NASA/CR—97-206225

Low Cost Manufacturing Approach of High Temperature PMC Components

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National Aeronautics and
Space Administration

Lewis Research Center

November 1997

This report contains preliminary findings, subject to revision as analysis proceeds.

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Available from

NASA Center for Aerospace Information
800 Elkridge Landing Road
Linthicum Heights, MD 21090-2934
Price Code: A05

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Springfield, VA 22100
Price Code: A05

Section I - Introduction

The overall objective is to develop a satisfactory sheet molding compound (SMC) of a high temperature polyimide, such as PMR-II-50, V-CAP75, or NB2-76, and to develop compression molding processing parameters for a random, chopped fiber, high temperature, sheet molding compound that will be more affordable than the traditional hand lay-up fabrication methods. Compression molding will reduce manufacturing costs of composites by: (1) minimizing the conventional machining required after fabrication due to the use of full 360° matched tooling, (2) reducing fabrication time by minimizing the intensive hand lay-up operations associated with individual ply fabrication techniques, such as ply orientation and ply count, and (3) possibly reducing component mold time by advanced B-staging prior to molding.

This program is an integral part of Allison's T406/AE engine family's growth plan, which will utilize technologies developed under NASA's Sub-sonic Transport (AST) programs, IHPTET initiatives, and internally through Allison's IR&D projects. Allison is aggressively pursuing this next generation of engines, with both commercial and military applications, by reducing the overall weight of the engine through the incorporation of advanced, lightweight, high temperature materials, such as polymer matrix composites. This infusion of new materials into the engine is also a major factor in reducing engine cost because it permits the use of physically smaller structural components to achieve the same thrust levels as the generation that it replaced. A lighter, more efficient propulsion system translates to a substantial cost and weight savings to an airframe's structure.

The eventual goal of this project is to develop SMC technology to an acceptable state for use in aerospace applications, particularly turbine engine component applications. Utilization of high temperature capable resins, such as V-CAP or PMR-II, will enable us to expand the application of composite components into latter stages of a gas turbine compressor. These applications were not previously feasible because of the temperature and life-at-temperature limitations associated with the PMR-15 resin system. Allison has selected a vane compressor endwall for a growth of our T406/AE engine family as the candidate composite component, if the SMC technology is developed to a satisfactory level. This component was selected due to the potential weight savings, operating environment, and the low risk associated in the event the PMC endwall fails. A 65% weight savings will result from manufacturing the vane endwall using advanced PMC materials, instead of the current nickel-based alloy. Also, the complete endwall assembly part count will decrease from 78 to 10, due to the elimination of bushings in the PMC design.

Section II - Technical Results Summary

The Statement of Work for this program consists of four separate tasks that are listed below:

- Task I - Materials & Supplier Selection,
- Task II - Composite Processing Development,
- Task III - Composite Physical & Mechanical Testing, and
- Task IV - Reporting.

All of the reports that were generated during this program and the dates that each report covered are listed below.

Report No.	Report Type	EDR No.	Dates Covered
1	Bimonthly	17232	Oct 20, 1994 - Dec 31, 1994
2	Bimonthly	17293	Jan 1, 1995 - Feb 28, 1995
3	Bimonthly	17374	Mar 1, 1995 - Apr 30, 1995
4	Bimonthly	17439	May 1, 1995 - Jun 30, 1995
5	Bimonthly	17556	Jul 1, 1995 - Aug 31, 1995
6	Bimonthly	17619	Sep 1, 1995 - Oct 31, 1995
7	Bimonthly	17649	Nov 1, 1995 - Dec 31, 1995
8	Bimonthly	90016	Jan 1, 1996 - Feb 29, 1996
9	Final	90017	Mar 1, 1996 - Apr 10, 1996

Task I - Materials & Supplier Selection

Task I was completed. The objective of Task I was the selection of the materials to be used in the sheet molding compound, the supplier of those materials, and the vendor to produce the SMC. With respect to the materials used in the SMC, Allison, working with NASA LeRC, must select: (1) a high temperature polyimide resin system, (2) a graphite fiber, (3) the aspect ratio range of the fibers to examine, and (4) the fiber/resin ratio to be investigated.

The following fiber, resin, and sheet molding compounds were selected or produced during this effort. (Reference Bimonthly Reports EDR's 17293, 17374, and 17556 for complete details.)

Selected Fiber Description:

Purchased from Amoco Performance Products, Inc., Greenville, SC.

Carbon fiber:	T-650/35 3K
Sizing (by fiber weight percent):	1.23% HTS sizing

Selected Resin Description:

Supplied by NASA LeRC, Cleveland, OH.

Resin:	PMR-II-50
Solids Content as provided to SMC Manufacturer:	78.6% Imide Solids
Viscosity (at 25°C) Required for SMC Manufacture:	1200±100cp

Manufactured SMC Description:

Purchased from Quantum Composites, Inc., Midland, MI.

Allison Material Code	*Quantum Lot No.*	*Fiber Length (mm/in)*	*Fiber Content (Weight %)*	*Amount Produced (kg/lb)*
PMR-II-Lot A	040451	25.4 / 1.0	54.3	3.2 / 7.0
PMR-II-Lot B	080354	12.7 / 0.5	48.6	1.8 / 4.0
PMR-II-Lot C	080456	6.4 / 0.25	46.3	0.5 / 1.0
PMR-II-Lot D	081454	6.4 / 0.25	43.6	0.7 / 1.5
PMR-II-Lot E	081453	6.4 / 0.25	55.8	0.5 / 1.0
PMR-II-Lot F	081751	25.4 / 1.0	57.6	1.8 / 4.0

Task II - Composite Processing Development

The objective of this task is to optimize the fiber/resin ratio in order to develop a satisfactory compression molding cure and postcure cycle for the SMC prepared in Task I. Allison will then use that cure and postcure cycle developed to produce satisfactory laminates. The criteria for determining satisfactory laminates will include, at a minimum, (1) being free of significant shrink marks or bubbles, (2) being free from internal cracks and delaminations, and (3) obtaining adequate room temperature (RT) flexural strength (in the principal SMC fiber direction), according to ASTM D790. Task II was completed.

SMC Manufacturing Cycles

The expected outcome of these process trials was to manufacture several 102x203mm (4x8in) panels suitable for mechanical testing. Initial processing trials included of 25mm (1.0in) button coupons consisting of three or four layers of SMC. These trials progressed to 25x254mm (1x10in) coupon processing trials, which concluded with 102x203mm (4x8in) coupon fabrication. The table below summarizes all of the coupons fabricated under this contract. (Reference Bimonthly Reports EDR's 17439, 17556, 17619, and 17649 for complete details.)

The coupons used for testing, coupons PMR-II-LotF-49 through -58, were sent to Cincinnati Testing Laboratories, Inc. (CTL) in mid-December, 1995 for mechanical and physical testing. After receiving the ten test panels, CTL cut them into coupons in preparation for destructive testing. The individual test coupons were then shipped to NASA LeRC for C-Scanning prior to testing. (Reference Bimonthly Report EDR 90016 for C-Scans.)

Coupon Type	*Qty Produced*	*Material Used Prefix: PMR-II-*
25mm (1.0in) Button	12	LotA-1 thru LotA-12
	13	LotA-26 thru LotA-36, LotA-38 thru LotA-39
25x254mm (1x10in) Coupons	13	LotA-13 thru LotA-25
102x203mm (4x8in) Panels	6	LotA-40 thru LotA-45
	3	LotE-46 thru LotE-48
	10	LotF-49 thru LotF-58

From all of the above material processing trials, the basic compression, molding, and postcure cycles developed for the fabrication process for the PMR-II-50 SMC are shown below.

PMR-II-50 SMC Compression Cycle

1. Preheat mold to 121°C (250°F)
2. Load four layers SMC into mold
3. Raise pressure to 690 kPa (100 psi) & hold pressure for 3 minutes
4. Relieve pressure to 35 kPa (5 psi) & hold for 30 minutes
5. Turn heat off, cool to under 79°C (175°F) at 35 kPa (5 psi) pressure
6. Imidize at 177°C (350°F) for 30 minutes in vacuum.

PMR-II-50 SMC Molding Cycle

1. Preheat mold to 316°C (600°F)
2. Load imidized panel into hot mold
3. Wait 3 minutes
4. Close mold and increase pressure 6895 kPa (1000 psi)
5. Increase temperature to 371°C (700°F) in 30 minutes
6. Hold temperature at 371°C (700°F) for two hours
7. Cool under pressure to 204°C (400°F) and unload
8. Postcured with a final hold at 371°C (700°F) for 16 hours in air

PMR-II-50 SMC Postcure Cycle

1. Room temperature to 232°C (450°F) in 60 minutes
2. Hold temperature constant for 60 minutes

3. Increase temperature to 288°C (550°F) in 60 minutes
4. Hold temperature constant for 60 minutes
5. Increase temperature to 343°C (650°F) in 60 minutes
6. Hold temperature constant for 60 minutes
7. Increase temperature to 371°C (700°F) in 60 minutes
8. Hold temperature constant at 371°C (700°F) for 16 hours in air

Task III - Composite Physical & Mechanical Testing

The objective of this was to perform physical and mechanical testing on the laminates that were prepared in Task II. A summary of the physical testing results are shown in the following table. The complete report from CTL is included in the appendix of this report. Task III was completed.

Physical Property Evaluated	*Average*	*Std Dev*
Specific Gravity	1.48	0.09
Coef of Linear Thermal Expansion (in/in/°F)	1.33×10^{-6}	0.44×10^{-6}
Specific Heat (J/g°C) @ 316°C	0.5839	
(cal/g°C) @ 316°C	0.1395	
Glass Transition Temperature (°C)	378	
Thermal Conductivity (W/m°K)	0.4166-0.4289	

All of the mechanical testing was performed using five composite coupons at room temperature and two elevated temperatures 204 and 316°C (400 and 600°F). Each of the following five graphs displays one standard deviation for each tested temperature.

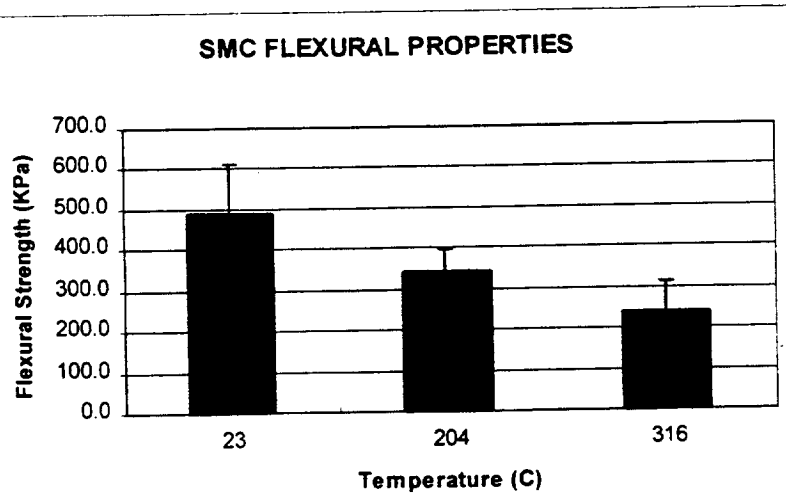

Figure 1 - Flexural strength of the PMR-II-50 SMC vs. temperature.

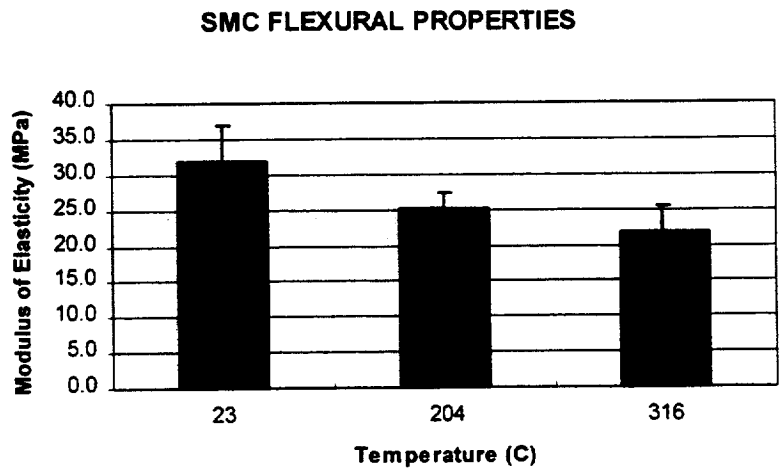

Figure 2 -Flexural Modulus of Elasticity of the PMR-II-50 SMC vs. temperature.

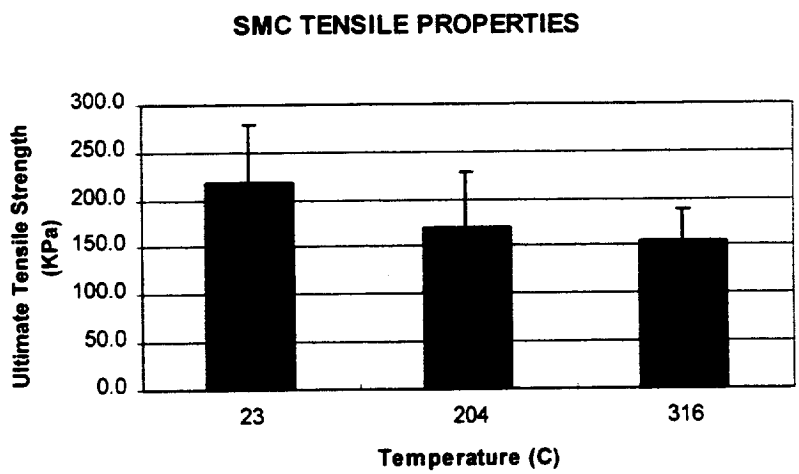

Figure 3 - Ultimate Tensile Strength of the PMR-II-50 SMC vs. temperature.

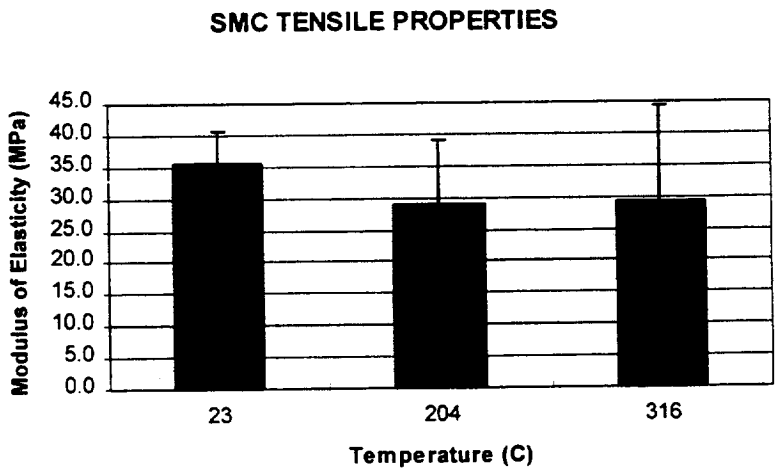

Figure 4 -Tensile Modulus of Elasticity of the PMR-II-50 SMC vs. temperature.

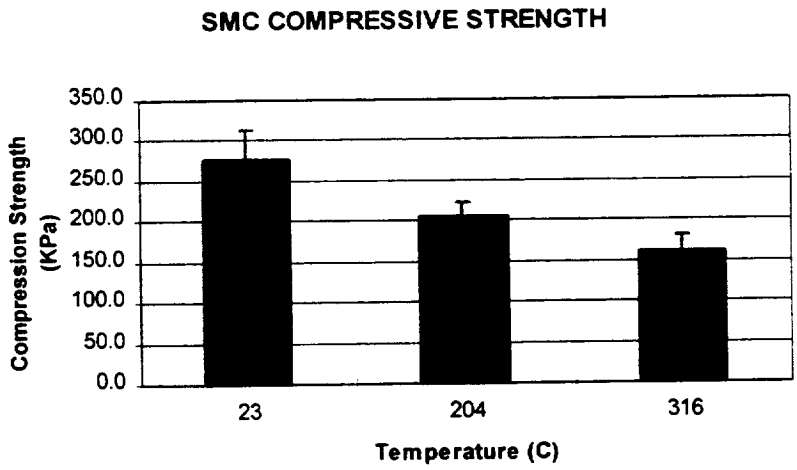

Figure 5 -Compression Strength of the PMR-II-50 SMC vs. temperature.

Section III - Recommendations & Conclusions

The overall objective of this program was to develop a satisfactory sheet molding compound (SMC) using a high temperature polyimide resin and to develop compression molding processing parameters for this SMC. This objective was accomplished. A SMC using T-650/35 3K carbon fiber and PMR-II-50 resin was successfully manufactured by Quantum Composites. Through many processing trials, Allison, with considerable help from NASA LeRC, was able to develop a fabrication process for the new SMC. This process included a compression, molding, and postcure cycle. Although this process was not fully optimized, Allison was able to produce ten 100x200mm (4x8in) panels suitable for physical and mechanical testing.

Quantum Composites has performed well throughout this entire effort and has been extremely helpful. Most of the difficulties that have arisen with their work with the PMR-II-50 SMC can be attributed to their attempt to adapt their production processes to our small laboratory sample runs. Since at the beginning of this program the specific resin/fiber ratio for the new SMC was not known, Quantum was agreeable to perform two or three short runs of SMC at different resin/fiber ratios. Due to our limited amounts of resin and fiber, we found it necessary to create SMC that was only 152mm (6in). This would allow Quantum to increase their overall run time in an attempt to tailor their process to the PMR-II-50 resin without using all of our material. This narrow SMC, however, can produce a non-uniform thickness across the width of the material. Typically, the majority of these edge irregularities would be scraped with the much wider SMC that Quantum usually manufactures.

During the program, Quantum was also asked to modify the fiber length from 25.4mm (1.0in) to 6.4 and 12.7mm (0.25 and 0.50in). During Quantum's attempts using the 12.7mm fibers, there were considerable fiber wet-out problems due to the shorter fiber length. Nearly 50% of the SMC was dry and did not contain any resin. The shorter fibers would tend to "match stick" and stand straight up and not lay horizontally as did the longer fibers. This condition would be ideal from a material mechanical properties view point since it would increase the Z-axis properties. The top and bottom layers of the SMC were wet, but the center did not contain any resin. The top and bottom "layers" could be peeled apart very easily down the dry middle section. This wet-out phenomena could be caused by the additional fiber surface area caused by the shorter fibers. Several potential solutions to the dry fiber problem were discussed. One option was to lower the aerial density of the fiber by 30% of the SMC before the resin was introduced. This would result in a thinner ply of SMC. It was finally decided to complete the work at Quantum by producing SMC with the longer 25.4mm fiber length and a lower aerial density. Based on the variations in the produced SMC, Allison expected variations in the mechanical data generated using this material.

When asked to manufacture this SMC in the future, Allison will (1) use 25.4mm (1.0in) length fibers, (2) select a resin/fiber ratio, and (3) allow Quantum to produce the PMR-II-50 compound in longer, continuous runs in order to stabilize the manufacturing process.

Section IV - New Technology

This program was an adaptation of procedures that are outlined in U.S. Patent 5,126,085, entitled *Process for Preparing Polyimide Sheet Molding Compound.* The patented process utilized the PMR-15 resin system in the production of the SMC. Based on papers presented at previous NASA HITEMP Reviews, this new SMC produced during this NASA program using PMR-II-50 resin should have the following improvements over the PMR-15 based product of the patented process: (1) increased thermal oxidative stability, and (2) increased temperature capability.

Allison is investigating possible non-aerospace applications for this newly developed SMC material. One such potential application would be a pressure seal for the Hybrid Engine Program. This program is part of the Administration's new effort to develop cleaner, more fuel efficient cars and trucks. In September, 1993, the U.S. Department of Energy (DoE) awarded a contract to a team headed by General Motors Corp. to develop a "hybrid" vehicle that combines electric propulsion with conventional heat engine systems. An example would be a gas turbine driving an alternator connected to an electric propulsion system using a battery, flywheel, or capacitor for energy storage.

Appendix

Cincinnati Testing Laboratories Test Report

MECHANICAL/THERMAL/PHYSICAL PROPERTIES OF POLYIMIDE SHEET MOLDING COMPOUND MATERIAL

PERFORMED FOR:

ALLISON ENGINE COMPANY
INDIANAPOLIS, INDIANA

REQUESTOR: KEVIN KANNMACHER

PERFORMED BY:

CINCINNATI TESTING LABORATORIES, INC.
CINCINNATI, OHIO

PURCHASE ORDER NO.: N519590
CTL JOB NO.: 432-2177-00

MARCH 1996

APPROVED BY: P. Braun

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UNIVERSITY OF DAYTON RESEARCH INSTITUTE

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TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

FLEXURAL PROPERTIES

Date: March 1, 1996

P.O. No.: N 519590

Customer: Allison Engine Company

Requestor: Kevin Kannmacher

Material: Polyimide Sheet Molding Compound

Specification: ASTM D790-92, Method I

Pre-Conditioning: 40 Hrs./74 Deg. F./50% R.H.

Test Condition: 74 Deg. F./50% R.H.

Span (L): 1.215 L/d Ratio: 16/1

Equipment: Tinius Olsen 12 kip Electomatic #31

Machining Source: CTL

Test Speed: 0.03 in./min.

Support Radius: 1/8 in.

Nose Radius: 1/4 in.

Specimen Length: 2 in.

Flexural strength (S) = $\frac{3PL}{2bd^2}$

Modulus of elasticity (E_B) = $\frac{L^3m}{4bd^3}$

S = Flexural strength in psi
E_B = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Depth of beam in inches
L = Span in inches
m = Initial slope of load-deflection curve in lbs./inch

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	m (lbs./in.)	E_B (psi x 10^6)
49-F2	47,490	174.5	0.082	0.995	4,211	3.44
53-F1	94,680	339.5	0.081	0.996	6,356	5.38
53-F2	74,720	269.0	0.081	1.000	5,217	4.40
57-F1	61,960	152.0	0.067	0.996	3,212	4.81
57-F2	76,940	189.5	0.067	1.000	3,363	5.01
AVG.	71,160					4.61
S.D.	17,636					0.74
C.V.(%)	24.8					16.1

Test Technician: D. Browning — D. Browning

Approved: P. Braun — P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

FLEXURAL PROPERTIES

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D790-92, Method I

Test Speed: 0.04 in./min.

Pre-Conditioning: 30 Min. @ 400 Deg. F.

Support Radius: 1/8 in.

Test Condition: 400 Deg. F.

Nose Radius: 1/4 in.

Span (L): 1.520 L/d Ratio: 17/1

Specimen Length: 2 in.

Equipment: Tinius Olsen 12 kip Electomatic #31

Machining Source: CTL

Flexural strength (S) = $\frac{3PL}{2bd^2}$

Modulus of elasticity (E_B) = $\frac{L^3m}{4bd^3}$

S = Flexural strength in psi
E_B = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Depth of beam in inches
L = Span in inches
m = Initial slope of load-deflection curve in lbs./inch

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	m (lbs./in.)	E_B (psi x 10^6)
49-F1	37,130	118.0	0.085	1.003	2,317	3.30
50-F1	55,790	195.0	0.089	1.006	3,000	3.71
50-F2	50,750	169.5	0.087	1.006	2,575	3.41
52-F2	55,770	227.0	0.096	1.007	4,225	4.16
56-F1	47,960	191.0	0.095	1.006	3,593	3.66
AVG.	49,480					3.65
S.D.	7,678					0.33
C.V.(%)	15.5					9.0

Test Technician: D. Browning
D. Browning

Approved: P. Braun
P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

FLEXURAL PROPERTIES

Customer: Allison Engine Company

Requestor: Kevin Kannmacher

Material: Polyimide Sheet Molding Compound

Specification: ASTM D790-92, Method I

Pre-Conditioning: 30 Min. @ 600 Deg. F.

Test Condition: 600 Deg. F.

Span (L): 1.520 L/d Ratio: 15/1

Equipment: Tinius Olsen 12 kip Electomatic #31

Machining Source: CTL

Date: March 1, 1996

P.O. No.: N 519590

Test Speed: 0.04 in./min.

Support Radius: 1/8 in.

Nose Radius: 1/4 in.

Specimen Length: 2 in.

Flexural strength (S) = $\frac{3PL}{2bd^2}$

Modulus of elasticity (E_B) = $\frac{L^3m}{4bd^3}$

S = Flexural strength in psi
E_B = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Depth of beam in inches
L = Span in inches
m = Initial slope of load-deflection curve in lbs./inch

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	m (lbs./in.)	E_B (psi x 10^6)
52-F1	28,240	124.0	0.100	1.001	3,333	2.92
54-F1	26,460	124.0	0.103	1.007	3,333	2.66
56-F2	39,120	169.0	0.099	1.005	3,614	3.25
58-F1	29,880	127.0	0.098	1.009	3,158	2.92
58-F2	50,930	229.0	0.101	1.005	4,800	4.07
AVG.	34,930					3.16
S.D.	10,193					0.55
C.V.(%)	29.2					17.4

Test Technician: D. Browning D. Browning

Approved: P. Braun P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

TENSILE PROPERTIES

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D638-94b

Test Speed: 0.20 in./min.

Pre-Conditioning: 40 Hrs./74 Deg. F./50% R.H.

Test Condition: 74 Deg. F./50% R.H.

Specimen Type: I

Equipment: MTS 20 kip #19

Machining Source: CTL

Tensile strength (S) = P/bd

Modulus of elasticity (Et) = ΔP/bdY

S = Ultimate tensile strength in psi
Et = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches
Y = Strain in inches/inch
PR = Poisson Ratio

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Et (psi x 10^6)	* Strain @ Failure (%)	P.R.	Failure Location
49-T1	41,270	1,740	0.083	0.508	3.61	1.25	0.26	Radius
53-T1	27,140	1,103	0.080	0.508	3.91	0.75	0.29	Radius
53-T2	36,750	1,528	0.082	0.507	7.89	0.48		Gage
57-T1	19,020	557	0.058	0.505	4.02	0.49		Gage
57-T2	34,650	1,061	0.061	0.502	6.40	0.55		Gage
AVG.	31,770				5.17	0.70	0.28	
S.D.	8,766				1.89	0.32	0.02	
C.V.(%)	27.6				36.6	45.7	7.1	

* Apparent strain due to failure outside extensometer.

Test Technician: R. Bushelman

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

TENSILE PROPERTIES

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D638-94b

Test Speed: 0.20 in./min.

Pre-Conditioning: 10 Min. @ 400 Deg. F.

Test Condition: 400 Deg. F.

Specimen Type: I

Equipment: MTS 20 kip #19

Machining Source: CTL

Tensile strength (S) = P/bd

Modulus of elasticity (Et) = ΔP/bdY

S = Ultimate tensile strength in psi
Et = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches
Y = Strain in inches/inch

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Et (psi x 10^6)	Strain @ Failure (%)	Failure Location
49-T2	31,050	1,304	0.083	0.506	3.53	1.25	Gage
52-T1	17,810	865	0.096	0.506	2.26	0.89	Gage
54-T1	13,060	666	0.101	0.505	3.92	*0.35	Radius
56-T2	29,110	1,558	0.106	0.505	5.70	0.70	Gage
58-T2	31,820	1,699	0.107	0.499	5.63	0.58	Gage
AVG.	24,570				4.21	0.75	
S.D.	8,564				1.47	0.34	
C.V.(%)	34.9				34.9	45.3	

* Apparent strain due to failure outside extensometer.

Test Technician: R. Bushelman

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

TENSILE PROPERTIES

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D638-94b

Test Speed: 0.20 in./min.

Pre-Conditioning: 10 Min. @ 600 Deg. F.

Test Condition: 600 Deg. F.

Specimen Type: I

Equipment: MTS 20 kip #19

Machining Source: CTL

Tensile strength (S) = P/bd

Modulus of elasticity (Et) = ΔP/bdY

S = Ultimate tensile strength in psi
Et = Modulus of elasticity in psi x 10^6
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches
Y = Strain in inches/inch

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Et (psi x 10^6)	Strain @ Failure (%)	Failure Location
50-T1	25,040	1,098	0.087	0.504	3.01	1.01	Gage
50-T2	19,440	859	0.088	0.502	2.36	*0.61	Gage
52-T2	18,200	890	0.097	0.504	2.99	*0.67	Gage
54-T2	29,990	1,560	0.103	0.505	7.61	0.52	Gage
56-T1	20,550	1,052	0.102	0.502	5.35	0.37	Gage
AVG.	22,640				4.26	0.64	
S.D.	4,850				2.19	0.24	
C.V.(%)	21.4				51.4	37.5	

* Apparent strain due to failure outside extensometer.

Test Technician: R. Bushelman

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

COMPRESSIVE STRENGTH

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D695-91

Test Speed: 0.05 in./min.

Pre-Conditioning: 40 Hrs./74 Deg. F./50% R.H.

Test Condition: 74 Deg. F./50% R.H.

Specimen Type: Dogbone (Fig. 5)

Equipment: Tinius Olsen 12 kip Electomatic #31
Sacma Support Fixture, S/N 1514

Machining Source: CTL

Compression strength (S) = P/bd

S = Compression strength in psi
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Failure Location
49-C1	35,880	1,525	0.085	0.500	Gage
53-C1	41,130	1,642	0.080	0.499	Radius
53-C2	42,340	1,687	0.080	0.498	Gage
57-C1	33,830	996	0.059	0.499	Radius
57-C2	47,420	1,535	0.065	0.498	Gage
AVG.	40,120				
S.D.	5,403				
C.V.(%)	13.5				

Test Technician: R. Reeder

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

COMPRESSIVE STRENGTH

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D695-91

Test Speed: 0.05 in./min.

Pre-Conditioning: 10 Min. @ 400 Deg. F.

Test Condition: 400 Deg. F.

Specimen Type: Dogbone (Fig. 5)

Equipment: Tinius Olsen 12 kip Electomatic #31
Sacma Support Fixture, S/N 1514

Machining Source: CTL

Compression strength (S) = P/bd

S = Compression strength in psi
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Failure Location
52-C1	29,260	1,431	0.098	0.499	Gage
54-C1	27,150	1,352	0.100	0.498	Gage
56-C2	33,500	1,685	0.101	0.498	Gage
58-C1	30,280	1,511	0.100	0.499	Gage
58-C2	28,570	1,500	0.105	0.500	Gage
AVG.	29,750				
S.D.	2,384				
C.V.(%)	8.0				

Test Technician: R. Reeder

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

COMPRESSIVE STRENGTH

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D695-91

Test Speed: 0.05 in./min.

Pre-Conditioning: 10 Min. @ 600 Deg. F.

Test Condition: 600 Deg. F.

Specimen Type: Dogbone (Fig. 5)

Equipment: Tinius Olsen 12 kip Electomatic #31
Sacma Support Fixture, S/N 1514

Machining Source: CTL

Compression strength (S) = P/bd

S = Compression strength in psi
P = Break load in lbs.
b = Specimen width in inches
d = Specimen thickness in inches

Specimen (No.)	S (psi)	P (lbs.)	d (in.)	b (in.)	Failure Location
50-C1	27,040	1,217	0.090	0.500	Radius
50-C2	20,230	868	0.086	0.499	Gage
52-C2	23,230	1,078	0.093	0.499	Radius
54-C2	25,690	1,305	0.102	0.498	Gage
56-C1	20,830	963	0.093	0.497	Radius
AVG.	23,400				
S.D.	2,965				
C.V.(%)	12.7				

Test Technician: R. Reeder

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

SPECIFIC GRAVITY/(RELATIVE DENSITY)

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D792-91, Method A

Wgt. of Wire(W): 1.1631
Except Panel No. 55: 1.1689

Pre-Conditioning: 1 Hr. @ 250 Deg. F.

Test Condition: 74 Deg. F./50% R.H.

Specimen Size: Various

Equipment: Mettler Balance S/N 57688

Machining Source: CTL

Sp.Gr. = a/a-b

Panel (No.)	Dry Wgt. (gms.) (a)	Wgt. (gms.) in H_2O (b)+W	Specific Gravity
49	1.6039	1.6253	1.40
50	1.8089	1.8000	1.54
51	1.5626	1.5805	1.36
52	2.2299	1.9987	1.60
53	1.6789	1.7239	1.50
54	2.1683	1.7230	1.35
55	3.1914	2.3442	1.58
56	2.0614	1.8057	1.45
57	1.2621	1.5912	1.51
58	2.5895	2.0733	1.54
AVG.			1.48
S.D.			0.09
C.V.(%)			6.1

Test Technician: R. Reeder

Approved: P. Braun

TEST REPORT

CINCINNATI TESTING LABORATORIES, INC.

Report No. 432-2177-00

COEFFICIENT OF LINEAR THERMAL EXPANSION

Customer: Allison Engine Company

Date: March 1, 1996

Requestor: Kevin Kannmacher

P.O. No.: N 519590

Material: Polyimide Sheet Molding Compound

Specification: ASTM D696-91 (Modified Temperature Range)

Pre-Conditioning: 40 Hrs./74 Deg. F./50% R.H.

Test Condition: 74 Deg. F. to 600 Deg. F. to 74 Deg. F.

Specimen Size: 1/2 in. x 2 in.

Method: Quartz-tube Dilatometer

Temperature Range(T): 74 Deg. F. to 600 Deg. F.

ΔT: 526 F. Degrees

Equipment: Dial Indicator: S/N 1104 Cal.: 12/15/95 Due: 3/15/96

Machining Source: CTL

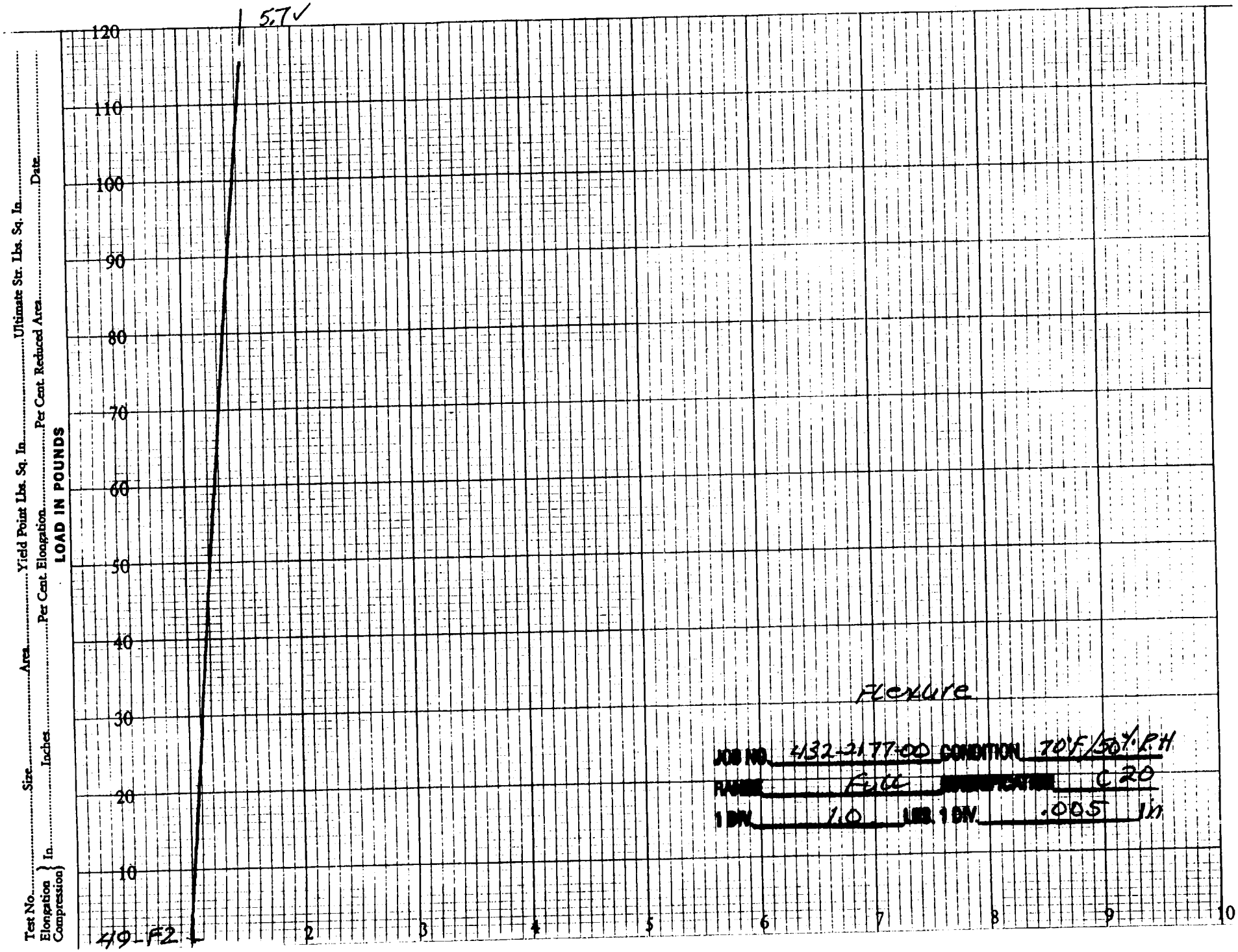
Coefficient of linear thermal expansion(a) = $\Delta L/L(\Delta T)$

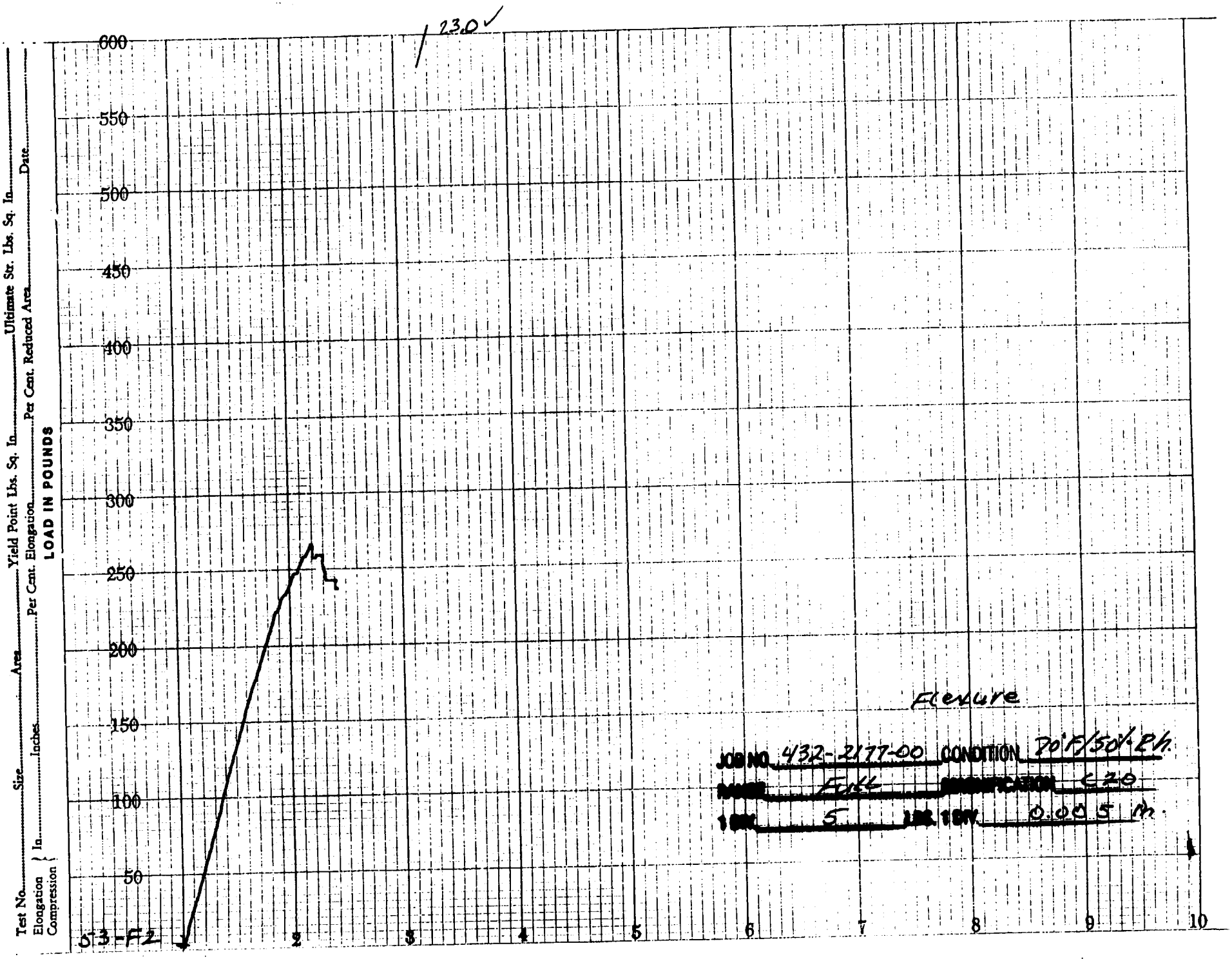
Specimen (No.)	Length(L) (in.)	ΔL (in.)	(a) Coefficient of Linear Thermal Expansion (in./in./Deg. F.)
52	2.001	0.001725	1.64×10^{-6}
53	1.989	0.001065	1.02×10^{-6}
AVG.			1.33
S.D.			0.44
C.V.(%)			33.1

Test Technician: R. Reeder

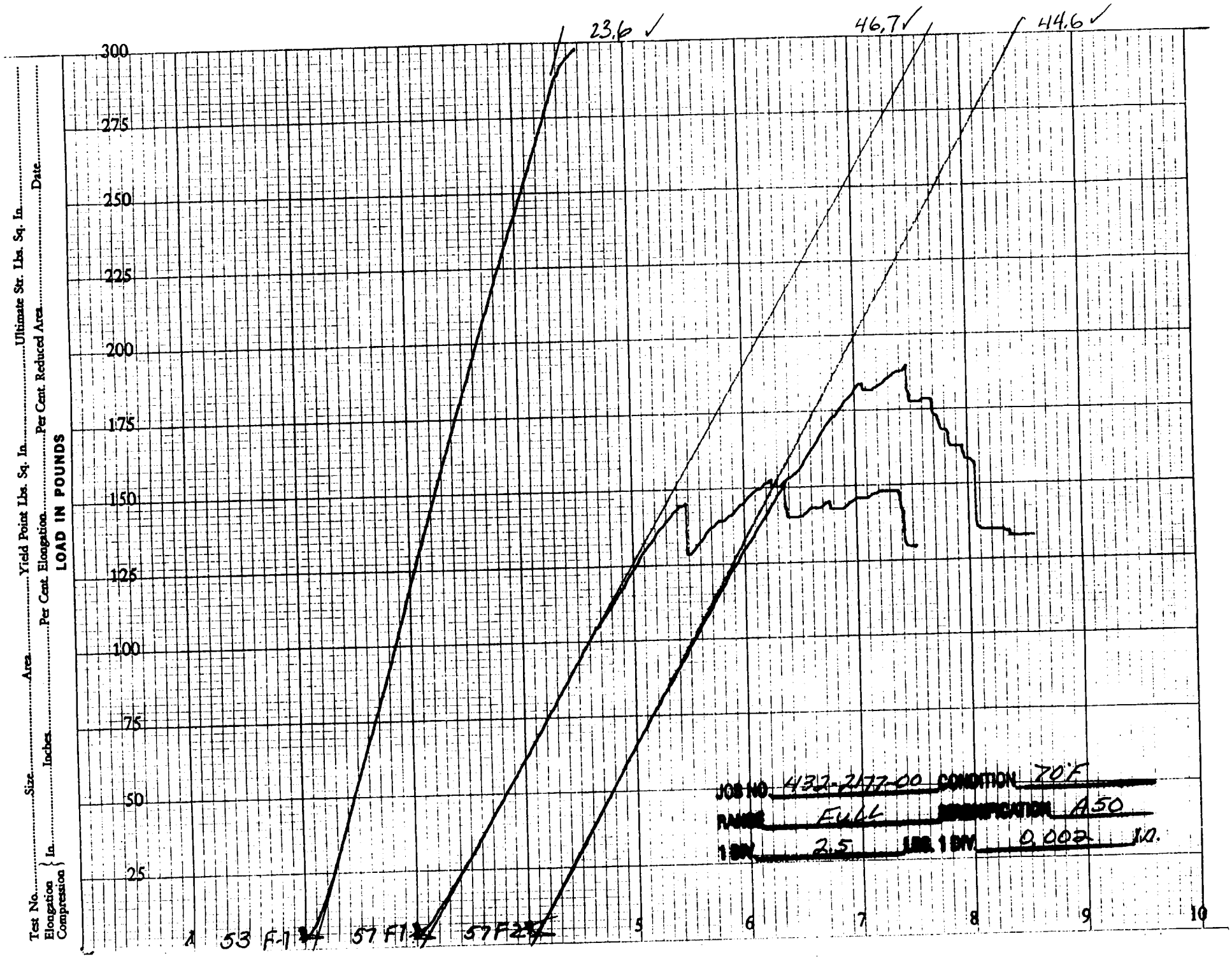
Approved: P. Braun

FLEXURAL PROPERTIES

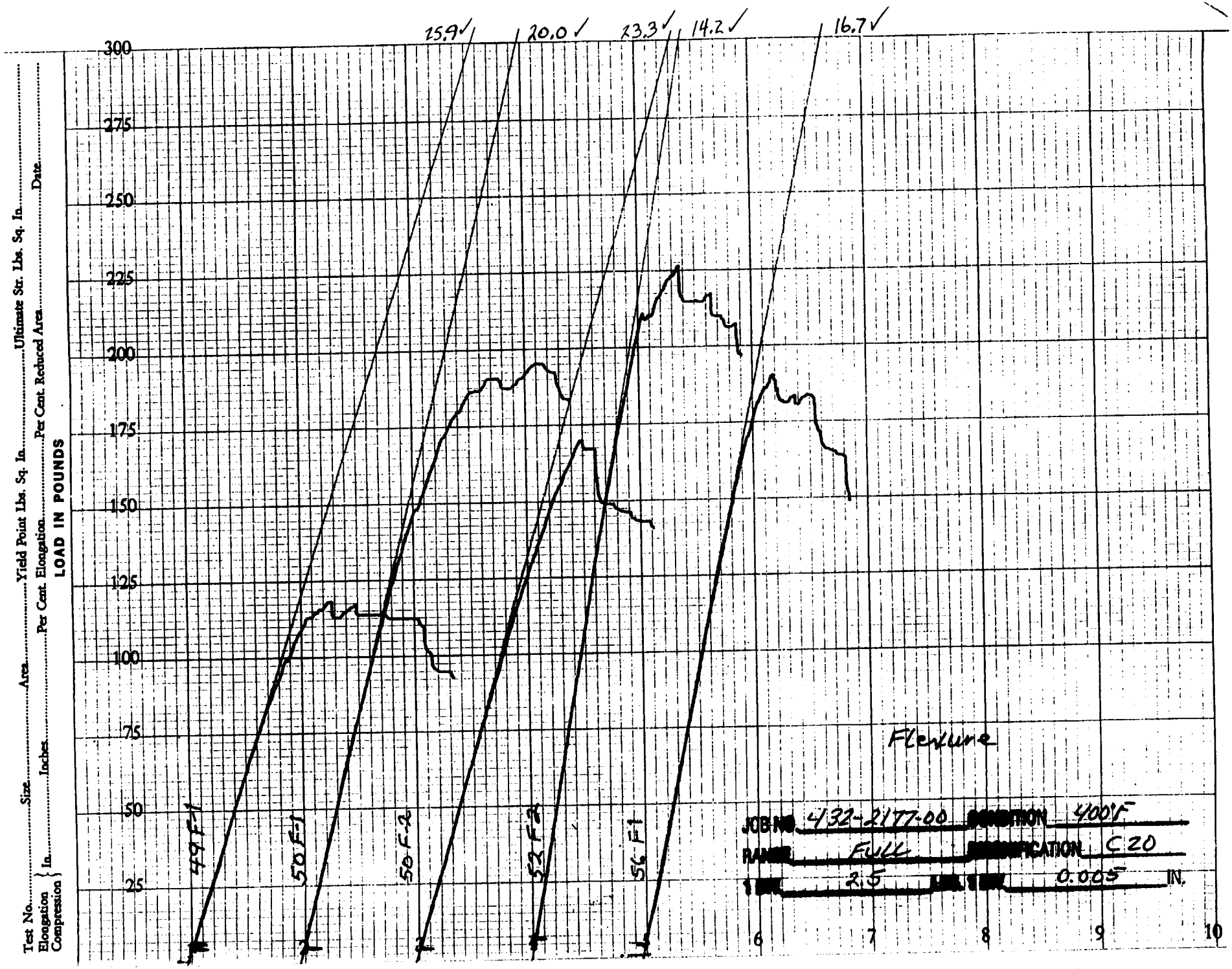

5.7✓
120
110
100
90
80
70
60
50
40
30
20
10
49-F2
2
3
4
5
6
7
8
9
10
Flexure
JOB NO. 432-2177-00 CONDITION 70°F/50% RH
RANGE Full SPECIFICATION C20
1 DIV. 1.0 LBS. 1 DIV. .005 in
Test No. Size Area Yield Point Lbs. Sq. In. Ultimate Str. Lbs. Sq. In.
Elongation } In. Inches Per Cent. Elongation Per Cent. Reduced Area Date
Compression }
LOAD IN POUNDS

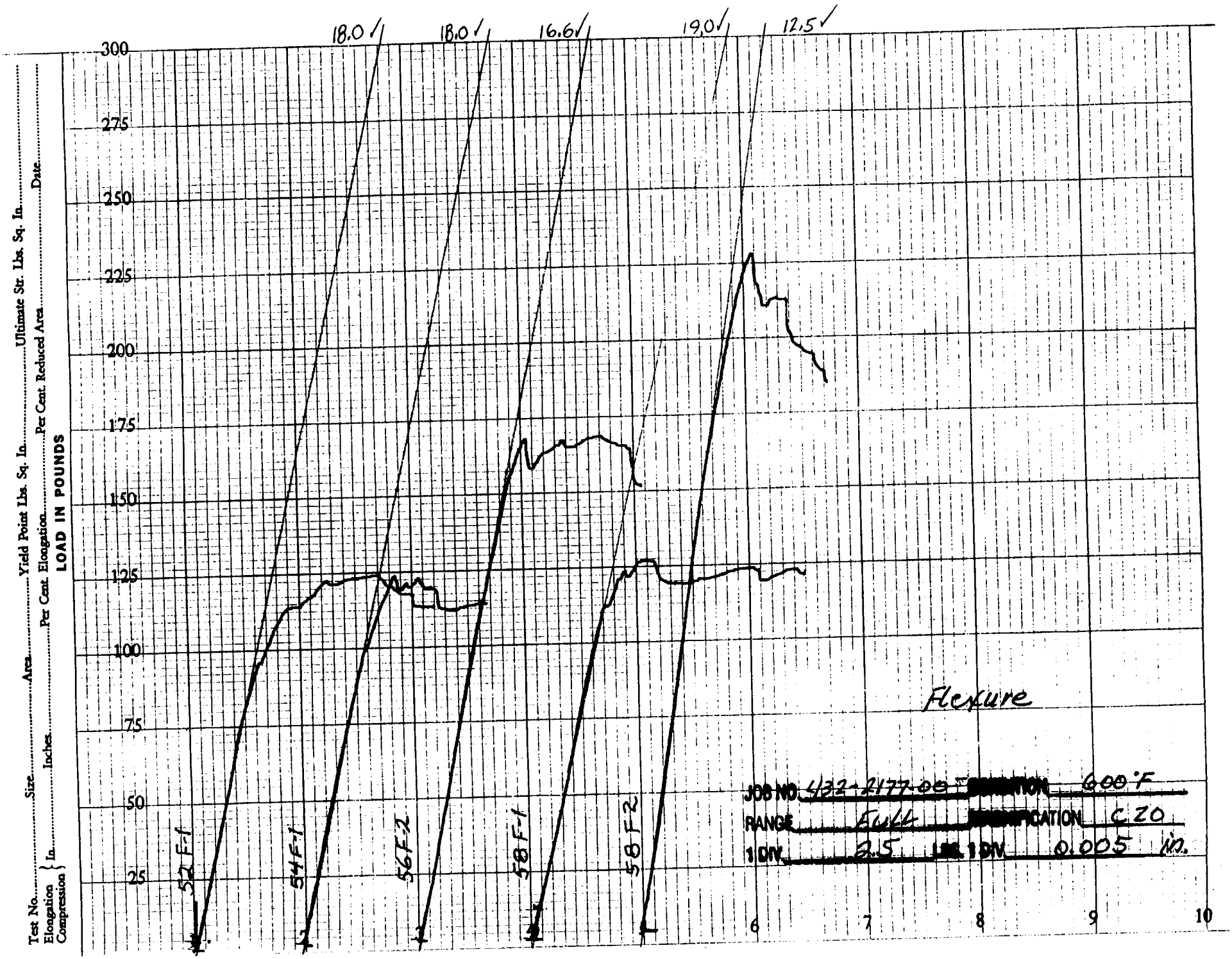


23.0
600
550
500
450
400
350
300
250
200
150
100
50
2
3
4
5
6
7
8
9
10
53-F2
Flexure
JOB NO. 432-2177-00 CONDITION 70°F/50% Rh.
Full
C20
5
0.005 in.
Test No. Size Area Yield Point Lbs. Sq. In. Ultimate Str. Lbs. Sq. In.
Elongation } In. Inches Per Cent. Elongation Per Cent. Reduced Area Date
Compression }
LOAD IN POUNDS



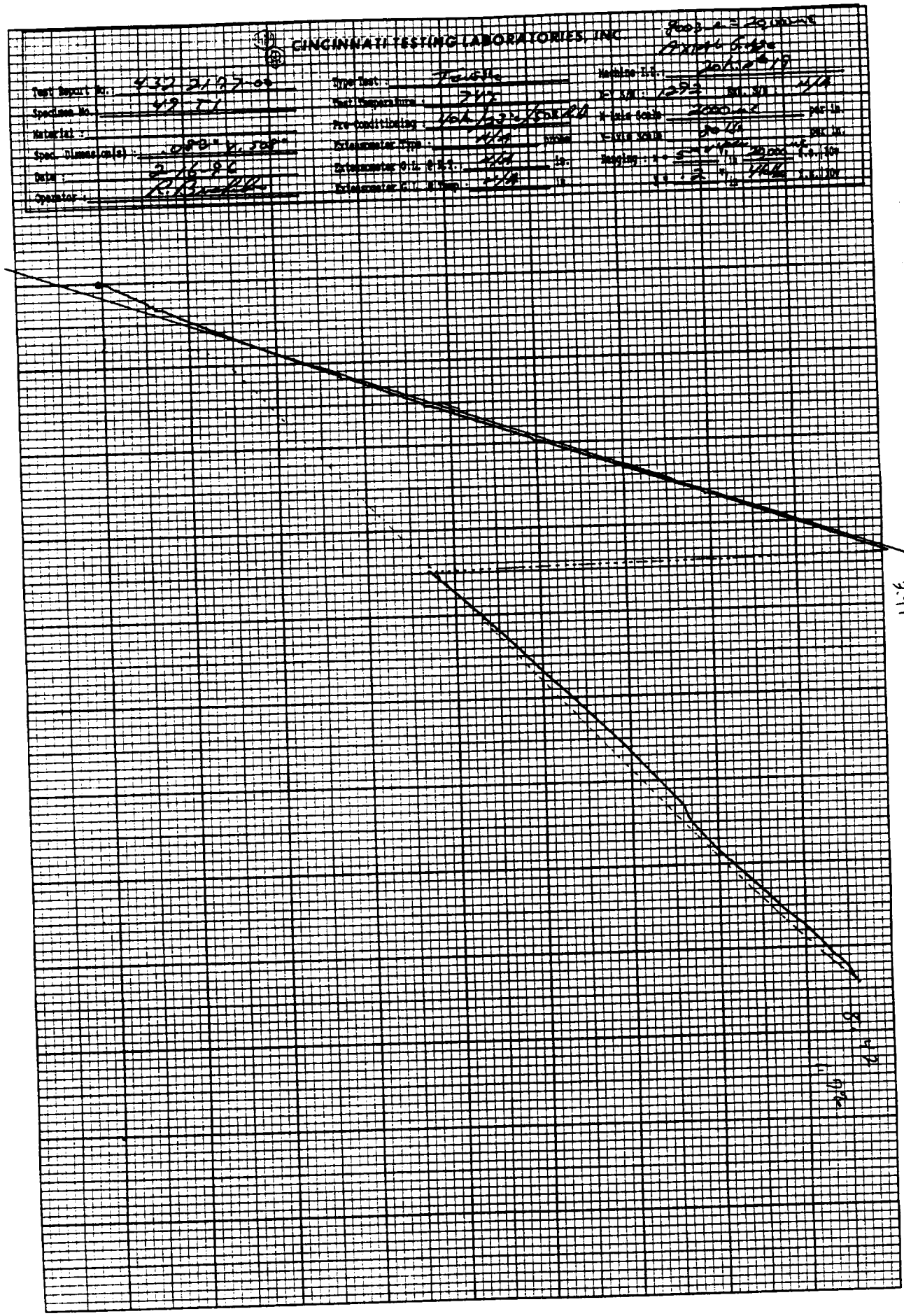
23.6 ✓
46.7 ✓
44.6 ✓
300
275
250
225
200
175
150
125
100
75
50
25
5
6
7
8
9
10
53 F-1
57 F1
57 F2
JOB NO. 432-2177-00 CONDITION 70°F
RANGE Full SPECIFICATION A50
1 DIV. 2.5 LBS. 1 DIV. 0.002 IN.
Test No. Size Area Yield Point Lbs. Sq. In. Ultimate Str. Lbs. Sq. In.
Elongation Compression In. Inches Per Cent. Elongation Per Cent. Reduced Area Date
LOAD IN POUNDS

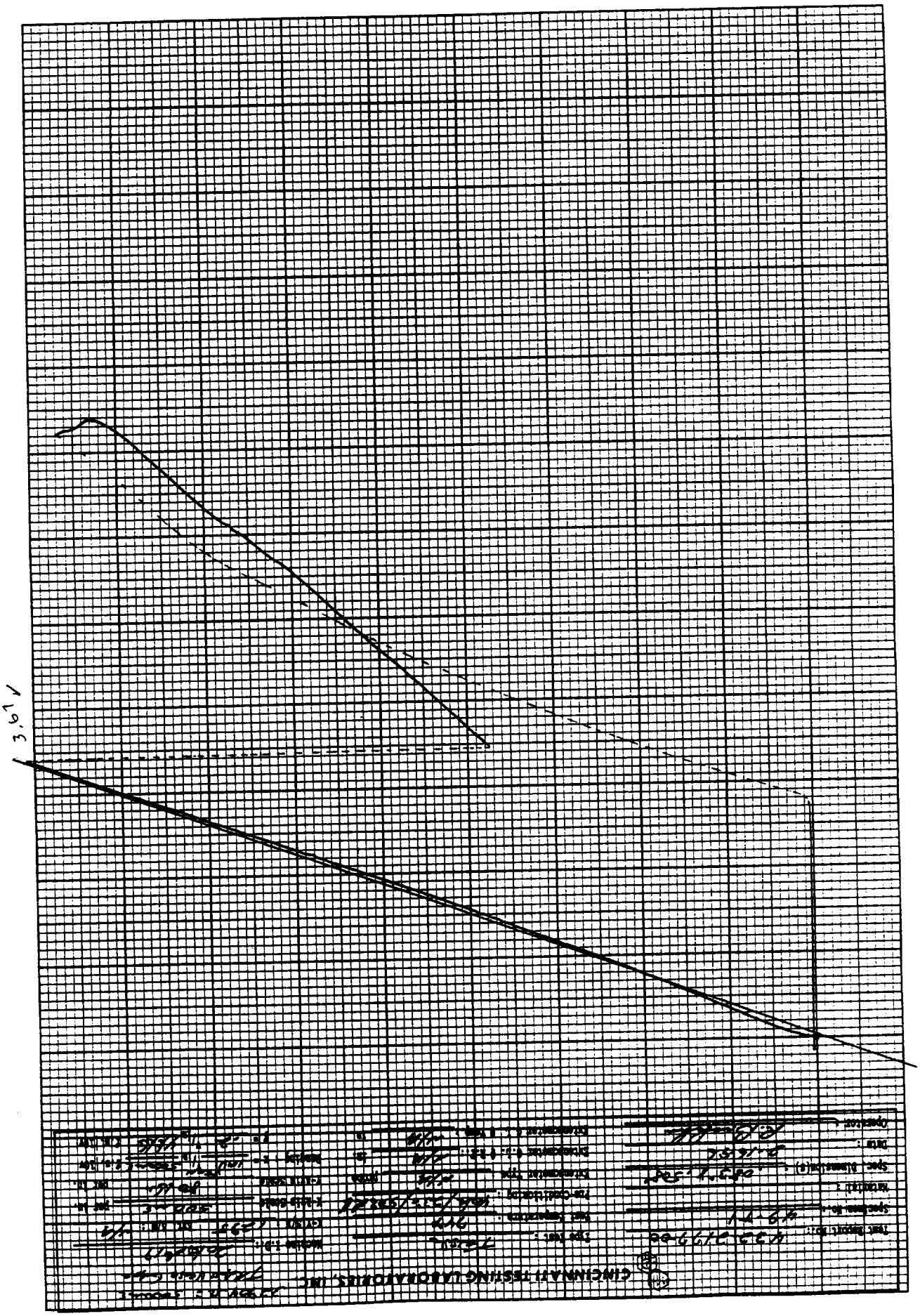

Test No. ..... Size ..... Area ..... Yield Point Lbs. Sq. In. ..... Ultimate Str. Lbs. Sq. In. ..... Date.....
Elongation } In. ..... Inches ..... Per Cent. Elongation ..... Per Cent. Reduced Area .....
Compression }
LOAD IN POUNDS
300
275
250
225
200
175
150
125
100
75
50
25
6
7
8
9
10
25.9
20.0
23.3
14.2
16.7
46 F1
50 F1
50 F2
52 F2
56 F1
Flexure
JOB NO. 432-2177-00
400°F
RANGE FULL
CALIBRATION C20
2.5
0.005 IN.

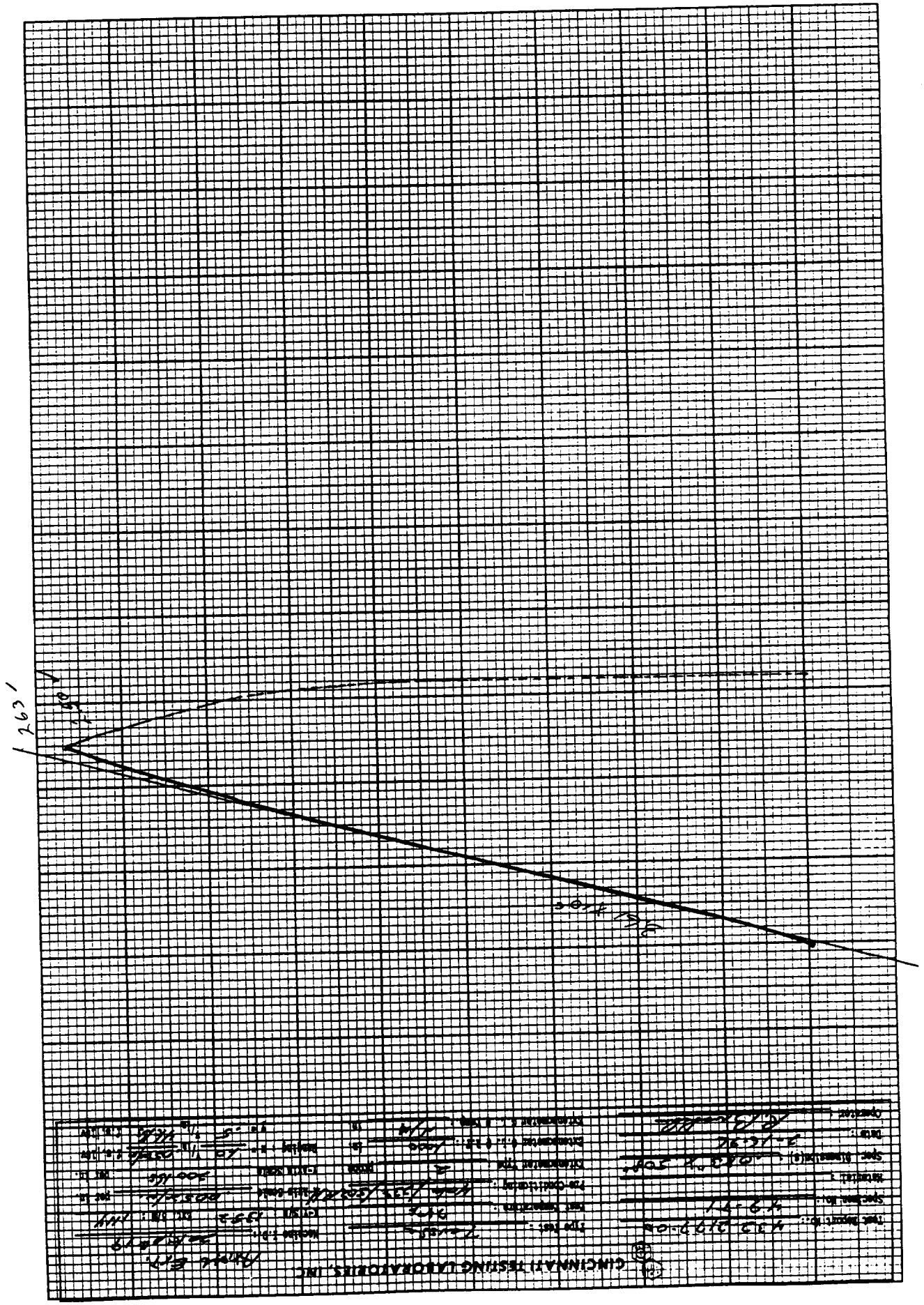


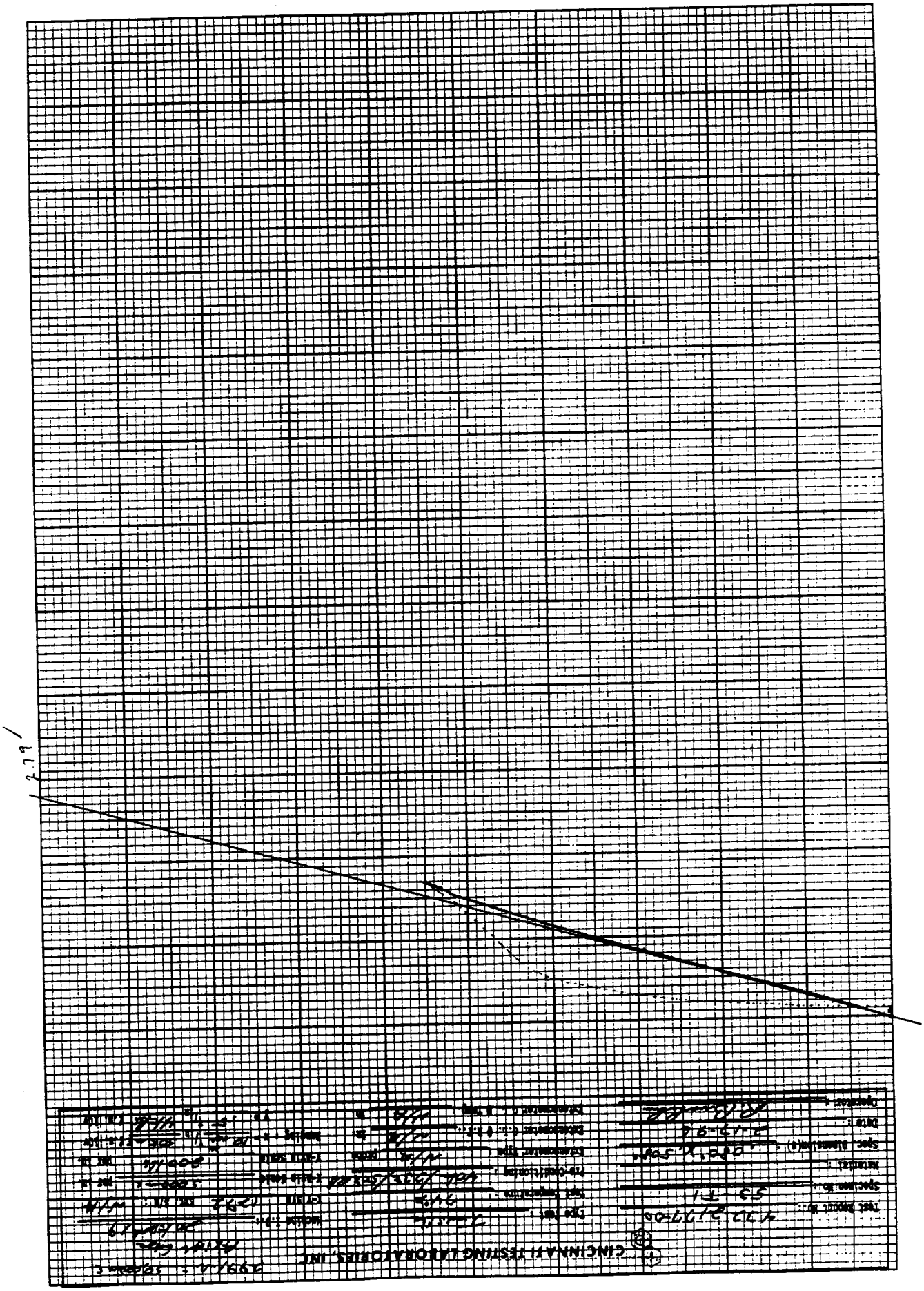
Test No. ..... Size ..... Area ..... Yield Point Lbs. Sq. In. ..... Ultimate Str. Lbs. Sq. In. .....
Elongation } In. ..... Inches ..... Per Cent. Elongation ..... Per Cent. Reduced Area ..... Date .....
Compression }
LOAD IN POUNDS
300
275
250
225
200
175
150
125
100
75
50
25
18.0
18.0
16.6
19.0
12.5
52F-1
54F-1
56F-2
58F-1
58F-2
6
7
8
9
10
Flexure
JOB NO. 432-2177-00
600°F
RANGE Full
CZO
1 DIV. 2.5
1 DIV. 0.005 in.

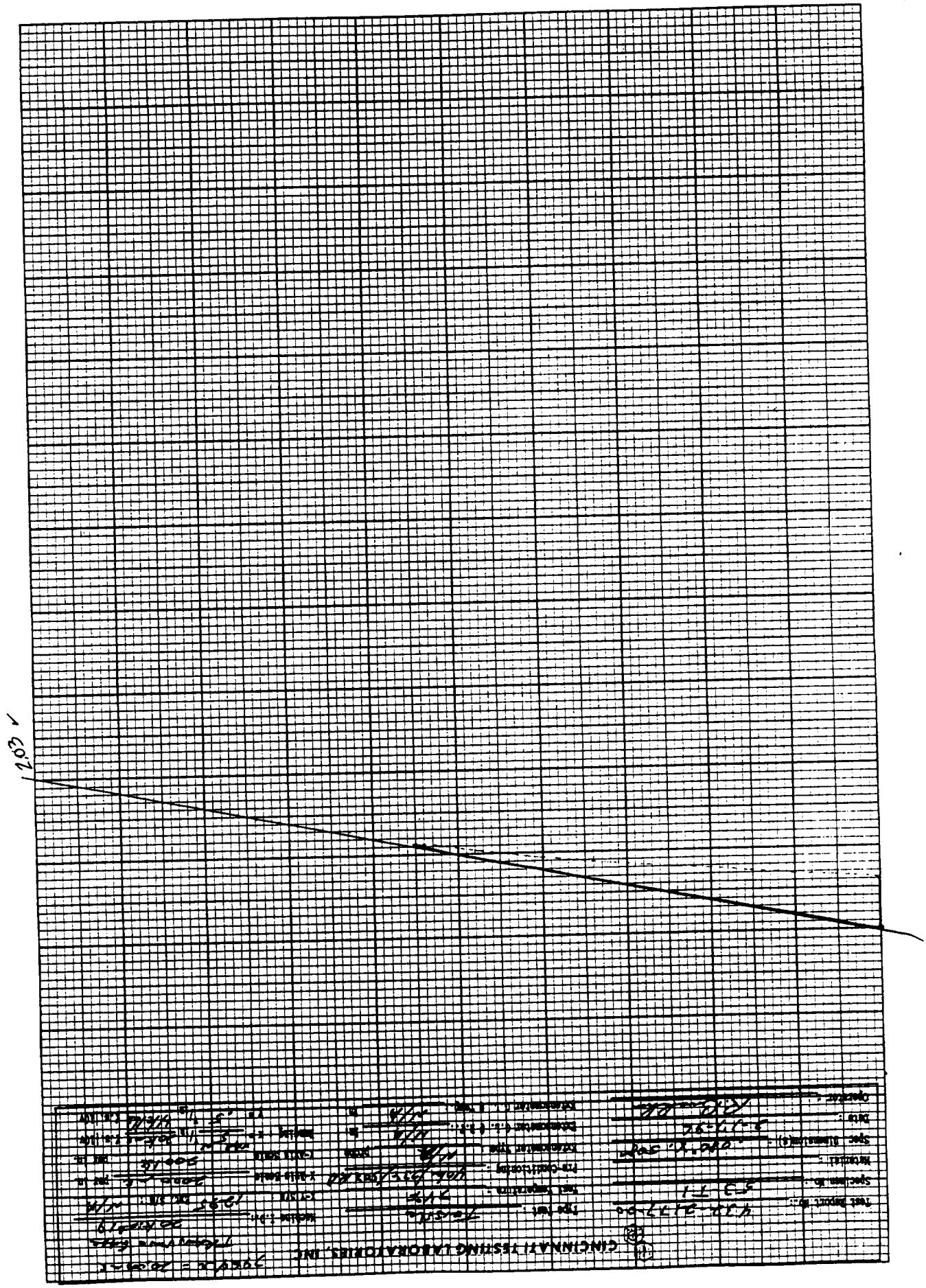
TENSILE PROPERTIES

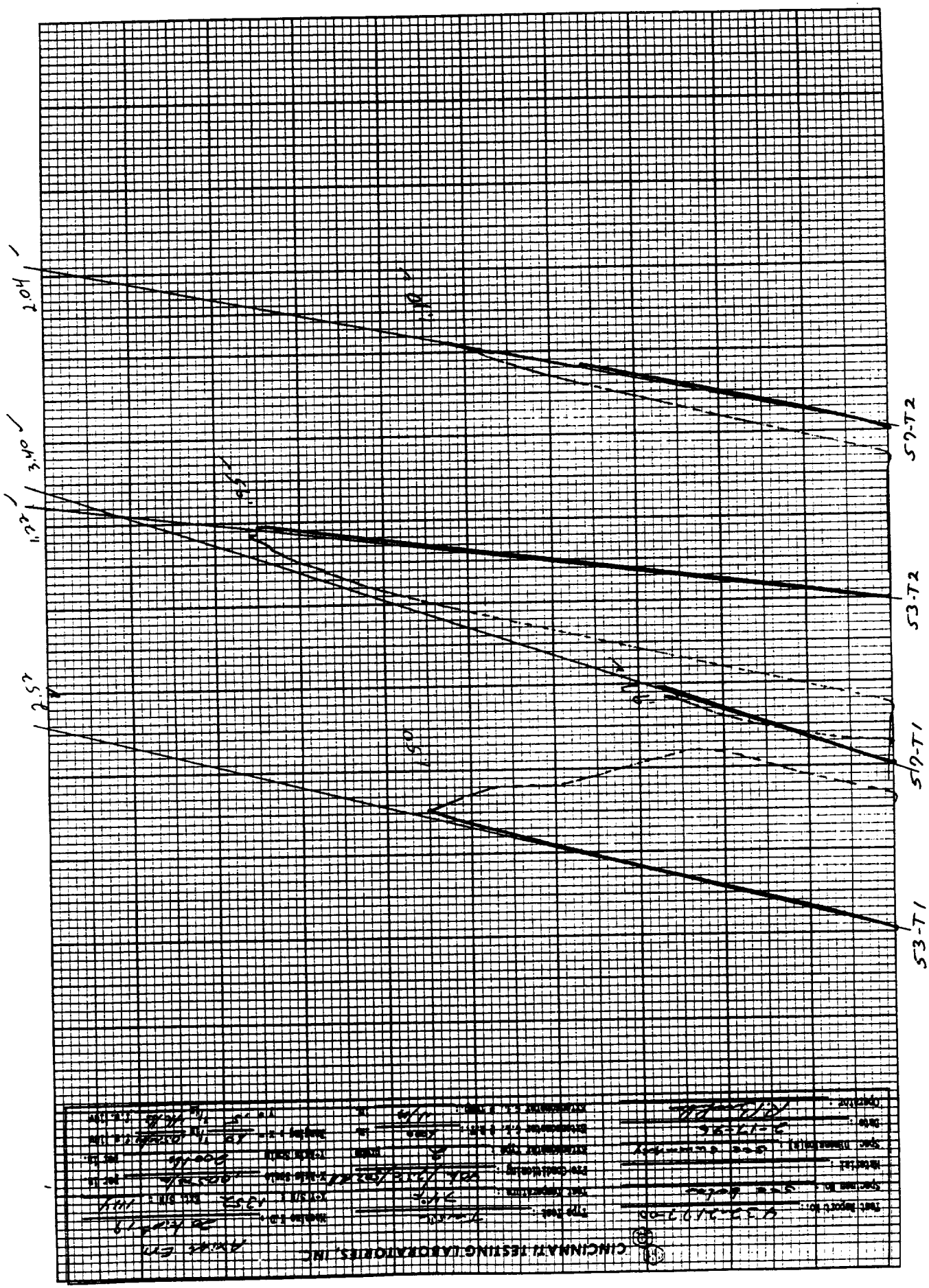

CINCINNATI TESTING LABORATORIES, INC.
Test Report No.: 432 2177-00
Specimen No.: 49 T1
Material:
Spec. Dimension(s): .083" x .508"
Date: 2-16-96
Operator: R. Brackett
Type Test: Tensile
Test Temperature: 74°F
Pre-Conditioning: 40h/23°C/50%RH
Extensometer Type: N/A probe
Extensometer G.L. @ R.T.: N/A in.
Extensometer G.L. @ Temp: N/A in.
Machine I.D.: 20k.ph 19
X-Y S/N: 1292
X-Axis Scale: 2000 mV per in.
Y-Axis Scale: 80 lb per in.
Ranging: X = 5 mV/in 20,000 mV f.s. 10v
Y = .2 V/in 40 lb f.s. 10v
3.49 ft
8.42 ft


3.67 V
CINCINNATI TESTING LABORATORIES, INC.

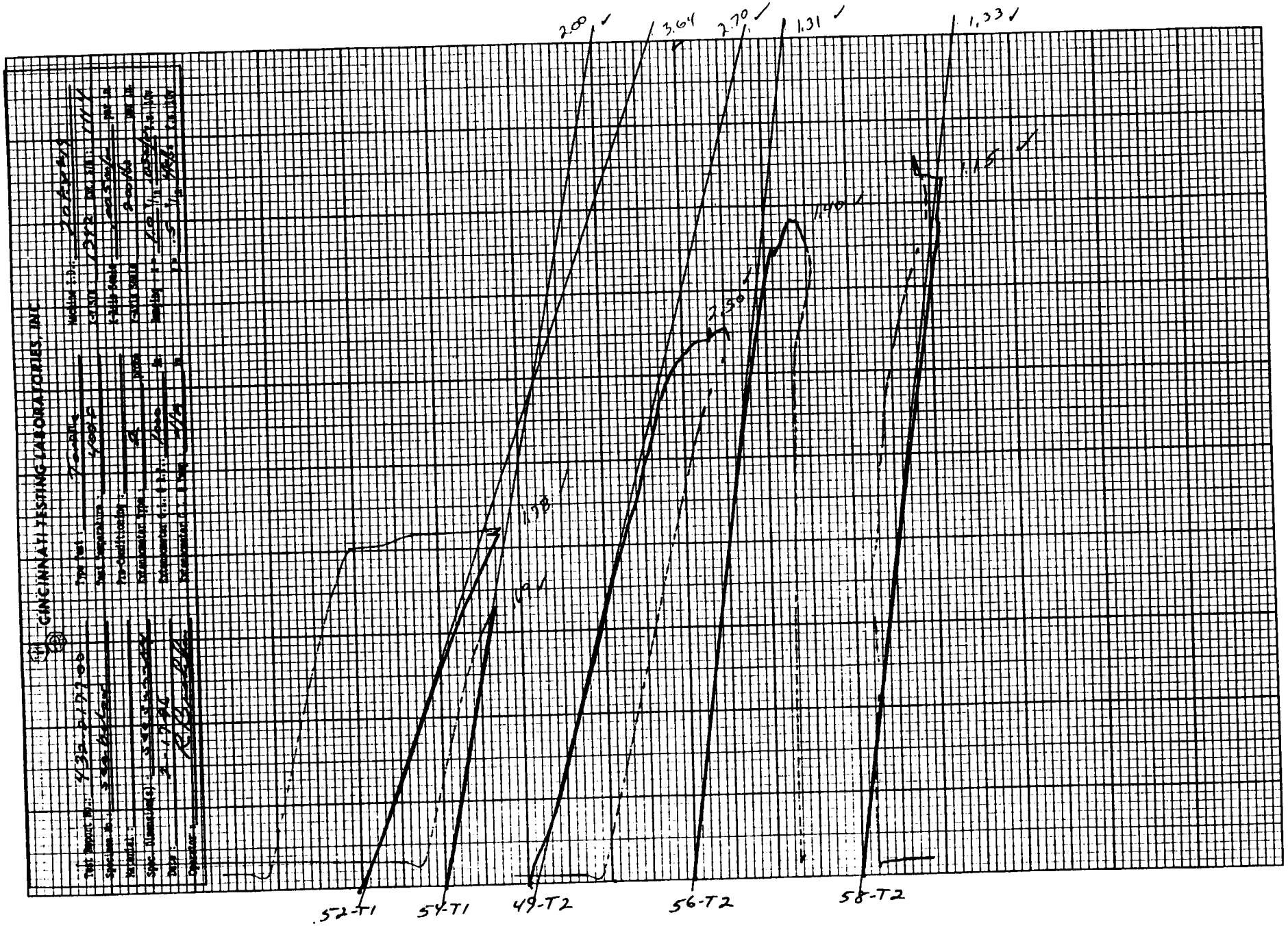

CINCINNATI TESTING LABORATORIES, INC.


CINCINNATI TESTING LABORATORIES, INC.
Test Report No.:
Specimen No.:
Material:
Spec. Dimension(s):
Date:
Operator:
Type Test:
Test Temperature:
Pre-Conditioning:
Extensometer Type:
Extensometer C.L.
Extensometer C.L. @ Temp.
Machine I.D.:
X-Axis Scale
Y-Axis Scale
Loading Rate
Gage Length
Max. Load
Max. Stress
Max. Strain
Elong. Max. Load
Elong. Break
Modulus
Yield Stress
Yield Strain
Offset
Break Load
Break Stress
Break Strain
Elong. Break
Elongation
Reduction of Area
Poisson Ratio
Comments


CINCINNATI TESTING LABORATORIES, INC.
Test Report No.:
Specimen No.:
Material:
Spec. Dimension(s):
Date:
Operator:
Type Test:
Test Temperature:
Pre-Conditioning:
Extensometer Type:
Extensometer G.L. & P.F.:
Extensometer G.L. & Temp.:
Machine I.D.:
X-Axis Scale
Machine Y-Axis Scale
Bending X-Axis Scale
Bending Y-Axis Scale
2.03

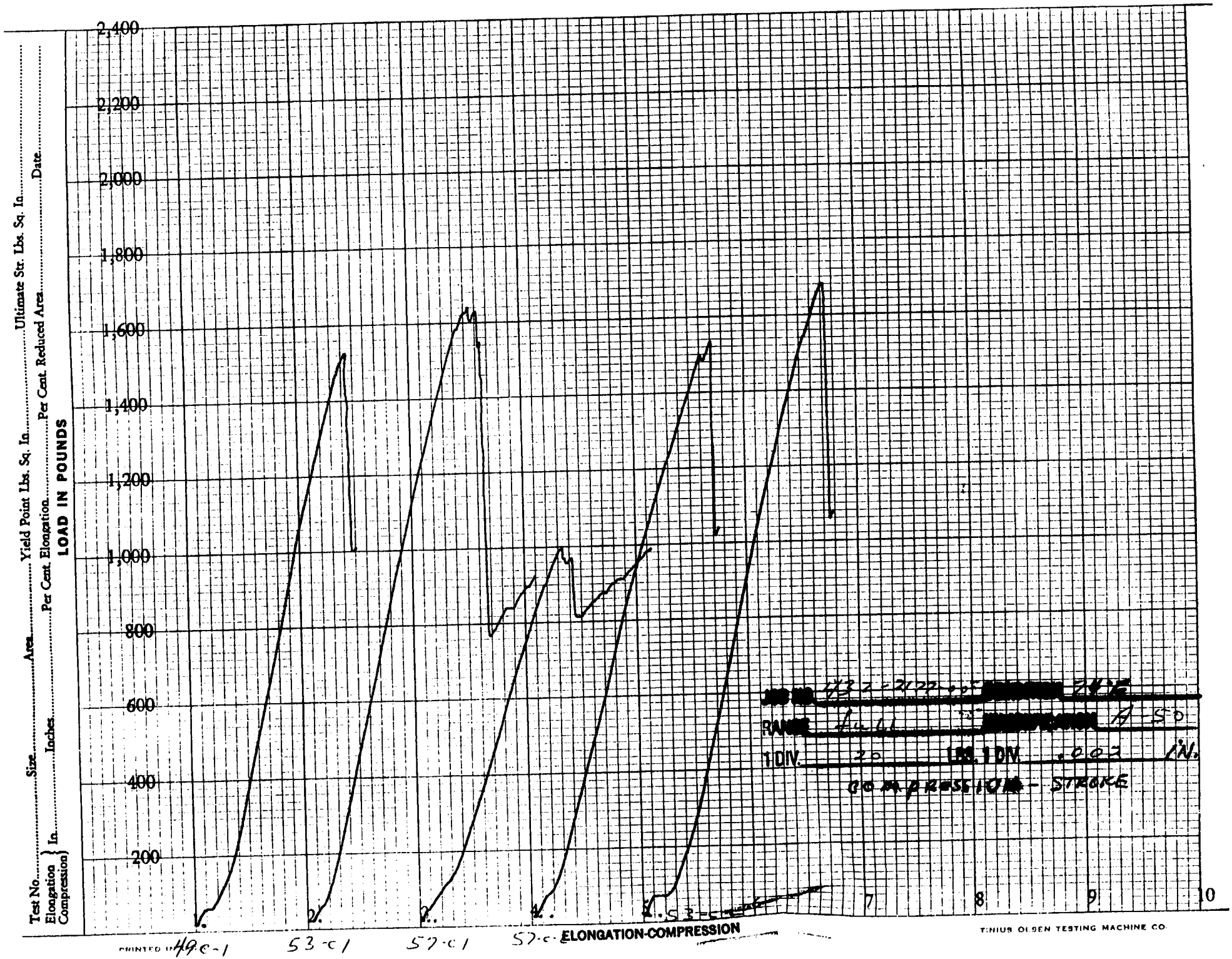


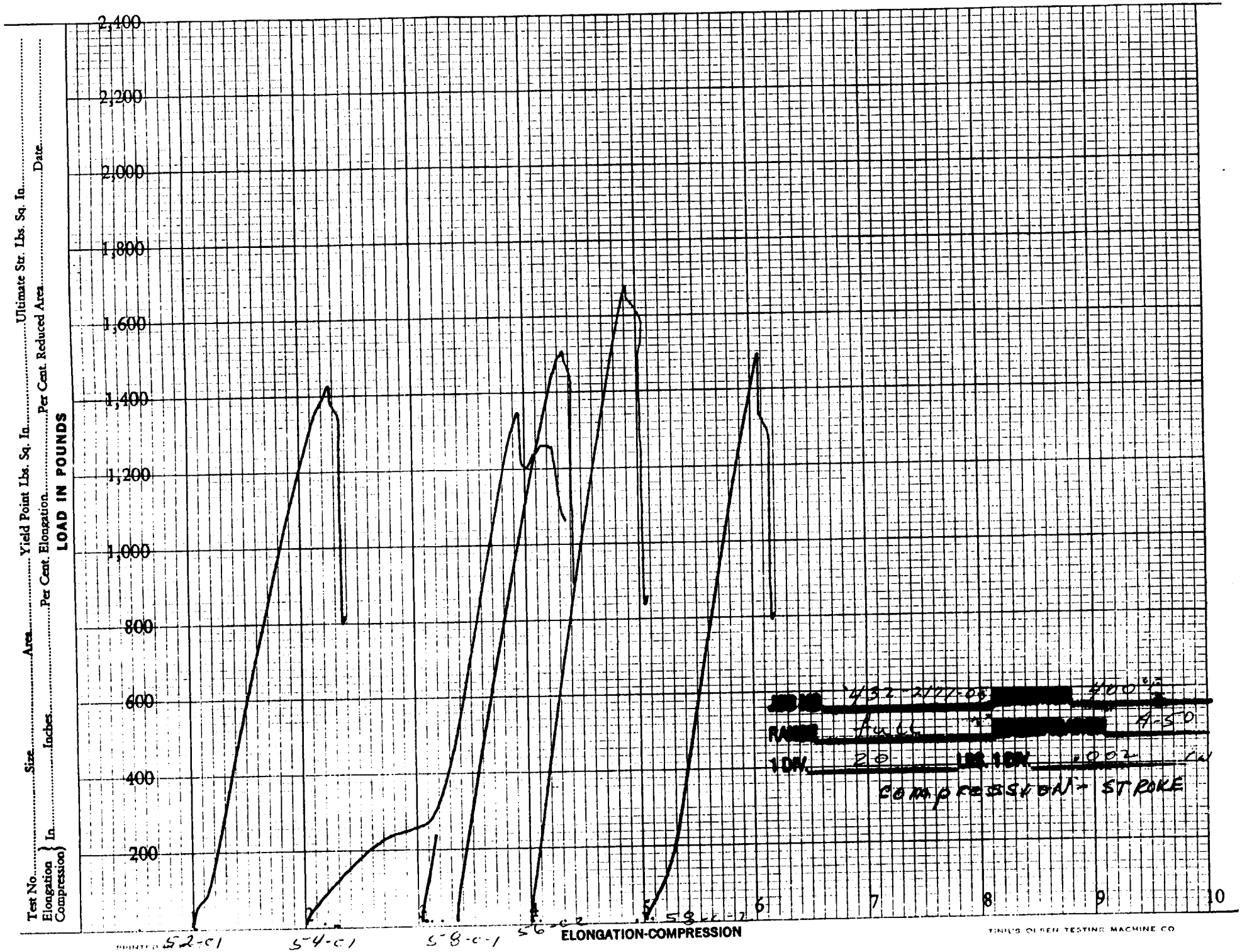
2.04
3.40
1.22
2.52
1.50
57-T2
53-T2
57-T1
53-T1
CINCINNATI TESTING LABORATORIES, INC.

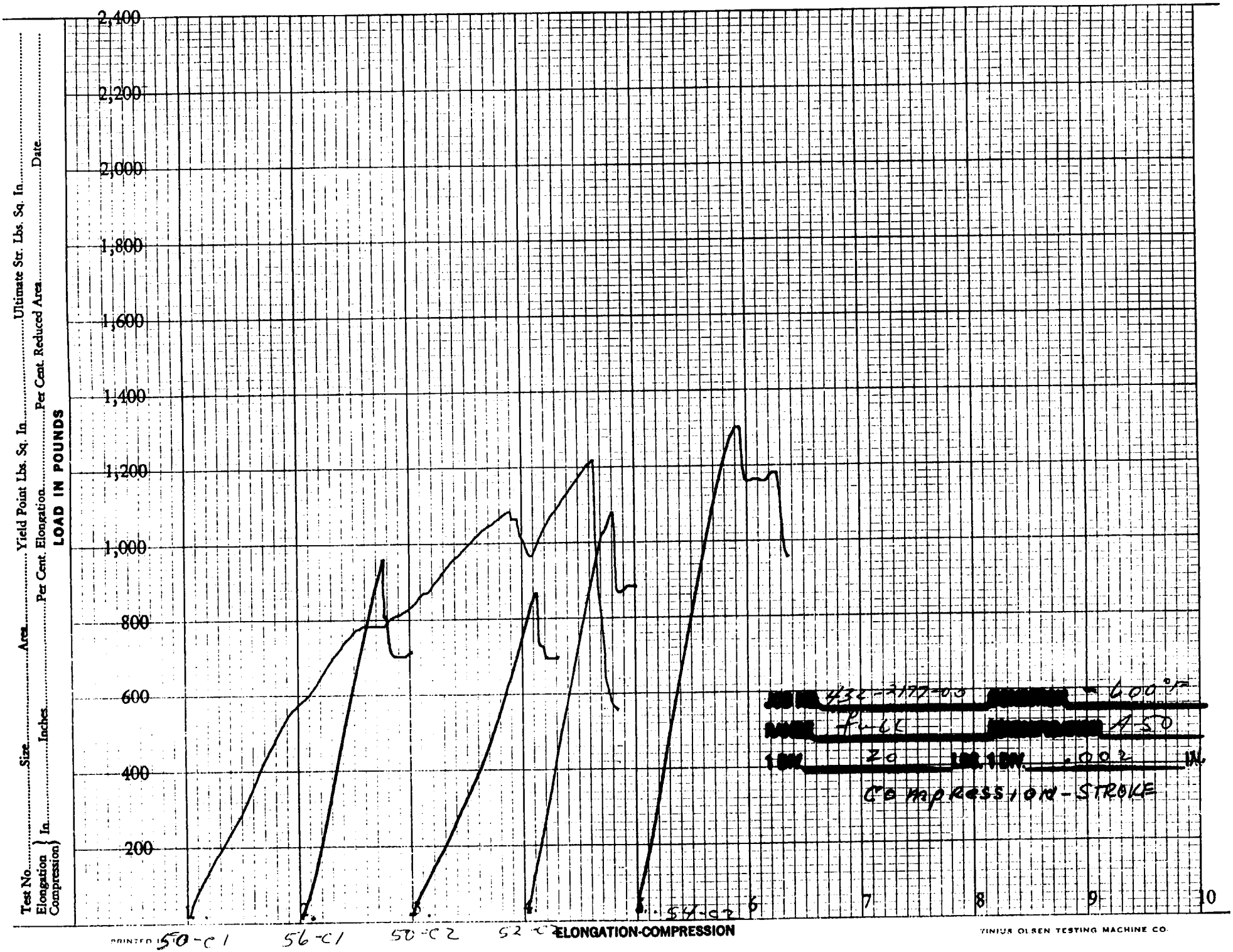

CINCINNATI TESTING LABORATORIES, INC.
2.00
3.64
2.70
1.31
1.33
1.18
1.40
2.50
1.78
1.91
52-T1
54-T1
49-T2
56-T2
58-T2

CINCINNATI TESTING LABORATORIES, INC.
3.83
1.01
2.74
1.46
3.03
54-T2
50-T2
52-T2
56-T1
50-T1

COMPRESSIVE STRENGTH


Test No. ..... Size ..... Area ..... Yield Point Lbs. Sq. In. ..... Ultimate Str. Lbs. Sq. In. .....
Elongation } In. ..... Inches ..... Per Cent. Elongation ..... Per Cent. Reduced Area ..... Date .....
Compression }
LOAD IN POUNDS
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
1
2
3
4
5
7
8
9
10
ELONGATION-COMPRESSION
RANGE full
1 DIV. 20 LBS. 1 DIV. .002 IN.
COMPRESSION - STROKE
49c-1
53-c1
57-c1
57-c
TINIUS OLSEN TESTING MACHINE CO.

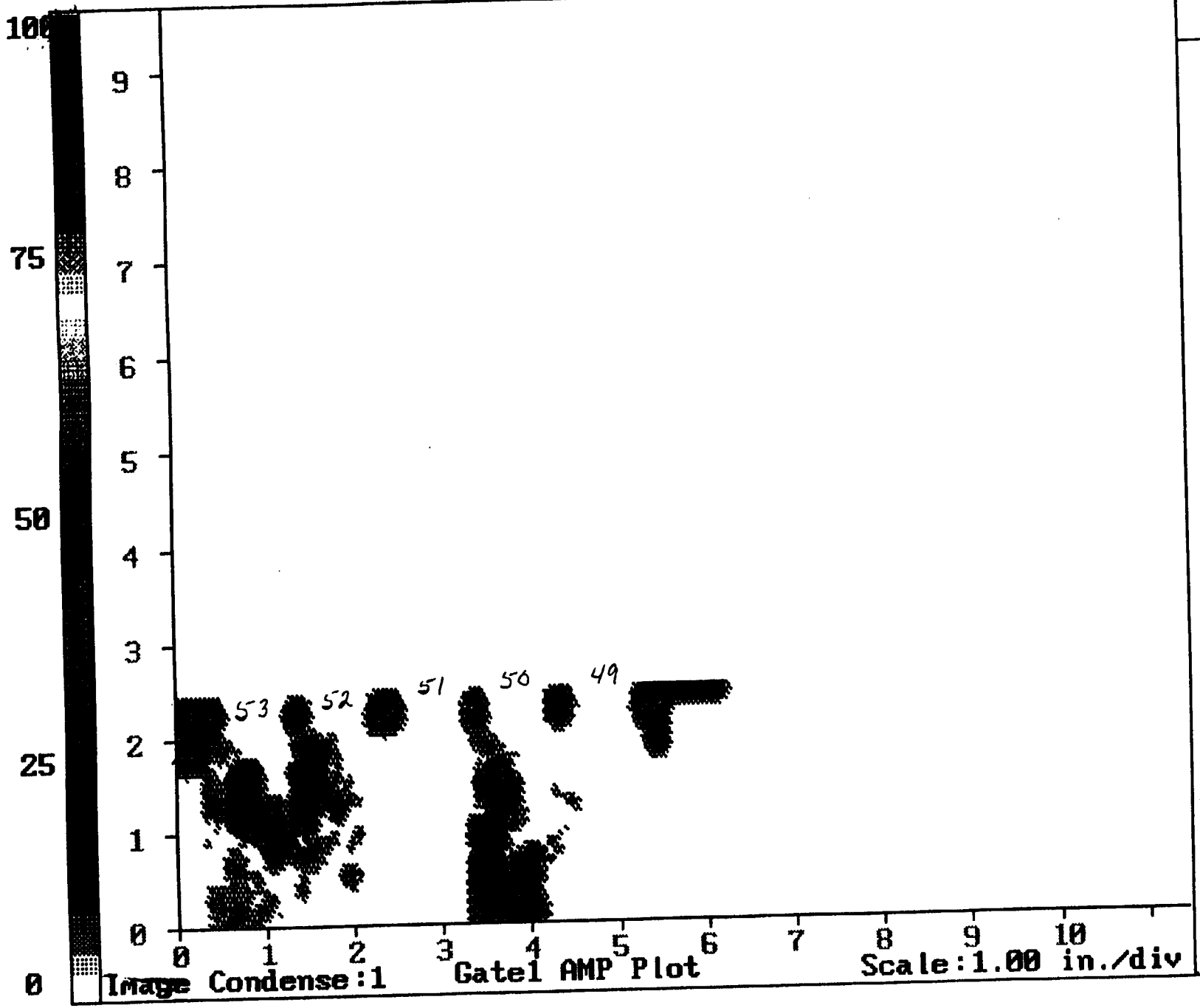

Test No. ..... Size ..... Area ..... Yield Point Lbs. Sq. In. ..... Ultimate Str. Lbs. Sq. In. .....
Elongation } In. ..... Inches ..... Per Cent. Elongation ..... Per Cent. Reduced Area ..... Date .....
Compression }
LOAD IN POUNDS
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
1
2
3
4
5
6
7
8
9
10
52-01
54-01
58-01
56-02
58-02
ELONGATION-COMPRESSION
1 DIV. 20
LBS. 1 DIV. .002
COMPRESSION - STROKE
TINIUS OLSEN TESTING MACHINE CO


Test No.
Size
Area
Yield Point Lbs. Sq. In.
Ultimate Str. Lbs. Sq. In.
Elongation } In. Inches
Compression)
Per Cent. Elongation
Per Cent. Reduced Area
Date
LOAD IN POUNDS
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
1
2
3
4
5
6
7
8
9
10
50-C1
56-C1
50-C2
52-C2
54-C2
ELONGATION-COMPRESSION
PRINTED IN
VINIUS OLSEN TESTING MACHINE CO.
[redacted] 432-2177-03 [redacted] 600°F
[redacted] F-6K [redacted] 450
[redacted] 20 [redacted] .002 IN.
COMPRESSION-STROKE

C-SCANS

Title: FLEX-F1 (49-53)

13:50,1-17-1996



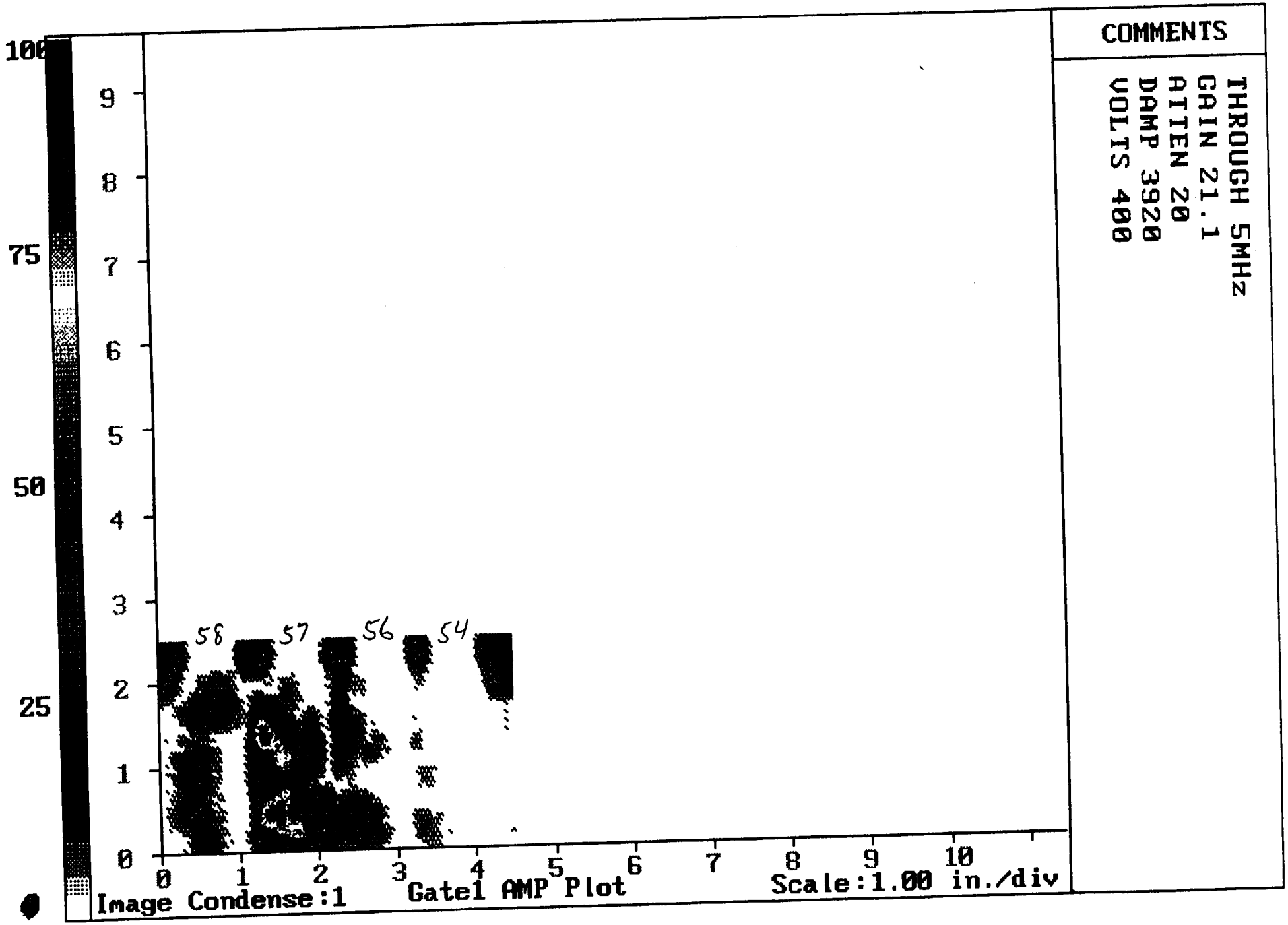
COMMENTS

THROUGH 5MHz
GAIN 21.1
ATTEN 20
DAMP 3920
VOLTS 400

Footnote: JKS135

Title: FLEX-F1 (54,56,57,58)

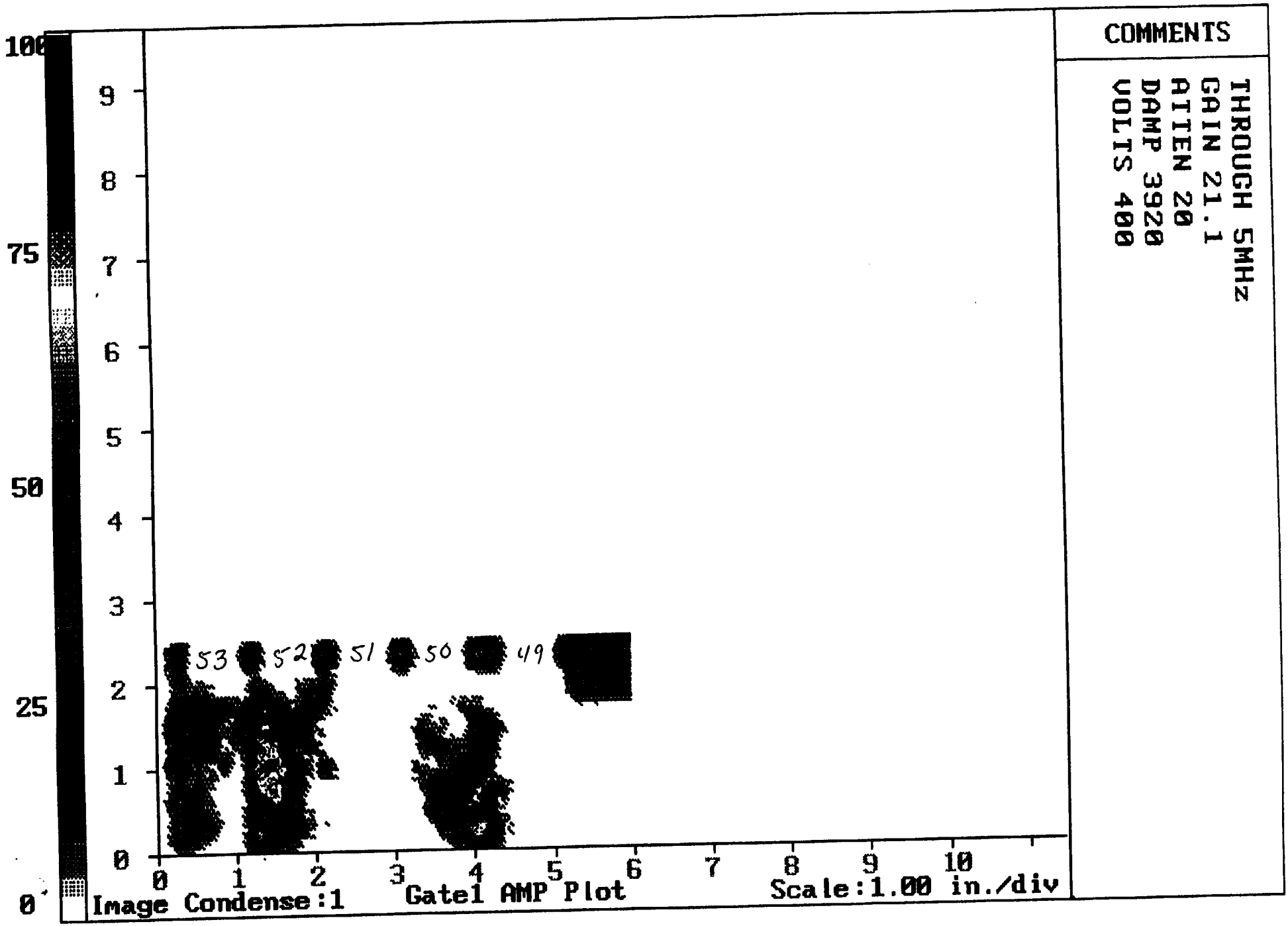
14:10,1-17-1996



Footnote: JKS136

Title: FLEX-F2 (49-53)

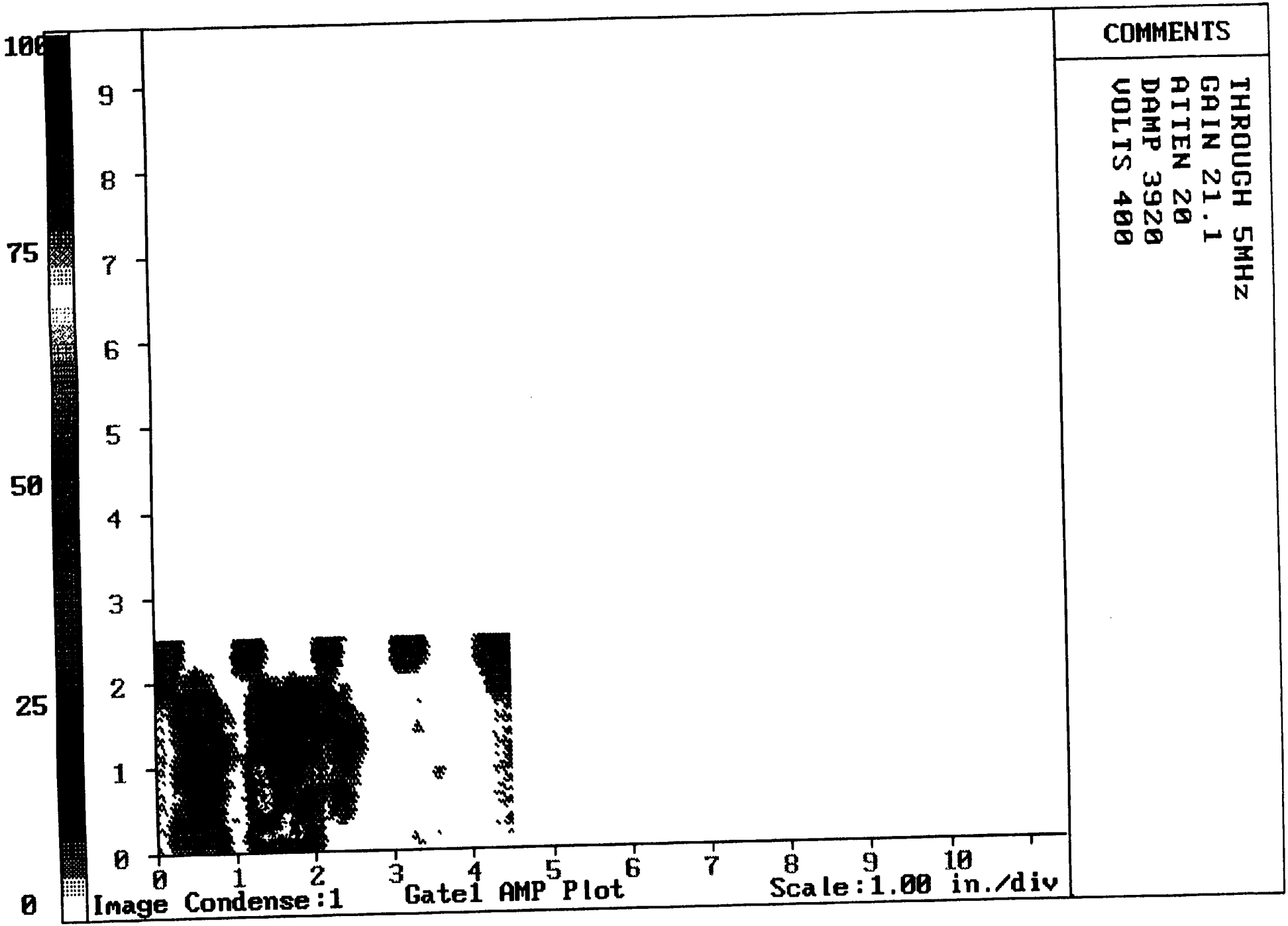
14:55,1-17-1996



Footnote: JKS137+

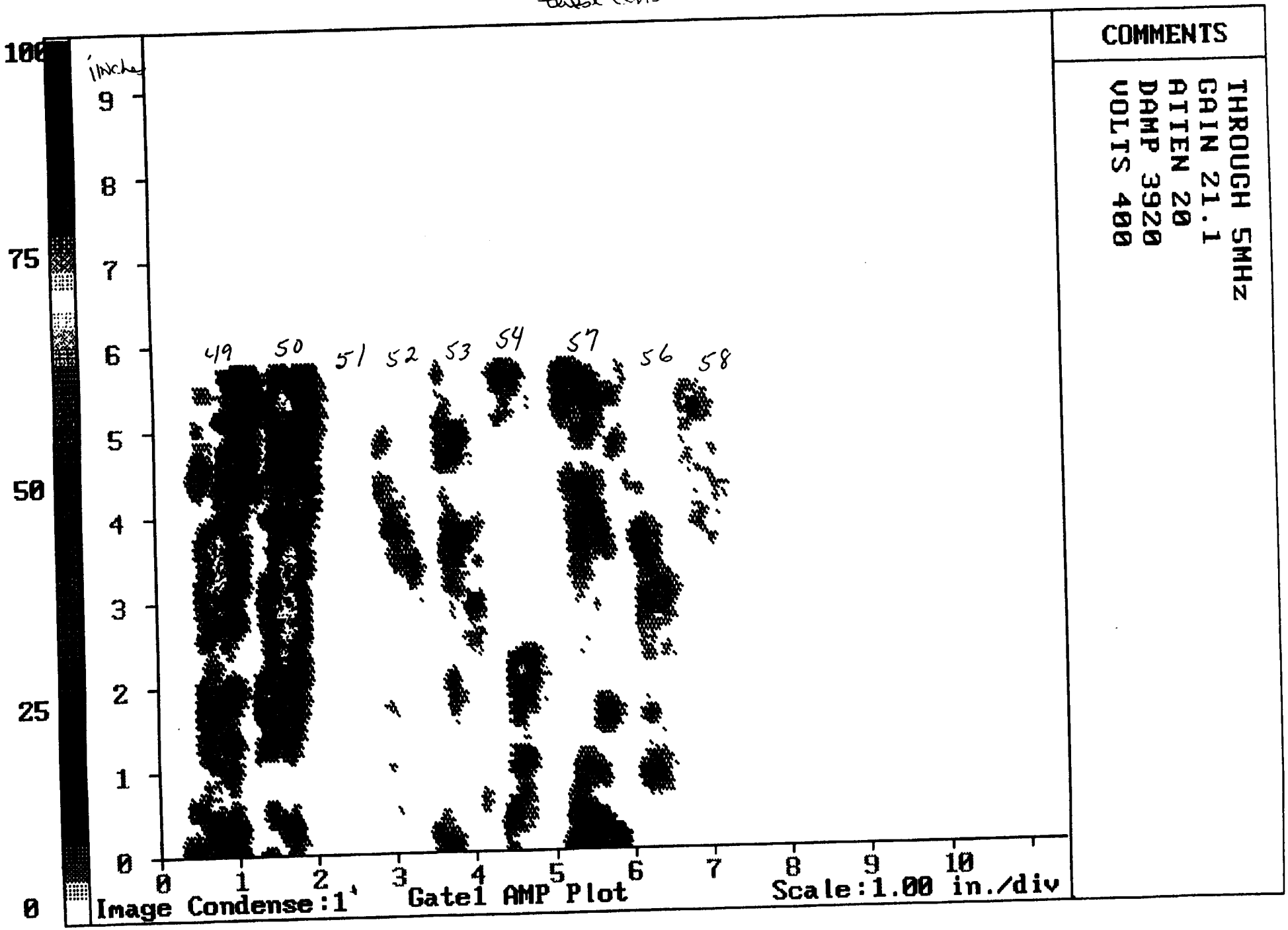
Title: FLEX-F2 (54,56,57,58)

15:15,1-17-1996



Footnote: JKS138

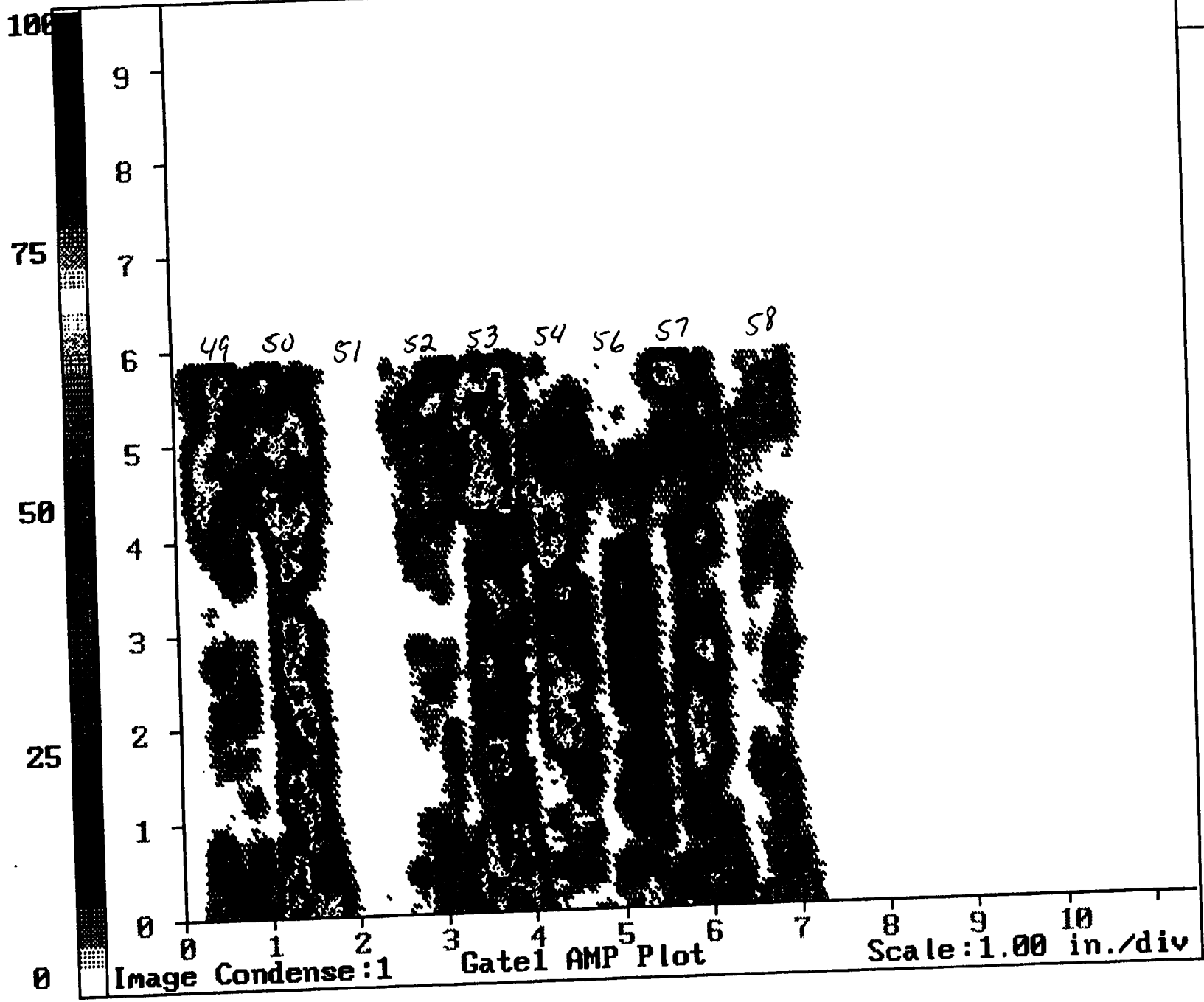
Title: LG TENSILE BARS T1 (49-58) only scanned narrow part of these tensile 09:53,1-22-1998



Footnote: JKS141

10:48,1-22-1996

Title: LG TENSILE BARS T2 (49-58)



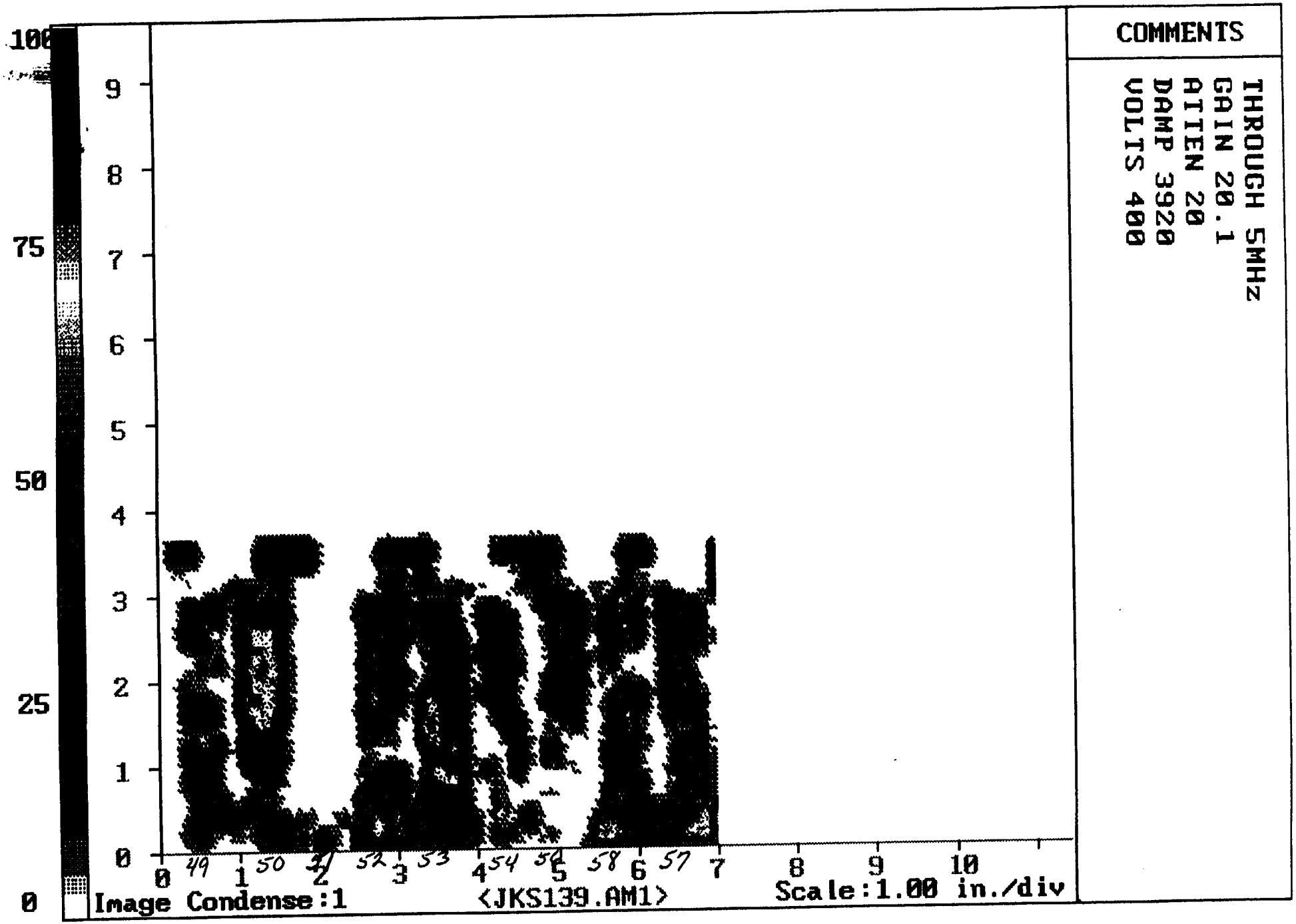
COMMENTS

THROUGH 5MHz
GAIN 21.1
ATTEN 20
DAMP 3920
VOLTS 400

Footnote: JKS142

Title: SM TENSILE BAR C1 (49-58)

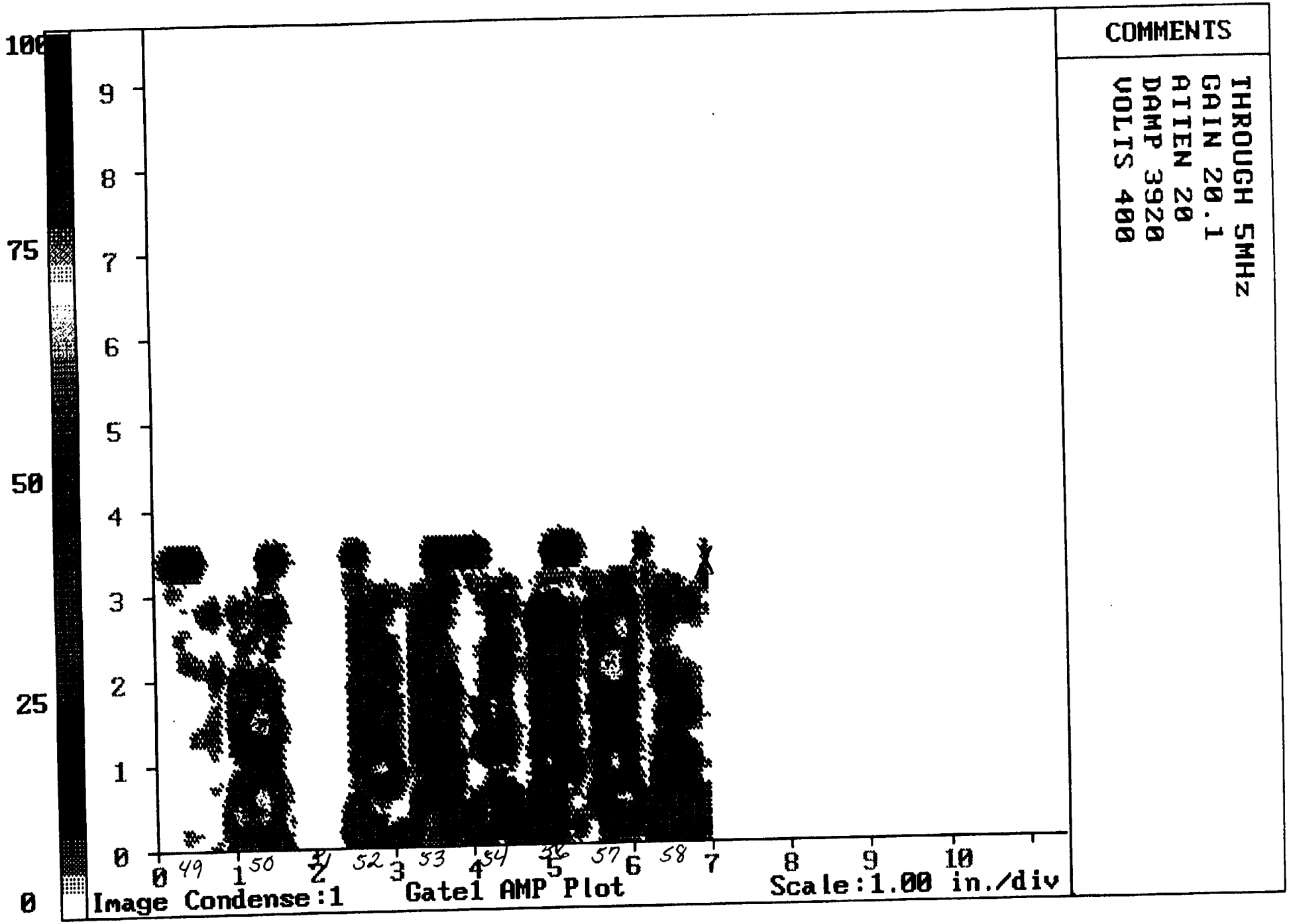
13:44,1-18-1996



Footnote: JKS139

Title: SM TENSILE BAR C2 (49-58)

12:10,1-18-1996



Footnote: JKS140

UDRI TEST DATA

To: Dewey Browning
Cincinnati Testing Lab
From: Mary Galaska
University of Dayton Research Institute
Date: March 15, 1996

Specific Heat Measurement

The specific heat of your sample was measured on a TA Differential Scanning Calorimeter (DSC) 2910 using the routine method as described by TA. This method requires separate scans of a reference, a sapphire standard and then the sample. The scans were run at 10°C/minute through your temperature of interest (600°F) (316°C) in a nitrogen atmosphere. The raw data is converted to ASCII files and fed directly to our computer program for determining specific heat.

The specific heat of your sample was determined to be 0.5839 J/g°C or 0.1395 cal/g°C at 316°C.

Glass Transition Temperature

Your sample was analyzed for Tg using a TA Dynamic Mechanical Analyzer (DMA) 983. The sample was run from room temperature to 450°C at 2°C/minute in a nitrogen atmosphere at a fixed frequency of 1.0 Hz. The Tg is normally taken as the peak of the loss modulus curve and read from the tabulated data. The Tg of your sample was determined to be 378°C.

ThermalConductivity Measurement

The thermal conductivity of your sample was determined by using a modified TA DSC as described in the enclosed paper. The sample was first analyzed at room temperature and then was analyzed at 600°F. The results reported are an average of seven measurements.

The thermal conductivity of your sample at RT is between 0.4166 and 0.4289 W/mK.

When measuring the thermal conductivity of your sample at 600 °F, the lubricant had to be eliminated due to the extreme heat requirement. The instrument was calibrated with two Pyrex 7740 cylindrical glass specimens and these experimental values were used to calculate the thermal conductivity of your specimen. Six measurements were taken of each specimen to obtain a more accurate average.

The thermal conductivity of your sample at 600°F (316°C) was determined to be between 0.257 and 0.296 W/mK.

CALCULATION OF HEAT CAPACITY USING TA 2910 DSC

The calculation of heat capacity by Differential Scanning Calorimetry (DSC) (ASTM E1356) has been routinely performed for years. In TA's DSC, the experimenter performs three scans. Empty reference pan, a standard material (such as sapphire) of known specific heat, and the sample material. The three scans are plotted on a single graph of (mW) vs. temperature.

In order to calculate the heat capacity of the sample, at a specified temperature, a cell constant "E" for that temperature must be calculated using equation #1. From the graph, the heat flow (ΔY) is determined graphically and converted to mW in equation #1. The heat capacity for the sapphire standard is obtained at different temperatures from a table of known values supplied by TA. After "E" has been determined, the heat capacity of the sample can be calculated by solving equation #2 for Cp and substituting in the respective values of E, ΔY, m and Hr for the specified temperature. At the University of Dayton Research Institute, we have written a computer program that will perform heat capacity calculations from DSC data. For this program, the samples are run by the routine procedure described by TA but the data is converted to ASCII files where it is read directly by the program. The calculation performed is slightly different from the routine procedure. Since the heat flow data (mW) is read directly there is no need for the conversion factor ΔQs. In addition, equation #1 and equation #2 are solves simultaneously resulting in the simpler equation #3.

Equation #1 $$E = \frac{Cp \quad Hr \quad m}{60 \quad \Delta qs \quad \Delta Y}$$

Equation #2 $$Cp = \frac{E \quad 60 \quad \Delta qs \quad \Delta Y}{Hr \quad m}$$

Where

Cp = heat capacity

Hr = heating rate °C/min

Δqs = converts cm to mW

m= mass (mg)

E = cell constant

ΔY = distance between standard or sample and the reference in cm

Equation #3 $$Cp_{sm} = \frac{Cp_{st} \; M_{st} \; \Delta Y_{sm}}{M_{sm} \; \Delta Y_{st}}$$

Where

Cp_{st} = heat capacity of standard

Cp_{sm} = heat capacity of sample

M_{sm} = mass of sample

ΔY_{st} = mW reference - mW standard

ΔY_{sm} = mW reference - mW sample

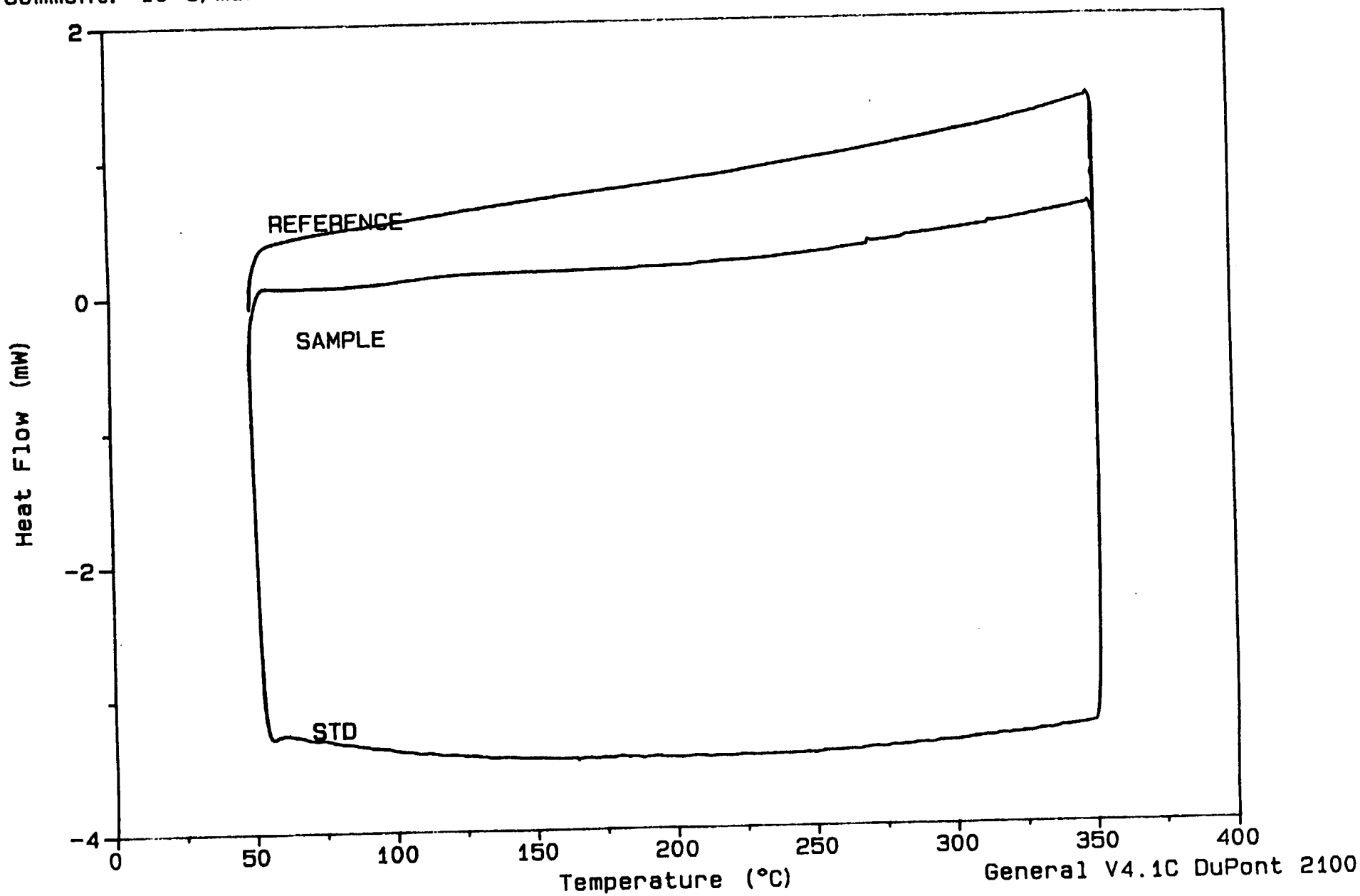
M_{st} = mass of standard

Your sample was analyzed for Cp by performing DSC runs on a reference, a sapphire standard, and your sample at 10°C/min through your temperature of interest and then using the program to calculate the Cp from this data. The heat capacity of your sample at 600°F (316°C) was determined to be 0.5839 J/g°C or 0.1395 cal/g°C.

Sample: SMC SAMPLE - CINCI TESTING LAB
Size: 8.0660 mg
Method: DSC-Cp
Comment: 10°C/min

DSC

File: NDSC1783.03
Operator: GALASKA
Run Date: 10-Jan-96 16:15



FILE: 10°C/min

STANDARD: 10°C/min

SAMPLE: SMC SAMPLE - CINCI TESTING LAB

COMMENTS: 10°C/min

TEMPERATURE DEGREES C	HEAT CAP. J/g - deg.C	HEAT CAP. CAL/g - deg.C
310.00	.5845	.1397
311.00	.5856	.1399
312.00	.5866	.1402
313.00	.5884	.1406
314.00	.5905	.1411
315.00	.5773	.1379
316.00	.5839	.1395
317.00	.5859	.1400
318.00	.5874	.1404
319.00	.5897	.1409
320.00	.5917	.1414

Date: March 3, 1996
To: Cincinnati Testing Lab
From: Mary Galaska, Dr. Richard Chartoff

Your sample was analyzed for Tg using the TA Dynamic Mechanical Analyzer 983 in the fixed frequency mode with a frequency of 1.0 Hz. The heating rate was 2°C/min in a nitrogen atmosphere. The Tg is normally taken as the peak of the loss modulus curve E" (Pa) and read from the tabulated data. The Tg of your sample was determined to be 378°C.

Introducing the 983 DMA

Overview

The Du Pont 983 Dynamic Mechanical Analyzer (DMA) is a highly sophisticated thermal analysis module that can be used independently or with the Du Pont 9900 Thermal Analyzer running at least version 5.0 software. The 983 DMA is an instrument that offers a rapid and sensitive means to simultaneously obtain an elastic modulus (stiffness) and a mechanical damping (toughness) for materials. The 983 DMA has three major parts: the drive assembly where the sample is clamped and enclosed by the oven, the oven where the temperature is controlled and the DMA base where the system electronics are housed.

The 983 DMA module measures changes in the viscoelastic properties of materials resulting from changes in temperature, frequency, and time. There are four modes of operation, resonant frequency, fixed frequency, stress relaxation, and creep. Each of these modes measures different aspects of the viscoelastic properties.

Principles of Operation

The sample is clamped between two parallel arms and is deformed under a constant stress, oscillating stress or a constant strain, depending on the experiment mode. The behavior of the sample under this deformation is monitored by a linear variable displacement transducer (LVDT). The following sections describe the four modes of operation.

- Resonant Frequency Mode

When operating the 983 DMA in the resonant mode, the sample and arms form a compound resonance system. The sample is displaced and set into oscillation. Normally, a system so displaced would oscillate at the system's resonant frequency, with constantly decreasing amplitude due to the loss of energy (damping) within the sample. The electronics of the 983 DMA, when operating in the resonant mode, are designed to compensate for this loss of energy in the sample. The amplitude signal from the LVDT is fed into a circuit which in turn provides an output signal to the electromechanical driver. The driver supplies additional energy to the driven arm forcing the coupled system to oscillate at a constant amplitude.

The frequency of oscillation is directly related to the stiffness or storage modulus of the sample under investigation, while the energy needed to maintain constant oscillation amplitude is a measure of the damping within the sample.

- Fixed Frequency Mode

The fixed frequency mode is similar to the resonant frequency except that, the oscillation frequency is fixed. The sample is forced to undergo oscillatory motion using a sinusoidal driver signal. The sample displacement is monitored by the LVDT and the lag between the driver signal and the LVDT is the phase angle. The phase angle and drive signal are used to calculate the storage, loss modulus and tan delta of the sample.

- Stress Relaxation Mode

In the stress relaxation mode, the sample is flexed by displacing the arm position a specified amount. The amount of power required to maintain the selected position is then monitored as a function of time. Additionally, sample recovery is measured when the sample is released to an unstressed state.

Technical Specifications

Table 1.1
Measurement Ranges

Modulus Range	1MPa to 200 GPa
Modulus Precision (5-30 Hz Resonant)	5%
Tan delta:	
Resonant Frequency	0.002 to 1.0
Fixed Frequency	0.002 to 10
Amplitude Range (peak to peak)	0.1 to 2.0 mm
Resonant Frequency	2 to 85 Hz
Fixed Frequency Range	0.001 to 10.0 Hz
Phase Angle Range	0.0 to 2.8 rad
Phase Angle Precision	0.001 rad (0.06 deg)
Stress Relaxation Drift (at 300 °C for 1 hour)	< 5%
Creep Drift (at 300 °C for 1 hour)	< 5%
Temperature Range with LNCA	ambient to 500 °C -150 to 500 °C

Table 1.2
Sampling System

Length Range	6 to 65 mm vert. 6 to 57 mm horiz.
Max. Thickness	12 mm vert. 12 mm horiz.
Max. Width	15 mm vert. 5 mm horiz.

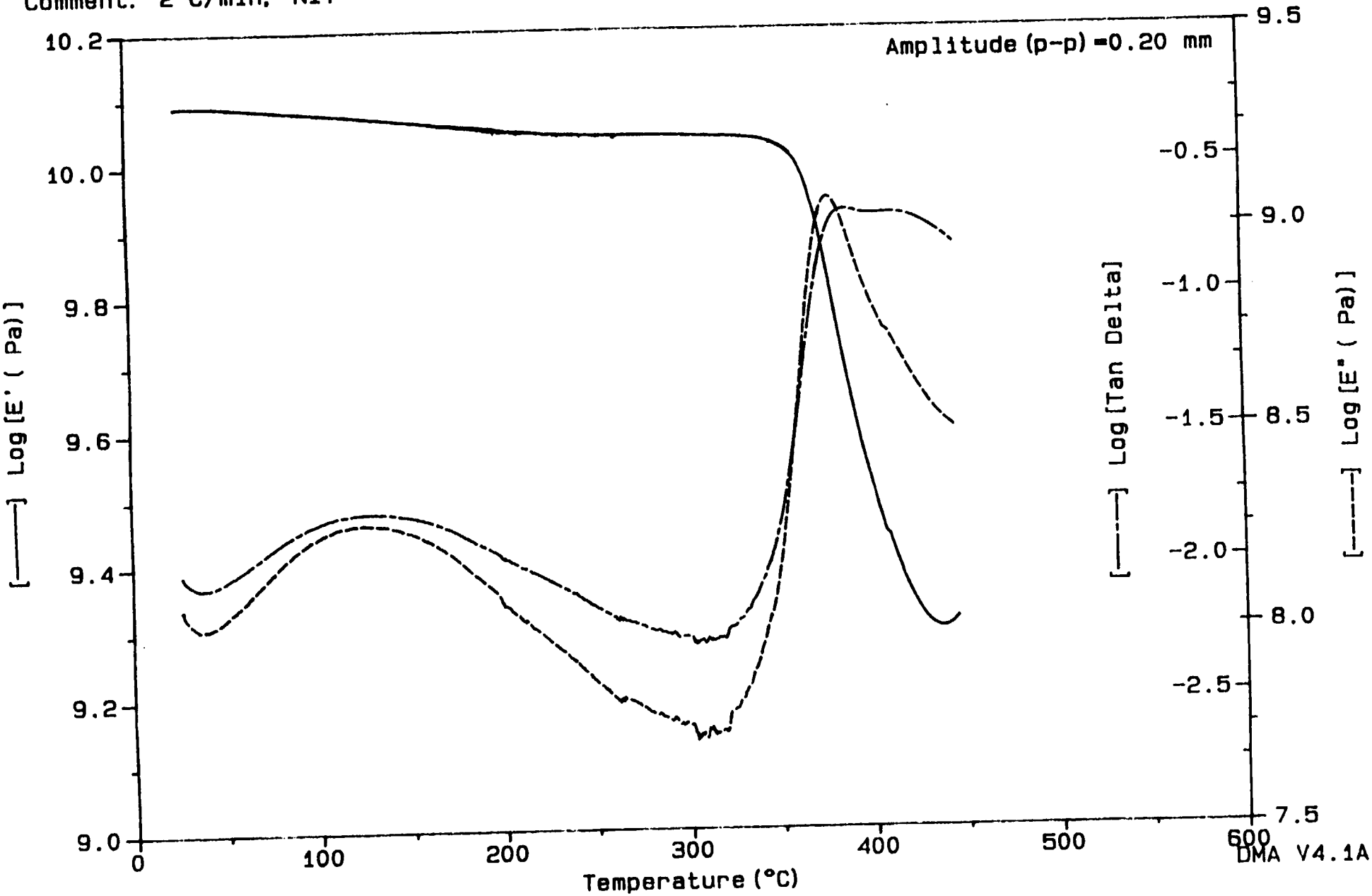
Table 1.3
Temperature Control

Program Heating Rate	0.01 to 50 °C/min.
Isothermal Stability at 100 °C for 1 hr. subambient	 ±0.1 °C ±1.0 °C
Temperature Precision	±0.1 °C
Programmed Cooling Rate with LNCA	1 to 5 °C/min. to -150 °C
Cool Down Time (Ambient to -120 °C with the LNCA)	15 min.
Purge Gas	N_2 or air

Sample : SMC SAMPLE CINCI TEST
Size : 25.45 x 12.93 x 2.11 mm
Method : DMA-2°C/MIN
Comment: 2°C/min, NIT

DMA

File : C:RUN2401.01
Operator: GALASKA
Run Date: 11-Jan-96 12:31



DMA V4.1A 01/18/96 15:03:53

File : C:RUN2401.01 Run date : 11-Jan-96 12:31
Comment : 2°C/min, NIT

Sample : SMC SAMPLE CINCI TEST
Module : DMA Fixed Frequency
Method : DMA-2°C/MIN
Operator : GALASKA

Size : 25.45 x 12.93 x 2.11 mm
Poisson's Ratio : 0.440
Length Correction : 0.000 mm
Shear Distortion : 1.500
Oscillation Amplitude : 0.200 mm

Clamping Distance : 8.00 mm
Moment of Inertia : 2.360 g-m^2
C Prime : 0.0212 mm/(mV-sec^2)
Parallel Stiffness : 0.3210 N-m (storage), 0.1740 N-m (loss at 17.690 Hz)
Series Compliance : 1.2380 um/N (storage), 0.0220 um/N (loss at 86.220 Hz)

Frequency = 1.000 Hz

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
27.00	12.29	0.1131	0.009204
28.00	12.30	0.1105	0.008983
29.00	12.30	0.1088	0.008843
30.00	12.31	0.1073	0.008718
31.00	12.31	0.1060	0.008607
32.00	12.31	0.1052	0.008540
33.00	12.31	0.1043	0.008470
34.00	12.32	0.1034	0.008395
35.00	12.31	0.1028	0.008346
36.00	12.31	0.1021	0.008295
37.00	12.31	0.1024	0.008315
38.00	12.31	0.1025	0.008325
39.00	12.31	0.1024	0.008318
40.00	12.31	0.1022	0.008307
41.00	12.30	0.1024	0.008322
42.00	12.30	0.1031	0.008378
43.00	12.30	0.1036	0.008427
44.00	12.30	0.1041	0.008467
45.00	12.29	0.1046	0.008506
46.00	12.29	0.1053	0.008567
47.00	12.29	0.1060	0.008628
48.00	12.28	0.1068	0.008692
49.00	12.28	0.1077	0.008770
50.00	12.28	0.1088	0.008859
51.00	12.27	0.1099	0.008952
52.00	12.27	0.1109	0.009037
53.00	12.26	0.1120	0.009135
54.00	12.25	0.1129	0.009213
55.00	12.25	0.1136	0.009276
56.00	12.24	0.1145	0.009365
57.00	12.24	0.1160	0.009479
58.00	12.23	0.1167	0.009546
59.00	12.22	0.1180	0.009657

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
60.00	12.22	0.1192	0.009757
61.00	12.21	0.1203	0.009851
62.00	12.20	0.1217	0.009974
63.00	12.19	0.1233	0.01011
64.00	12.19	0.1246	0.01022
65.00	12.18	0.1257	0.01032
66.00	12.17	0.1271	0.01044
67.00	12.17	0.1285	0.01056
68.00	12.16	0.1296	0.01066
69.00	12.15	0.1310	0.01078
70.00	12.15	0.1325	0.01091
71.00	12.14	0.1338	0.01102
72.00	12.13	0.1354	0.01116
73.00	12.13	0.1371	0.01131
74.00	12.12	0.1381	0.01140
75.00	12.11	0.1398	0.01154
76.00	12.10	0.1409	0.01163
77.00	12.10	0.1426	0.01179
78.00	12.09	0.1444	0.01195
79.00	12.08	0.1462	0.01210
80.00	12.08	0.1474	0.01221
81.00	12.07	0.1490	0.01234
82.00	12.07	0.1507	0.01249
83.00	12.06	0.1519	0.01260
84.00	12.05	0.1530	0.01270
85.00	12.04	0.1544	0.01282
86.00	12.04	0.1556	0.01292
87.00	12.04	0.1572	0.01306
88.00	12.03	0.1588	0.01320
89.00	12.02	0.1598	0.01329
90.00	12.01	0.1606	0.01337
91.00	12.01	0.1622	0.01351
92.00	12.00	0.1636	0.01363
93.00	12.00	0.1646	0.01372
94.00	11.99	0.1659	0.01383
95.00	11.99	0.1672	0.01395
96.00	11.98	0.1684	0.01405
97.00	11.97	0.1696	0.01417
98.00	11.96	0.1703	0.01423
99.00	11.96	0.1709	0.01429
100.00	11.95	0.1722	0.01440
101.00	11.95	0.1733	0.01450
102.00	11.94	0.1744	0.01460
103.00	11.93	0.1752	0.01468
104.00	11.93	0.1759	0.01474
105.00	11.92	0.1768	0.01483
106.00	11.91	0.1782	0.01496
107.00	11.91	0.1788	0.01501
108.00	11.90	0.1789	0.01503
109.00	11.89	0.1801	0.01514
110.00	11.89	0.1812	0.01524
111.00	11.88	0.1815	0.01528
112.00	11.87	0.1820	0.01533
113.00	11.87	0.1828	0.01541

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
114.00	11.86	0.1832	0.01544
115.00	11.86	0.1832	0.01543
116.00	11.84	0.1834	0.01548
117.00	11.84	0.1839	0.01553
118.00	11.83	0.1845	0.01559
119.00	11.83	0.1848	0.01562
120.00	11.82	0.1849	0.01563
121.00	11.81	0.1850	0.01566
122.00	11.80	0.1850	0.01568
123.00	11.80	0.1851	0.01569
124.00	11.79	0.1856	0.01575
125.00	11.78	0.1857	0.01578
126.00	11.77	0.1856	0.01576
127.00	11.77	0.1855	0.01577
128.00	11.76	0.1855	0.01578
129.00	11.75	0.1854	0.01579
130.00	11.74	0.1852	0.01578
131.00	11.73	0.1848	0.01575
132.00	11.72	0.1848	0.01576
133.00	11.71	0.1841	0.01572
134.00	11.71	0.1842	0.01573
135.00	11.70	0.1843	0.01575
136.00	11.70	0.1840	0.01573
137.00	11.69	0.1834	0.01569
138.00	11.68	0.1834	0.01570
139.00	11.67	0.1831	0.01569
140.00	11.66	0.1825	0.01565
141.00	11.66	0.1816	0.01558
142.00	11.65	0.1815	0.01558
143.00	11.64	0.1807	0.01552
144.00	11.63	0.1803	0.01550
145.00	11.62	0.1797	0.01546
146.00	11.62	0.1791	0.01542
147.00	11.61	0.1787	0.01539
148.00	11.60	0.1776	0.01531
149.00	11.59	0.1770	0.01526
150.00	11.59	0.1764	0.01522
151.00	11.58	0.1758	0.01518
152.00	11.57	0.1749	0.01512
153.00	11.56	0.1744	0.01508
154.00	11.56	0.1737	0.01503
155.00	11.55	0.1726	0.01495
156.00	11.54	0.1719	0.01489
157.00	11.53	0.1708	0.01481
158.00	11.53	0.1699	0.01474
159.00	11.52	0.1691	0.01468
160.00	11.51	0.1681	0.01460
161.00	11.50	0.1672	0.01453
162.00	11.50	0.1663	0.01446
163.00	11.49	0.1653	0.01439
164.00	11.48	0.1642	0.01431
165.00	11.47	0.1630	0.01421
166.00	11.46	0.1619	0.01412
167.00	11.45	0.1610	0.01406

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
168.00	11.45	0.1597	0.01395
169.00	11.44	0.1584	0.01385
170.00	11.43	0.1573	0.01376
171.00	11.43	0.1563	0.01363
172.00	11.42	0.1552	0.01359
173.00	11.42	0.1538	0.01348
174.00	11.41	0.1525	0.01337
175.00	11.40	0.1513	0.01327
176.00	11.40	0.1499	0.01315
177.00	11.39	0.1485	0.01303
178.00	11.39	0.1472	0.01293
179.00	11.38	0.1458	0.01281
180.00	11.38	0.1446	0.01271
181.00	11.37	0.1432	0.01259
182.00	11.36	0.1418	0.01248
183.00	11.36	0.1407	0.01238
184.00	11.36	0.1393	0.01227
185.00	11.35	0.1380	0.01216
186.00	11.34	0.1369	0.01207
187.00	11.34	0.1358	0.01198
188.00	11.33	0.1346	0.01188
189.00	11.33	0.1332	0.01176
190.00	11.32	0.1322	0.01168
191.00	11.31	0.1312	0.01159
192.00	11.30	0.1296	0.01146
193.00	11.30	0.1287	0.01139
194.00	11.28	0.1274	0.01129
195.00	11.27	0.1263	0.01120
196.00	11.25	0.1252	0.01113
197.00	11.22	0.1235	0.01101
198.00	11.19	0.1216	0.01087
199.00	11.14	0.1200	0.01077
200.00	11.05	0.1167	0.01057
201.00	10.99	0.1162	0.01057
202.00	10.99	0.1147	0.01045
203.00	10.98	0.1140	0.01038
204.00	10.98	0.1124	0.01024
205.00	10.97	0.1114	0.01016
206.00	10.96	0.1107	0.01010
207.00	10.96	0.1097	0.01001
208.00	10.95	0.1091	0.009959
209.00	10.95	0.1076	0.009831
210.00	10.94	0.1066	0.009744
211.00	10.93	0.1056	0.009663
212.00	10.93	0.1059	0.009686
213.00	10.93	0.1047	0.009581
214.00	10.92	0.1037	0.009499
215.00	10.91	0.1024	0.009389
216.00	10.89	0.1010	0.009273
217.00	10.89	0.1008	0.009255
218.00	10.88	0.09997	0.009186
219.00	10.88	0.09904	0.009106
220.00	10.87	0.09833	0.009046
221.00	10.87	0.09749	0.008972

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
222.00	10.86	0.09640	0.008877
223.00	10.85	0.09558	0.008806
224.00	10.85	0.09476	0.008734
225.00	10.84	0.09388	0.008658
226.00	10.84	0.09318	0.008597
227.00	10.83	0.09249	0.008538
228.00	10.83	0.09152	0.008451
229.00	10.83	0.09067	0.008376
230.00	10.82	0.08997	0.008315
231.00	10.82	0.08912	0.008239
232.00	10.81	0.08870	0.008204
233.00	10.81	0.08764	0.008109
234.00	10.80	0.08698	0.008051
235.00	10.80	0.08613	0.007976
236.00	10.79	0.08507	0.007881
237.00	10.79	0.08443	0.007823
238.00	10.79	0.08343	0.007732
239.00	10.78	0.08320	0.007716
240.00	10.78	0.08212	0.007619
241.00	10.78	0.08132	0.007545
242.00	10.77	0.08049	0.007470
243.00	10.77	0.07952	0.007381
244.00	10.77	0.07859	0.007298
245.00	10.76	0.07811	0.007257
246.00	10.76	0.07714	0.007166
247.00	10.76	0.07614	0.007079
248.00	10.76	0.07534	0.007004
249.00	10.75	0.07487	0.006962
250.00	10.75	0.07393	0.006878
251.00	10.75	0.07295	0.006789
252.00	10.74	0.07236	0.006733
253.00	10.74	0.07204	0.006707
254.00	10.74	0.07111	0.006621
255.00	10.74	0.07047	0.006563
256.00	10.73	0.07000	0.006523
257.00	10.73	0.06931	0.006460
258.00	10.73	0.06859	0.006393
259.00	10.72	0.06786	0.006329
260.00	10.72	0.06747	0.006291
261.00	10.73	0.06623	0.006170
262.00	10.77	0.06573	0.006104
263.00	10.75	0.06636	0.006172
264.00	10.85	0.06658	0.006136
265.00	10.96	0.06730	0.006143
266.00	10.95	0.06652	0.006074
267.00	10.97	0.06692	0.006098
268.00	10.97	0.06634	0.006045
269.00	10.97	0.06623	0.006036
270.00	10.97	0.06583	0.005999
271.00	10.97	0.06518	0.005941
272.00	10.97	0.06493	0.005920
273.00	10.97	0.06443	0.005876
274.00	10.97	0.06390	0.005827
275.00	10.96	0.06376	0.005816

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
276.00	10.96	0.06336	0.005779
277.00	10.96	0.06267	0.005716
278.00	10.96	0.06209	0.005664
279.00	10.96	0.06180	0.005638
280.00	10.96	0.06160	0.005620
281.00	10.96	0.06119	0.005583
282.00	10.96	0.06087	0.005555
283.00	10.96	0.06151	0.005614
284.00	10.96	0.06117	0.005583
285.00	10.95	0.06050	0.005524
286.00	10.95	0.06048	0.005522
287.00	10.95	0.06012	0.005489
288.00	10.95	0.05946	0.005429
289.00	10.95	0.05918	0.005403
290.00	10.95	0.05887	0.005376
291.00	10.95	0.05963	0.005447
292.00	10.95	0.06000	0.005481
293.00	10.94	0.05826	0.005323
294.00	10.94	0.05746	0.005251
295.00	10.94	0.05796	0.005297
296.00	10.94	0.05746	0.005250
297.00	10.94	0.05796	0.005298
298.00	10.94	0.05815	0.005316
299.00	10.94	0.05759	0.005265
300.00	10.94	0.05737	0.005246
301.00	10.94	0.05748	0.005256
302.00	10.93	0.05588	0.005111
303.00	10.78	0.05402	0.005014
304.00	10.65	0.05320	0.004997
305.00	10.65	0.05350	0.005024
306.00	10.65	0.05408	0.005079
307.00	10.64	0.05460	0.005131
308.00	10.64	0.05348	0.005025
309.00	10.77	0.05370	0.004987
310.00	10.92	0.05654	0.005178
311.00	10.91	0.05692	0.005216
312.00	10.76	0.05522	0.005131
313.00	10.63	0.05414	0.005095
314.00	10.63	0.05452	0.005130
315.00	10.62	0.05473	0.005152
316.00	10.62	0.05551	0.005227
317.00	10.62	0.05536	0.005213
318.00	10.62	0.05562	0.005238
319.00	10.62	0.05502	0.005179
320.00	10.69	0.05649	0.005285
321.00	10.85	0.06041	0.005563
322.00	10.88	0.06203	0.005698
323.00	10.88	0.06181	0.005681
324.00	10.88	0.06253	0.005749
325.00	10.87	0.06281	0.005777
326.00	10.87	0.06396	0.005883
327.00	10.86	0.06593	0.006070
328.00	10.86	0.06654	0.006129
329.00	10.85	0.06720	0.006194

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
330.00	10.85	0.06904	0.006365
331.00	10.84	0.07055	0.006510
332.00	10.83	0.07164	0.006612
333.00	10.83	0.07285	0.006728
334.00	10.82	0.07605	0.007031
335.00	10.81	0.07779	0.007195
336.00	10.81	0.07977	0.007383
337.00	10.80	0.08172	0.007570
338.00	10.78	0.08517	0.007898
339.00	10.78	0.08890	0.008249
340.00	10.76	0.09135	0.008487
341.00	10.75	0.09407	0.008749
342.00	10.74	0.09850	0.009168
343.00	10.73	0.1029	0.009588
344.00	10.71	0.1061	0.009907
345.00	10.56	0.1089	0.01032
346.00	10.39	0.1133	0.01091
347.00	10.37	0.1187	0.01145
348.00	10.35	0.1263	0.01220
349.00	10.33	0.1352	0.01309
350.00	10.30	0.1430	0.01388
351.00	10.27	0.1526	0.01486
352.00	10.31	0.1650	0.01599
353.00	10.45	0.1815	0.01736
354.00	10.45	0.1989	0.01903
355.00	10.40	0.2163	0.02080
356.00	10.35	0.2364	0.02284
357.00	10.29	0.2595	0.02522
358.00	10.23	0.2860	0.02797
359.00	10.14	0.3159	0.03115
360.00	10.06	0.3501	0.03481
361.00	9.962	0.3900	0.03916
362.00	9.850	0.4342	0.04409
363.00	9.726	0.4828	0.04967
364.00	9.593	0.5360	0.05590
365.00	9.444	0.5927	0.06280
366.00	9.278	0.6525	0.07036
367.00	9.101	0.7148	0.07858
368.00	8.893	0.7752	0.08726
369.00	8.671	0.8356	0.09640
370.00	8.501	0.9010	0.1060
371.00	8.298	0.9607	0.1158
372.00	8.074	1.014	0.1257
373.00	7.840	1.060	0.1354
374.00	7.600	1.100	0.1449
375.00	7.354	1.133	0.1541
376.00	7.107	1.156	0.1628
377.00	6.861	1.172	0.1709
Tg = 378.00	6.615	1.178	0.1782
379.00	6.371	1.177	0.1848
380.00	6.136	1.168	0.1903
381.00	5.911	1.153	0.1950
382.00	5.694	1.132	0.1988
383.00	5.486	1.106	0.2016

DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
384.00	5.290	1.077	0.2037
385.00	5.106	1.047	0.2050
386.00	4.930	1.014	0.2057
387.00	4.764	0.9810	0.2059
388.00	4.608	0.9482	0.2058
389.00	4.461	0.9153	0.2052
390.00	4.323	0.8837	0.2044
391.00	4.194	0.8537	0.2035
392.00	4.069	0.8244	0.2026
393.00	3.954	0.7973	0.2016
394.00	3.843	0.7716	0.2008
395.00	3.737	0.7473	0.2000
396.00	3.637	0.7244	0.1992
397.00	3.542	0.7042	0.1988
398.00	3.452	0.6853	0.1985
399.00	3.365	0.6654	0.1978
400.00	3.282	0.6486	0.1976
401.00	3.201	0.6325	0.1976
402.00	3.124	0.6173	0.1976
403.00	3.050	0.6034	0.1978
404.00	2.980	0.5902	0.1981
405.00	2.912	0.5778	0.1984
406.00	2.846	0.5650	0.1985
407.00	2.784	0.5535	0.1988
408.00	2.754	0.5476	0.1988
409.00	2.737	0.5442	0.1988
410.00	2.684	0.5342	0.1990
411.00	2.631	0.5239	0.1991
412.00	2.580	0.5139	0.1992
413.00	2.532	0.5040	0.1991
414.00	2.486	0.4942	0.1988
415.00	2.442	0.4847	0.1985
416.00	2.400	0.4753	0.1981
417.00	2.360	0.4664	0.1976
418.00	2.323	0.4577	0.1970
419.00	2.289	0.4491	0.1962
420.00	2.256	0.4408	0.1953
421.00	2.225	0.4326	0.1944
422.00	2.195	0.4245	0.1934
423.00	2.169	0.4169	0.1922
424.00	2.144	0.4094	0.1909
425.00	2.120	0.4020	0.1896
426.00	2.099	0.3952	0.1882
427.00	2.080	0.3885	0.1868
428.00	2.062	0.3820	0.1853
429.00	2.046	0.3757	0.1836
430.00	2.032	0.3699	0.1820
431.00	2.020	0.3646	0.1804
432.00	2.010	0.3593	0.1788
433.00	2.002	0.3542	0.1770
434.00	1.995	0.3494	0.1751
435.00	1.990	0.3448	0.1732
436.00	1.988	0.3406	0.1713
437.00	1.988	0.3369	0.1695

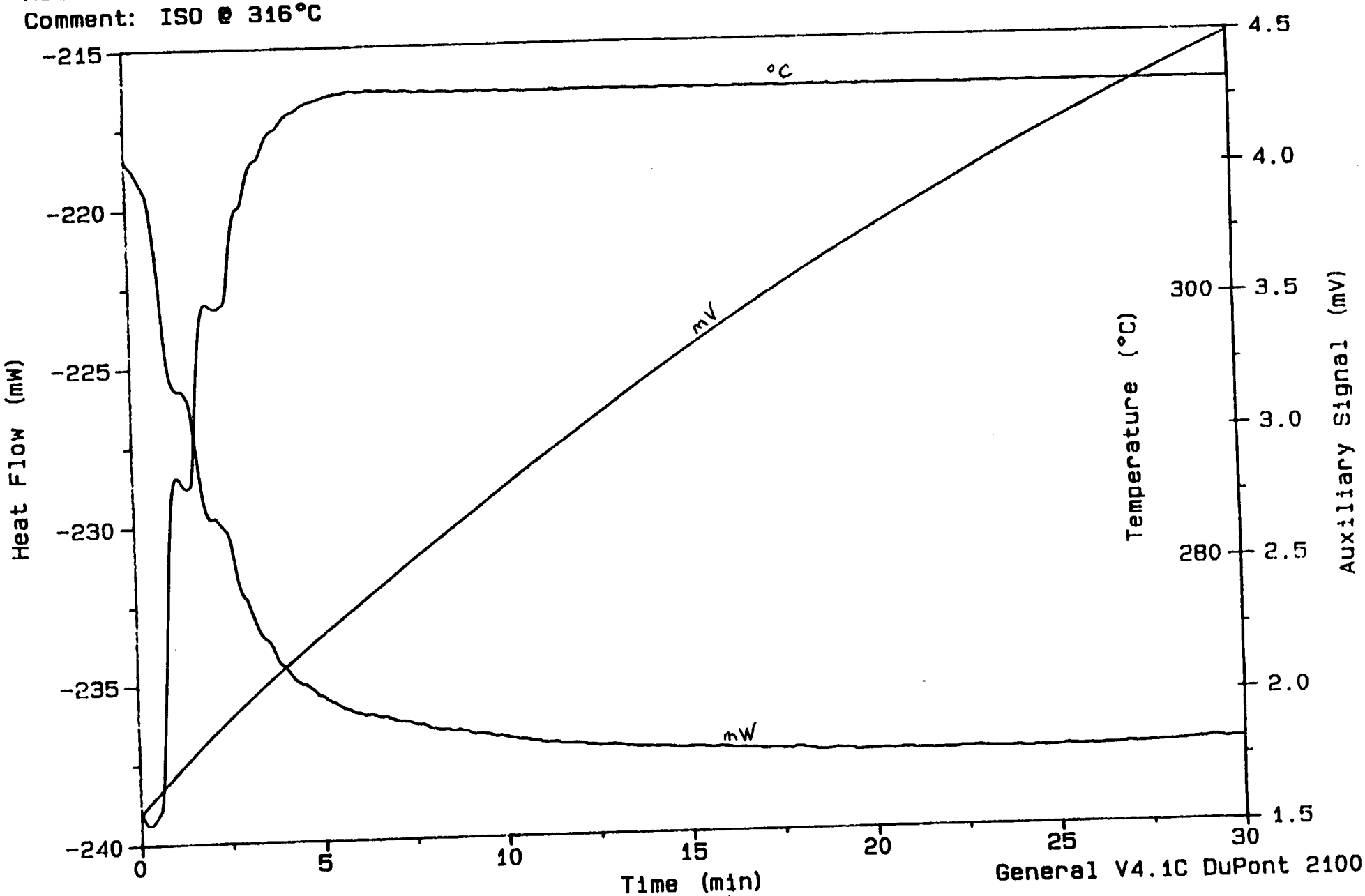
DMA V4.1A 01/18/96 15:03:53

Temperature (°C)	E' (GPa)	E" (GPa)	Tan Delta
438.00	1.989	0.3332	0.1673
439.00	1.992	0.3296	0.1653
440.00	1.998	0.3264	0.1634
441.00	2.006	0.3233	0.1612
442.00	2.014	0.3202	0.1589
443.00	2.027	0.3176	0.1567
444.00	2.041	0.3154	0.1546
445.00	2.056	0.3129	0.1522

Sample: CINCINNATI TESTING LAB
Size: 2.1300 mg
Method: THERM COND HI TEMP
Comment: ISO @ 316°C

DSC

File: RUN006.02
Operator: GALASKA
Run Date: 13-Mar-96 10:28



General V4.1C DuPont 2100

03/13/96 14:31:27

General Analysis

File: RUN006.04 Run Date: 13-Mar-96 14:13
Program: General v4.1C Run Number: 33

DuPont 2100 Thermal Analysis -- DSC

Sample: CINCINNATI TESTING LAB
Size: 2.1300 mg
Cell Constant: 1.0000
Operator: GALASKA
Method: THERM COND HI TEMP
Comment: ISO @ 316°C

Time min	Heat Flow mW	Auxiliary Signal mV	Temperature °C
0.00			
1.00	-216.9	1.861	281.45
2.00	-221.1	1.997	298.21
3.00	-223.6	2.121	306.85
4.00	-225.4	2.233	312.03
5.00	-226.5	2.345	315.02
6.00	-227.2	2.451	316.17
7.00	-227.8	2.557	316.49
8.00	-228.3	2.660	316.51
9.00	-228.7	2.764	316.47
10.00	-229.0	2.867	316.43
11.00	-229.3	2.968	316.40
12.00	-229.5	3.067	316.39
13.00	-229.7	3.164	316.38
14.00	-229.9	3.257	316.37
15.00	-230.1	3.350	316.36
16.00	-230.1	3.438	316.34
17.00	-230.2	3.524	316.33
18.00	-230.4	3.611	316.34
19.00	-230.5	3.695	316.34
20.00	-230.6	3.777	316.34
21.00	-230.6	3.857	316.33
22.00	-230.7	3.933	316.32
23.00	-230.7	4.008	316.31
24.00	-230.7	4.081	316.29
25.00	-230.7	4.153	316.25
26.00	-230.8	4.223	316.24
27.00	-230.8	4.290	316.26
28.00	-230.9	4.356	316.28
29.00	-230.9	4.421	316.28
30.00			
31.00			

THERMAL CONDUCTIVITY OF POLYMERS BY DSC

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ABSTRACT

Differential Scanning Calorimetry (DSC) is commonly used to measure the heat flow in and out of a sample as a function of time and temperature. The rate at which heat travels through a sample, its thermal conductivity, is an important processing property. Thermal conductivities of most polymers are between 0.1 and 2.0 W/mK [2] depending on the molecular weight and crosslinking. A highly crystalline polymer will have a greater conductivity than the equivalent amorphous material and thermal conductivity will vary with degree of crystallinity.

In this paper, a method for determining the thermal conductivity of polymeric materials through a simple modification of the TA 910 DSC analyzer will be described. An external chromel-alumel thermocouple (Type K), covered by a copper heat sink, is used to record the temperature at the top of the test specimen (T_2). Heat is supplied by the DSC unit to hold the sample isothermally at the desired test temperature (T_1). The temperature gradient (T_1 - T_2) along with the cylindrical sample dimensions is used in the Fourier heat flow equation to calculate the thermal conductivity of the material with respect to a standard.

$$K_s = K_r \times \frac{mW_s}{mW_r} \times \frac{L_s}{L_r} \times \frac{D^2_r}{D^2_s} \times \frac{\Delta T_r}{\Delta T_s}$$

where,

K = thermal conductivity, W/mK
mW = Heat Flow, mW
L = specimen length, mm
D = specimen diameter, mm
ΔT = temperature differential (T_1- T_2) (^oC)
r = reference
s = sample

APPARATUS

The auxiliary mV signal (signal B) is imported into the TA2100 controller from the DSC 910 cell base by using an external Type K thermocouple with a cold junction. This mV output signal was calibrated and found to be very accurate in determining the temperature. Heat is generated by the DSC unit, travels through the specimen to the external thermocouple, which is set in copper. A large copper heat sink with a hole for the thermocouple sits on a steel spacer with two windows, then is closed off by a steel cover and convection shield. The whole unit is then covered by an open-top glass cover. A transite cover with a hole lined up with the DSC sample platform is placed just above the DSC cell to reduce the convection heat losses. See Figure 1.

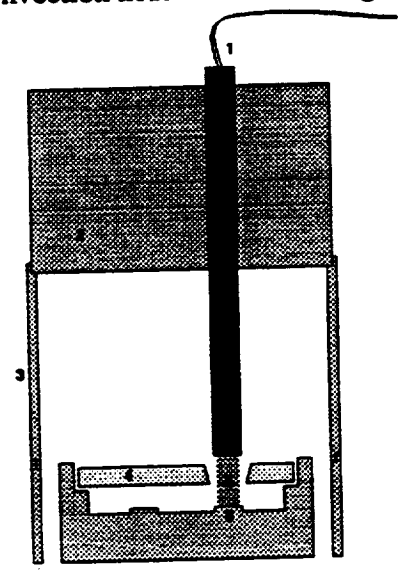

Figure 1. Diagram of DSC cell modification. 1. external thermocouple, 2. copper heat sink, 3.steel spacer, 4. transite cover, 5. sample, 6. DSC sample platform.

EXPERIMENTAL PROCEDURE

With the TA 2100 Controller on the Signal Control screen, the signal B (mV) was zeroed with the external thermocouple in the ice bath. The heat flow signal A (mW) was zeroed when a stable reading was obtained at room temperature. A silicone lubricant was used to ensure better contact between the external thermocouple, the sample, and the DSC cell. The sample was put in place through the window. The thermocouple was introduced into the copper heat sink and locked in place with its bottom touching the sample. The window was closed and the glass cover placed over the unit. The DSC was then heated to 25°C and held isothermally for 12 minutes recording the signals A (mW) and B (mV). Cylindrical samples of Pyrex 7740, vulcanized natural rubber, LDPE, HDPE and a photoresin (Ciby-Geigy cibatool 5081.1) were tested. At least six measurements of each sample were made to obtain a reasonable average. The DSC was cooled to room temperature in between each run.

SAMPLE PREPARATION

Six different materials were tested with this method. These include: 1. Pyrex 7740 glass, 2. photopolymer 5081.1, 3. low density polyethylene, 4. high density polyethylene, 5. polystyrene, 6. a natural rubber reference compound as used by Sircar and Wells [1]. The Pyrex 7740 samples were cut from a 6mm rod and machined to give flat parallel ends. The natural rubber reference compound (100 NR-SMR5, 3.0 sulfur, 5.0 zinc oxide, 0.5 stearic acid, 1.0 phenyl-β- napthylamine, 3.0 pine tar, 0.75 MBT) was mixed on a 6" x 12" roll mill then cured for 80 minutes at 275°F. This compound was found to be stable and give reproducible results at 25°C as reported by Sircar and Wells [1]. Samples of this material were prepared in a mold with a cylindrical cavity of 6.26 mm. The length could be varied depending on the amount of material placed in the hole. The material was compressed and cured to form cylinders. Two samples with lengths of 14.84 and 13.90 mm were tested. The data from these two samples was used to calculate the experimental thermal conductivity reference point at 25°C. The literature value for this reference material was taken as 0.151W/mK [1]. The thermal conductivity of the natural rubber samples was also calculated at the higher temperatures using the 25°C data as the reference.

The LDPE, HDPE and polystyrene samples were also prepared in this mold at an oven temperature of 350°F. Samples with lengths of 12.90, 13.94 and 11.37 mm respectively were tested.

The photopolymer sample was prepared by using a 1" section of a 5 mm glass tube as a mold for containing the liquid. The bottom was plugged with a butyl rubber and the tube was positioned vertically on a flat surface. It was filled with the photoresin and placed in a vacuum oven for about 15 minutes at room temperature to remove dissolved gasses. The sample was then exposed to a UV light for 2 hours, rotating 1/4 turn every half hour. When the sample was completely cured, the glass tube was carefully broken to recover the sample. The sample ends were sanded until they were flat and parallel with no voids. A cylindrical sample with a length of 13.32 mm and a diameter of 5.06 was used for this study.

RESULTS

This method was found to give acceptable values of thermal conductivity for the polymers tested as listed in Table 1. The values cited are an average of six measurements for each sample. The experimental data for the Pyrex 7740 and the polystyrene samples agreed favorably with the literature values to within 2%. However, the comparison of the experimental and literature values of the polyethylene samples was not as close. This difference could be due to a number of reasons including the samples' thermal history, its crystallinity, or to small undetectable voids in the test specimen.

The thermal conductivity of the natural rubber reference sample agreed with the value cited by Sircar and Wells [1]. A literature value was not available for the photopolymer sample. The thermal conductivity of the rubber compound and the photopolymer sample decreased slightly with increasing temperature as seen in Figure 2.

TABLE 1

Sample (length, mm)	Temperature (°C)	Thermal Conductivity (W/mK)	Literature Value (W/mK)
Natural Rubber	25	0.145	0.151 [1]
(d = 5.75mm)	40	0.116	
(l = 13.90mm)	60	0.106	
	80	0.101	
Natural Rubber	25	0.153	0.151 [1]
(d = 5.75mm)	40	0.112	
(l = 14.84mm)	60	0.107	
	80	0.102	
Photopolymer 5081.1	25	0.222	n/a
(d = 5.06mm)	40	0.204	
(l = 13.32mm)	60	0.193	
	80	0.188	
HDPE	25	0.59	0.46 to 0.50 [4]
(d = 5.71mm)			
(l = 13.94mm)			
LDPE	25	0.49	0.33 to 0.38 [4]
(d = 5.71mm)			
(l = 12.90mm)			
Polystyrene	25	0.14	0.14 [2]
(d = 5.96mm)			
(l = 11.37mm)			
Pyrex 7740	30	1.075	1.101 [5]
(d = 5.95mm)	40	1.117	1.116
(l = 12.10mm)	60	1.140	1.145
	70	1.168	1.159
	80	1.180	1.174
	100	1.202	1.203

CONCLUSIONS

This modified DSC method is an easy and quick way to determine thermal conductivity of polymeric compounds. It also has the advantage of using small samples and takes only minutes for each determination. However, it is recommended to make at least six measurements on each sample at each temperature of interest to obtain a more accurate average value for the thermal conductivity. It was also found that the room temperature should be maintained at a constant temperature to get more consistent values at lower temperatures.

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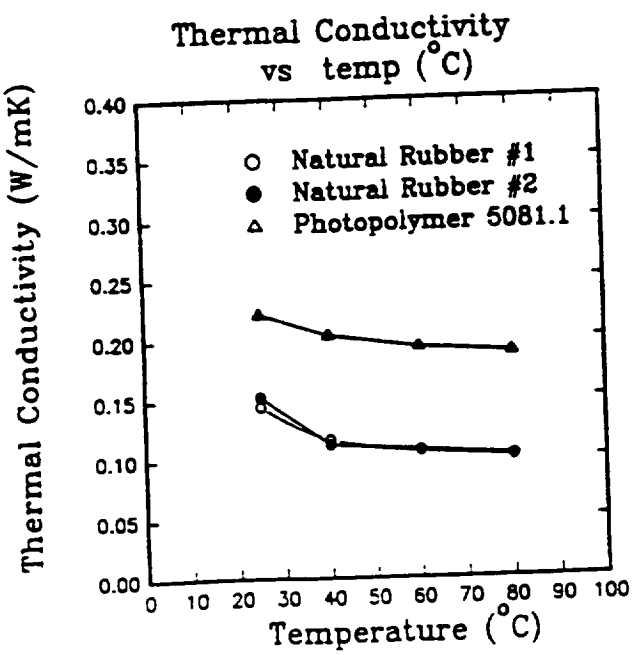

Figure 2. Thermal Conductivity verses Temperature of natural rubber and photopolymer samples.

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13. ABSTRACT ***(Maximum 200 words)***
The overall objective is to develop a satisfactory sheet molding compound (SMC) of a high temperature polymide, such as PMR-11-50, VCAP-75, or NB2-76, and to develop compression molding processing parameters for a random, chopped fiber, high temperature, sheet molding compound that will be more affordable than the traditional hand lay-up fabrication methods. Compression molding will reduce manufacturing costs of composites by: (1) minimizing the conventional machining required after fabrication due to the use of full 360' matched tooling, (2) reducing fabrication time by minimizing the intensive hand lay-up operations associated with individual ply fabrication techniques, such as ply orientation and ply count, and (3) possibly reducing component mold time by advanced B-staging prior to molding. This program is an integral part of Allison's T406/AE engine family's growth plan, which will utilize technologies developed under NASA's Sub-sonic Transport (AST) programs, UHPTET initiatives, and internally through Allison's IR&D projects. Allison is aggressively pursuing this next generation of engines, with both commercial and military applications, by reducing the overall weight of the engine through the incorporation of advanced, lightweight, high temperature materials, such as polymer matrix composites. This infusion of new materials into the engine is also a major factor in reducing engine cost because it permits the use of physically smaller structural components to achieve the same thrust levels as the generation that it replaced. A lighter, more efficient propulsion system translates to a substantial cost and weight savings to an airframe's structure.

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