400	1.510	7.652	19.91	
	403	1.924	5.843	18.92	
	337	2.222	1.582		5.75
7010 T7651 (S-L)	410	2.195	4.425	18.12	
	413	1.837	7.740	23.57	
	415	1.662	8.841	23.67	
	416	1.967	6.664	22.46	
TA-11 Forged (T-L)	49	2.310	10.670	52.23	
	50	1.605	23.34	64.18	
	51	1.784	19.98	62.38	
	52	1.706	21.03	62.28	
	53	1.558	24.41	64.92	
	54	1.579	23.34	62.59	

* Maximum Load used for K_{IC} calculation.
Initiation (deviation from linearity) load used for K_{ISCC} calculation.

** Specimen 396 showed visible eccentricity of the precrack.
This result would be considered invalid.

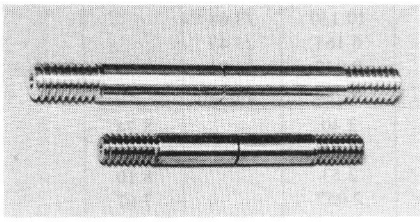

Fig 1. Miniature Specimens

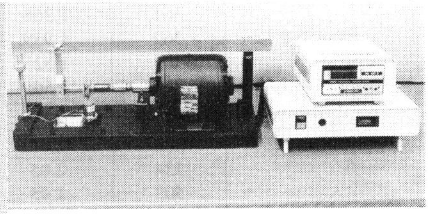

Fig 2. Rotating Bend Fatigue Precracking Rig

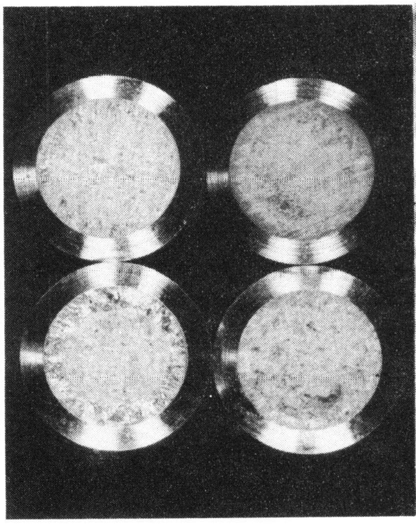

Fig 3. Fracture Surfaces K_{IC} Specimen

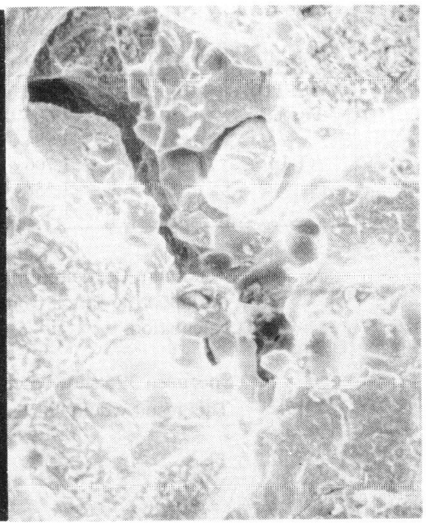

Fig 4. Fracture Surface K_{ISCC} Specimen