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Machining Parameter Study

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DEVELOPMENT DIVISION

JULY - SEPTEMBER 1971

SANL 712-019

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MACHINING PARAMETER STUDY

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The purpose of this project is to determine to what extent fabrication techniques affect the measured mechanical properties of HE.

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Section I

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MACHINING PARAMETER STUDY

ABSTRACT

Tests indicate that certain machine tool conditions cause differences in the measured tensile creep of LX-04-1. Eight machining conditions were studied; high RPM, high feed rate, and shallow depth of cut gave the best results in terms of longest time to rupture while requiring moderate machining time.

DISCUSSION

A total of sixty-four LX-04-1 tensile creep specimens were used to evaluate machining effects on test specimens. Specimen blanks (see Fig. 1) were cored at LLL from six W58 forward hemispheres. Thirty-two of these were finished at LLL into 4-inch tensile specimens (see Fig. 2) per the machining parameter schedule (see Table I). The remaining thirty-two were finished at Pantex per the same schedule.

Testing was carried out on creep frames holding four specimens at a time (two Pantex and two LLL specimens), as shown in Figs. 3 and 4. A ten-channel Data Acquisition System*(1)* was used to reduce the cost and minimize testing variables. Paper tapes from the DAS were processed on a PDP-8/I computer. All were tested at 120 F with a 45-pound load.

The procedure used to process data from the DAS tapes on the PDP-8/I computer was the following:

PASS I

The paper tape from the DAS was filtered for noise and edited for bad data punches. The voltage readings were converted to micro-strain, and time (which was in hours, minutes, and seconds) was converted to decimal hours. A new tape was punched with a detail listing of test results.

PASS II

The new edited tape was used to plot strain versus time on an X-Y recorder.

The second pass was repeated on several tests with increased amplification for closer examination of the curves.

PASS III

Parameters were computed for each curve to fit the equation:

$$J-J_o = AT^M + B(T-T_2) \qquad (1)$$

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(1)Built by Systems Instruments Research, Inc., Atlanta, Ga.

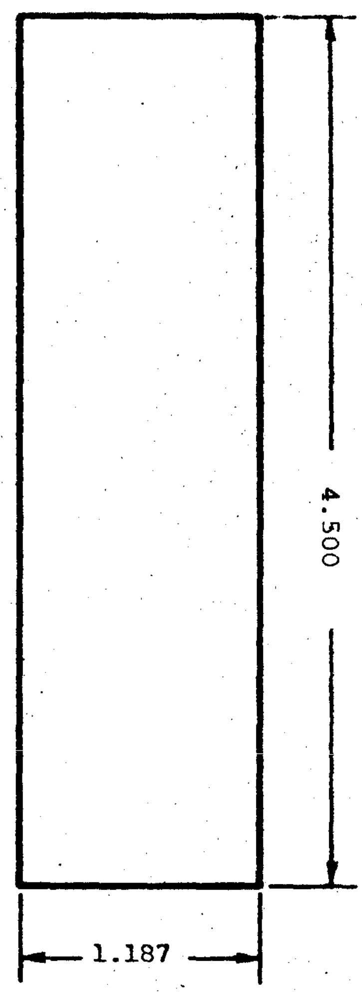

Fig. 1. Cored Specimen Blank

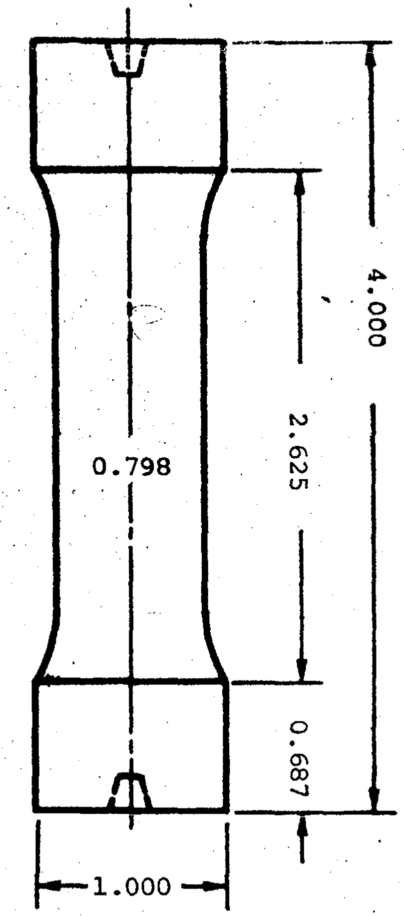

Fig. 2. Finished Tensile Specimen

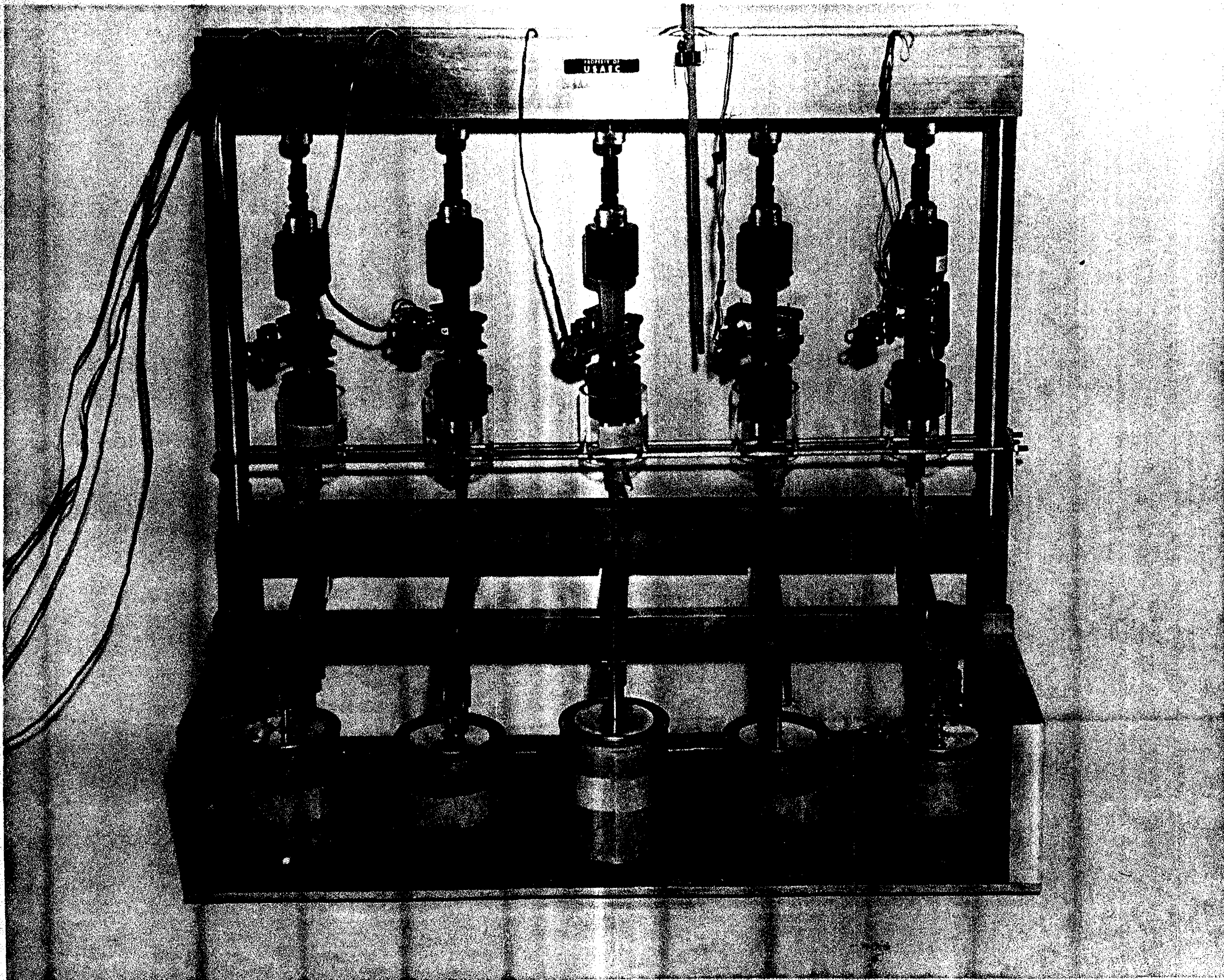

Fig. 3. Multiple Creep Frame with Tensile Creep Setup

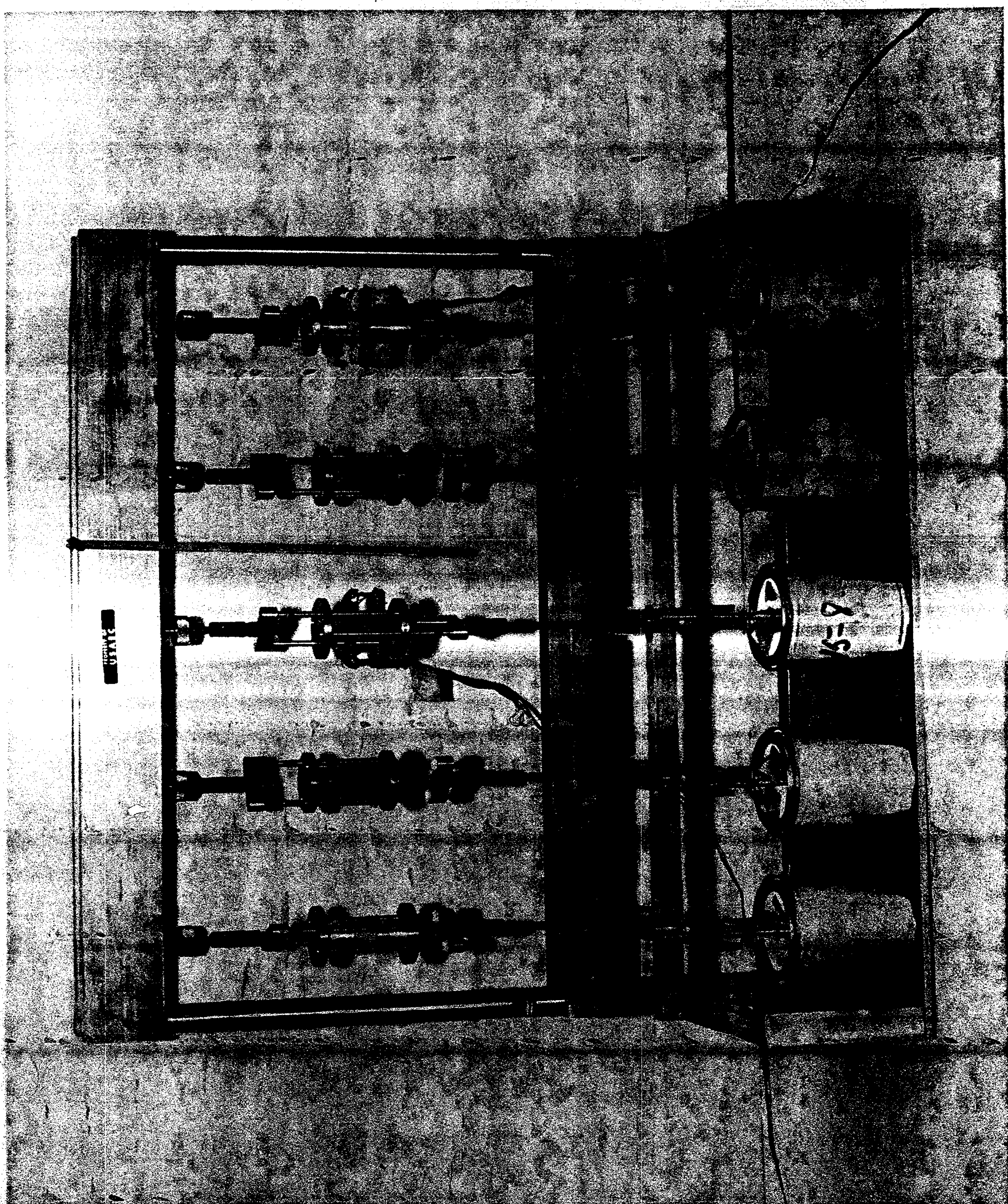

Fig. 4. Multiple Creep Frame with Compression Creep Setup

where J = Strain/Stress, μinch/inch psi

J_o, A, M, and B are parameters which are calculated from the experimental curves

T - Time, hrs
T_2 = First transition, or beginning of straight line portion of a creep curve, typically illustrated in Fig. 5.
T_4 = Failure time, hrs
T_5 = 90% Rupture time, hrs

NOTE: T_2, T_4 and Rupture can occur at the same time.

PASS IV

From average values of each group, final parameters were computed and the average curve was plotted by computer using equation (1).

Table I. Machining Parameter Tests Schedule

R = Rotational speed, rpm. H = high max 525 or 200 linear feet/min.
L = low ∿100
F = Feed rate, inch per revolution; H = ∿.035 ipr, L = ∿.001 ipr
D = Depth of cut, inches, H = 2 passes at ∿.050 inch, rest at ∿.010 inch
L = ∿.010 inch.
H = High
L = Low

Constants
1. 0.032-inch cutter set 90 degrees to work piece axis.
2. Final cut to give 32 finish or better on the HE surface.
3. Tail stock pressure 8 psi.
4. Machine in one direction only (toward the head stock).
5. Four LLL and four PX samples for each of the variables constants.

Variables

Test A: HR, HF, HD	Test C: LR, HF, HD
Test A': HR, LF, HD	Test C : LR, LF, HD
Test B: HR, HF, LD	Test D: LR, HF, LD
Test B': HR, LF, LD	Test D : LR, LF, LD

The combination of high RPM (525) and 0.035 IPR feed rate did not produce satisfactory results as to specimen surface finish. To produce specimens with the desired surface finish the feed rate was reduced to 0.0115 IPR in Test A, B, C and D. This was the only major variation from the machining parameter schedule. Some tests were lost due to plant power failure. A record of the actual values for each operation used is shown in Table II. All tensile specimens were machined with the pole end (of the original hemisphere) at the head stock and tested with the pole end up.

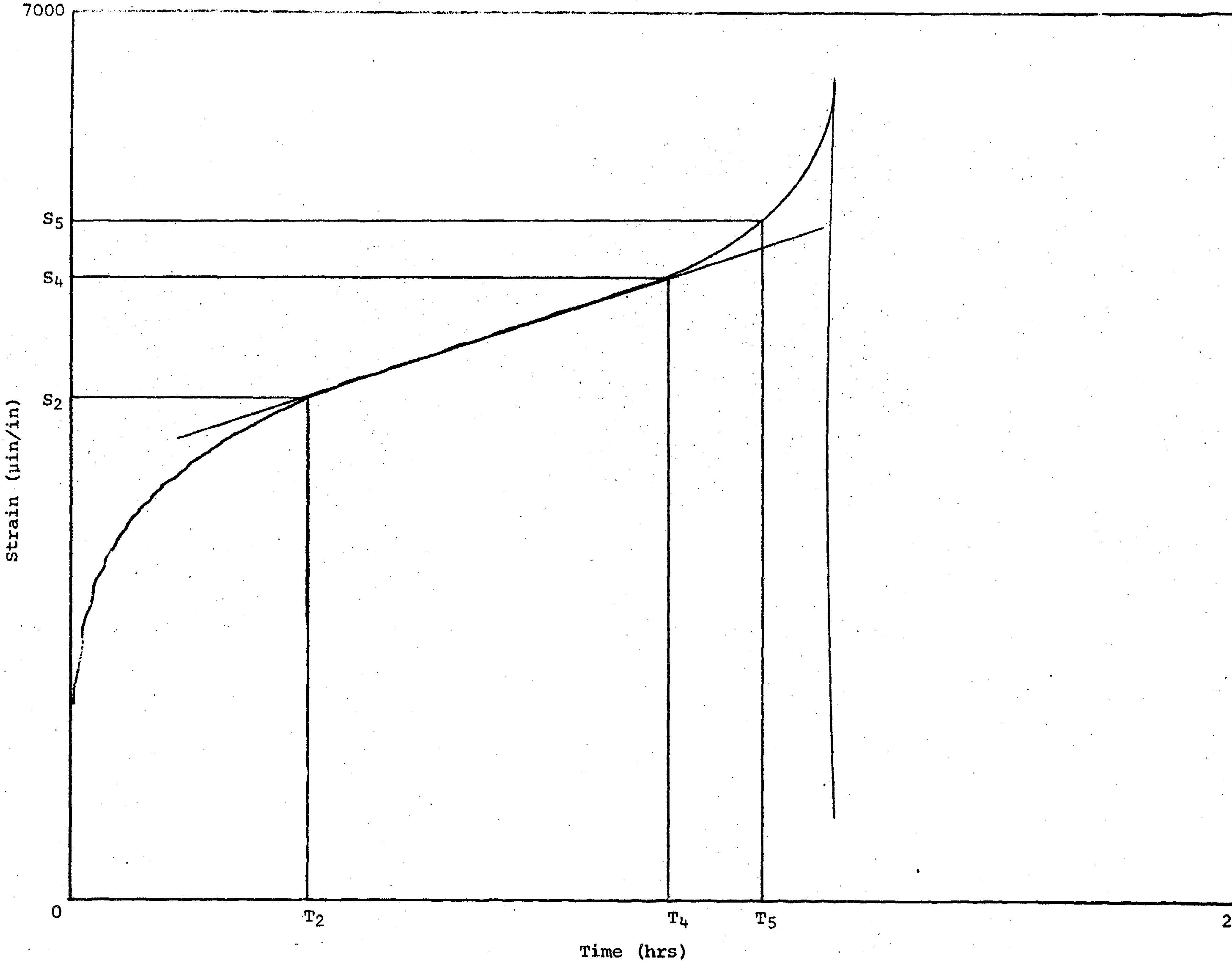

Fig. 5. A Typical Strain Versus Time Curve

Table II. Record of Actual Machining Parameter Used

Test No.	Specimen No.	Rotational Speed (RPM)	Feed Rate (IPR)	Depth of Cuts to Finish Specimen (inches)				
				Pass Number				
				1	2	3	4	5
A	82-104-06-12 Z4	455	.0115	.050	.050	.010	.010	
A	82-106-07-25 Z4	455	.0115	.050	.050	.010	.010	
A	82-105-10-05 Z4	455	.0115	.050	.050	.010		
A	82-104-12-09 Z4	455	.0115	.050	.050	.010		
A'	82-105-10-05 Z2	455	.0017	.050	.040	.010		
A'	82-106-07-25 Z2	455	.0017	.050	.050	.010		
A'	82-106-08-06 Z2	455	.0017	.050	.050	.010	.008	.002
A'	82-104-12-09 Z2	455	.0017	.050	.050	.010	.005	.005
B	82-105-11-15 Z2	455	.0115	12 cuts of .010				
B	82-103-14-20 Z2	455	.0115	12 cuts of .010				
B	82-103-11-13 Z2	455	.0115	12 cuts of .010				
B	82-103-11-13 Z2	455	.0115	12 cuts of .010				
B'	82-106-08-06 Z8	455	.0017	12 cuts of .010				
B'	82-104-12-09 Z8	455	.0017	12 cuts of .010				
B'	82-105-10-05 Z8	455	.0017	12 cuts of .010				
B'	82-105-11-15 Z8	455	.0017	12 cuts of .010				
C	82-103-14-20 Z4	107	.0115	.050	.050	.010		
C	82-105-11-51 Z4	107	.0115	.050	.050	.010	.010	
C	82-103-11-13 Z4	107	.0115	.050	.050	.010	.010	
C	82-106-08-06 Z4	107	.0115	.050	.050	.010	.010	
C'	82-106-07-25 Z8	107	.0017	.050	.050	.010		
C'	82-103-14-20 Z8	107	.0017	.050	.050	.010		
C'	82-103-11-13 Z8	107	.0017	.050	.050	.010		
C'	82-104-06-12 Z8	107	.0017	.050	.050	.010		
D	82-105-11-14 Z6	107	.0115	12 cuts of .010				
D	82-103-14-20 Z6	107	.0115	12 cuts of .010				
D	82-106-07-25 Z6	107	.0115	12 cuts of .010				
D	82-106-08-06 Z6	107	.0115	12 cuts of .010				
D'	82-105-10-05 Z6	107	.0017	11 cuts of .010				
D'	82-103-11-13 Z6	107	.0017	11 cuts of .010				
D'	82-104-06-12 Z6	107	.0017	11 cuts of .010				
D'	82-104-12-09 Z6	107	.0017	11 cuts of .010				

Table III. Tensile Creep Data of Test A
(120 F at 90 psi)

Piece No.	Channel No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-105-10-05 Z4	1	6	1940	0.203	1680	0.642	2050	2.03	2580	4.30	3090	4.120	3050
82-104-12-09 Z4	4	6	2450	0.510	2455	1.613	3190	5.10	4180	7.30	4620	6.570	4495
82-106-07-25 Z4	2	6	2710	0.380	2590	1.202	3195	3.80	3995	7.62	4720	6.858	4585
Mean			2366.67	0.3643	2241.67	1.1523	2811.67	3.6433	3585.0	6.4067	4143.33	5.8493	4043.33
Standard Deviation			391.709	0.1541	491.08	0.4874	659.633	1.5410	875.2580	1.8314	913.5840	1.5046	861.4310

Creep Equation: $J = J_O + AT^M + B(T - T_2)$ $J_O = 7.1530$ $A = 23.2008$ $M = 0.2650$ $B = 2.2449$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{1/2}$

Table IV. Tensile Creep Data of Test A'
(120 F at 90 psi)

Piece No.	Channel No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-106-07-25 Z5	1	6	2670	0.205	2300	0.648	2840	2.05	3760	6.56	5360	5.904	5160
82-104-12-09 Z2	2	2	2180	0.540	2200	1.708	2820	5.40	3705	11.19	4650	10.071	4490
82-106-07-25 Z2	4	6	2380	0.340	2180	1.075	2770	3.40	3670	7.7	4695	6.930	4510
82-106-07-25 Z7	5	6	2360	0.352	2220	1.113	2850	3.52	3795	6.56	4495	6.300	4450
82-106-08-06 Z2	1	6	2590	0.296	2300	0.936	2900	2.96	3700	4.85	4070	4.410	3995
82-106-07-25 Z1	4	6	2660	0.316	2420	0.999	3020	3.16	3810	9.67	4940	9.594	4930
82-106-07-25 Z3	3	6	2660	0.363	2485	1.148	3100	3.63	3910	8.02	4690	7.218	4550
Mean			2500.0	0.3446	2300.71	1.0896	2900.0	3.4457	3764.29	7.7929	4700.0	7.2039	4583.57
Standard Deviation			193.477	0.1011	115.065	0.3198	118.181	1.0105	82.5106	2.1144	394.705	2.0133	372.344

Creep Equation: $J = J_O + AT^M + B(T - T2)$ $J_O = 10.5047$ $A = 21.1327$ $M = 0.3181$ $B = 2.3916$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{\frac{1}{2}}$

Table V. Tensile Creep Data of Test B
(120 F at 90 psi)

Piece No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-103-11-13 Z2	6	3275	0.720	3470	2.277	4095	7.20	5090	18.12	6080	16.308	5920
82-103-11-13 Z3	2	2550	0.640	2670	2.024	3200	6.40	3980	18.14	4825	16.326	4695
82-103-11-13 Z1	6	2400	0.760	2535	2.403	3070	7.60	3735	18.00	4284	16.200	4175
82-103-11-13 Z7	6	2650	0.920	2910	2.909	3555	9.20	4490	17.66	4930	15.894	4840
82-105-11-15 Z2	6	2060	0.788	2290	2.492	3015	7.88	3980	20.8	5000	18.72	4830
82-103-11-13 Z5	6	2540	0.860	2860	2.720	3610	8.60	4750	18.66	5610	16.794	5445
82-103-14-20 Z2	6	2140	0.813	2385	2.571	3060	8.13	3890	17.64	4370	15.876	4280
Mean		2516.43	0.7859	2731.43	2.4852	3372.14	7.8586	4273.57	18.4314	5014.14	16.5883	4883.57
Standard Deviation		399.702	0.0918	398.156	0.2901	399.677	0.9176	508.257	1.0996	643.196	0.9896	618.626

Creep Equation: $J = J_O + AT^M + B(T - T_2)$ $J_O = 12.8514$ $A = 18.7908$ $M = 0.2965$ $B = .7783$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)(T_2))^{1/2}$

Table VI. Tensile Creep Data of Test B'
(120 F at 90 psi)

Piece No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-106-08-06 Z7	6	2540	0.785	2800	2.482	3520	7.85	4180	12.2	4880	11.232	4730
82-105-11-15 Z8	6	2380	0.780	2575	2.467	3170	7.80	3660	18.00	4660	16.416	4520
82-106-08-06 Z5	4	2500	0.260	2280	0.822	2735	2.60	3390	7.6	4280	6.840	4130
82-104-12-09 Z8	6	2300	0.280	2100	0.886	2530	2.80	3330	2.8	3330	2.520	3230
Mean		2430.0	0.5263	2438.75	1.6643	2988.75	5.2625	3640.0	10.15	4287.5	9.252	4152.5
Standard Deviation		110.151	0.296	310.387	0.936	443.441	2.9601	387.553	6.4897	684.756	5.9549	663.341

Creep Equation: $J = J_O + AT^M + B(T - T_2)$ $J_O = 0.00$ $A = 30.2984$ $M = 0.1739$ $B = 1.4720$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{1/2}$

Table VII. Tensile Creep Data of Test C
(120 F at 90 psi)

Piece No.	Channel No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-105-11-15 Z3	2	2	2175	0.922	2430	2.916	3140	9.22	4090	16.19	4655	15.822	4640
82-106-08-06 Z4	3	6	2240	0.580	2390	1.834	2790	5.80	3500	13.35	4250	12.015	4140
82-105-11-15 Z7	1	6	2100	0.420	2050	1.328	2560	4.20	3405	7.46	4050	6.714	3740
Mean			2171.67	0.6407	2290.0	2.026	2830	6.4067	3665.0	12.333	4318.3	11.517	4173.33
Standard Deviation			70.071	0.2565	208.806	0.8112	292.06	2.5644	377.112	4.4529	308.247	4.5744	450.93

Creep Equation: $J = J_O + AT^M + B(T - T_2)$ $J_O = 14.4614$ $A = 12.9996$ $M = 0.3786$ $B = 1.2249$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{\frac{1}{2}}$

Table VIII. Tensile Creep Data of Test C'
(120 F at 90 psi)

Piece No.	Channel No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-104-06-12 Z1	4	2	2490	0.400	2385	1.265	3050	4.00	3940	9.8	4900	8.820	4735
82-103-14-20 Z8	3	6	2340	0.432	2280	1.366	2800	4.32	3475	9.8	4020	8.820	3945
82-104-06-12 Z8	1	6	2450	0.285	2120	0.901	2760	2.85	3535	8.0	4610	7.20	4475
82-106-07-25 Z8	3	6	2800	0.420	2760	1.328	3270	4.20	4250	9.70	5150	8.820	5010
82-104-06-12 Z5	2	6	2410	0.412	2390	1.303	2890	4.12	3740	11.17	4810	10.820	4765
82-104-06-12 Z7	1	6	2350	0.252	2120	0.797	2560	2.52	3265	4.63	3800	4.167	3690
Mean			2473	0.3668	2342.5	1.1600	2888.33	3.6683	3700.83	8.850	4548.33	8.1078	4436.67
Standard Deviation			170.02	0.0776	237.187	0.2454	246.534	0.7759	354.622	2.2996	528.6030	2.2464	513.0260

Creep Equation: $J = J_O + AT^M + B(T - T_2)$ $J_O = 13.6141$ $A = 17.5546$ $M = 0.3455$ $B = 1.8173$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{1/2}$

Table IX. Tensile Creep Data of Test D
(120 F at 90 psi)

Piece No.	Channel No.	Rupture Mode Location	30 Min Creep McSt	T_1 Hrs.	S_1 McSt	T_3 Hrs.	S_3 McSt	First Transition T_2 Hrs.	First Transition S_2 McSt	Failure T_4 Hrs.	Failure S_4 McSt	90% Rupture T_5 Hrs.	90% Rupture S_5 McSt
82-106-07-25 Z6	3	6	2610	0.614	2710	1.942	3385	6.14	4155	12.45	4760	11.610	4690
82-103-14-20 Z6	4	6	2690	0.322	2445	1.018	3115	3.22	3925	6.86	4800	6.174	4640
82-104-12-10 Z5	2	6	2495	0.524	2510	1.657	3210	5.24	4185	11.18	5110	10.062	4930
Mean			2598.33	0.4867	2555.0	1.5390	3236.67	4.8667	4088.33	10.1633	4890.00	9.2820	4753.3
Standard Deviation			98.0408	0.1495	138.116	0.4732	136.989	1.4954	142.267	2.9304	191.583	2.8007	155.048

Creep Equation: $J = J_O + AT^M + B(T = T_2)$ $J_O = 0.00$ $A = 32.8853$ $M = 0.2042$ $B = 1.6817$

Where: $T_1 = 0.1(T_2)$ and $T_3 = ((T_1)\ (T_2))^{\frac{1}{2}}$

Table X. Tensile Creep Data of Test D'

								First Transition		Failure		90% Rupture	
Ch No	Pc NO	Mode	30 Min Creep McSt	T_1 (hrs)	S_1 McSt	T_3 (hrs)	S_3 McSt	T_2 (hrs)	S_2 McSt	T_4 (hrs)	S_4 McSt	T_5 (hrs)	S_5 McSt
5	05	6	1920	1.040	2160	3.289	3180	10.40	3180	38.60	4145	35.56	4140
	09	6	1545	1.10	1950	3.478	2170	11.00	2735	21.90	3365	21.83	3270
	05	6	2000	1.060	2300	3.352	2840	10.60	3610	26.50	4650	29.50	4700
3	05	6	2000	1.085	2270	3.431	2870	10.85	3560	30.00	4795	27.00	4600
Mean			1866	1.071	2170	3.387	2765	10.71	3271	29.25	4288	28.47	4178
Standard Dev.			217	0.027	158	0.184	425	0.26	406	7.06	557	5.70	652

Creep equation: $J = J_o + AT^M + B(T-T_2)$ $J_o = 22.9056$ $A = 1.1220$ $M = 1.0472$ $B = 0.6095$

Where: $T_1 = 0.1(T_2)$ and $T_3 = [(T_1)(T_2)]^{1/2}$

Table XI. Student's t Analysis

	Group A	Group A'	Group B	Group B'	Group C	Group C'	Group D	Group D'
T calc	-	-0.979	-13.187	-0.949	-2.131	-1.586	-1.880	-5.350
DF	-	8	8	5	4	7	4	5
t_{95}	-	1.860	1.860	2.015	2.132	1.895	2.132	2.015
Sig	-	No	Yes	No	No	No	No	Yes
T calc		-	-11.831	-0.913	-2.285	-0.867	-1.467	-7.737
DF		-	12	9	8	11	8	9
t_{95}		-	1.782	1.833	1.860	1.796	1.860	1.833
Sig	No	-	Yes	No	Yes	No	No	Yes
T calc			-	3.429	3.652	9.836	6.858	-4.136
DF			-	9	8	11	8	9
t_{95}			-	1.833	1.860	1.796	1.860	1.833
Sig	Yes	Yes	-	Yes	Yes	Yes	Yes	Yes
T calc				-	-0.496	0.461	-0.003	-3.984
DF				-	5	8	5	6
t_{95}				-	2.015	1.860	2.015	1.943
Sig	No	No	Yes	-	No	No	No	Yes
T calc					-	1.602	0.706	3.602
DF					-	7	4	5
t_{95}					-	1.895	2.132	2.015
Sig	No	Yes	Yes	No	-	No	No	Yes
T calc						-	-0.742	-6.738
DF						-	7	8
t_{95}						-	1.895	1.860
Sig	No	No	Yes	No	No	-	No	Yes
T calc							-	-4.329
DF							-	5
t_{95}							-	2.015
Sig	No	No	Yes	No	No	No	-	Yes
								-
								-
								-
								-
	Yes	Yes	Yes	Yes	Yes	Yes	Yes	-

T calc = Calculated value of student's t
DF = Degrees of Freedom
t_{95} = Table values of t at 95% confidence
Sig = Significant difference does (or does not) exist

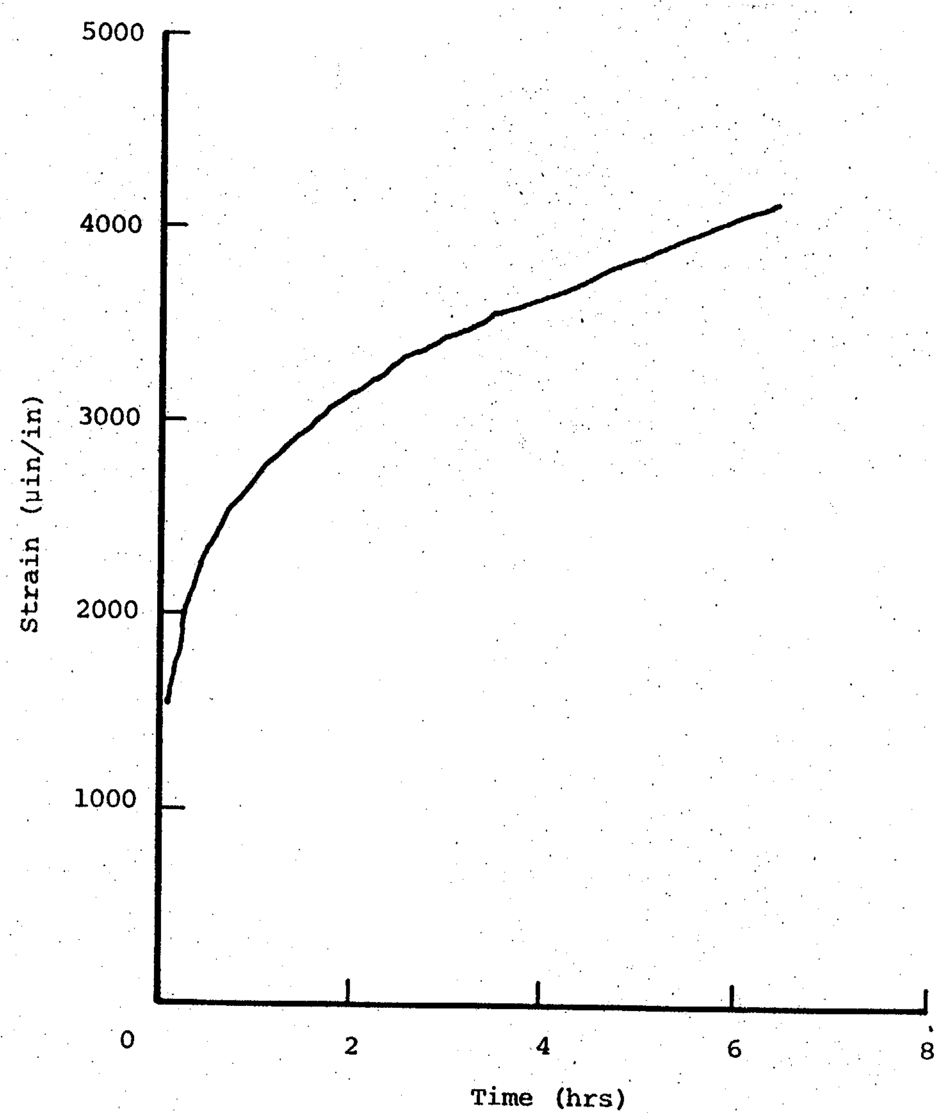

Fig. 6. Average Plot of Test A

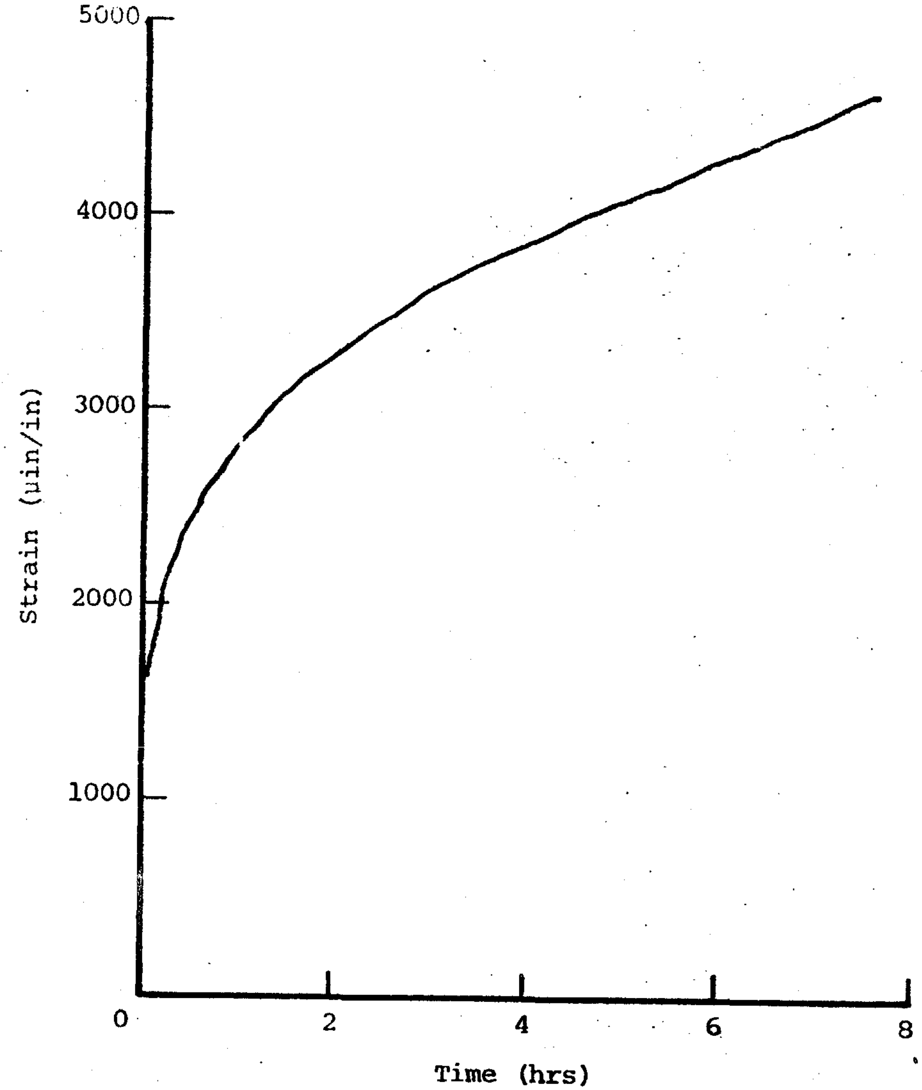

Fig. 7. Average Plot of Test A'

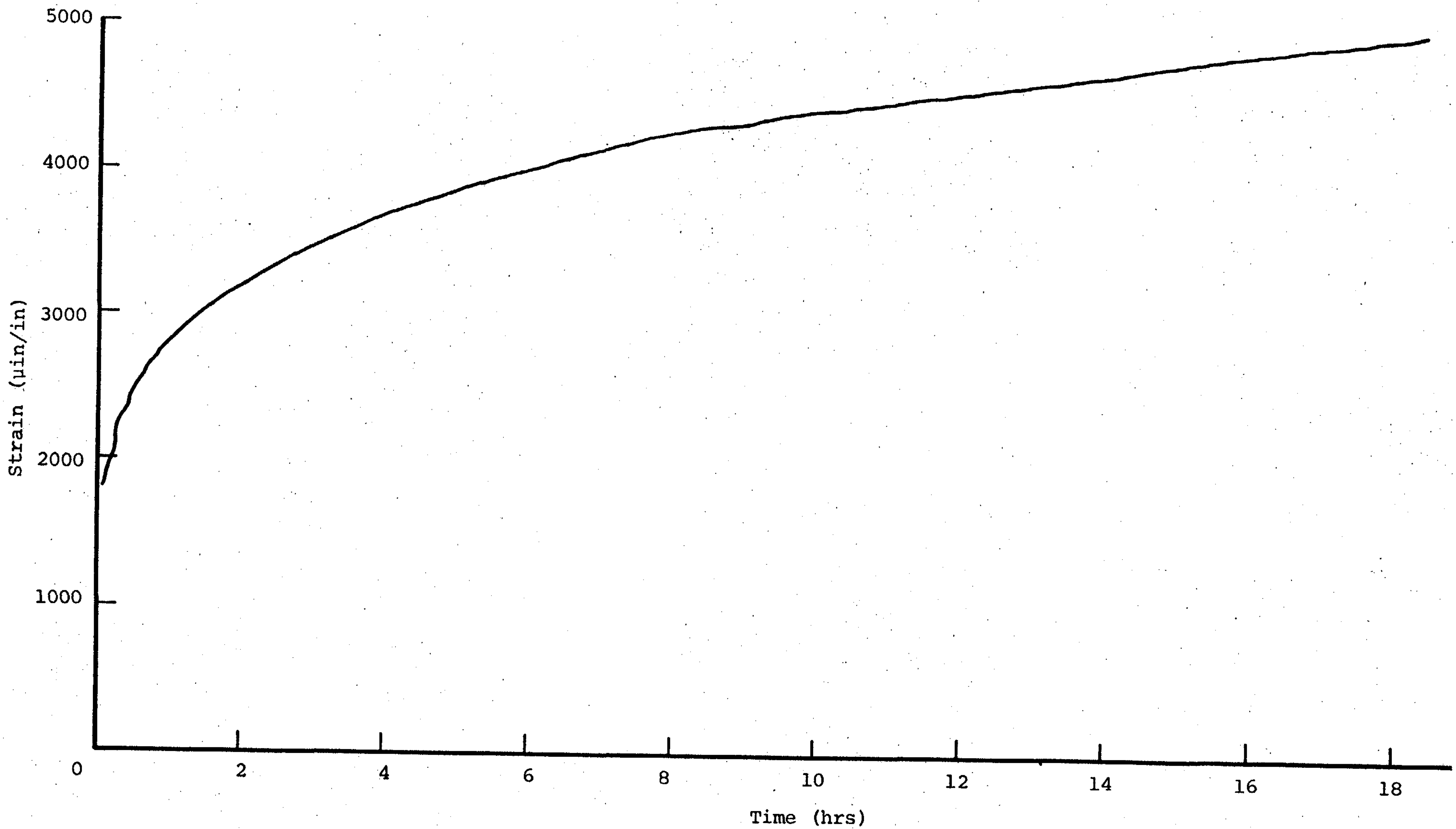

Fig. 8. Average Plot of Test B

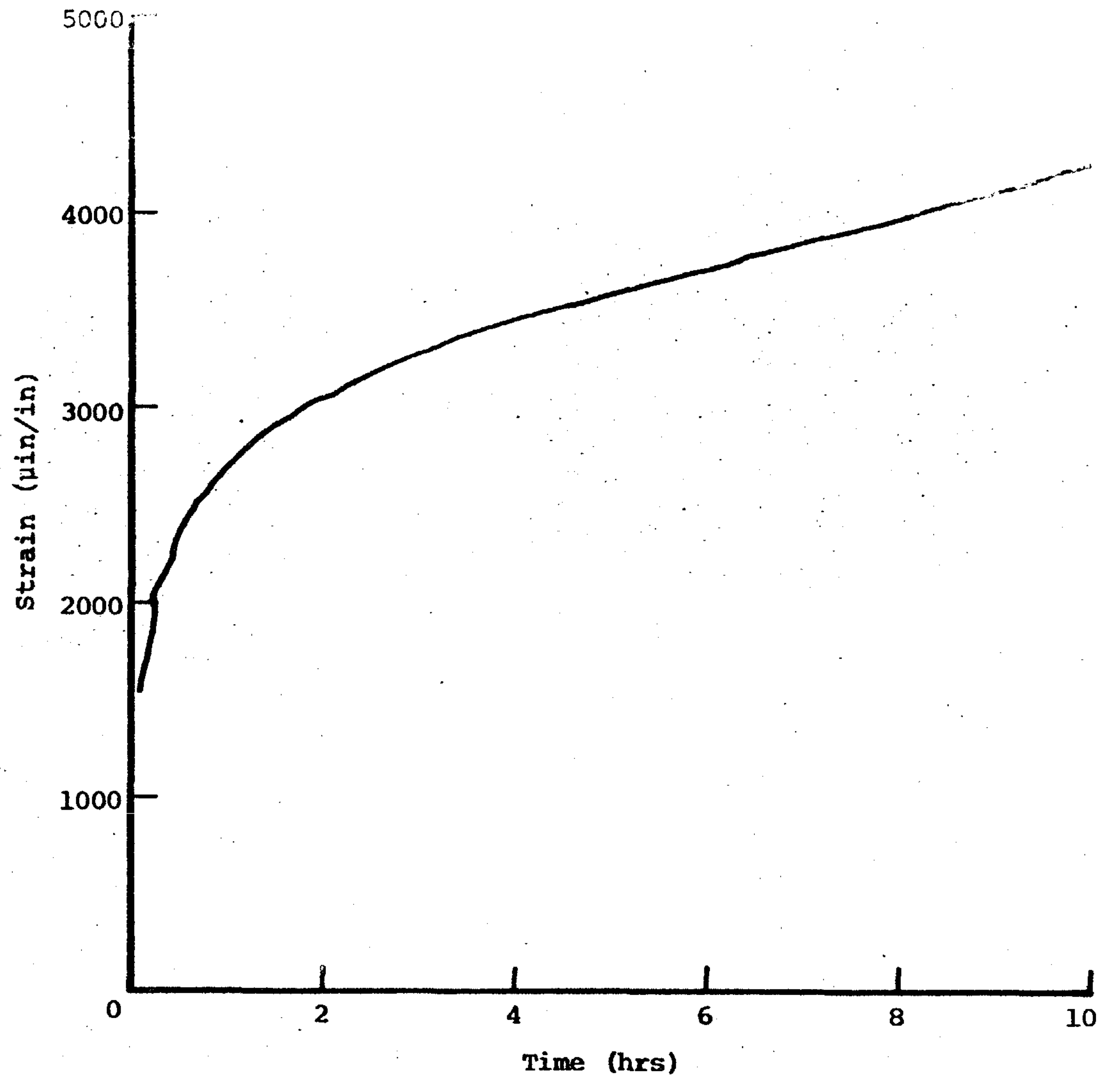

Fig. 9. Average Plot of Test B'

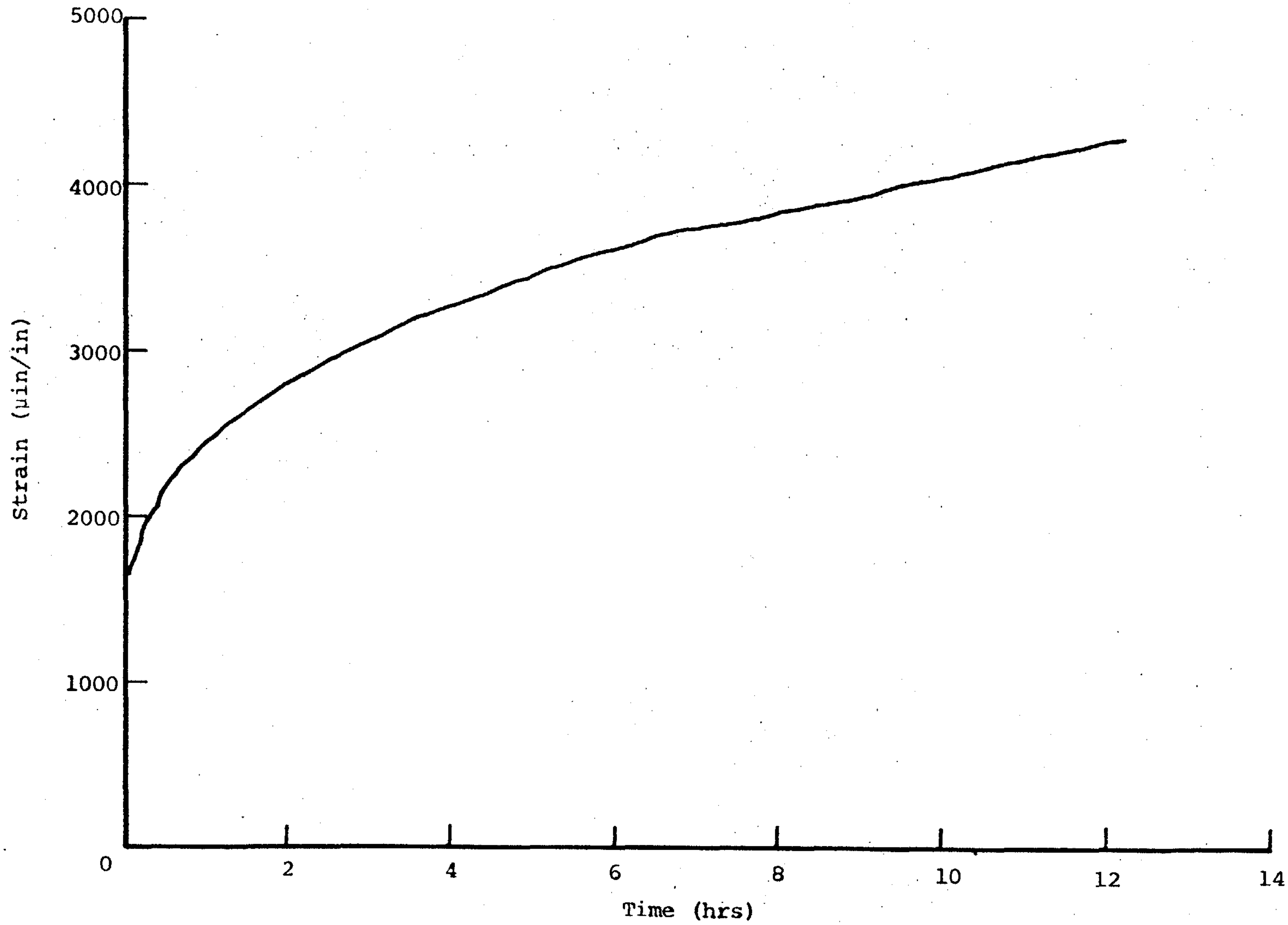

Fig. 10. Average Plot of Test C

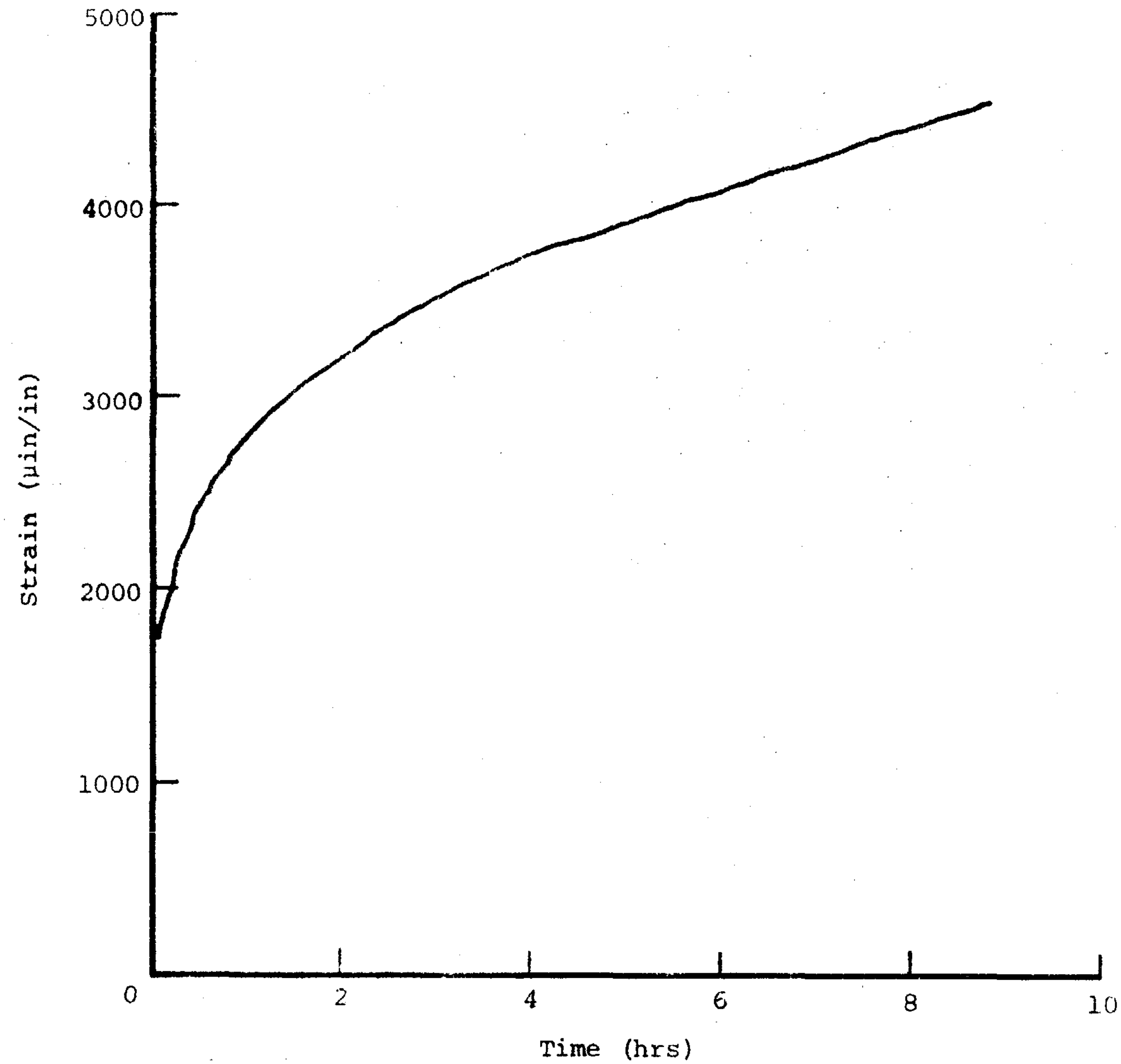

Fig. 11. Average Plot of Test C'

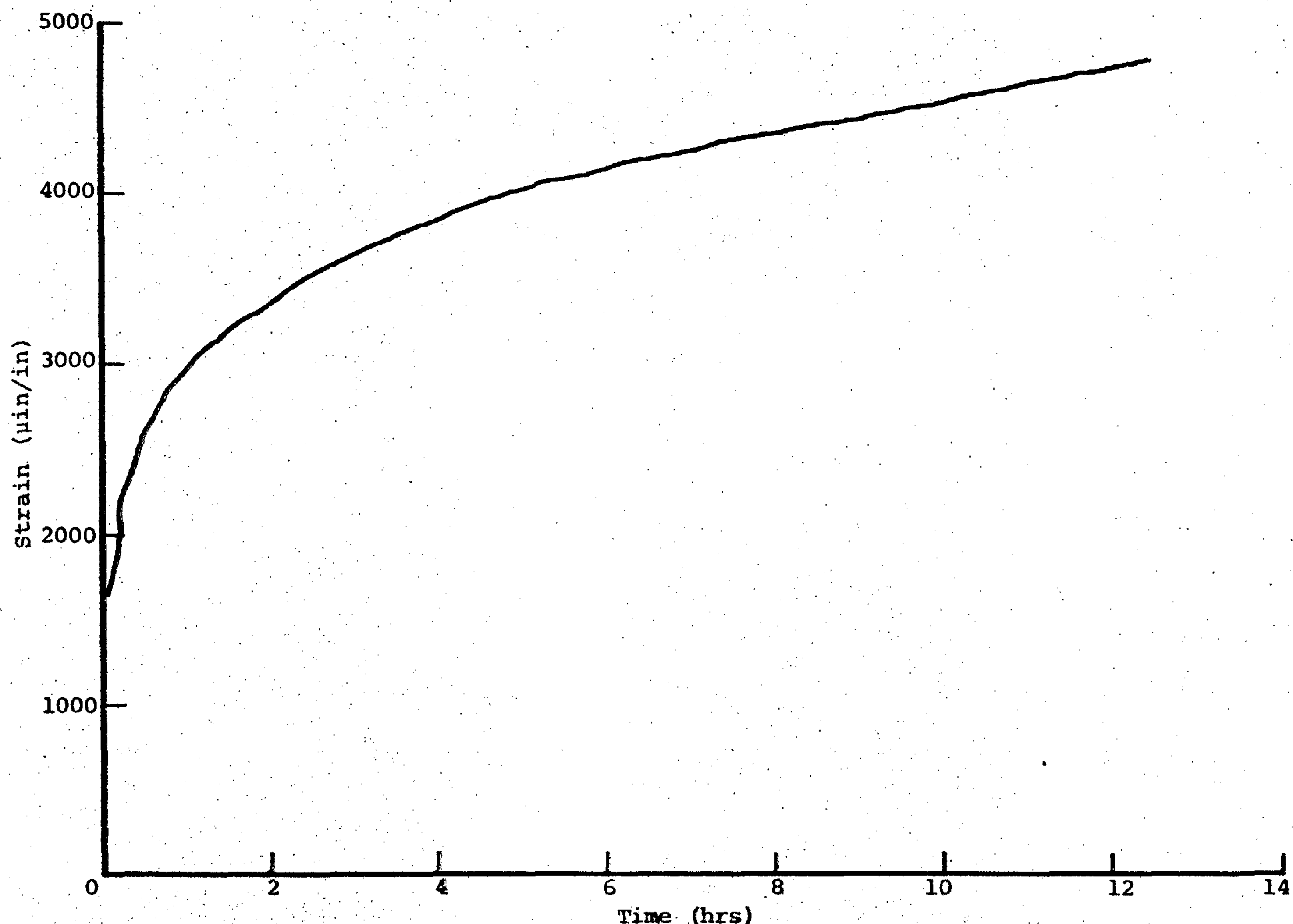

Fig. 12. Average Plot of Test D

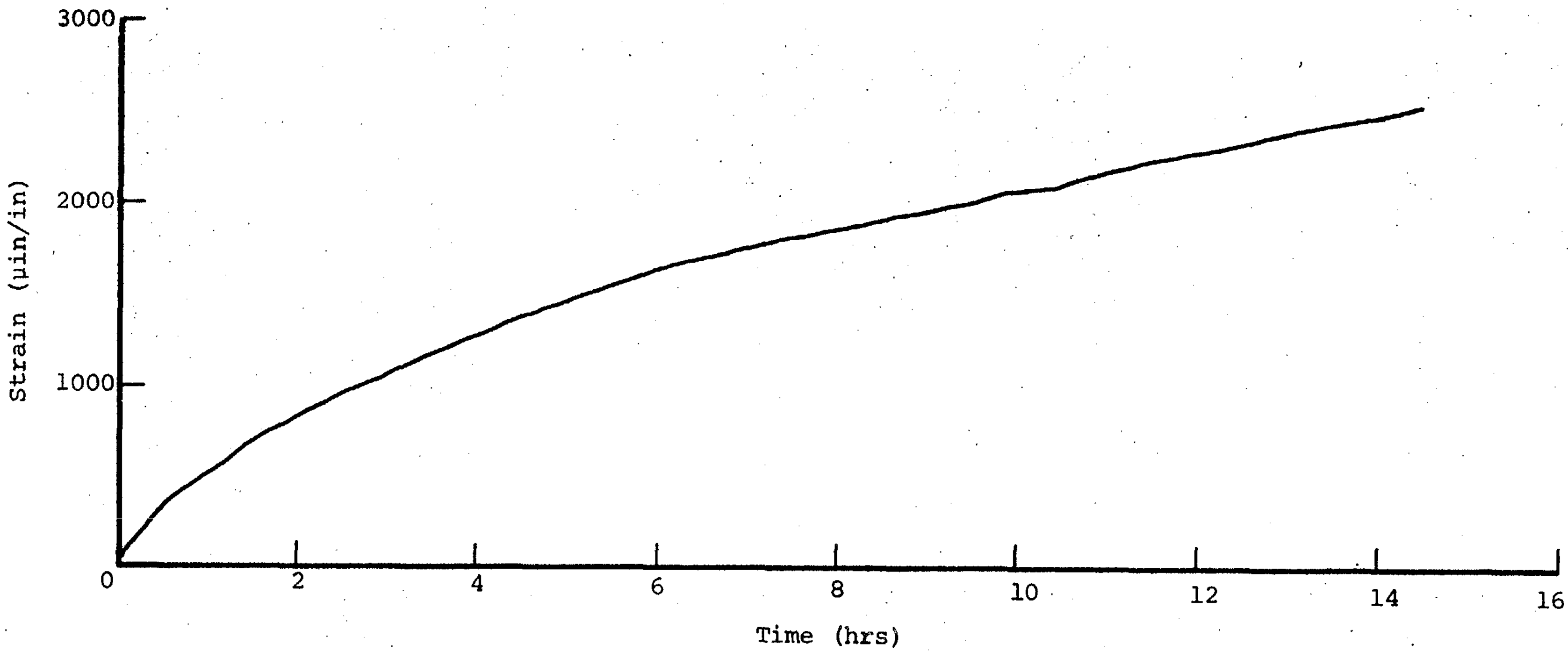

Fig. 13. Average Plot of Test D'

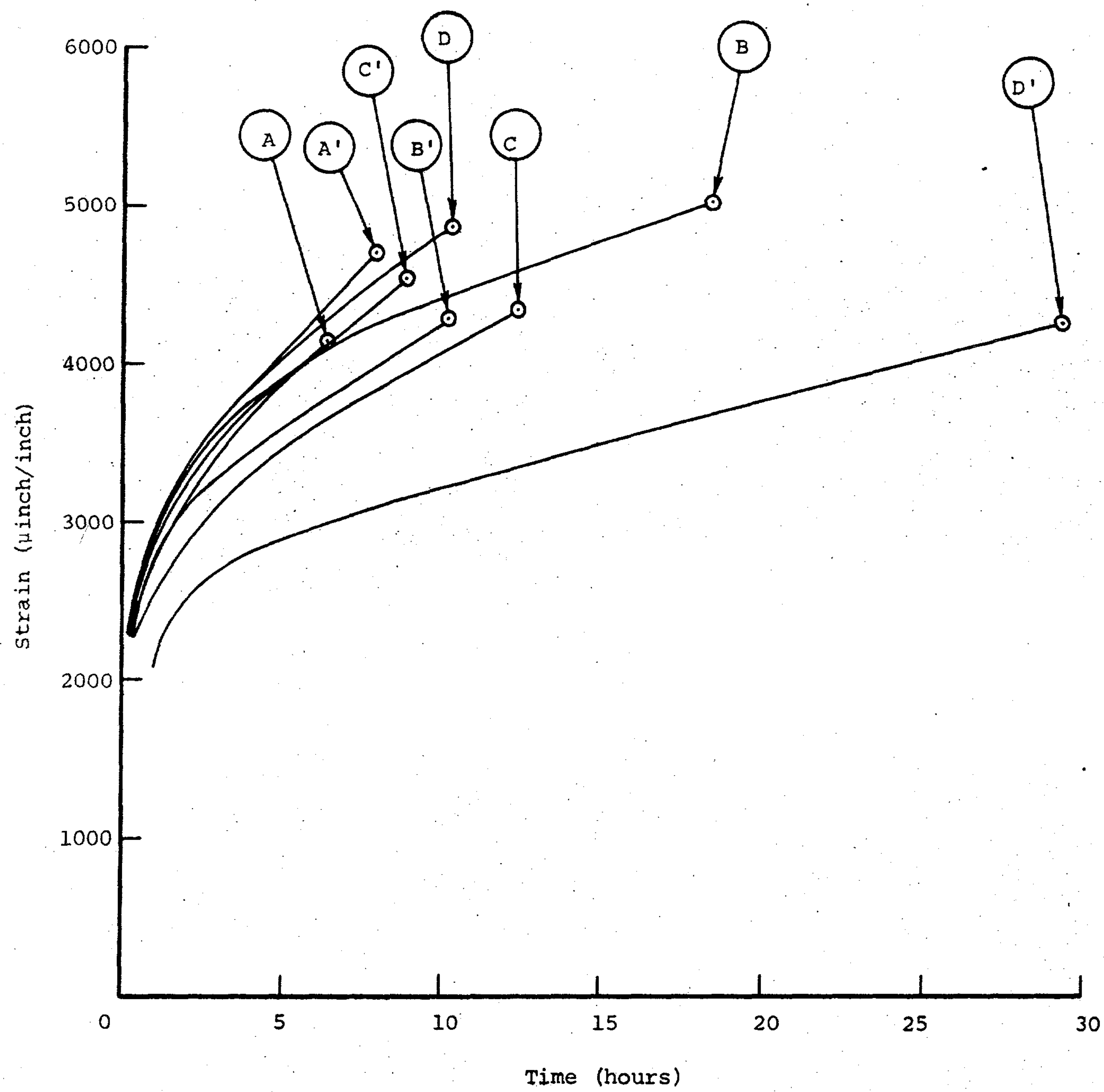

Fig. 14. Group Average Plots of Eight Machining Conditions

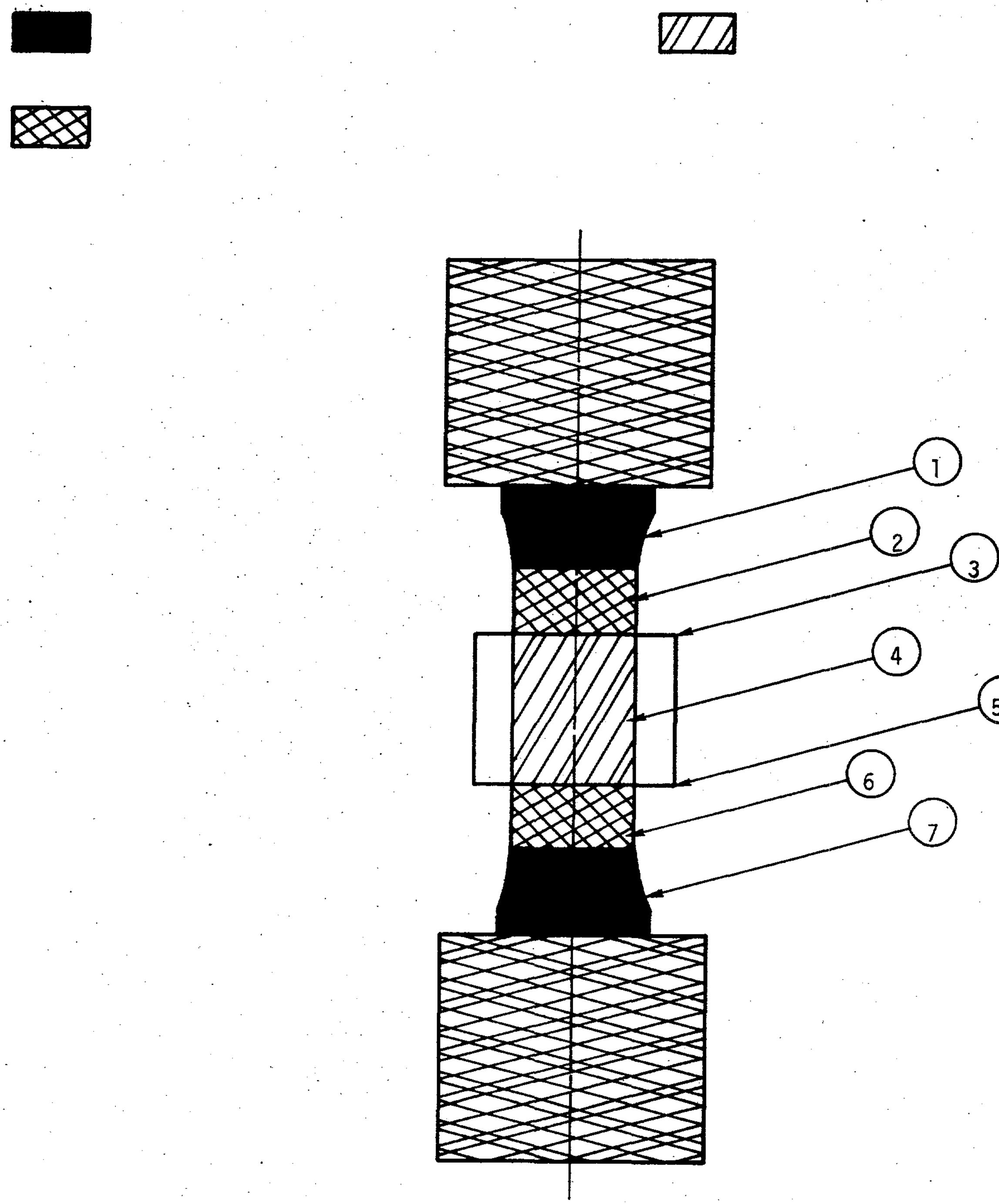

Fig. 15. Illustration of the Code for Rupture Mode Location

The data are given in Tables III thru X. Average curves for the eight groups are shown in Figs. 6 thru 13. The averages from all eight groups are plotted in Fig. 14. The code for the rupture mode location is shown in Fig. 15.

CONCLUSIONS

None of the groups have any significant difference in strain at failure. The time to failure shows differences, and Test D was significantly ($P > .95$) longer than any of the others.

The student's "t" test*(2)* was applied to each pair of test groups. The mean times to failure (along with standard deviations and number of specimens) were used in the calculations and the results were compiled in Table XI. Group D' was significantly, ($P > .95$) larger than all other groups. Group B was significantly larger than the remainder, and the rest, did not differ significantly among themselves.

From the standpoint of producing the highest quality specimen, group D' would be preferred, with group B being second. But a major factor to be considered is the time required to machine a specimen. Allowing one-third minute between passes, the time to machine one specimen in each group was as follows:

Group A	= 4.4 minutes	Group C	= 13.0 minutes
Group A'	= 22.0 minutes	Group C'	= 67.0 minutes
Group B	= 13.2 minutes	Group D	= 43.0 minutes
Group B'	= 66.1 minutes	Group D'	= 267.9 minutes

NOTE: Neither set-up time nor time needed to mount a blank are included because these are similar for all groups.

The longer the time it takes to machine a specimen, the more it costs. A considerable cost penalty is taken if group D' is chosen. On the other hand, group B can be machined in a reasonable length of time. Considering both time to fail and time to machine, group B would be the logical choice.

This experiment was designed to give an indication of the combination of usual variables which would be the most effective in producing quality specimens. This purpose was accomplished. Optimum machining conditions were not determined, nor is their determination planned.

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(2)Henry L. Alder and Edward B. Roessler, Probability and Statistics (San Francisco: W. H. Freeman and Company, 1964), pp. 129-132, 278.

APPENDIX

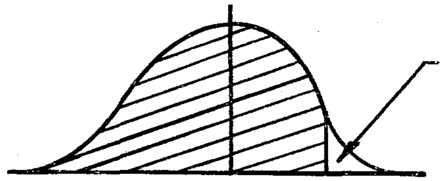
APPENDIX

Student's t method of determining whether or not the difference between two sample means is significantly different consists of assuming, first of all, that the two samples come from the same population and that their sample means are not significantly different from each other. This is called the null hypothesis*(3)*. Given: two samples a and b:

Mean:	$M_a = 6.4067$	$M_b = 18.4314$
Standard Dev:	$S_a = 1.8314$	$S_b = 1.0996$
Number:	$N_a = 3$	$N_b = 7$
Null Hypothesis:	$M_a = M_b$	

Next the confidence level is chosen. In this report the 95% confidence level was selected. This means that one is willing to accept a 5% risk of making a type 1 error. A type 1 error would occur if it happens that the hypothesis being tested is actually true and we concluded that it was false.

A single-tailed test is being used*(4)*. This simply means that 5% of the area under the student's t curve is excluded, and all of this area occurs under one tail (or side).



Based upon the null hypothesis that the two samples come from the same population, an overall standard deviation is calculated.

$$S = \left[\frac{\Sigma(A - M_a) + \Sigma(B - M_b)}{N_a + N_b - 2}\right]^{\frac{1}{2}} \qquad (2)$$

Rather than recalculate, the individual standard deviation may be used:

$$S = \left[\frac{(N_a - 1)\,S_a^2 + (N_b - 1)\,S_b^2}{N_a + N_b - 2}\right]^{\frac{1}{2}} \qquad (3)$$

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(3)Alder, Ibid., p 114

(4)Alder, Ibid., p 113

$$S = \frac{(3 - 1)\ (1.8314)^2 + (7 - 1)\ (1.0996)^{2^{1/2}}}{3 + 7 - 2} \quad (4)$$

$$S = 1.3211 \quad (5)$$

The student's t is calculated as follows*(5)*:

$$t = \frac{M_a - M_b}{S(1/N_a + 1/n_b)^{1/2}} \quad (6)$$

The denominator is equation [5] is the standard deviation of the mean differences.

$$t = \frac{6.4067 - 18.4314}{(1.3211)\ (1/3 + 1/7)^{1/2}} \quad (7)$$

$$t = -13.187 \quad (8)$$

The negative sign can be ignored; it merely indicates that $M_a < M_b$. The degrees of freedom is calculated.

$$df = N_a + N_b - 2 \quad (9)$$

$$df = 3 + 7 - 2 = 8 \quad (10)$$

From a table of student's t distribution using 95% single-tailed area and df = 8,
t = 1.860 (11)

Since the absolute value of the calculated t (Equation 7) exceeds the tabular t (Equation 10), one rejects the null hypothesis and concludes that a significant difference does indeed exist between samples a and b.

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(5)Alder, Ibid., p 130