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THE FATIGUE BEHAVIOUR OF CIRCUMFERENTIALLY NOTCHED ALUMINIUM AL--ETC(U)
AUG 78 J Y MANN, F G HARRIS
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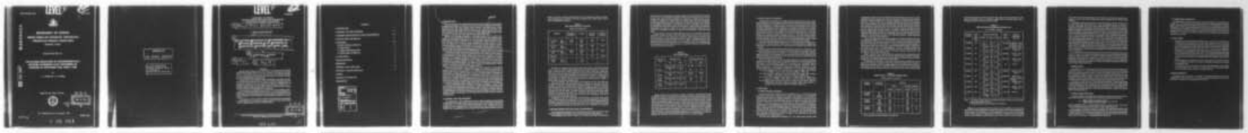

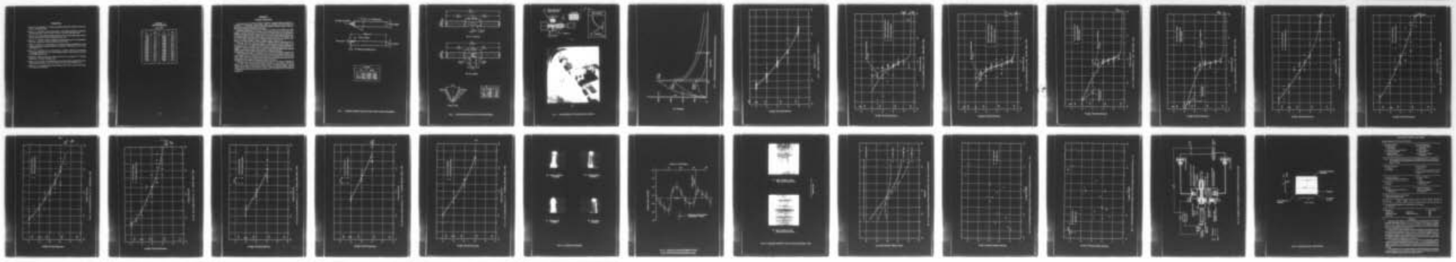

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STRUCTURES NOTE 447

THE FATIGUE BEHAVIOUR OF CIRCUMFERENTIALLY NOTCHED ALUMINIUM ALLOY SPECIMENS AS AFFECTED BY NOTCHING TOOL DWELL TIME

by

J. Y. MANN and F. G. HARRIS

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(10) J. Y. MANN ~~and~~ F. G. HARRIS

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SUMMARY

Rotating cantilever fatigue tests were carried out on V-notched specimens of DTD683 aluminium alloy having K_t *values of 1·20, 1·45, 2·35 and 4·35. The respective notch radii were 4·7, 2·0, 0·46 and 0·01 mm. In all cases the notches were plunge-cut machined in a lathe using carbide tip form tools and tool dwell times of zero and 200 revolutions before tool withdrawal from the finished notch.*

Tool dwell times of 200 revolutions resulted in significantly greater fatigue lives than zero dwell times for specimens of low K_t *(1·45 and 1·2). However, the fatigue test results for specimens of higher* K_t *(4·35 and 2·35) did not indicate any significant effects of notching tool dwell times. The use of different form tools for the notch of* $K_t = 1{\cdot}2$ *resulted in significantly different fatigue lives for specimens machined with 200 revolutions dwell time, but not for those machined with zero dwell time.*

No correlation was established between tool dwell times and the hardness, surface residual stresses and surface finish of the notches of $K_t = 1{\cdot}2$ *to explain the differences in fatigue lives. However, the horizontal forces measured during the machining of the two notches of high* K_t *were less than half those measured during the machining of the notches of low* K_t.

The consistent use of zero revolutions dwell time should enable greater reproducibility in average fatigue lives to be achieved, as changes in the form tool and operator appear to have no significant effects under such notching conditions.

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1. INTRODUCTION

Cylindrical specimens with circumferential grooves have been used for many years to assess the fatigue notch sensitivity of materials, and have been extensively employed in investigations involving the four major types of fatigue loading conditions—axial, plane bending, rotating bending and torsion. By adopting different radii at the root of the notch the severity of the stress concentrating effect under load can be readily altered. Although parallel sided notches have been used in some instances, the majority of circumferentially notched specimens have incorporated a Vee-form with a flank angle of between about 45° and 90°.

Because of the increasing requirement to use fatigue specimens which are more representative of actual design features, and also to cope with the greater current emphasis on the measurement of fatigue crack propagation rates—for which edge or centrally notched specimens in flat material are better suited—the use of circumferentially notched specimens to obtain axial load fatigue data for structural fatigue applications has declined. However, circumferential notches have particular applications in the case of shafts and axles subjected to torsional or rotating bending conditions. In addition, circumferentially notched specimens tested in relatively simple rotating bending fatigue machines, can provide useful information when making initial appraisals and comparisons of the fatigue behaviour of materials, processes, etc.

The common methods of producing circumferentially notched specimens involve the use of accurately prepared lathe form tools or grinding wheels and the notches are usually machined in the specimens by a plunge cutting operation. The notches may be machined in more than one stage, i.e. a roughing cut followed by a finishing cut to size and profile, and the resulting machining marks are usually perpendicular to the direction of principal tensile stress to which the specimen is subsequently subjected. Turning or grinding may, or may not, be followed by a notch root radius polishing operation, one objective of this process being to produce scratches parallel to the direction of principal tensile stress. Techniques for polishing notches in fatigue specimens have been described by Vitovec and Binder (Ref. 1).

Lathe-cut circumferentially notched specimens have been employed at the Aeronautical Research Laboratories (ARL) in a number of investigations into the fatigue characteristics of aluminium alloys (see for example Refs 2 to 4). Problems have been encountered with the reproducibility of fatigue behaviour between batches of notched specimens manufactured at various times and by different machinists. One machining variable which was identified and thought to be of possible significance was the "dwell time" of the form tool at the root of the notch before its retraction. It was postulated that the action of the tool in rubbing against the surface of the notch after it had ceased the actual cutting operation might cause work hardening and introduce compressive residual stresses which could be beneficial as regards fatigue life.

In order to eliminate the effects of different "dwell times" a Colchester 5 × 20 Chipmaster tool room lathe was modified so that the dwell time—in terms of lathe spindle revolutions—could be pre-set and the tool automatically retracted after such time. This report covers an investigation into the effects of tool dwell times of zero, 200 and 1,000 revolutions on the fatigue behaviour of notched specimens of DTD 683/3 aluminium alloy having four different notch root radii, and includes the results of measurements of tool cutting forces and specimen response during the cutting operation.

2. MATERIAL AND TEST SPECIMENS

The material used in this investigation was part of a batch of extruded 19 mm (0·75 inch) diameter DTD 683/3 aluminium alloy which had been used in previous fatigue investigations at ARL (Refs 3, 5, 6). The average chemical composition was zinc 5·80%, copper 1·37%, magnesium 2·38%, manganese 0·31%, iron 0·25%, silicon 0·17%, chromium 0·12% and titanium 0·05%. Approximately 40 bars of material (with average tensile properties as given in

Table 1) were used to produce specimen blanks which were subsequently selected at random to provide eight groups of 60 each for the major investigation and a further group of about 90 for a supplementary investigation.

TABLE 1
Static Tensile Properties of Test Material
(based on 24 tensile tests)

Property	Specification DTD 683/3	Average	Standard deviation	Coefficient of variation
0·1% proof stress (psi) (MPa)	67,200 463	87,700 605	1200 8	0·014
0·2% proof stress (psi) (MPa)	—	89,200 615	1200 8	0·014
Ultimate tensile stress (psi) (MPa)	78,400 541	96,800 667	1100 8	0·011
Elongation (%)	7	8·5	0·07	0·078
( ) Proof/UTS (0·1%) (0·2%)	—	0·91 0·92	—	—

The blanks were plunge-cut notched using Carbaloy 883 carbide tip form tools of the type shown in Figure 1 to produce fatigue specimens (Fig. 2*b*) having root radii of 4·7 mm (0·185 inch), 2 mm (0·080 inch), 0·46 mm (0·018 inch) and 0·10 mm (0·004 inch). During this operation the tools were advanced perpendicular to the specimen axes at a feed rate of 3·8 mm (0·15 inch) per minute using a lathe speed of 5 Hz (300 revs per minute), i.e. metal removal (on diameter) was approximately 0·025 mm (0·001 inch) per revolution of the specimen. A copious supply of soluble oil coolant was used during the notching operation. Appendix 2 briefly describes the automatic notching system.

Based on preliminary visual observations of the cutting action of the 2 mm radius tool, zero and 200 revolutions dwell time were adopted as 'standards' for each notch to compare the effects of dwell time on fatigue behaviour. Successive notches of a particular radius were machined using the alternative dwell times. During the notching operation it was observed that, for dwell times other than zero, metal removal continued after the cutting tool infeed had ceased, and that the number of specimen revolutions at which the 'cutting' action ceased increased with increasing notch radius. For example, by 200 revolutions no further metal removal was observed with the 2 mm radius tool, whereas some was apparent in the case of the 4·7 mm tool even after 800 revolutions.

Subsequently, a batch of 4·7 mm radius notched specimens was produced using a dwell time of 1,000 revolutions, with a different form tool to that used originally, and by a different machinist. At the same time a further series of 4·7 mm radius specimens (designated Series B1) was notched using 200 and zero revolutions dwell time so that a cross-check could be made of any possible effects on fatigue life associated with the use of a different tool or machinist.

3. SPECIMEN DEFLECTION/TOOL FORCE MEASUREMENTS

After completing the notching of most of the fatigue specimens, measurements were made of the force/deflection characteristics of the specimens during the notching operation.

The arrangement used is shown in Figure 3. For horizontal force/deflection measurements an MTS Type 632.11M extensometer was rigidly mounted on the lathe bed behind the specimen with one of its two arms lightly contacting the specimen surface through a film of oil. The amplified strain signal from the extensometer was recorded on a continuous trace recorder. A number of specimens with notches machined to different depths were loaded horizontally by dead-weights through a copper wire looped around the notch in the same set-up to 'calibrate' the force/deflection characteristics of the specimens at various notch depths. This procedure was followed for all four notches involved in this investigation. Vertical (upward) force/deflection measurements were made in a similar way, but with the extensometer mounted above the specimens. No cutting fluid or lubricant was used while notching specimens to determine cutting forces.

Average maximum horizontal bending deflections just prior to actuating the dwell time counter were 0·012 mm for the 0·1 mm and 0·46 mm radii, 0·03 mm for the 2 mm radius and 0·05 mm for the 4·7 mm radius notches respectively. Typical time/force records for three of the four notches at various dwell times are shown in Figure 4. The maximum forces which occurred during the cutting of notches in each of a number of individual specimens of the different notch radii are indicated in Table 2. It is thought that the elastic recovery (straightening) of the specimen after the tool infeed had ceased, i.e. during the dwell phase, resulted in further removal of metal from the notch root.

TABLE 2
Forces During Notching

Notch radius (mm)	Horizontal Force		Vertical (upward) force	
	(N)	*(lbf)*	*(N)*	*(lbf)*
4·7	334; 311; 334; 289; 289; 289	75; 70; 75; 65; 65; 65	267; 300	60; 67·5
Average	307	69	285	64
2	222; 200; 178	50; 45; 40	222; 267	50; 60
Average	200	45	245	55
0·46	89; 89; 76; 89	20; 20; 17; 20	89	20
Average	85	19	89	20
0·10	68; 85; 89; 133	15; 19; 20; 30	—	—
Average	93	21		

During the study of the cutting forces, variations were found in the differences between the diameters of zero and non-zero dwell time specimens notched on different occasions. This resulted from difficulties in being able to accurately adjust and reproduce the relative distance between the microswitch actuator pin and the mechanical stop of the lathe cross-slide. In some cases the tool continued to feed in for up to five spindle revolutions after the dwell time counter was activated; but nevertheless this represents a small fraction of the 200 and 1,000 revolutions dwell time adopted in this investigation. Thus, the resultant differences in diameters (ranging from about 0·05 to 0·2 mm) were not expected to have any significant effects on the fatigue lives of the relevant specimens. Nevertheless, in order to check this point, a series of 200 revolutions dwell time 4·7 mm radius specimens was notched with the second tool to provide two groups of specimens whose average diameters differed from the corresponding zero dwell time specimens by, respectively, 0·05 mm (the B1 Series) and 0·15 mm (the B2 Series).

4. FATIGUE TESTS AND RESULTS

All fatigue tests were carried out in the ARL single-point loading rotating cantilever fatigue machines operating at a cyclic frequency of 200 Hz. The alternating stresses quoted are nominal stresses calculated on the net cross-section of the specimens using simple elastic theory. During the major investigation 11 different machines were used, and the specimens for the various notch/dwell time/alternating stress combinations were distributed throughout these machines in a quasi-random manner. For the supplementary investigation (which involved 4·7 mm radius notch specimens alone) only three machines were used. During the fatigue tests on the three smallest radii notches the testing machines were located in a laboratory which was neither temperature nor humidity controlled. All fatigue tests on the 4·7 mm radius notched specimens were however made in a laboratory with nominal environmental conditions of 21°C and 55% R.H. At least 50 specimens were used to determine each of the notched S/N diagrams shown in Figs 6 to 9, with seven specimens being tested at each stress level/notch/dwell time condition.

The results of the fatigue testing program on 4·7 mm radius specimens to investigate "tool" (Section 2) and "diameter difference" effects (Section 3) and which formed the supplementary investigation are given in Figs 10 and 11. In these instances five specimens were tested at each stress level.

Fatigue data for unnotched polished specimens (Fig. 5) were taken from Reference 5. This represents the pooling of the two sets of data for DTD 683/3 which were reported at that time.

The average S/N curves shown in Figures 5 to 11 were derived from a least squares regression analysis of the data on the assumptions of a log-normal distribution of life and that the curves could be described by polynominal functions. In most cases, second-order or third-order curves were found to be the best fit to the data.

There were marked variations in the macroscopic appearances of the fractures in different specimens. The fatigue fracture regions were generally classified into the three groupings listed below which were those adopted by Finney (Ref. 3) during a previous investigation using the same batch of material, and supplemented by a fourth classification—'flat-conical'. The test points in Figures 6 to 11 indicate which *predominated* in individual specimens as, in many instances, the fatigued surfaces exhibited a combination of two of these fracture classifications.

(1) 'smoth' transverse—very flat transverse fracture surface, Figure 12(*a*)—specimen no. AA78BD, 0·1 mm, zero rev. dwell time, 40,000 psi, 12,000 cycles.

(2) 'coarse' transverse—rough uneven transverse fracture surface, Figure 12(*b*)—specimen no. AA89AL, 2 mm, 200 rev. dwell time, 35,000 psi, 1,846,000 cycles.

(3) 'cup and cone'—completely conical fracture or predominantly so, Figure 12(*c*)—specimen no. AA87BJ, 4·7 mm, 200 rev. dwell time, 37,500 psi, 235,000 cycles.

(4) 'flat-conical'—small conical region adjacent to notch then black fretted region and predominantly transverse at greater crack depths, Figure 12(*d*)—specimen no. AA52BC, 0·46 mm, 200 rev. dwell time, 27,500 psi, 585,000 cycles.

5. DISCUSSION

5.1 Effect of dwell time on fatigue life

Four of the S/N curves, namely those for the notches of $K_t = 4{\cdot}35$ (0·1 mm rad.) and 2·35 (0·46 mm rad.) shown in Figures 6 and 7, indicate clear evidence of the 'discontinuity' phenomenon which Finney has reviewed in Reference 8. Nevertheless, for each of these two notches of higher K_t there are no significant differences in the fatigue lives of specimens notched using dwell times of zero and 200 revolutions. However, the results for the larger radii notches (2 mm, $K_t = 1{\cdot}45$ and 4·7 mm, $K_t = 1{\cdot}2$) indicate that, at the lower alternating stresses, the average fatigue lives of specimens machined using a dwell time of 200 revolutions are significantly greater (at the 5% level of significance) than those of specimens machined with zero dwell time. That is, comparing stresses of ±241 MPa (35,000 psi), ±224 MPa (32,500 psi) and ±207 MPa (30,000 psi) for the 2 mm notch and ±224 MPa (32,500 psi) and ±207 MPa (30,000 psi) for the 4·7 mm notch. Furthermore, it is of interest to note (see Table 2) that the horizontal cutting forces associated with machining the notches of higher K_t were significantly less than those measured for the two notches of lower K_t.

The results of the supplementary investigation on 4·7 mm radius notched specimens which are presented in Figures 10 and 11 also indicate that longer fatigue lives are associated with 200 revolutions dwell time machining than with zero dwell time; but that there are no significant differences between the fatigue lives of specimens machined with 200 and 1000 revolutions dwell time. As expected, there was no significant difference between the lives of specimens tested to check the effect of small differences in diameter ("diameter difference" effect) resulting from variations in the relative positions of the mechanical stop and counter actuator switch on the lathe cross-slide. Series B1 and B2 results were pooled to derive the average S/N curves shown on Figures 10(*a*) and 10(*b*). However, for specimens machined with 200 revolutions dwell time using a different lathe form tool, the fatigue lives at two of the three stresses at which comparative fatigue tests were made were significantly greater than those machined using the original tool—see Figures 9(*b*) and 10(*b*). For zero dwell time specimens—compare Figures 9(*a*) and 10(*a*)—no such 'tool' effect is apparent.

In order to determine whether the increased fatigue lives associated with longer dwell times were attributable to *differences* in the work hardening or the stresses introduced (or modified) during machining under the various conditions, a series of hardness measurements (see Table 3) were taken at the surface of several notches of 4·7 mm radius specimens; and measurements of surface stresses (using a multi-exposure X-ray back reflection method described in Reference 9) were made on several other 4·7 mm radius specimens—see Table 4. The latter specimens were subsequently fatigue tested at ±224 MPa (32,500 psi). For the zero and 200 revolutions dwell time specimens the average residual stresses and associated standard deviations were −125 (s.d. 36) and −142 (s.d. 26) MPa respectively.

Neither the hardness tests nor the residual stress measurements show any significant differences in the respective average values for specimens machined using the different dwell times. Furthermore, no correlation is apparent between the origins of the fatigue fractures in the different specimens and the residual surface stresses at these positions.

An additional zero-dwell-time 4·7 mm radius notched specimen (AA41BM) was used to map out the variation in longitudinal surface stress around the circumference of the notch by taking stress measurements at intervals of approximately 30°. The results are shown in Figure 13. This specimen was also tested at ±224 MPa (32,500 psi) and gave a life of 2,318,300 cycles. The main fracture origin occurred at about 285°, thus giving no clear correlation with a position

TABLE 3
Hardness Tests on 4·7 mm Radius Notched Specimens

(Vickers machine, 2·5 kg load)

Specimen Number	Dwell time (revolutions)	Hardness			
		Notch		Grip-end of specimen	
		Average	Std. dev.	Average	Std. dev.
AA52BM	zero	201	3	209	6
AA53CC	zero	201	8	203	6
	(Average)	201		206	
AA52BJ	200	203	6	203	6
AA62CD	200	212	6	215	9
	(Average)	207		209	
AA56CE	1000	209	3	218	6
AA61CE	1000	203	3	206	9
	(Average)	206		212	

Note: Specimens were part of Series B—see Figure 10.

of minimum compressive residual surface stress, which might have been postulated as a likely fatigue crack initiation point. It is probably co-incidental that the estimated surface stress at the origin was close to the average value of 167 MPa.

TABLE 4
Residual Surface Stress Measurements and Fatigue Lives

(S_a = 224MPa; 32,500 psi)

Specimen number	Dwell time (revolutions)	Surface stress MPa (ksi)			Fatigue life (cycles)	Origin of fatigue failure (position)
		Position 1	Position 2	Position 3		
AA52BG	zero	−138 (−20·0)	−148 (−21·5)	−177 (−25·7)	1,521,000	(i) Between 1 and 2 (ii) Between 2 and 3 (iii) Between 3 and 1
		[Average −154 (−22·3)]				
AA60CD	zero	−146 (−21·2)	−170 (−24·7)	−187 (−27·1)	1,551,000	Between 1 and 2, closer to 1.
		[Average −168 (−24·4)]				
AA65BM	zero	−79 (−11·5)	−85 (−12·3)	−100 (−14·5)	2,068,000	Between 1 and 3, closer to 3
		[Average −88 (−12·8)]				
AA61BJ	zero	−106 (−15·4)	−84 (−12·2)	−88 (−12·8)	4,871,000	Between 1 and 3, closer to 1.
		[Average −93 (−13·5)]				
AA49CB	zero	−143 (−20·7)	−121 (−17·6)	−108 (−15·7)	10^8	Run-out
		[Average −124 (−18·0)]				
AA60BG	200	−107 (−15·5)	−105 (−12·2)	−135 (−19·6)	14,850,000	Between 1 and 2, closer to 1.
		[Average −116 (−16·8)]				
AA54CC	200	−152 (−22·0)	−165 (−23·9)	−154 (−22·3)	38,660,000	Machine malfunction; specimen damaged
		[Average −157 (−22·8)]				
AA63CB	200	−159 (−23·1)	−199 (−28·9)	−136 (−19·7)	43,967,000	Between 1 and 2, closer to 2.
		[Average −165 (−23·9)]				
AA89CC	200	−171 (−24·8)	−103 (−14·9)	−160 (−23·2)	53,060,000	Between 1 and 3, closer to 3.
		[Average −145 (−21·0)]				
AA70CJ	200	−135 (−19·6)	−119 (−17·3)	−122 (−17·7)	$1{\cdot}04 \times 10^8$	Run-out
		[Average −125 (−18·1)]				

Note: 1. All surface stresses measured in longitudinal direction at notch root at three radial positions approximately 120° apart.
2. Fatigue specimens were part of Series B—see Figure 10.

Differences in the surface finishes of the notches were also considered as a reason for the increased life of 200 and 1000 revolutions dwell time compared with zero dwell time specimens. Firstly, because of the possibility of a small longitudinal step at the notch surface resulting from the sudden cessation of cutting under zero dwell time conditions, but more particularly because of the continuation of metal removal at the notch for some time after the mechanical stop position of the tool had been reached. It was thought that the latter action might tend to smooth out many of the small circumferential grooves associated with the plunge cutting operation.

As indicated in Section 2, the amount of metal removal per revolution was only about 0·025 mm. Microscopic examination at up to about 30 magnification showed no evidence of any 'step' at the surface of any of the notches machined using zero dwell time. Even if such a step had been present its 'longitudinal' orientation would probably not have had any significant influence on fatigue behaviour. Because of the small radius of curvature at the root of the notch it was not possible to compare the surface finishes of the various specimens using the stylus type surface finish measuring equipment which was available. However, the surfaces of a number of the 4·7 mm radius notched specimens were examined using a metallurgical microscope at 100X to determine whether any qualitative differences in surface finish were apparent. Only one readily distinguishable difference was obvious in the surface finishes of the various groups of 4·7 mm radius specimens, namely that *all* zero dwell time and the first series of 200 revolutions dwell time specimens exhibited the type of turning marks shown by Figure 14(*a*), whereas the B series specimens machined using 200 and 1000 revolutions dwell time exhibited chatter marks either on part or completely around the notch circumference. An example is shown in Figure 14(*b*). As both series of 200 revolutions dwell time specimens gave increased endurances compared with their respective zero dwell time series, the significance of the presence or absence of chatter marks is not obvious.

It is of interest to note that the S/N data for the zero dwell time conditions for the notches of $K_t = 2 \cdot 35$ and $1 \cdot 45$ (Figs 7(*a*) and 8(*a*) respectively) are in general agreement with those reported in 1962 by Finney (Ref. 3), although his particular specimens were notched with high speed steel circular form tools compared with carbide tip tools used for this investigation. Nevertheless, the findings of the current investigation again emphasise the need to fully specify the procedures employed in the manufacture of fatigue test specimens if meaningful comparisons are to be made of experimental data.

5.2 Fatigue fractures

From Figures 6 to 11 it may be seen that the 'smooth' transverse fractures occurred only in specimens with a $K_t = 4 \cdot 35$, and this confirms earlier findings (Ref. 3) that such fractures are more common with notches of high K_t. Cup-and-cone fractures occurred with each of the other three notches studied and were most common at the higher alternating stresses—in fact, few 'cup-and-cone' failures occurred at nominal alternating stresses of less than 241 MPa (35,000 psi). Similarly, when cup-and-cone and coarse transverse fractures both occurred at the same stress level, the specimens with cup-and-cone fractures usually exhibited shorter lives.

Nevertheless, the basic reasons for the preferential development of cup-and-cone fatigue failures compared with the more 'conventional' transverse fractures in specimens of high strength extruded aluminium alloys when tested at high cyclic frequencies have yet to be resolved. Suffice to say that this behaviour and the frequently associated problem of a double distribution of fatigue lives provide some difficulties in the analysis and interpretation of fatigue data obtained under these testing conditions.

5.3 Fatigue strength reduction factors

A direct consequence of the differences in fatigue lives associated with zero and 200 revolutions dwell time is that the calculated values of the fatigue strength reduction factors

$$\left(K_f = \frac{\text{fatigue strength of unnotched specimens}}{\text{fatigue strength of notched specimens}} \text{ at the same life}\right)$$

must be specifically related to a particular dwell time and, as shown for the 4·7 mm radius notch at 200 revolutions, the type of tool used is a further complicating factor.

Fig. 15 shows the variation of K_f with life for several of the experimental conditions used in this investigation. This particular illustration emphasises the effect of dwell time in relation to notches of different K_t in that, at lives exceeding about 10^6 cycles, the fatigue strength reductions caused by notches of $K_t = 1 \cdot 45$ machined using 200 revolutions dwell time are less than those of the notch of lower K_t ($K_t = 1 \cdot 2$) machined with zero dwell time.

5.4 Statistical aspects of fatigue data

The relationships between the mean life and the standard deviation of mean life for the notches of $K_t = 1 \cdot 2$ and $1 \cdot 45$ are shown in Figures 16 and 17. Although the standard deviations appear to generally increase with mean life—confirming one of the findings of a previous investigation on 7178-T6 aluminium alloy (Ref. 4), there are no consistent differences between the scatter in life for specimens machined with zero and 200 revolutions dwell time and no apparent differences in scatter for these two notch severities. The fatigue test results for the notches of $K_t = 4 \cdot 35$ and $2 \cdot 35$, as illustrated in Figures 6 and 7, preclude any similar comparisons being made in these cases.

6. CONCLUSIONS

1. The fatigue test results for specimens of higher K_t ($4 \cdot 35$ and $2 \cdot 35$) do not indicate any significant effects of notching tool dwell times, whereas specimens of low K_t ($1 \cdot 45$ and $1 \cdot 2$) notched with 200 revolutions dwell time (when tested at the lower alternating stresses) showed significantly longer fatigue lives than those notched with zero dwell times.
2. The use of different form tools for the notch of $K_t = 1 \cdot 2$ can result in significantly different lives for 200 revolutions dwell time, but not in the case of zero dwell time.
3. No correlation was established between tool dwell times and the hardness, surface residual stresses and surface finish of the notches of $K_t = 1 \cdot 2$ to explain the differences in fatigue lives. However, the horizontal forces measured during the machining of the two notches of high K_t were less than half those measured during the machining of the notches of low K_t.
4. This investigation again emphasises the need to fully specify the procedures employed in the manufacture of fatigue test specimens if meaningful comparisons are to be made of experimental data.
5. The consistent use of zero revolutions dwell time should enable greater reproducibility in average fatigue lives to be achieved, as changes in the form tool and operator appear to have no significant effects under such notching conditions.

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APPENDIX I
Stress Conversion Table

(psi to MPa)

psi	MPa	psi	MPa
2,500	17·2	40,000	275·8
5,000	34·5	45,000	310·3
7,500	51·7	50,000	344·7
10,000	69·0	55,000	379·2
12,500	86·2	60,000	413·7
15,000	103·4	65,000	448·2
17,500	120·7	70,000	482·6
20,000	137·9	75,000	517·1
22,500	155·1	80,000	551·6
25,000	172·4	85,000	586·1
27,500	189·6	90,000	620·5
30,000	206·8	95,000	655·0
32,500	224·1	100,000	689·5
35,000	241·3	105,000	723·9
37,500	258·6	110,000	758·4

APPENDIX II

Automatic Notching System

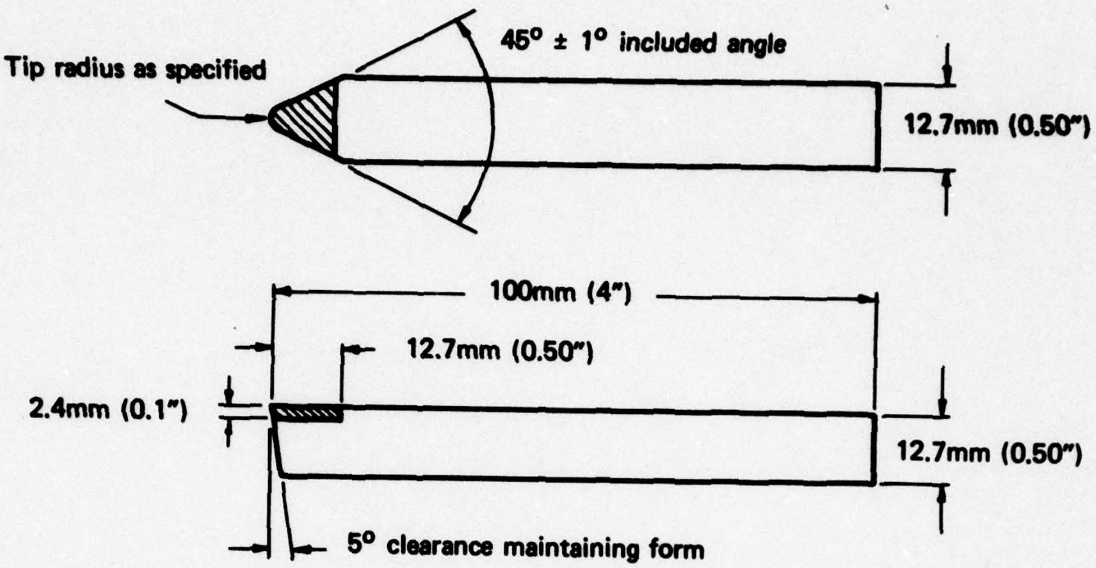
The system for the controlled notching of specimens by plunge cutting was based on a Colchester 5 × 20 Chipmaster toolroom lathe, which was modified so that rapid retraction of the cutting tool could be achieved after a predetermined number of spindle revolutions. Figure 18 illustrates the schematic arrangement of the system.

Mechanical modification to the lathe involved the mounting of an auxiliary cross slide (supported on flexure pivots) and tool holder on the normal cross slide. The movement of the auxiliary cross slide—only about 0·2 mm transverse to the lathe centre line—is controlled by two opposed hydraulic pistons of different areas. The purpose of the larger (preload) piston is to force the auxiliary cross slide and tool against a stop in the direction of the specimen, while that of the smaller (retraction) piston is to rapidly retract the tool from the specimen when pressure in the larger cylinder is suddenly released through a solenoid valve.

Movement of the tool towards the specimen is achieved using the screw-driven feed on the main cross slide. At an appropriate distance, corresponding to the desired depth of cut, a mechanical stop on the saddle is encountered and the screw-feed clutch automatically disengaged. At a distance of approximately 0·1 mm before reaching the mechanical stop, the contacting of a microswitch actuates a pulse transmitter circuit in the lathe spindle and a presetting electro-magnetic counter, capable of counting from 1 to 999,999 revolutions.

When the preset number of revolutions of tool 'dwell-time' are reached the solenoid valve to the preload cylinder is energised and the pressure in that cylinder released. Pressure in the small cylinder then causes the rapid outward movement of the auxiliary cross slide and tool away from the notch. For zero dwell time the auxiliary cross slide actually retracts the tool before the mechanical stop is reached, and maintains it clear of the notch.

The action of the tool in retracting is depicted in Figure 19. This shows a 'hesitation' of about 5 milli s after retracting about 0·02 mm, followed by rapid retraction. The marker indicates the actuation of the solenoid releasing pressure in the preload cylinder. The total delay is 22 milli s and tool retraction takes 11 milli s. Under the notching conditions used and a spindle speed of 300 revs per minute, these represent 0·37 revolutions and 0·19 revolutions respectively.



Tip radius	
mm	inches
4.7 ± 0.25 2 ± 0.125 0.46 ± 0.05 0.10 ± 0.005	0.185 ± 0.010 0.080 ± 0.005 0.018 ± 0.002 0.004 ± 0.0002

FIG. 1 CARBIDE TIPPED TOOLS FOR NOTCHING FATIGUE SPECIMENS

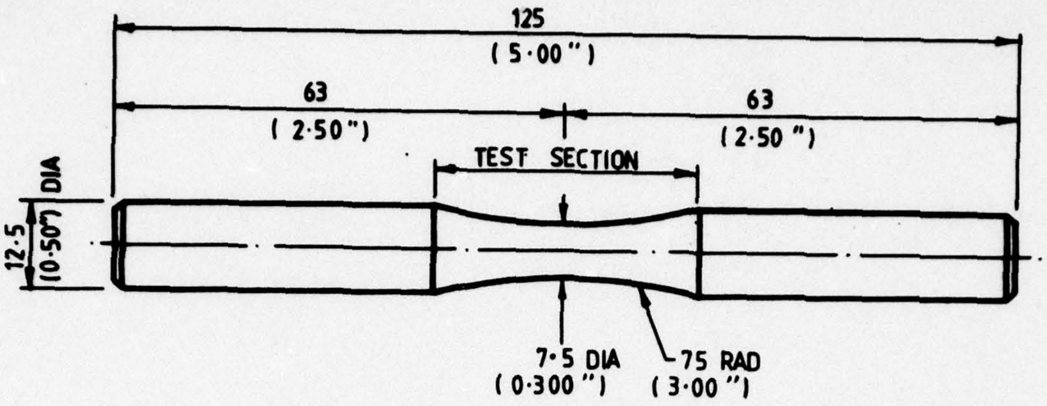


Fig. 2a Unnotched

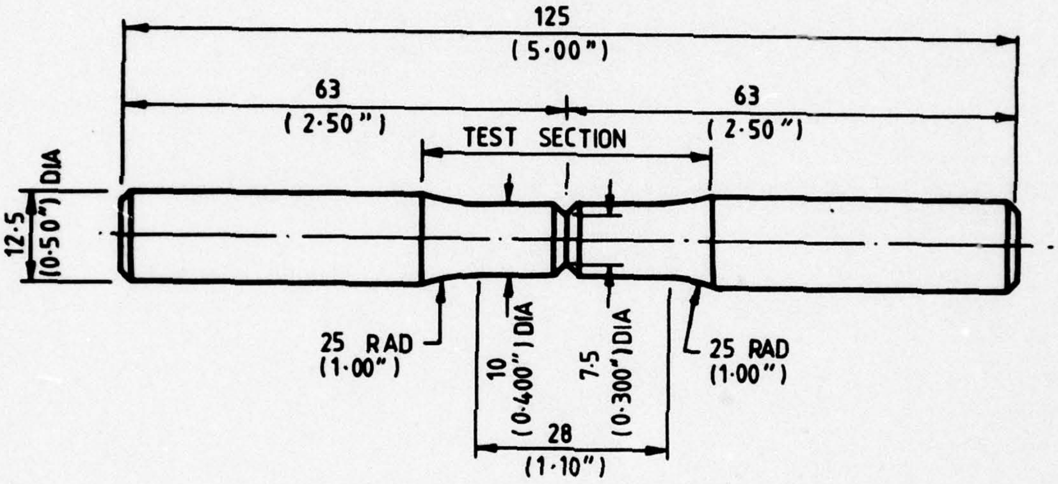
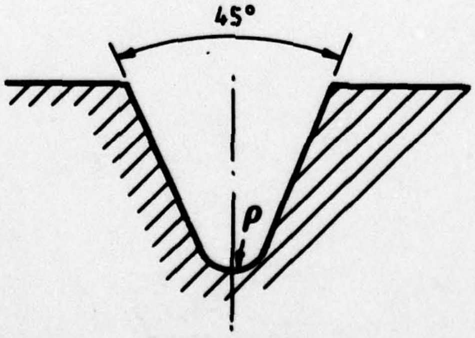


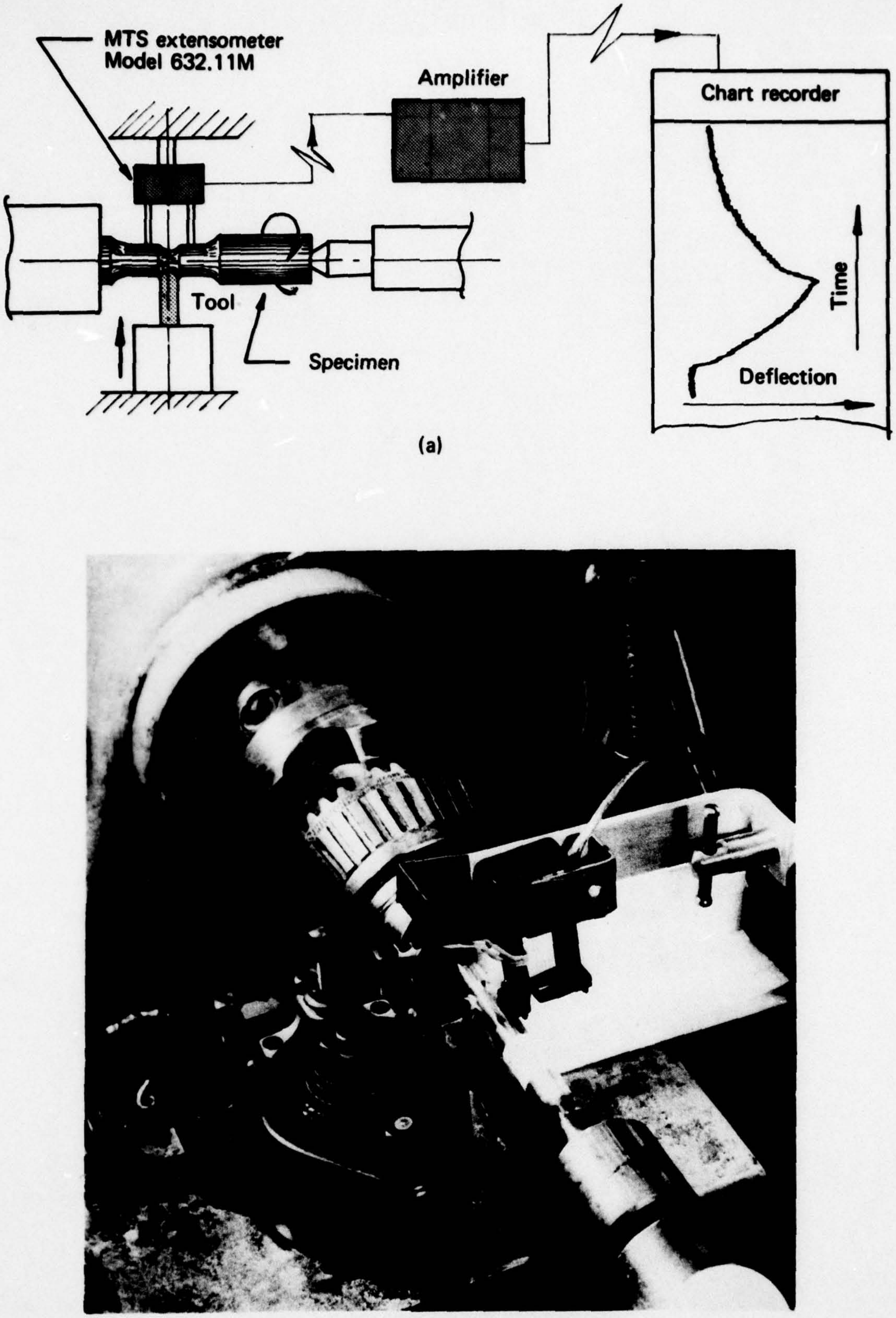
Fig. 2b Notched



Detail of notch

ρ		K_t(7)
mm	inches	
4.7	0.185	1.20
2.0	0.080	1.45
0.46	0.018	2.35
0.10	0.004	4.35

FIG. 2 ROTATING CANTILEVER FATIGUE SPECIMENS



(a)

(b)

FIG. 3 MEASUREMENT OF SPECIMEN DEFLECTION

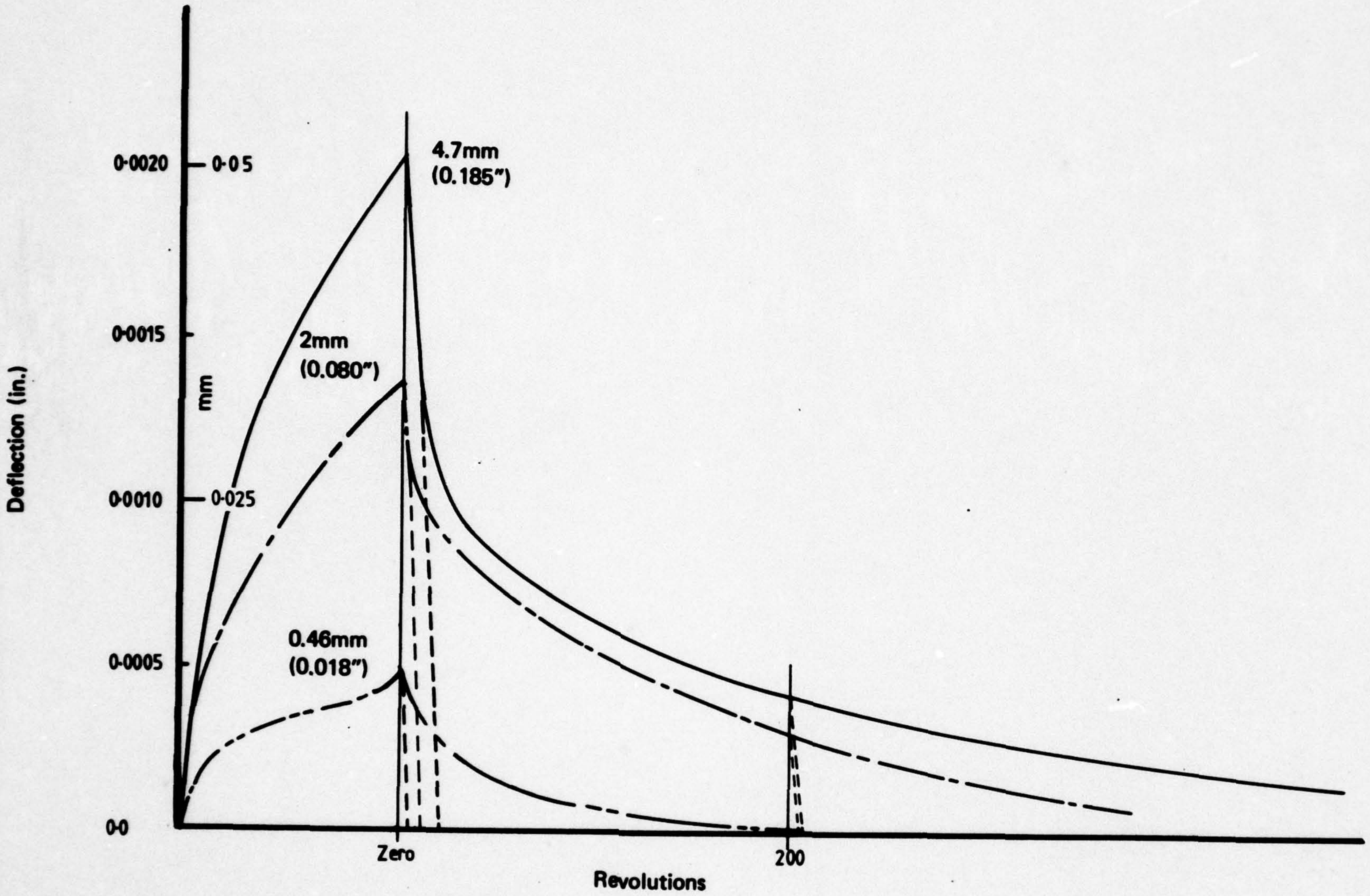


FIG. 4 SPECIMEN DEFLECTIONS DURING NOTCHING OPERATION

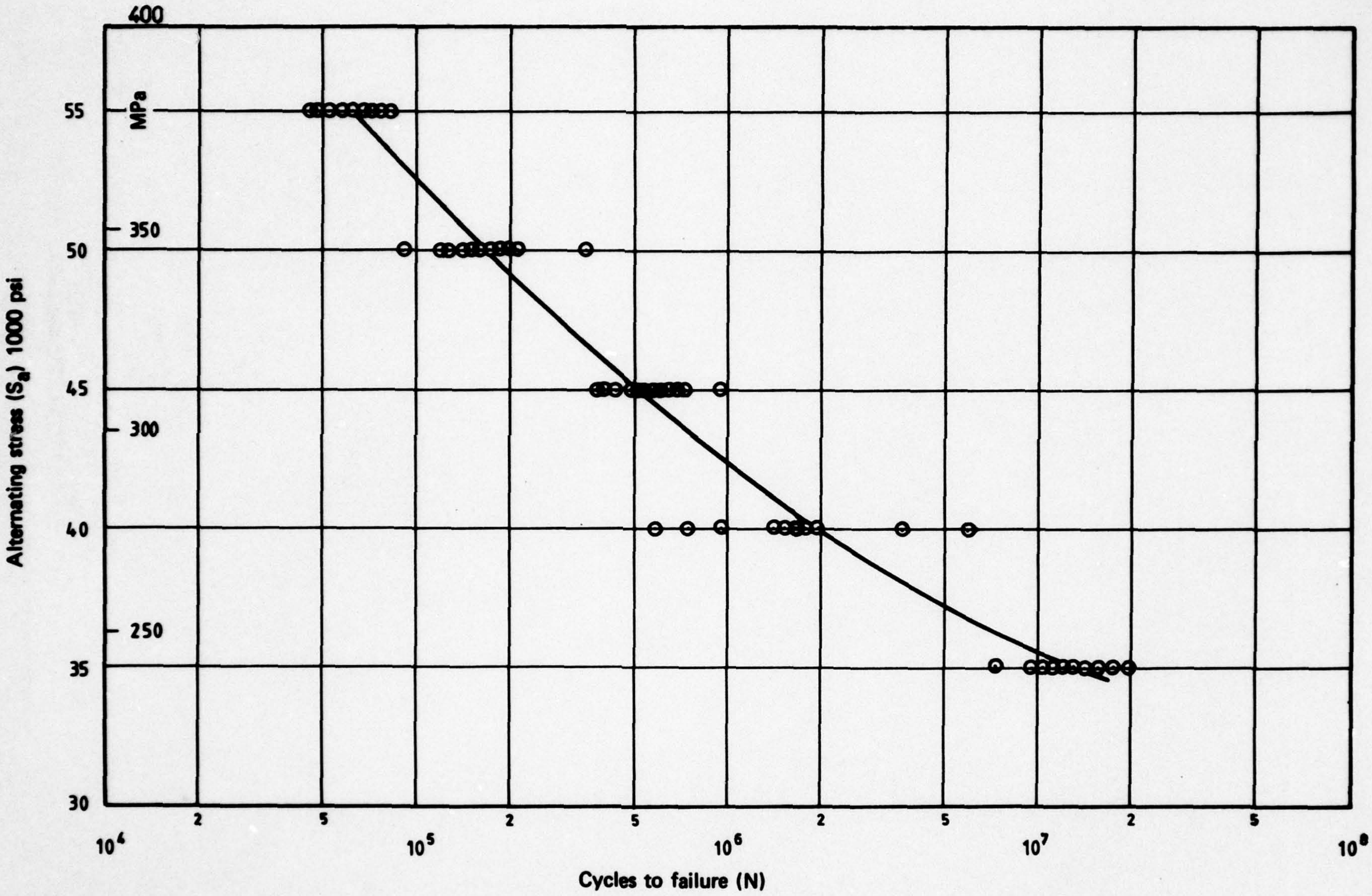


FIG. 5 UNNOTCHED DATA (FROM REF. 5)

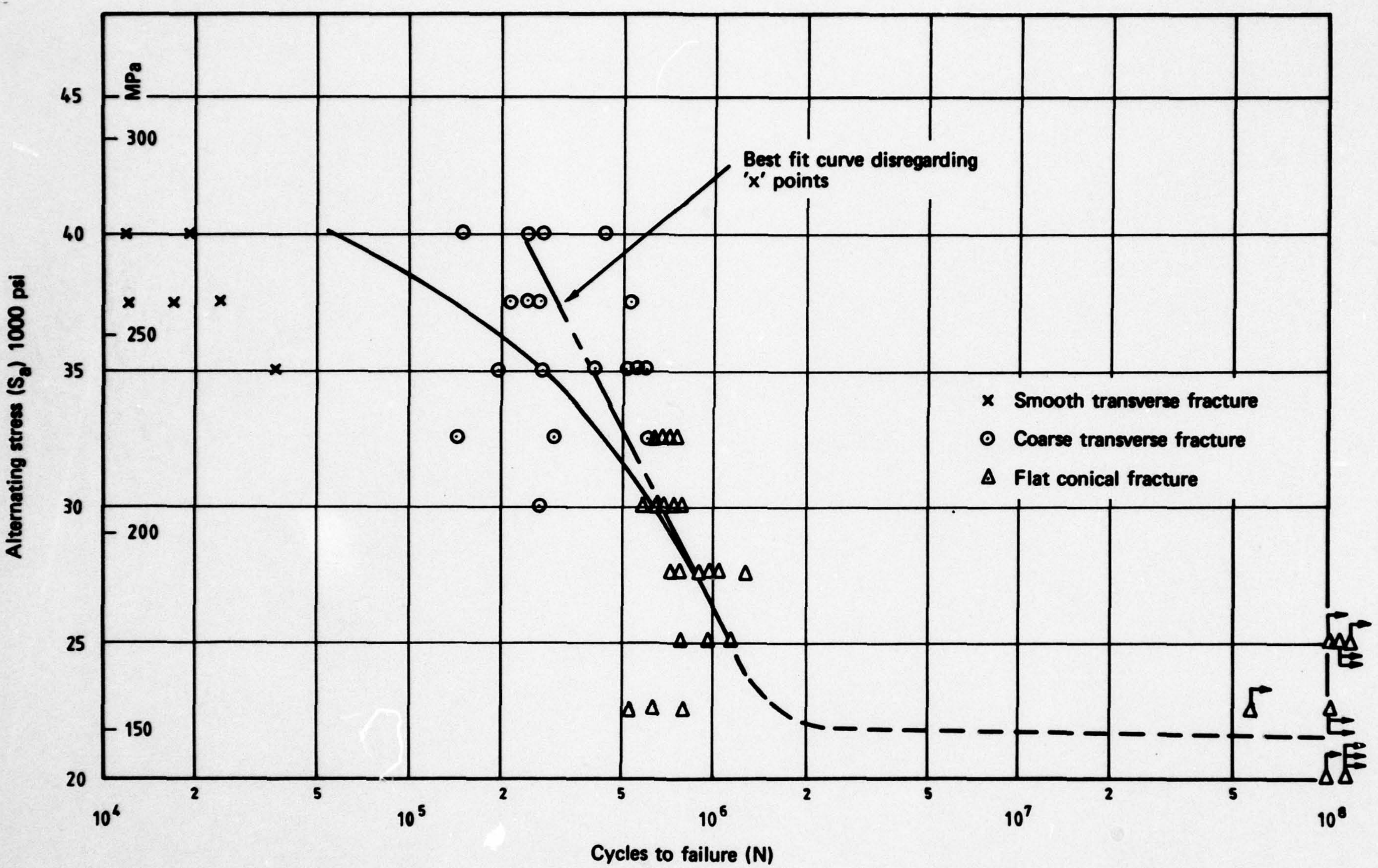


FIG. 6a 0.1mm (0.004") NOTCH, $K_t = 4.35$. ZERO DWELL TIME

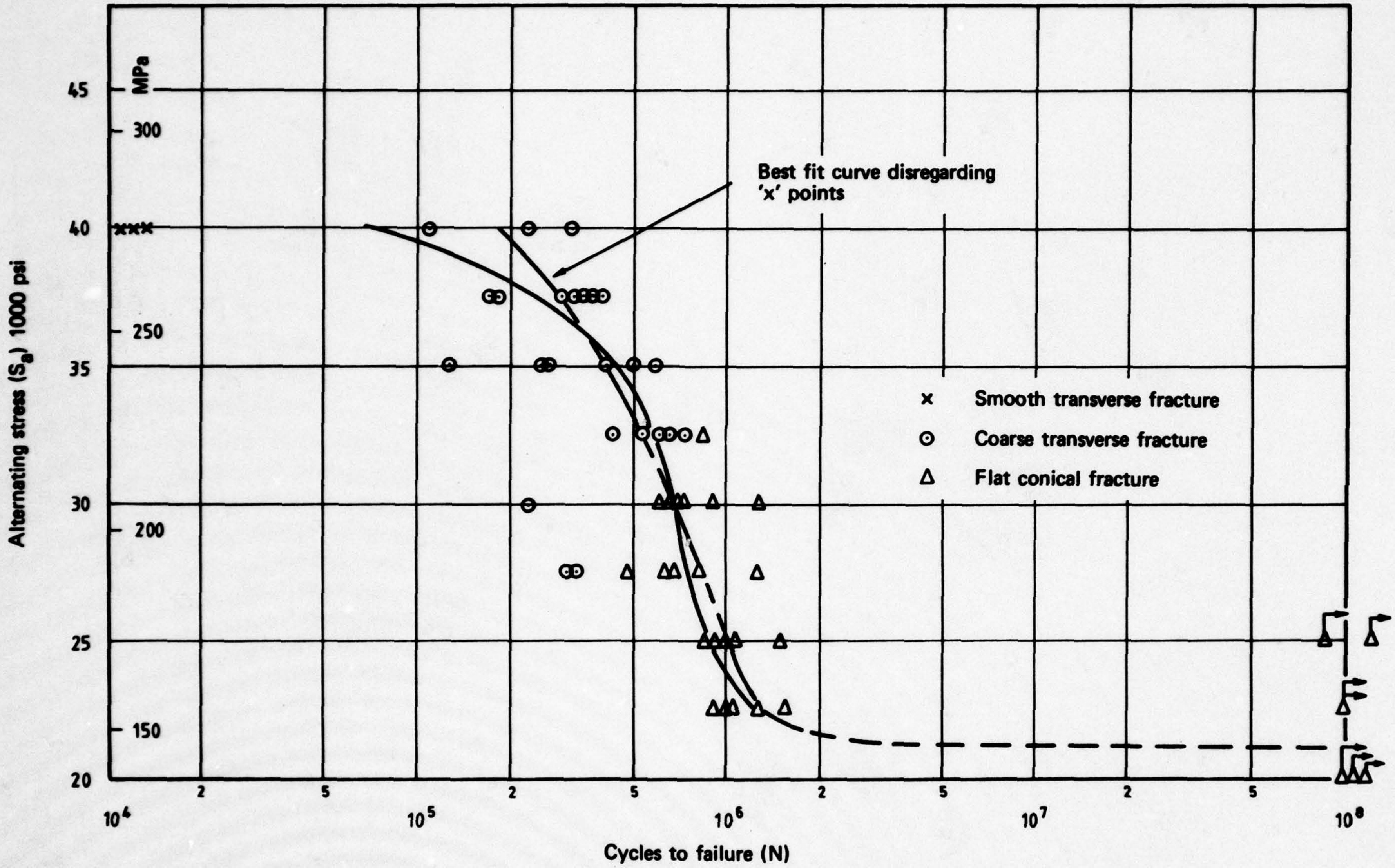


FIG. 6b 0.1mm (0.004") NOTCH, K_t = 4.35. 200 REV. DWELL TIME

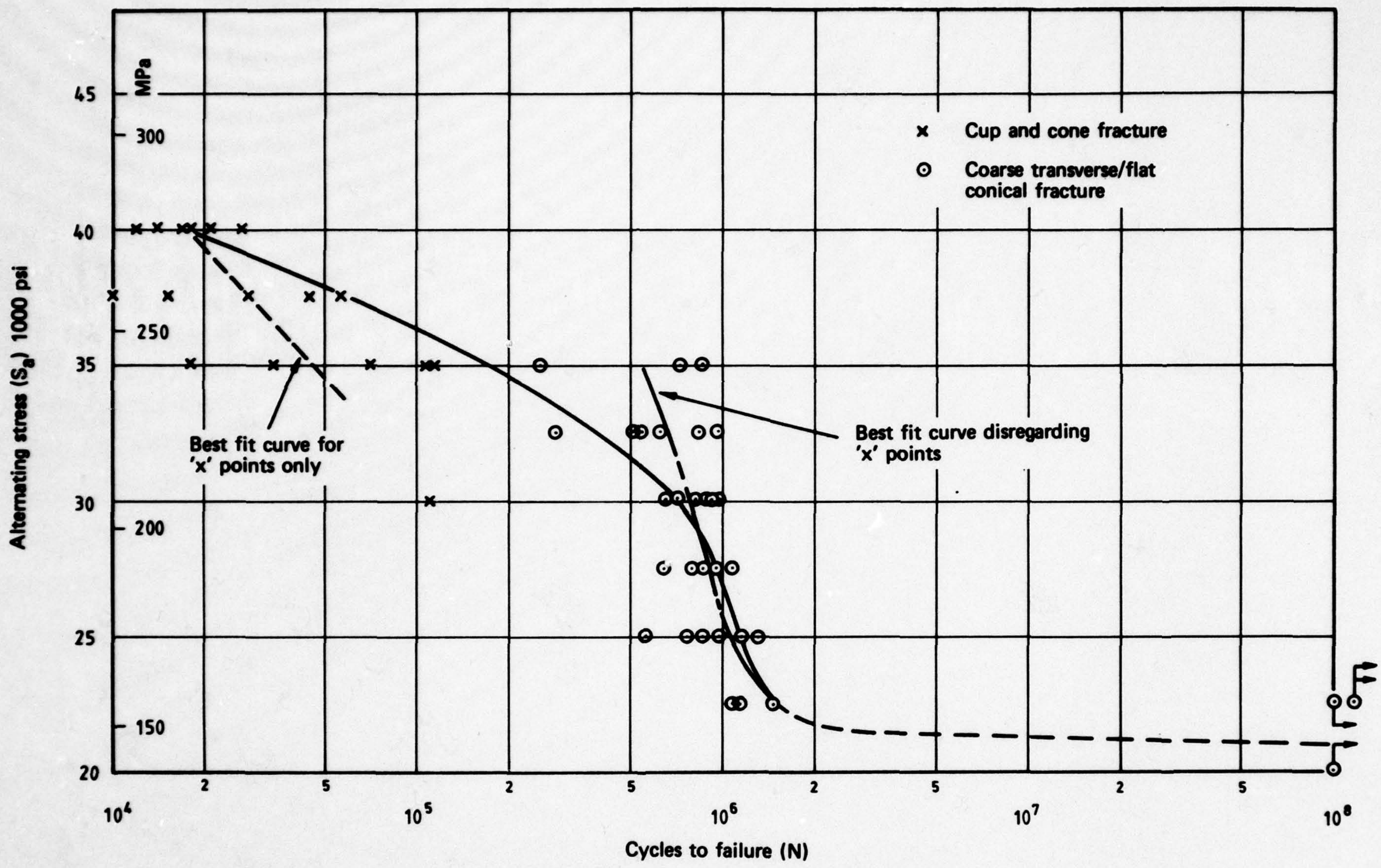


FIG. 7a 0.46mm (0.018") NOTCH; K_t = 2.35. ZERO DWELL TIME

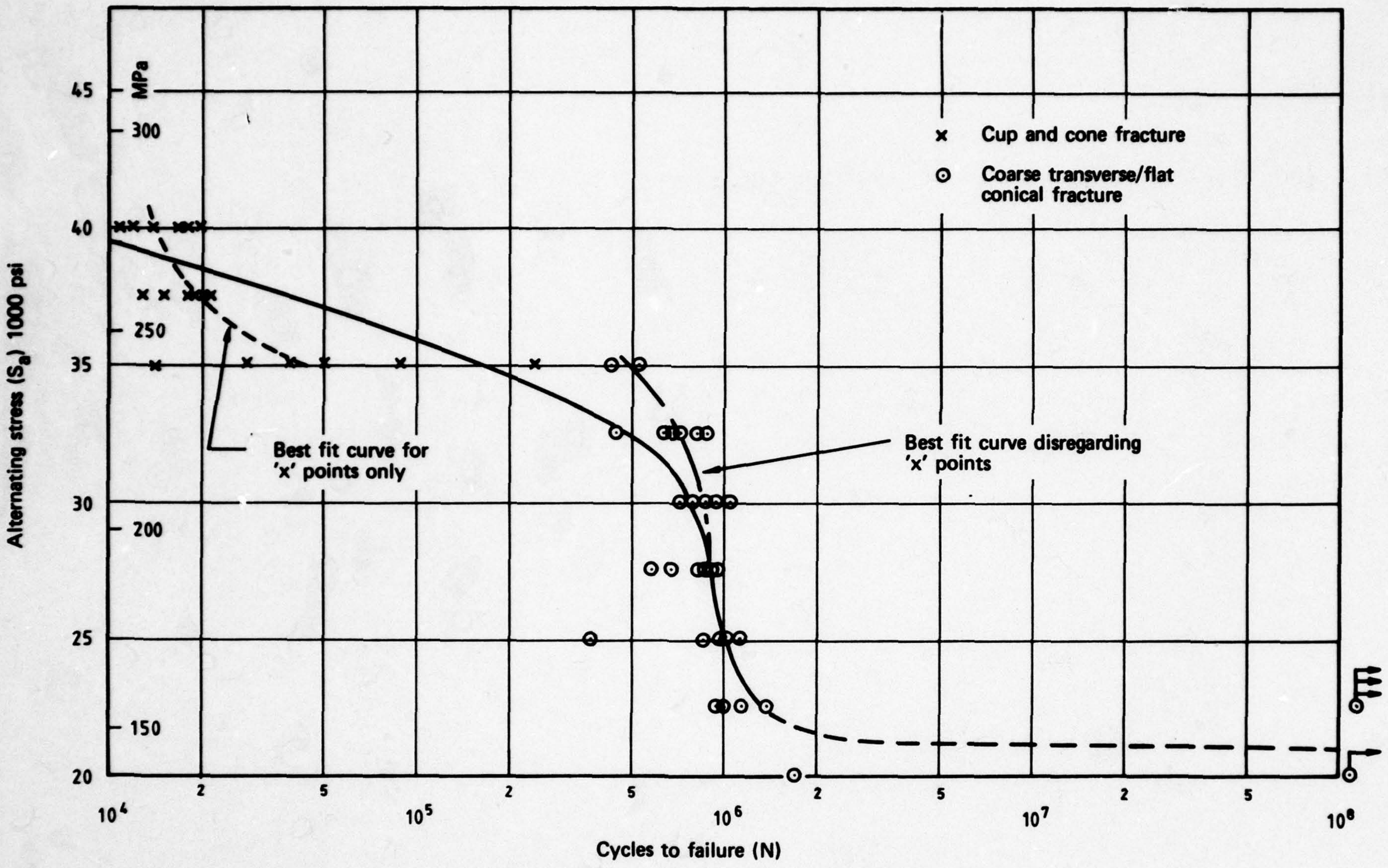


FIG. 7b 0.46mm (0.018") NOTCH, K_t = 2.35. 200 REV. DWELL TIME

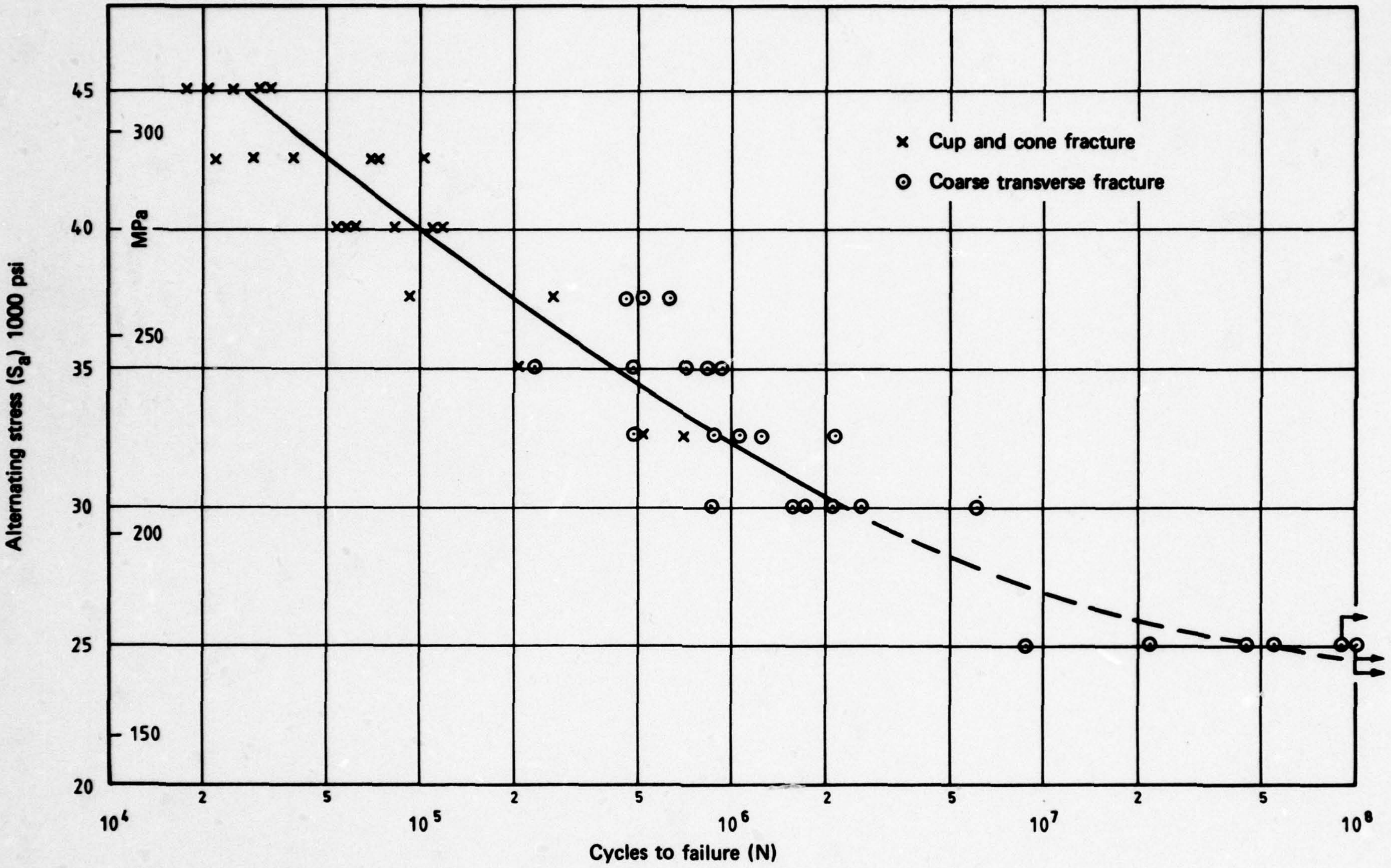


FIG. 8a 2mm (0.080") NOTCH, K_t = 1.45. ZERO DWELL TIME

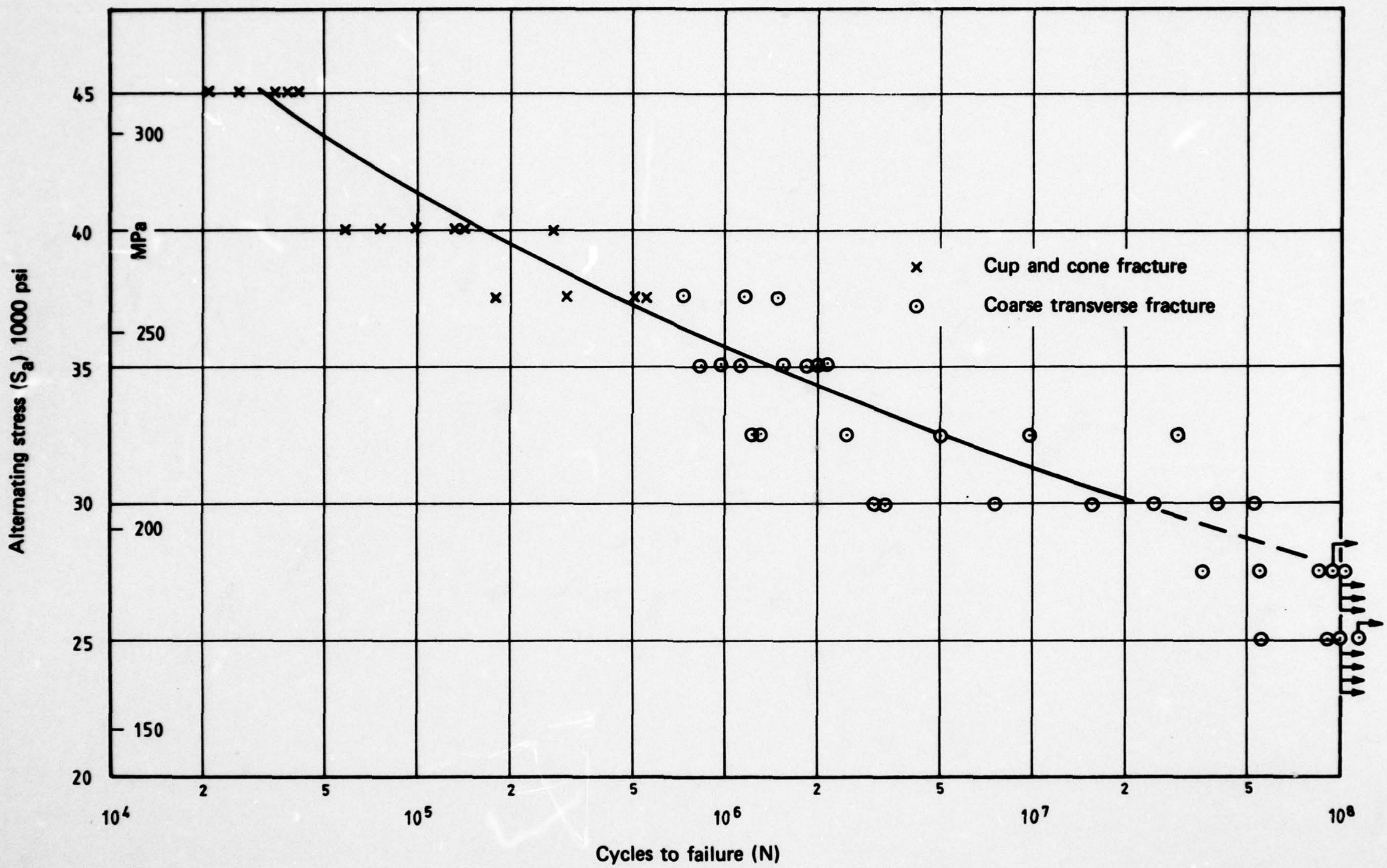


FIG. 8b 2mm (0.080") NOTCH, $K_t = 1.45$. 200 REV. DWELL TIME

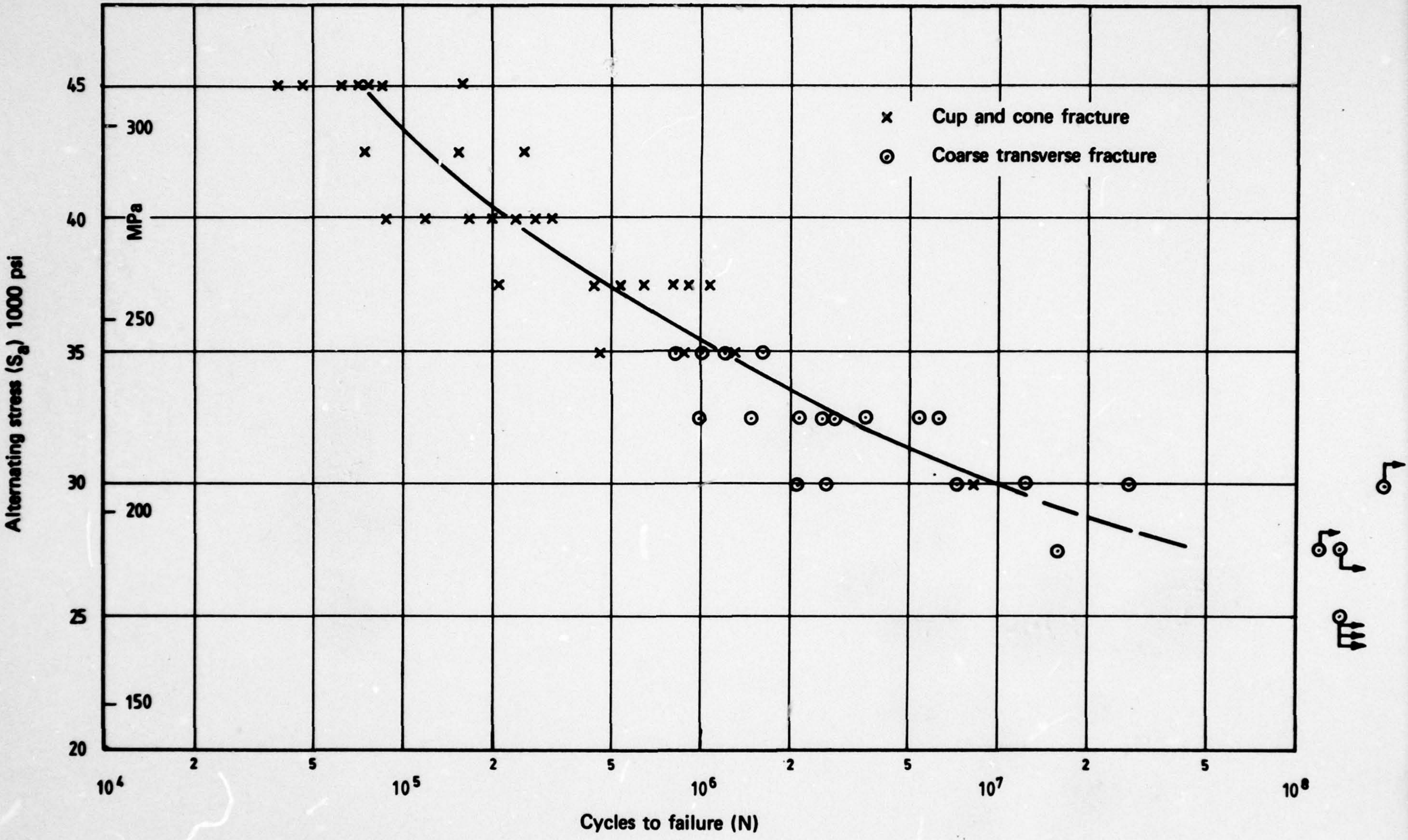


FIG. 9a 4.7mm (0.185") NOTCH, K_t = 1.2. ZERO DWELL TIME

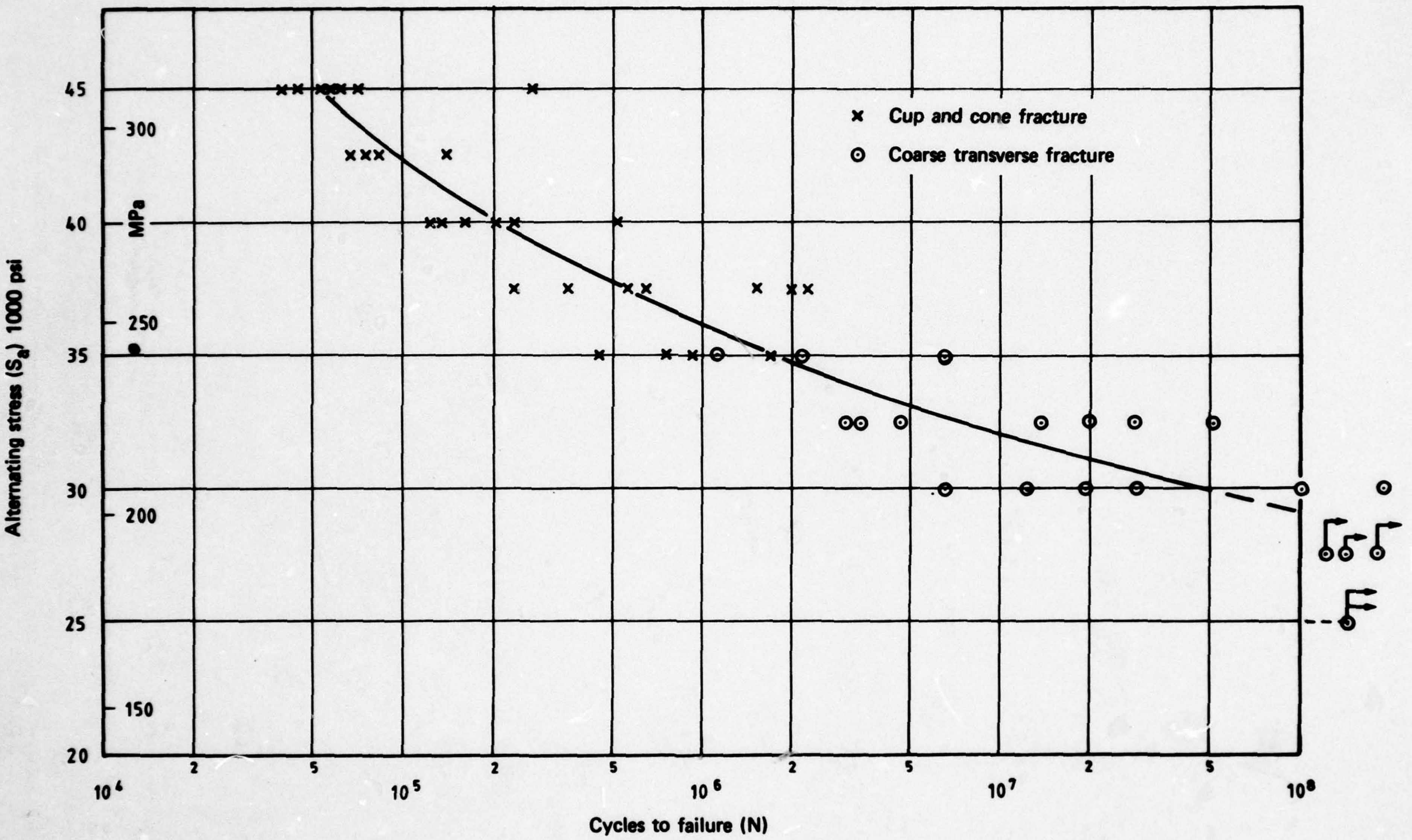


FIG. 9b 4.7mm (0.185") NOTCH, K_t = 1.2. 200 REV. DWELL TIME

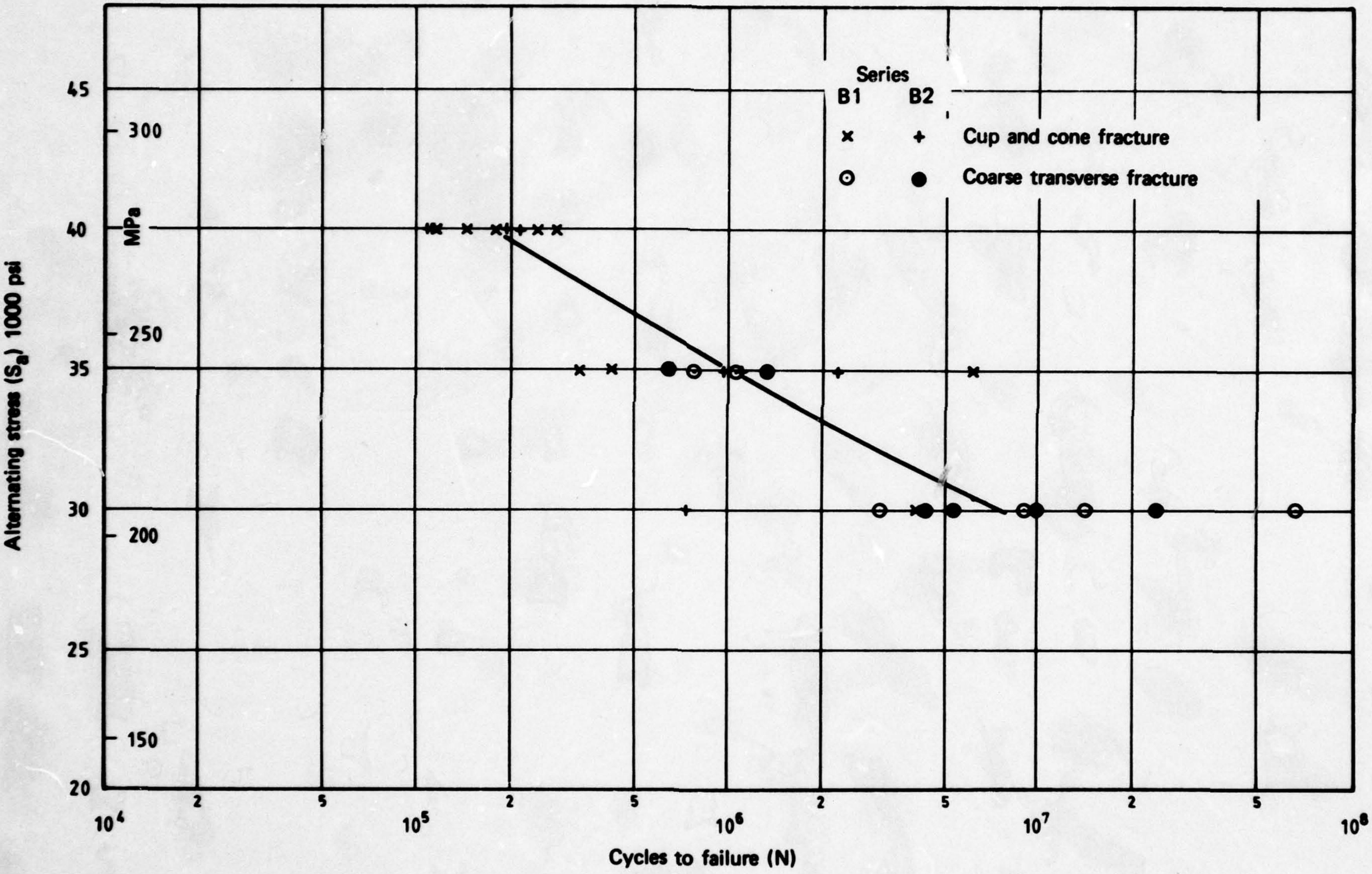


FIG. 10a 4.7mm (0.185") NOTCH, $K_t = 1.2$. 'B' SERIES, ZERO DWELL TIME

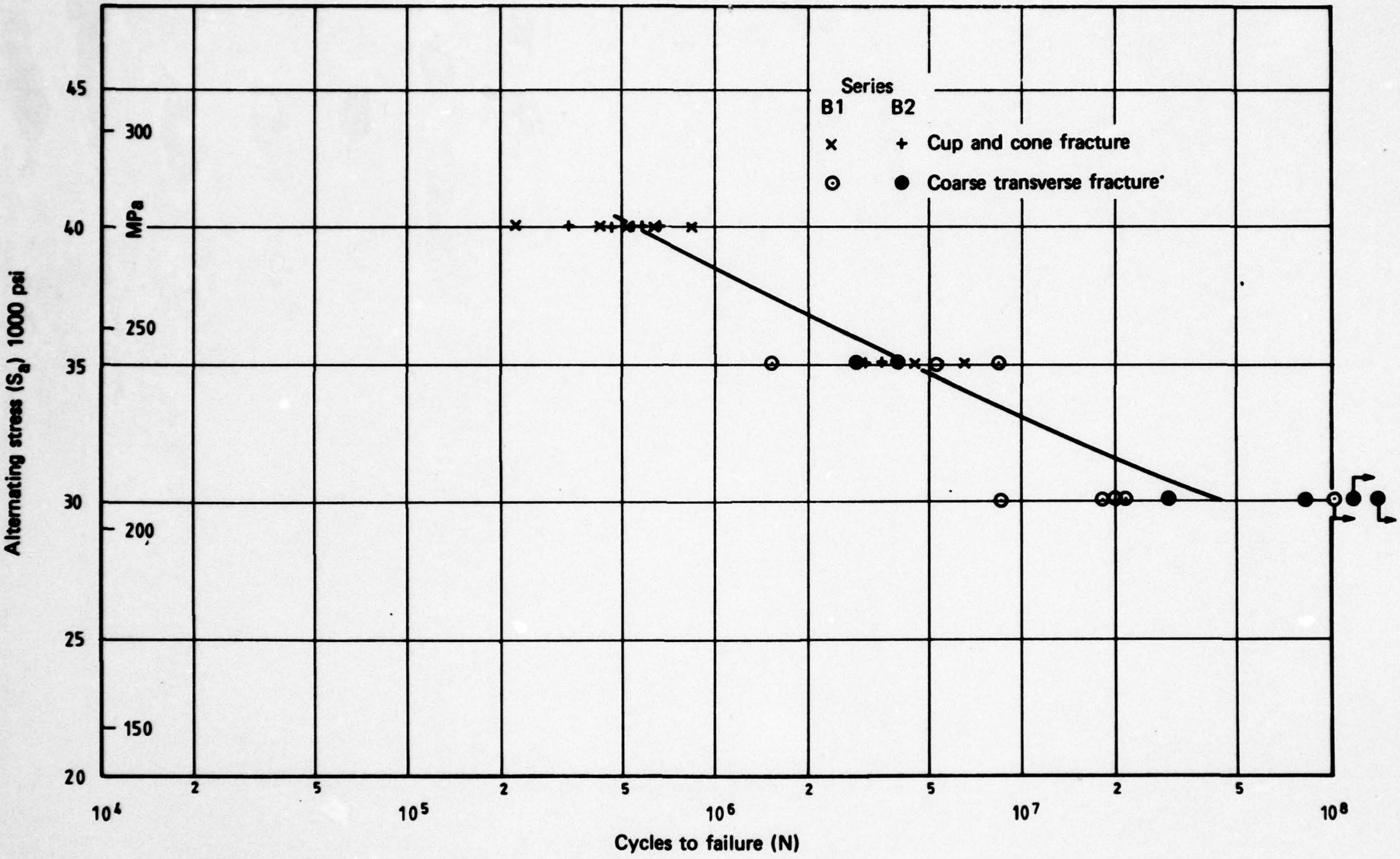


FIG. 10b 4.7mm (0.185") NOTCH, $K_t = 1.2$. 'B' SERIES, 200 REV. DWELL TIME

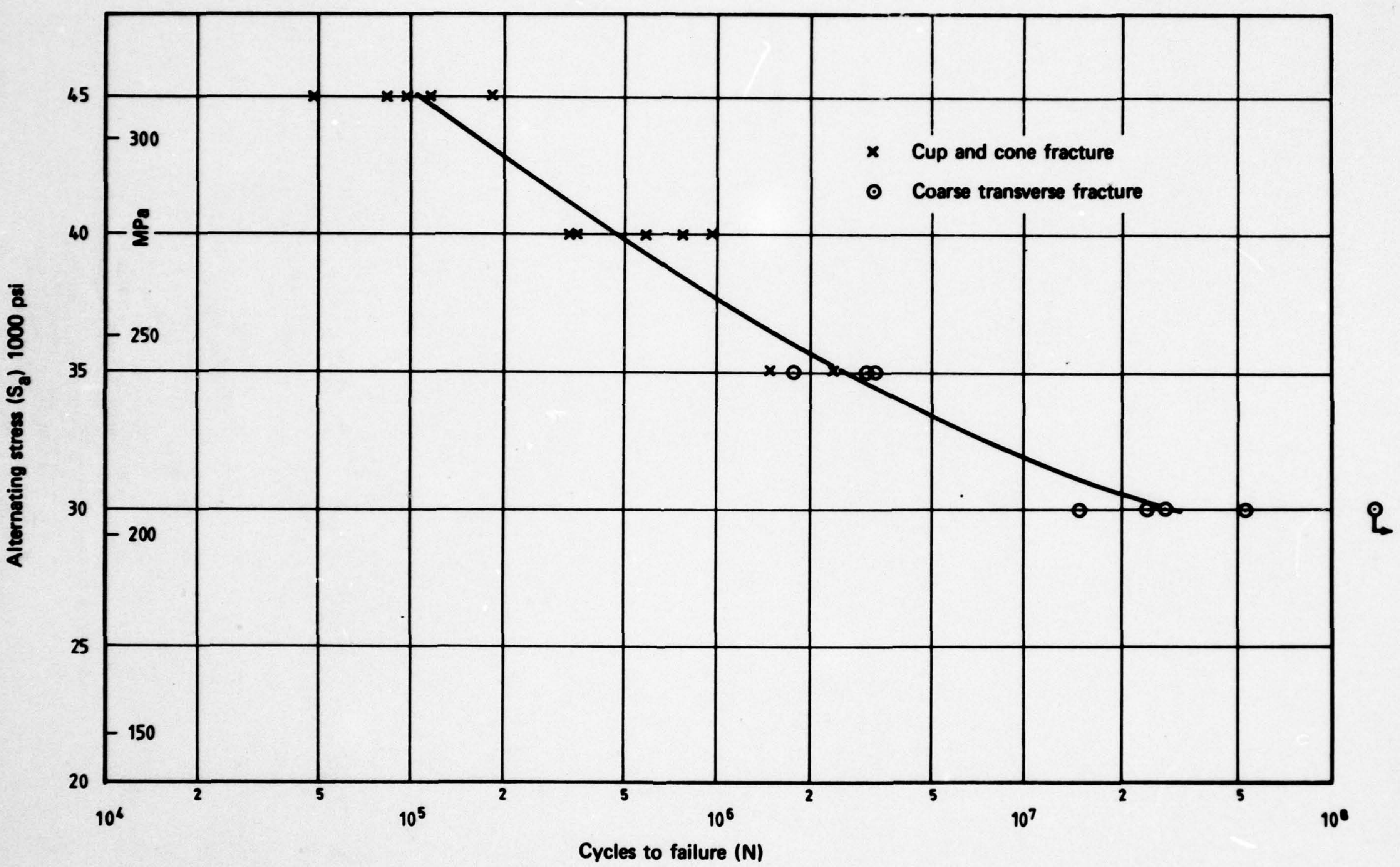


FIG. 11 4.7mm (0.185") NOTCH, $K_t = 1.2$. 'B' SERIES, 1000 REV. DWELL TIME

(a) Smooth transverse (AA78BD)

(b) Coarse transverse (AA89AL)

(c) Cup and cone (AA87BJ)

(d) Flat conical (AA52BC)

FIG. 12 FATIGUE FRACTURES

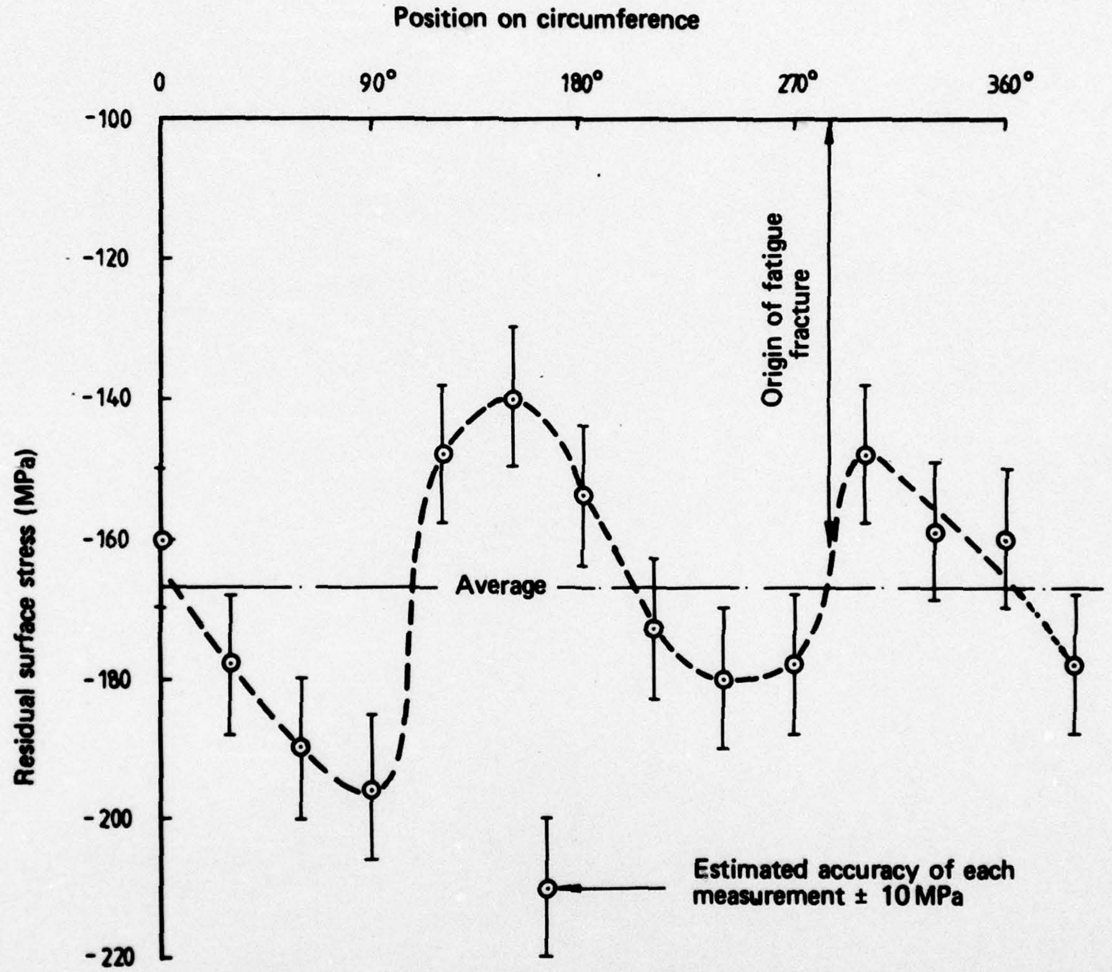
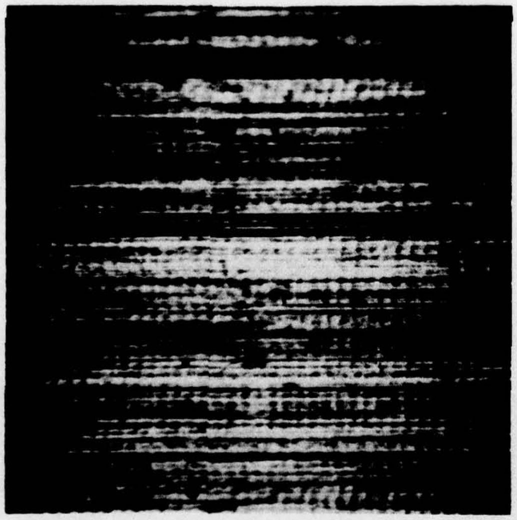


FIG. 13 RESIDUAL SURFACE STRESS PATTERN
4.7mm RADIUS NOTCHED SPECIMEN AA41BM

(a) Spec. AA81CD, A series
200 revolutions dwell time



(b) Spec. AA37BG, B series
200 revolutions dwell time

FIG. 14 SURFACE FINISH OF 4.7mm RADIUS NOTCHES (x 100)

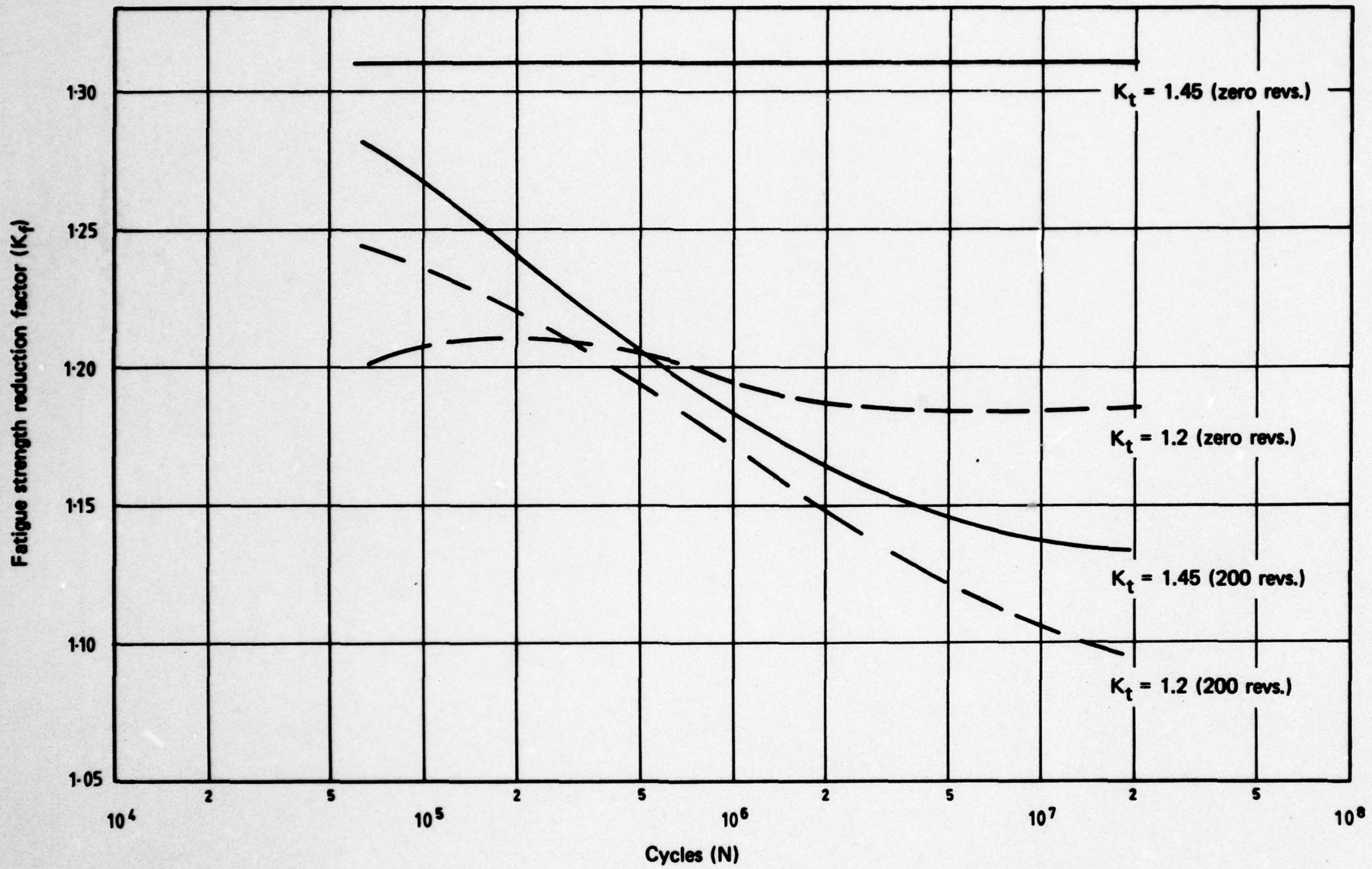


FIG. 15 FATIGUE STRENGTH REDUCTION FACTORS, 4.7mm AND 2mm NOTCHES

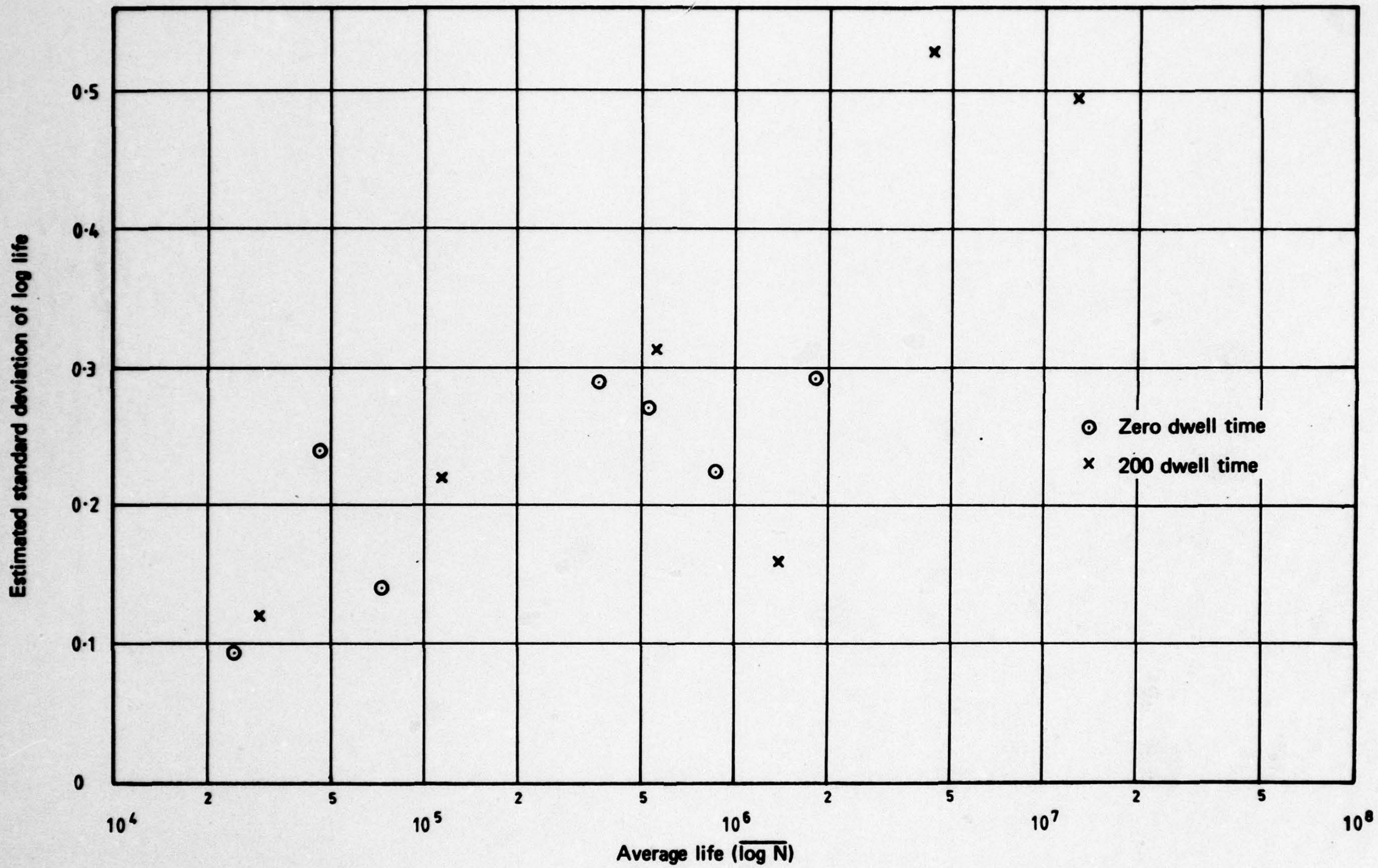


FIG. 16 RELATIONSHIP BETWEEN AVERAGE LIFE AND STANDARD DEVIATION, NOTCH K_t = 1.45

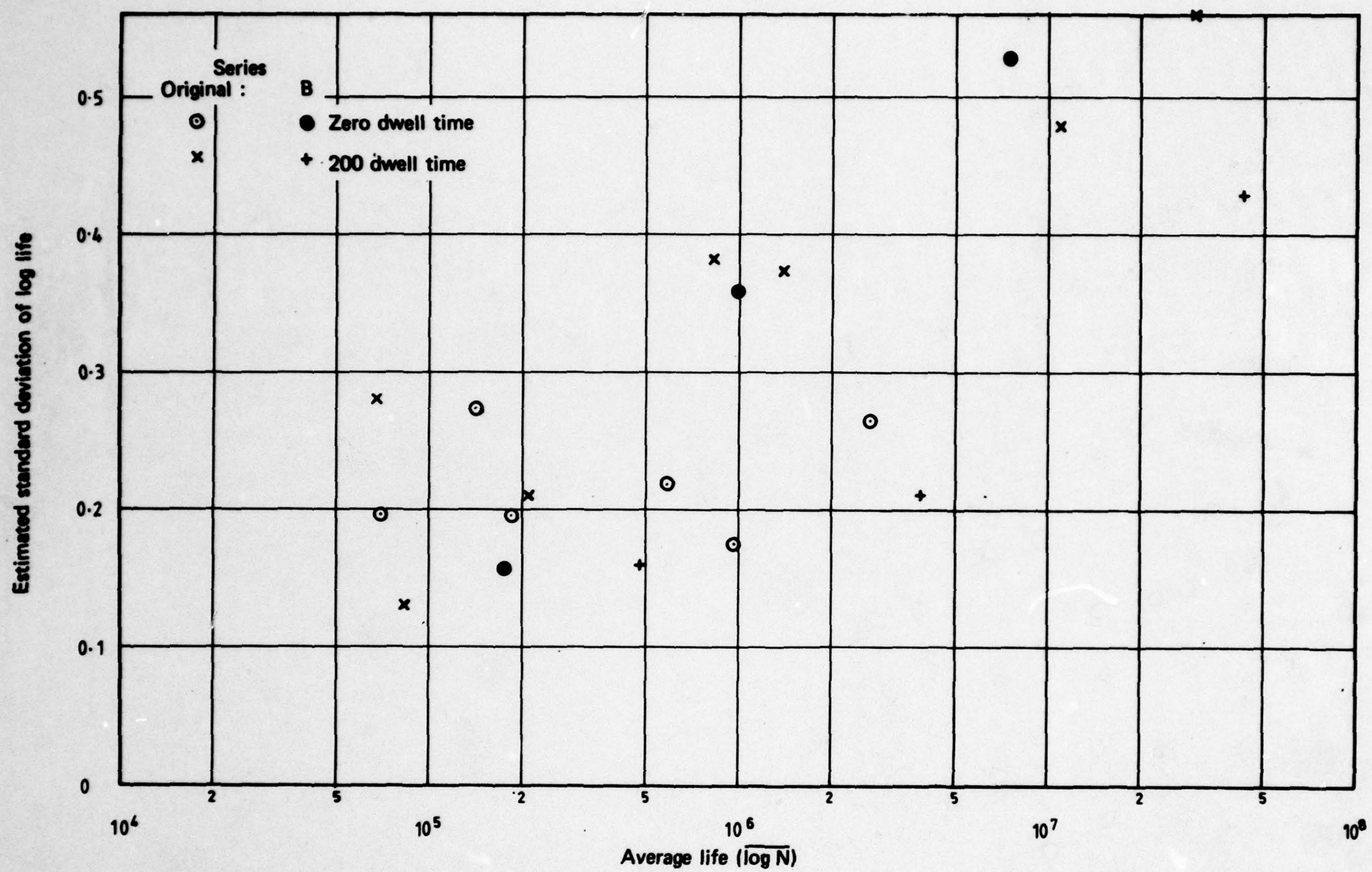


FIG. 17 RELATIONSHIP BETWEEN AVERAGE LIFE AND STANDARD DEVIATION, NOTCH K_t = 1.2

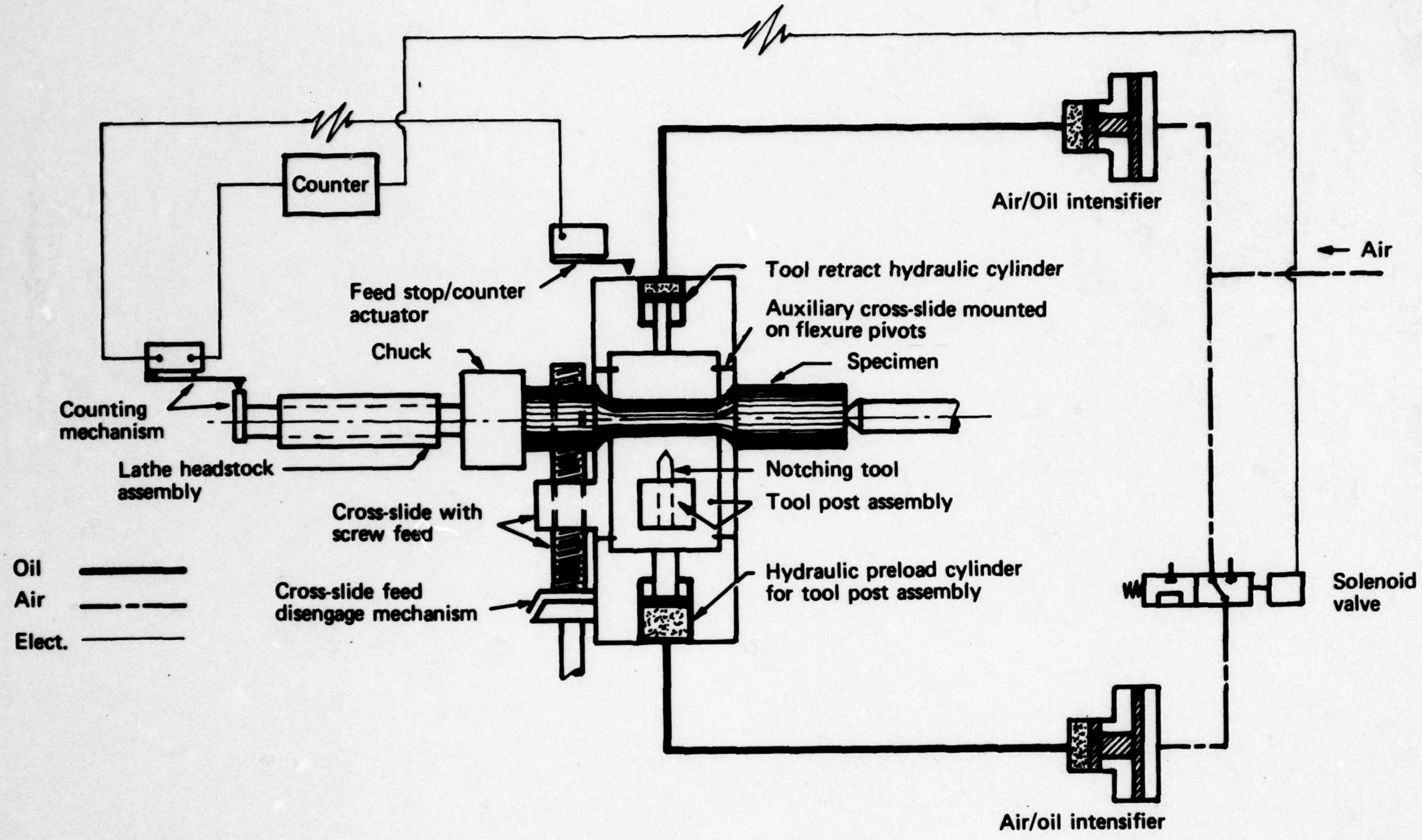


FIG. 18 SCHEMATIC ARRANGEMENT OF AUTOMATIC NOTCHING SYSTEM

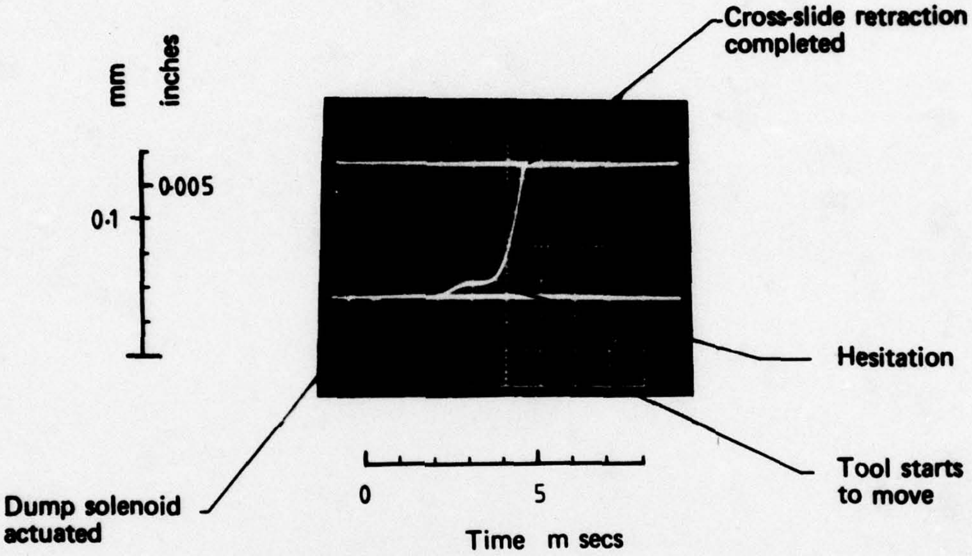


FIG. 19 NOTCHING TOOL RETRACTION

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Aluminium alloys	Fatigue notch factor
Notch tests	

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16. *ABSTRACT*

Rotating cantilever fatigue tests were carried out on V-notched specimens of DTD 683 aluminium alloy having K_t values of 1·20, 1·45, 2·35 and 4·35. The respective notch radii were 4·7, 2·0, 0·46 and 0·01 mm. In all cases the notches were plunge-cut machined in a lathe using carbide tip form tools and tool dwell times of zero and 200 revolutions before tool withdrawal from the finished notch.

Tool dwell times of 200 revolutions resulted in significantly greater fatigue lives than zero dwell times for specimens of low K_t (1·45 and 1·2). However, the fatigue test results for specimens of higher K_t (4·35 and 2·35) did not indicate any significant effects of notching tool dwell times. The use of different form tools for the notch of $K_t = 1\cdot 2$ resulted in significantly different fatigue lives for specimens machined with 200 revolutions dwell time, but not for those machined with zero dwell time.

No correlation was established between tool dwell times and the hardness, surface residual stresses and surface finish of the notches of $K_t = 1\cdot 2$ to explain the differences in fatigue lives. However, the horizontal forces measured during the machining of the two notches of high K_t were less than half those measured during the machining of the notches of low K_t.

The consistent use of zero revolutions dwell time should enable greater reproducibility in average fatigue lives to be achieved, as changes in the form tool and operator appear to have no significant effects under such notching conditions.

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