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Research and T..hnology Division
Wright-Patterson Air Force Base, Ohio

Materials Applications Division

EVALUAT.ON REPORT

.EDGE OPENING LOADING FRAC.URE TOUGHNESS TEST SPECIMEN

Repo... .. .A 65-30 Date: 2 August 65

Proj... Nr 7..106 Type Evaluation: Comparative

I. URPOSE

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II. ACTUAL DATA

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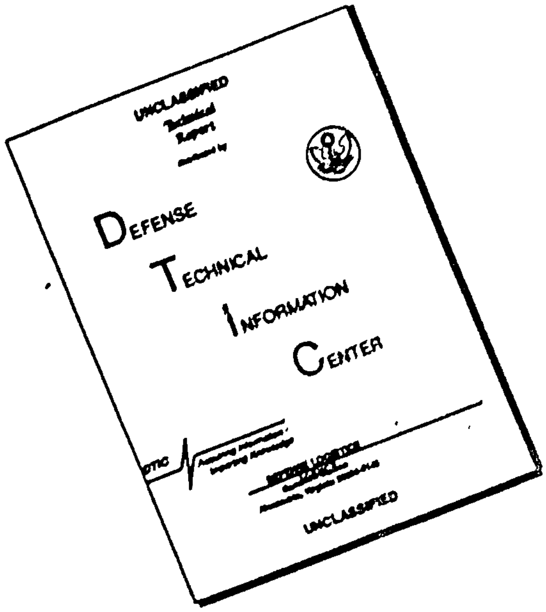

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Air Force Materials Laboratory
Research and Technology Division
Wright-Patterson Air Force Base, Ohio

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EVALUATION REPORT

WEDGE OPENING LOADING FRACTURE TOUGHNESS TEST SPECIMEN

Report Nr: MAA 65-30 | Date: 2 August 65

Project Nr: 738106 | Type Evaluation: Comparative

I. PURPOSE

The purpose of this investigation and analysis was to evaluate the wedge opening loading (WOL) specimen in fracture toughness testing and to present the results at the ASTM E-24 Fracture Toughness Testing Committee Meeting in the Fall of 1965.

II. FACTUAL DATA

1. Although a number of specimen types exist which are capable of determining accurate plain strain fracture toughness values, a need will always exist for a specimen which will give the greatest economy relative to the amount of material required, low testing machine capacity and minimum manpower requirements.

2. During the past two years, considerable work has been done on the development of a small specimen for fracture toughness testing by Westinghouse Electric Corporation. The specimen was developed primarily to determine the effect of nuclear environment on the fracture toughness of reactor structural materials.

3. This Wedge Opening Loading fracture toughness test specimen, abbreviated WOL, appears to have potential value in testing thick section materials whenever the material available for specimen fabrication is limited.

4. The materials used and the testing program performed are presented in Appendix I.

5. The test results and discussion are presented in Appendix II.

III. CONCLUSIONS

1. The results of these tests indicate that the WOL specimen yields valid K_{Ic} data, while requiring low applied loads and rendering test records which are readily analyzed and easily reduced.

IV. RECOMMENDATIONS

1. The WOL specimen type should be considered for plain strain fracture toughness testing where the material form is compatible and load capacity and/or material supply are limited.

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PUBLICATION REVIEW

This report has been reviewed and is approved.

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APPENDIX I

Materials

The materials utilized were two aluminum alloys: 7001-T75 and 7079-T6, in the form of scraps from forgings used on a previous test program. The tensile and fracture toughness properties of the materials were determined and reported in AFML-TR-65-150. The existence of these scraps, while limiting the number of specimens, provided an excellent opportunity for evaluating the specimen itself. All materials processing history, chemistry and heat treatment also have been reported in AFML-TR-65-150, but average tensile properties are repeated below for convenience.

Alloy	Test Direction	Yield Strength .2% Offset (Ksi)	Ult. Tensile Strength (Ksi)	% Elong.
7001-T75	Longitudinal	70.4	80.5	22.0
	Transverse	70.6	79.5	15.9
7079-T6	Longitudinal	69.3	77.4	15.2
	Transverse	68.8	77.5	13.5

Test Procedure

A specimen drawing is presented in Figure 1. Four specimens each (two longitudinal and two transverse) of 7001-T75 and 7079-T6, were fatigue precracked at 25 per cent of yield stress prior to fracture toughness testing in an Instron TTC testing machine at a crosshead rate of .02 in/min. Uncalibrated crack opening displacement was measured with a clip-on gage which was inserted into the specimen notch. Load-displacement curves were plotted, from which pop-in loads were determined. Pop-in events were readily determined from the test records and were invariably audible.

Stresses at the crack tip were determined according to the equation

$$\sigma_N = \frac{P}{Bh}\left(\frac{6\left(c + \frac{h}{2}\right)}{h} + 1\right)^{*}$$

where P = applied load
B = specimen thickness
h = uncracked depth
c = distance from load axis to crack tip
see Figure 1 for above dimensional designations

The plain strain fracture toughness, K_{Ic}, was determined from the equation

$$K_{Ic}^2 = \frac{C_1 \sigma_N^2 c}{(1-\nu^2)}^{*}$$

* A. J. Bush and W. K. Wilson, "Determination of Energy Release Rates for Biaxial Brittle Fracture Specimen", AEC Research and Development Report WERL-8844-2, August 1964.

where: σ_N = applied stress at the crack tip
c = distance from load axis to crack tip
ν = Poisson's ratio
C_1 = compliance factor

APPENDIX II

Results

The data shown in Table 1 are the average of two or more tests for each specimen geometrical configuration tested. The single edge notch (SEN), center notch (CN), slow notch bend (SB), and surface flaw (SF) specimens' data in Table 1 were previously generated prior to this investigation by the Design Information Inhouse Facility of the Materials Information Branch. The data obtained under this evaluation was generated from the same forgings as the above mentioned previously generated data. The data from all specimens are grouped according to crack plane orientations and crack propagation directions in cartesian coordinates as shown in Figure 2. The results were also averaged and are presented in Figure 2. The crack planes and propagation directions are oriented with respect to the two materials processing direction as shown in Figure 2 and pictorially presented in Figure 3. The average K_{Ic} (of the previously generated data from the specimens of various geometrical configurations) as compared with the WOL specimen is summarized in Table 2.

Discussion

One may conclude from observation of the data and cracks' description, tabulated in Tables 1 thru 2, plotted graphically in Figure 2 and described in Figure 3, respectively, that crack plane orientation and propagation direction has a definite effect on resulting K_{Ic} data. The crack propagation direction appears to have the greater effect based upon the limited tests performed. The results from an identical crack propagation direction and different crack plane orientations seem to correlate better than results from the same crack plane orientation and various propagation directions. This is with respect to each material of the same heat and processing condition. On this basis, results on 7001-T75 and 7079-T6 using the WOL specimen agree very well with previous results using other specimen types cracked in the X crack propagation direction. As shown in Table 2, the X direction average results for the WOL specimen's K_{Ic} of 7079-T6 and 7001-T75 aluminum alloys are 94.0 and 99.9 per cent, respectively, in agreement with average data generated on various other fracture specimens. The Y direction data of the WOL specimen for the above respective alloys are within 81.5 and 80.5 per cent agreement as can be observed from Table 2 also. With reference to Figure 2, the 7079-T6 alloy agreement is good in the Y direction. This disagreement is not as serious as it appears, since previous tests on this particular forging have shown that the material (7079) is severly inhomogeneous and the number of WOL specimens were limited to such an extent that good average values were not obtained. In this regard, it should be noted that the 7001-T75 material was much more homogeneous.

As indicated above, fracture toughness results are greatly influenced by grain structure and the presence of inhomogeneities. With highly worked microstructures, the relative orientation of the crack plane and propagation direction can greatly influence the fracture toughness data obtained and should therefore be noted. The presence of inhomogeneities can affect results for two reasons. The first is that since the equations for calculating K_{Ic} are based on the material being nearly an elastic continuum, the presence of inhomogeneous volumes leaves the equations somewhat suspect. The second, and for a more important reason, is that cracks propagating through inhomogeneous regions quite simply have environments different from each other and different from cracks propagating in regions without inhomogeneities. For this reason, microstructure should be examined and noted when reporting results, especially if there is considerable scatter in the data.

Lastly, it should be observed from the crack planes noted in Table 2 under "Specimen Type" and illustrated in Figure 3 that in binary space the crack planes are in the XZ and YZ reference planes for the comparative specimens' fracture data generated prior to this evaluation. On the other hand, the crack plane orientation for the WOL specimen tested in this program is in the XY reference plane. However, for the same material and crack propagation direction the fracture toughness results are in agreement for the average of the SEN, SB and CN specimens versus the WOL specimen results. Therefore, the crack plane orientations of the specimen data generated prior to this program and used as a comparison with the WOL crack plane data generated in this evaluation as summarized in Table 2 and sketched in Figure 3 does not appear to constitute a fallacy in the comparison. However, in a future program of this nature, crack planes oriented the same in binary space should also be investigated.

Since crack plane orientation did not appear to be significant, the WOL specimens fabricated for this program were not oriented the same as Figures 3A thru D with respect to the working direction. It should be noted also from Figure 3 that the crack plane is parallel to the specimen thickness, and the crack propagation direction is perpendicular to the thickness. Material line of reference is the working or forged direction which is the Y direction in Figure 3.

TABLE 1

AVERAGE K_{Ic} VALUES (KSI $\sqrt{in}$)(1)

Crack Description	Material	SEN	SF	SB	CN	WOL
XZ-Z	7001	--	29.0	24.6	--	--
XZ-X	7079	27.5	--	--	25.9	--
	7001	20.9	--	28.7	16.1	--
YZ-Y	7079	30.8	--	--	26.2	--
	7001	--	--	--	20.4	--
YZ-Z	7079	--	--	30.4	--	--
	7001	--	25.7	--	--	--
XY-Y	7079	--	--	--	--	23.2
	7001	--	--	--	--	16.4
XY-X	7079	--	--	--	--	25.2
	7001	--	--	--	--	22.1

Legend: SEN - Single Edge Notch Specimen
SF - Surface Flaw Specimen
SB - Slow Bend Specimen
CN - Center Notch Specimen
WOL - Wedge Opening Loading Specimen

(1) Average K_{Ic} values for each specimen configuration with respect to crack plane orientation and crack propagation direction.

TABLE 2

AVERAGE K_{Ic} VALUES (KSI $\sqrt{in}$)(2)

Propagation Direction	7079-T6	7001-T75	Specimen Type
X	26.7	21.9	Average of SEN, SB and CN (XZ-X)
	25.2	22.1	" " WOL (XY-X)
Y	28.5	20.4	Average of SEN and CN (YZ-Y)
	23.2	16.4	" " WOL (XY-Y)

(2)Crack plane orientations of comparative data is different from WOL specimen results. For identical crack propagation directions.

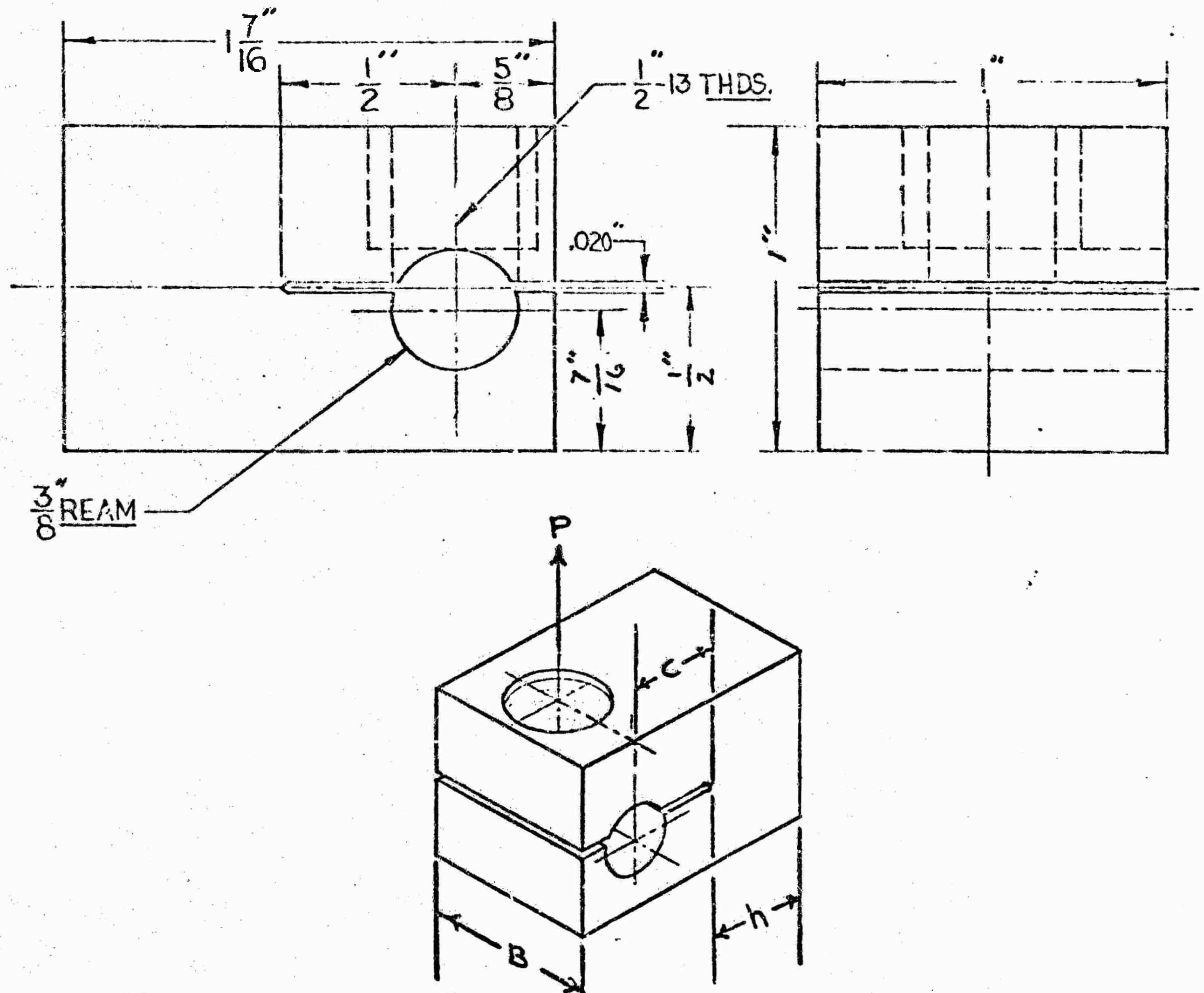
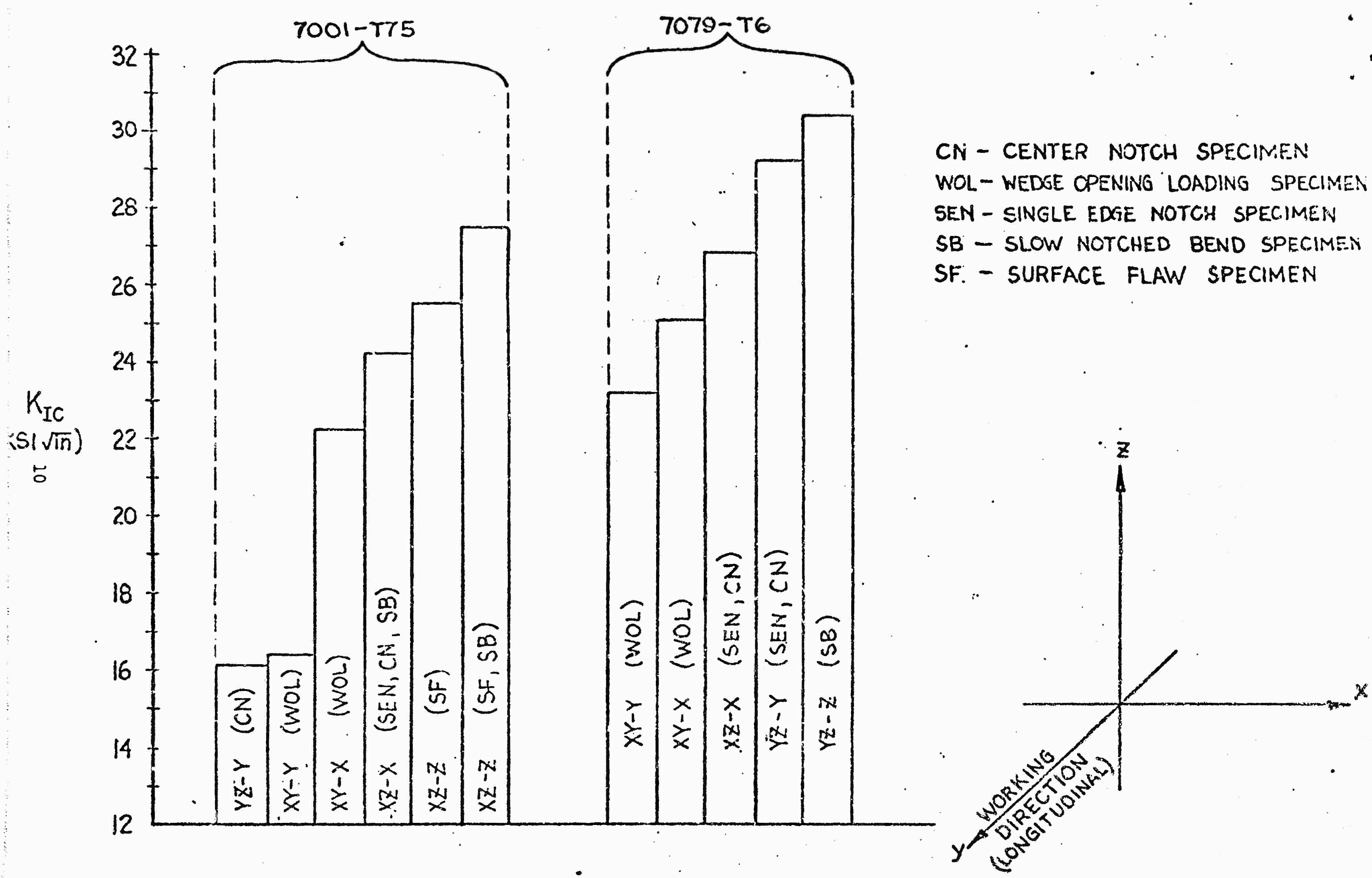
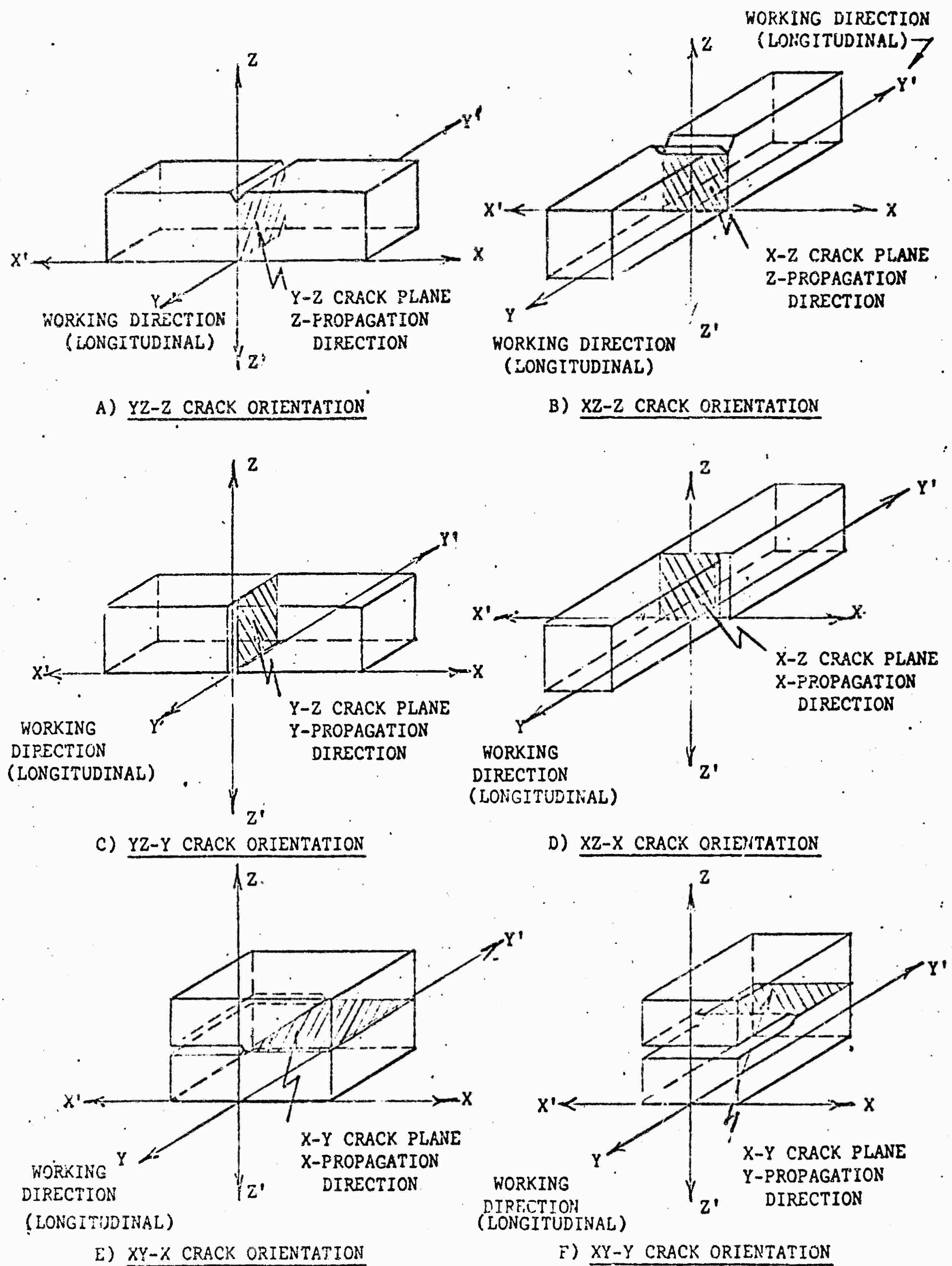


Figure 1. WOL Specimen



AVERAGE K_{IC} VALUES

Figure 2.



CRACK PLANE ORIENTATION AND CRACK PROPAGATION DIRECTION

Figure [illegible]