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Kansas City Division

BDX-613-135

BONDING STRENGTH
OF
ENCAPSULATING
MATERIALS TO
HOOKUP WIRE

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Technical Communications **Bendix** **Kansas City Division**

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ABSTRACT

Knowledge of the effect of rigorous conditioning on the bond strengths between encapsulating materials and insulated wire is necessary for the fabrication of encapsulated, insulated hookup wire for cable assemblies in weapon applications. Data of the effectiveness of bonds between two encapsulating systems and six types of insulated wire following temperature, thermal and mechanical shock, heat aging, ozone, humidity, and composite environment conditionings are presented in this report.

Information on best bonds obtained is included in the conclusions. Detailed data, presented both in tabular and graphic form, and illustrations are appended.

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I. INTRODUCTION

Cable assemblies in weapon applications must withstand very rigorous environmental conditions. To provide the necessary electrical and mechanical performance; the insulated hookup wire in the cable assemblies, or harnesses, must be encapsulated, or potted, at the connectors and the junctions.

Since data of bond strengths between encapsulating materials and insulated wires were not available in the past to assist the engineer, this evaluation was undertaken to fill this need.

Polyurethane and filled epoxy encapsulating systems previously had been found suitable for meeting the wide range of environments for cable assemblies in weapon applications. Six types of insulated wire were evaluated in an effort to meet the needs of the various applications and exposures. The wire types included irradiated polyolefin, polyvinylidene fluoride, chemically-etched polytetrafluoroethylene (PTFE), chemically-etched fluorinated-ethylene-propylene (FEP), a polyimide-FEP tape combination, and surface-treated polytetrafluoroethylene.

This report presents results of evaluation of the effectiveness of bonds obtained between the two encapsulating systems, and the six wire insulation materials under the following conditions:

1. No special conditioning. Adhesion determined at room ambient.

2. Temperature shock. Adhesion determined at room ambient.

3. Conditioning at high and at low temperatures. Adhesion determined at each temperature.

4. Mechanical shock and vibration. Adhesion determined at room ambient.

5. Heat aging. Adhesion determined at room ambient.

6. Humidity conditioning. Adhesion determined at room ambient.

7. Ozone conditioning. Adhesion determined at room ambient.

8. Combined conditioning of Steps 2, 4, 5, 6, and 7. Adhesion determined at room ambient.

II. MATERIALS USED

A. Potting Materials

The formulations of polyurethane and filled epoxy reported below were used for the encapsulation evaluations described in this report.

TYPE I--POLYURETHANE

Formulation	PBW
Adiprene L-100	100
Moca Curing Agent	11

TYPE II--EPOXY

Formulation	PBW
Epoxy Resin	100
Aluminum Oxide	300
Amine Curing Agent	20

B. Insulation Wire Types

The different wire constructions described in Table I, on the following page, were used in the adhesion evaluations.

The outer insulation surface of the first wire type, polytetrafluoroethylene, and the fifth wire type, fluorinated-ethylene-propylene, were chemically etched with a metallic sodium-naphthalene complex to produce a carbonaceous film (approximately one to two molecules thick) for improved bondability. The etched surface presumably had little effect on the electrical properties of the wire.

The fourth wire type, surface-treated polytetrafluoroethylene, had an additive proprietary treatment applied to it by the wire manufacturer which supposedly enhanced its potting bond strength.

TABLE I

Insulation Wire Constructions

WIRE TYPE	SIZE (AWG)	CONDUCTOR	INSULATION	WALL THICKNESS (Inches)	OD (Inches)	RATING*
Etched Polytetrafluoroethylene (TFET)	No. 20	Stranded (19/32) Silver-coated copper wire	Etched Polytetrafluoroethylene	0.009	0.059	600 volts RMS and 200°C
Jacketed Irradiated Polyolefin (VFPE)	No. 20	Stranded (19/32) tin-coated copper wire	Irradiated polyolefin (Jacketed with irradiated polyvinylidene fluoride)	0.0075	0.057	600 volts RMS and 150°C
Irradiated Polyolefin (IPE)	No. 20	Stranded (19/32) tin-coated copper wire	Irradiated polyolefin	0.010	0.060	600 volts RMS and 125°C
Surface-Treated Polytetrafluoroethylene (FLEX)	No. 20	Stranded (19/32) silver-coated copper wire	Polytetrafluoroethylene (Proprietary Treated)	0.010	0.060	600 volts RMS and 200°C
Etched Fluorinated-ethylene-propylene (FEPT)	No. 20	Stranded (19/32) silver-coated copper wire	Etched Fluorinated-ethylene-propylene	0.010	0.060	600 volts RMS and 200°C
Polyimide Fluorinated-ethylene-propylene (HFFH)	No. 20	Stranded (19/32) silver-coated copper wire	Two tapes, contra-helically wrapped with 50% overlap	0.007	0.056	600 volts RMS and 200°C

*All rated at maximum continuous temperature.

The tapes used for insulation in the sixth wire type, polyimide-(fluorinated-ethylene-propylene), were each 0.001 inch thick polyimide with 0.005 inch thick FEP on one side. The tapes were applied with the FEP sides back-to-back, so that the polyimide surface of the bottom tape was against the conductor, and so that the polyimide surface of the top tape was the outer surface of the finished wire.

III. TEST METHODS AND RESULTS

A. Preparation of Specimens

1. WIRE CUTTING AND CLEANING

Each type of insulated wire was cut into nine-inch lengths. The lengths were cleaned to remove grease, dirt, and surface contaminants by wiping each with a clean paper wipe dampened with clean acetone or MEK. The wires were allowed to dry at room temperature for a minimum of one hour. To prevent soiling or contaminating the cleaned insulation surfaces, the wire specimens were covered with clean paper wipes and handled with clean gloves. In all subsequent specimen preparations; no additives, primers, or additional surface treatments were used on the insulation prior to potting.

The polytetrafluoroethylene (Type TFET) and the fluorinated-ethylene-propylene (Type FEPT) insulated wires had already been chemically etched on the outside of the insulation by the wire manufacturers. Type FLEX designates a polytetrafluoroethylene insulated wire with a proprietary surface treatment also applied by the wire manufacturer.

2. ENCAPSULATION OF WIRE

The wire specimens were placed in the potting mold fixture (See Figure 15) in groups of six. Each group was potted in accordance with the process standard for its potting type. Figure 16 shows a finished potted wire specimen ready for testing.

The cure schedules used in the preparation of the encapsulated specimens are listed in Table II.

TABLE II

Cure Schedules for Encapsulated Specimens

POTTING TYPE		CURE TYPE	
TYPE	FORMULATION	TYPE	SCHEDULE
I	Adiprene L-100	1	4 hours at 160°F (Standard Cure*)
I	"	2	48 hours at Room Temperature
I	"	3	3 hours at 200°F
II	Epoxy-Aluminum Oxide	4	4 hours at 130°F plus 16 hours at 200°F
II	" " "	5	2 hours at 160°F plus (Standard Cure*) 6 hours at 250°F

*Unless otherwise specified, the "Standard Cure" was used for all specimens tested.

B. Conditioning and Testing Methods

Twelve specimens were conditioned and tested for each type of conditioning specified. The range (low and high value) and the average value for each group of twelve specimens are reported in Table A-1, Appendix A.

The bond strength between the potting material and the insulation type was determined, after the specimen group was subjected to the specified conditioning, by the application of a tensile load at the rate of one inch per minute. A specimen mounted in the tensile tester is shown in Figure 16.

The conditioning and testing conducted on each of the potted insulation groups is listed in Table III.

TABLE III

Testing-Conditioning and Code*

CODE		TESTING-CONDITIONING
TYPE	SUB TYPE	
A		Pulled at Temperature Specified
	a	at -65°F
	b	room temperature
	c	at 200°F
	d	at 250°F
	e	at 350°F
B		Thermal Shock - Three cycles - Pulled at room temperature
	a	200°F to -65°F
	b	250°F to -65°F
	c	350°F to -65°F
C		Mechanical Shock
	a	Vibration (1) 10-31 cps at 0.2 inch amplitude, plus (2) 31-2000 cps at 10 g's in two axis
	b	Shock - 100 g's through three planes at 10 msec each
D		Heat Aging - Pulled at room temperature
	a	96 hours at 200°F
	b	96 hours at 250°F
	c	96 hours at 350°F
E		Ozone Resistance - Pulled at room temperature
F		Humidity Resistance - Pulled at room temperature
G		Subjected to test types A through E - Pulled at room temperature
	a	200°F max. temperature limit
	b	250°F max. temperature limit
	c	350°F max. temperature limit

*The results obtained from these evaluation programs are quantitatively accumulated in Table A-1 and graphically plotted in Figures 19 and 20.

C. Effects of Conditioning and Testing on Bond Strength

1. EFFECTS OF DIFFERENT CURES

The effects of different cures on the bond strengths between the potting and the insulation were evaluated by using three groups of polyurethane-potted insulation, with a different cure schedule for each group; and by using two groups of epoxy and aluminum oxide-potted insulation, with a different cure schedule for each group. These groups were not subjected subsequently to any conditioning and were tensile pulled at room temperature. The results are tabulated in Table IV, and in Figure1.

The cure rate did not appear to affect the bond strength appreciably if the time-temperature relationship were sufficient to activate the curing agent.

2. EFFECTS OF TEMPERATURE

The effects of temperature on the bond strength between the potting material and the insulation were evaluated after temperature conditioning. Each potting-insulation group was conditioned in a chamber maintained at the specified temperature for a minimum of two hours. While still at the specified temperature, the specimens were tensile pulled to determine the bond strength of each. The specimens were:

a. Pulled at -65°F

b. Pulled at room temperature

c. Pulled at 200°F

d. Pulled at 250°F

e. Pulled at 350°F

The selection of temperature was made on the basis of the continuous rating of the insulation and/or the potting material.

The bond strengths were several times higher at -65°F than they were at room temperature, with the exception of the polyimide-FEP system in which the bond strengths equaled the tensile strength of the insulation system.

At elevated temperatures, as was expected, the bond strengths were low in comparison to the room temperature values. However, the values

TABLE IV

Effects of Different Cures on Bond Strength

POTTING		TYPE WIRE INSULATION	PULLOUT STRENGTH (Pounds)		TYPE OF FAILURE
COMPOUND	CURE		Avg.	Range	
Polyurethane	* 4 Hrs at 160°F	TFET	10.8	9.8 to 11.5	Adhesive
Polyurethane	48 Hrs at R.T.	TFET	11.8	10. to 13.5	Adhesive
Polyurethane	3 Hrs at 200°F	TFET	11.2	10.5 to 11.7	Adhesive
Polyurethane	* 4 Hrs at 160°F	HFFH	24.9	14.5 to 30.0	Insulation Broke Outside Potting
Polyurethane	48 Hrs at R.T.	HFFH	38.2	33.6 to 42.0	Insulation Broke Outside Potting
Polyurethane	3 Hrs at 200°F	HFFH	33.8	28.0 to 36.5	Adhesive
Epoxy-Al_2O_3	4 Hrs at 130°F plus 16 Hrs at 200°F	TFET	7.6	6.2 to 9.8	Adhesive
Epoxy-Al_2O_3	2 Hrs at 160°F * plus 6 Hrs at 250°F	TFET	9.4	8.8 to 10.2	Adhesive
Epoxy-Al_2O_3	4 Hrs at 130°F plus 16 Hrs at 200°F	HFFH	31.7	23.0 to 38	Insulation Broke Outside Potting
Epoxy-Al_2O_3	2 Hrs at 160°F * plus 6 Hrs at 250°F	HFFH	31.9	25 to 39.5	Insulation Broke Outside Potting

*Preferred Cure

obtained on the polyimide-FEP film (Type HFFH) were impressively high, a great deal higher than those of the closest insulation type. The results are tabulated in Table A-1, and presented graphically in Figures 2, 3, 4, and 5.

3. EFFECTS OF THERMAL SHOCK

The effects of thermal shock on bond strengths were evaluated after subjecting each group of specimens to three cycles of thermal shock. Each cycle consisted of four hours at a specified high temperature, with five minutes maximum transfer time, and then four hours at -65°F. All specimens were allowed to stabilize to room temperature before tensile pulling. Cycles for the different potting materials follow:

a. All polyurethane-potted specimens were cycled from 200°F to -65°F.

b. All epoxy-potted IPE type specimens were cycled from 250°F to -65°F.

c. All other epoxy-potted specimens were cycled from 350°F to -65°F.

Results are presented both in tabular and graphic form in Table A-1 and in Figures 6 and 7, respectively.

In most of the test groups, the bond strengths obtained were about the same as the strengths obtained on specimens, with the same types of potting and insulation, which received no special conditioning and were tensile pulled at room temperature.

4. EFFECTS OF VIBRATION AND MECHANICAL SHOCK

The specimens were tensile pulled to test the bond strengths after subjection to conditioning for vibration and mechanical shock.

a. Vibration

Each group of specimens was mounted on a hold-down plate (See Figure 17). For the vibration tests, a vibration exciter, was used in a sinusoidal node as follows:

(1) 10 to 31 cps at 0.2 inch amplitude

(2) 31 to 2000 cps at 10 g's in two axes, 15 minutes per axis.

b. Mechanical Shock

Following the vibration, each group was subjected to a drop load of a 100 g's through three mutually perpendicular planes for a shock duration of 10 milliseconds each. An AVCO drop table was used.

The bonds between the insulation and the potting material of all specimens were not affected appreciably by vibration or mechanical shock. The results are tabulated in Table A-1 and graphically presented in Figure 8.

5. EFFECTS OF HEAT AGING

Each set of specimens was conditioned in an air-circulating oven for the time, and at the temperature specified below:

a. The polyurethane-potted specimens were conditioned 96 hours at 200°F.

b. The Type IPE-epoxy group was conditioned 96 hours at 250°F.

c. All other epoxy-potted specimens were conditioned 96 hours at 350°F.

After conditioning all specimens were allowed to stabilize at room temperature before tensile pulling. The results are tabulated in Table A-1 and presented graphically in Figures 9 and 10.

6. EFFECTS OF OZONE

To determine each specimen's ozone resistance, its insulated wires were restrained so that a mechanical stress was applied to the junction of the insulated wire at its entrance to the potting. To accomplish this the insulated wires were bent sharply over and back along the side of the potting and fastened.

The bent specimens were placed in an ozone tester and conditioned for seven days at 120°F using an ozone concentration of 50 parts per 100,000,000. The specimens were allowed to stabilize at room temperature before tensile pulling. Results are tabulated in Table A-1 and graphically presented in Figure 11.

The bond strengths were consistent with data obtained on specimens, with the same types of potting and insulation, which did not receive any conditioning and were pulled at room temperature.

7. EFFECTS OF HUMIDITY

To determine the effects of humidity on bond strength over an extended period of time and temperature; each specimen was subjected to 10 continuous 24-hour cycles, with the relative humidity maintained at 95 percent and with temperatures varying from 25°C (77°F) to 65°C (149°F). Each cycle followed the profile shown in Figure 18. Following the last cycle, the specimens were allowed to stabilize at room atmospheric conditions for a minimum of 24 hours before tensile pulling. Results are tabulated in Table A-1 and presented graphically in Figure 12.

The bond strengths were consistent with data obtained on specimens, with the same types of potting and insulation, which did not receive any conditioning and which were pulled at room temperature.

8. EFFECTS OF COMPOSITE ENVIRONMENT

To determine the effects of the composite environment on bond strength, specimens with the same potting and insulation as those previously tested were subjected, in order; to temperature testing, thermal shock, vibration and mechanical shock, heat aging, ozone resistance testing, and humidity testing with the following limitations:

a. The polyurethane-potted specimens were conditioned according to the appropriate section of each test.

b. The IPE epoxy-potted specimens were conditioned according to the appropriate section of each test.

c. All other epoxy-potted specimens were conditioned according to the appropriate section of each test.

Upon completion of composite environment conditioning, the specimens were allowed to stabilize to room ambient conditions before tensile pulling. The results are tabulated in Table A-1 and presented graphically in Figure 13.

The only insulation groups which completed this conditioning satisfactorily were the TFET, HFFH, and VFPE types. The potting of half or more of the specimens of most of the other insulation types had separated completely from the wire following mechanical shock conditioning.

IV. SUMMARY

The bond strengths of the potting materials to the various types of insulation were affected appreciably by factors such as cleanliness, good workmanship and preparation, proper formulation of the encapsulant, and adequate cure time and/or temperature. The criticality of the cure was dependent on a minimum time and temperature relationship to activate the catalysis effectively; additional temperature or time did not offer increased bond strengths.

The insulation type that consistently offered the highest bond strength was the polyimide-(fluorinated-ethylene-propylene) tape-wrapped and heat-sealed construction (Type HFFH). The polyimide surface of the tape was the outside surface of the insulated wire.

The irradiated polyolefin jacketed with irradiated polyvinylidene fluoride insulation system (Type VFPE) offered the second highest bond strengths. However, cohesive failures were experienced between the interfaces of the two insulations, rather than between the encapsulant and the insulation interface. At elevated temperatures (200°F to 250°F), its bond strengths were no better than those of fluorocarbon wire.

The FLEX designation is a wire manufacturer's polytetrafluoroethylene (PTFE) insulated wire with a proprietary surface treatment to enhance its adhesion to encapsulation materials. However, test data consistently yielded results which were no better than results obtained on non-treated PTFE wire.

Three of the wire insulation types, IPE, FLEX, and FEPT, provided no adherance to the potting material following their subjection to the complete series of tests.

The polytetrafluoroethylene (Type TFET) and fluorinated-ethylene-propylene (Type FEPT) insulated wires, which were chemically etched to enhance their bond strength, were subject to failure between their interfaces and their etched surfaces.

V. CONCLUSIONS

1. The best adhesion was obtained consistently between the filled epoxy potting compound and the polyimide-FEP tape-wrapped insulated wire. However, the adhesion obtained with the polyurethane potting compound was in the same range as that obtained with epoxy. Bond strengths under most of the test environments varied between 20 and 40 pounds.

2. The irradiated polyolefin jacketed with irradiated polyvinylidene fluoride construction showed the next best adhesion to the encapsulating compounds. In general, a consistently higher bond strength was exhibited between this wire insulation and the polyurethane encapsulant, rather than the epoxy encapsulant.

3. Low tensile bonds were exhibited between the treated fluorocarbon insulations and the two encapsulants.

4. In general, the bond strengths of the various insulations to the encapsulants at -65°F were about double their bond strengths at room temperature.

5. At 200°F the polyurethane-encapsulated specimens retained about 50 percent of their corresponding room temperature strengths with most wire insulations.

6. The epoxy-encapsulated specimens showed erratic bond strengths at 350°F with the various wire insulations; the bond strengths were generally less than half of the room temperature values. The polyimide-FEP insulated wire, however, retained a bond strength of about 70 percent of the room temperature value.

7. Thermal shock appeared to have a beneficial effect on adhesion. The additional exposure to elevated temperatures during cycling apparently enhanced the cure of the encapsulating compounds.

8. Mechanical shock of the specimens had no obvious ill effect on the bond strengths between the encapsulating compounds and the various wire insulations.

9. Heat aging appeared to enhance the bond strengths, apparently because of the added cure of the encapsulants.

10. Exposure to ozone and to high humidity had no appreciable injurious effect on the bond strengths between the potting materials and the wire insulations.

11. The composite environment had only a very minor effect on the strength of the polyurethane-potted specimens; however, the bonds of the epoxy-potted specimens were severely degraded under corresponding exposures.

This latter condition may be attributed to the aggravated exposure experienced during thermal shock and heat aging of the specimens. The resilient nature of the polyurethane potting material undoubtably was responsible for its retention of adhesion to the insulated wire.

APPENDIX A

Tabulation of Bond Strengths After Conditioning and Testing

TABLE A-1

TABULATION OF BOND STRENGTHS AFTER CONDITIONING AND TESTING

TYPE WIRE INSULATION & POTTING	STRENGTH AT TEMPERATURE (POUNDS)															THERMAL SHOCK								
	ROOM TEMP.			-65°F			200°F			250°F			350°F			200° TO -65°F			250°TO -65°F			350°TO -65°F		
	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)
TFET																								
POLYURETHANE	10.8	9.8 - 11.5	P	38.2	34.2 - 44.5	A	6.6	6.3 - 7.1	P							11.1	10.6 - 11.6	A						
EPOXY	9.39	8.8 - 10.2	A	17.5	15.6 - 22	A							3.6	2.8 - 4.1	A							7.6	6.4 - 8.6	A
VFPE																								
POLYURETHANE	21.9	16.7 - 32.3	A	40	38 - 41.7	T	7.5	5.8 - 11.8	JF							20.1	18.2 - 21.8	A						
EPOXY	10.6	5.0 - 16.2	A	11.1	7.6 - 13.8	A							4.1	3.3 - 5.6	A							26.5	24.8 - 28.5	A
IPE																								
POLYURETHANE	14.5	11.7 - 18.3	A	30.1	26 - 38	C	5.6	3.6 - 7.0	A							13.8	12.3 - 14.5	A						
EPOXY	24	16.3 - 28.3	A	10.7	4.4 - 20.5	A				6.9	3.2 - 10.1	A							17.1	2.0 - 34.3	A			
FLEX																								
POLYURETHANE	3.1	2.2 - 3.5	A	8.6	2.7 - 11	A	2.8	2.2 - 3.8	A							4.6	3.6 - 5.9	A						
EPOXY	4.5	3.4 - 6.7	A	8.4	5.8 - 11.6	A							1.7	1.3 - 2.6	A							4.1	1.8 - 6.5	A
FEPT																								
POLYURETHANE	7.9	6.8 - 11.1	A	26.1	20.4 - 31.7	A	5.8	4.7 - 7.4	A							10.1	9.1 - 11.6	A						
EPOXY	7.3	7.6 - 14.1	A	11.8	4.4 - 15.5	A							6.2	3.4 - 7.9	A							9.8	7.8 - 12.5	A
HFFH																								
POLYURETHANE	24.9	14.5 - 30.0	C	37.9	33.7 - 40.7	C	23.4	20.3 - 27.2	A							31.5	29.6 - 34.1	A						
EPOXY	31.9	25.0 - 39.5	C	35.2	27.1 - 42.7	A							22.3	15.0 - 26.5	A							34.5	19.0 - 52.0	A

(I) FAILURE MODE

A = Adhesive
C = Cohesive
P = Partially Cohesive
JF = Jacket Pulled Off Insulation

T = Conductor Broke -- Potting Intact
F = Potting of 1/2 or More of Specimens Loose Following T-Shock

TABLE A-I
(Continued)

TABULATION OF BOND STRENGTHS AFTER CONDITIONING AND TESTING

TYPE WIRE INSULATION & POTTING	MECHANICAL SHOCK			HEAT AGING									OZONE RESISTANCE			HUMIDITY RESISTANCE			COMPOSITE OF ALL ENVIRONMENTS		
				96 HRS AT 200°F			96 HRS AT 250°F			96 HRS AT 350°F											
	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)	AVG	RANGE	(I)
TFET																					
POLYURETHANE	10.9	10.3 - 11.7	A	11.6	11.2 - 12.3	A							10.5	10.2 - 11.5	A	8.8	7.9 - 9.5	A	10.7	9.7 - 12.0	A
EPOXY	9.2	8.0 - 10.5	A							6.8	5.3 - 8.0	A	9.3	7.9 - 10.1	A	7.5	5.0 - 10.3	A	5.6	4.3 - 7.6	A
VFPE																					
POLYURETHANE	20.7	17.6 - 25.8	A	24.8	19.6 - 29.2	A							19.6	16.5 - 24.1	A	19.4	18.2 - 22.8	A	22.1	19.3 - 24.6	A
EPOXY	18.1	12.0 - 25.5	C							27.1	26.0 - 31.2	C	10.1	5.3 - 19.5	A	20.0	12.5 - 25.6	A	16.6	2.5 - 29.8	P
IPE																					
POLYURETHANE	16.2	13.8 - 24.5	A	16.2	15.4 - 17.6	A							13.7	11.6 - 15.0	A	13.5	11.7 - 14.6	A	19.4	17.3 - 22.5	A
EPOXY	23.9	14.4 - 28.3	A				33.5	31.3 - 35.3	P				19.8	13.2 - 28.4	A	13.6	12.8 - 16.7	A	3.9	0 - 20.0	F
FLEX																					
POLYURETHANE	5.0	4.3 - 6.9	A	4.7	3.9 - 5.5	A							4.6	3.6 - 6.2	A	3.2	2.4 - 4.4	A	3.5	2.0 - 5.7	A
EPOXY	4.3	3.0 - 6.2	A							5.1	3.3 - 7.1	A	4.6	3.3 - 6.0	A	4.2	3.0 - 5.8	A	2.7	0 - 6.5	F
FEPT																					
POLYURETHANE	9.9	9.0 - 11.6	P	9.9	8.8 - 11.5	A							9.6	8.0 - 10.7	A	10.5	8.7 - 12.5	A	10.9	8.5 - 13.0	A
EPOXY	9.9	3.0 - 12.3	A							7.1	6.2 - 13.3	A	8.0	6.6 - 12.6	A	8.3	4.8 - 12.3	A	2.6	0 - 9.7	F
HFFH																					
POLYURETHANE	29.7	26.0 - 33.6	A	32.5	19.4 - 37.3	C							30.8	28.1 - 34.2	A	29.8	24.7 - 35.5	A	36.8	29.7 - 43.0	C
EPOXY	32.3	25.7 - 38.5	A							32.9	28.5 - 39.1	A	34.4	23.0 - 44.5	A	35.4	26.0 - 41.5	A	30.8	20.0 - 35.5	A

APPENDIX B

Illustrations

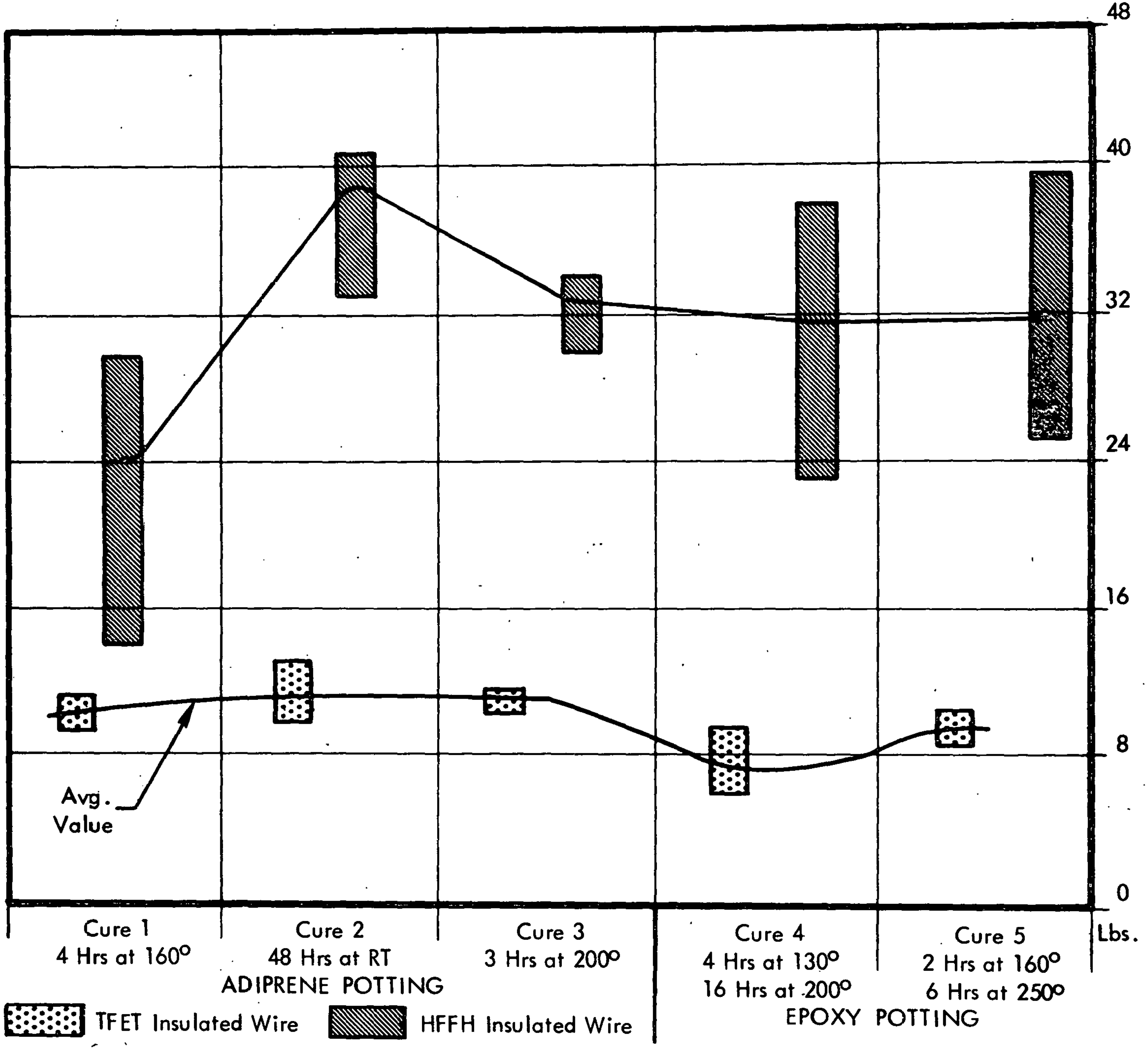


FIGURE 1. Effects of Different Cures on Bond Strength

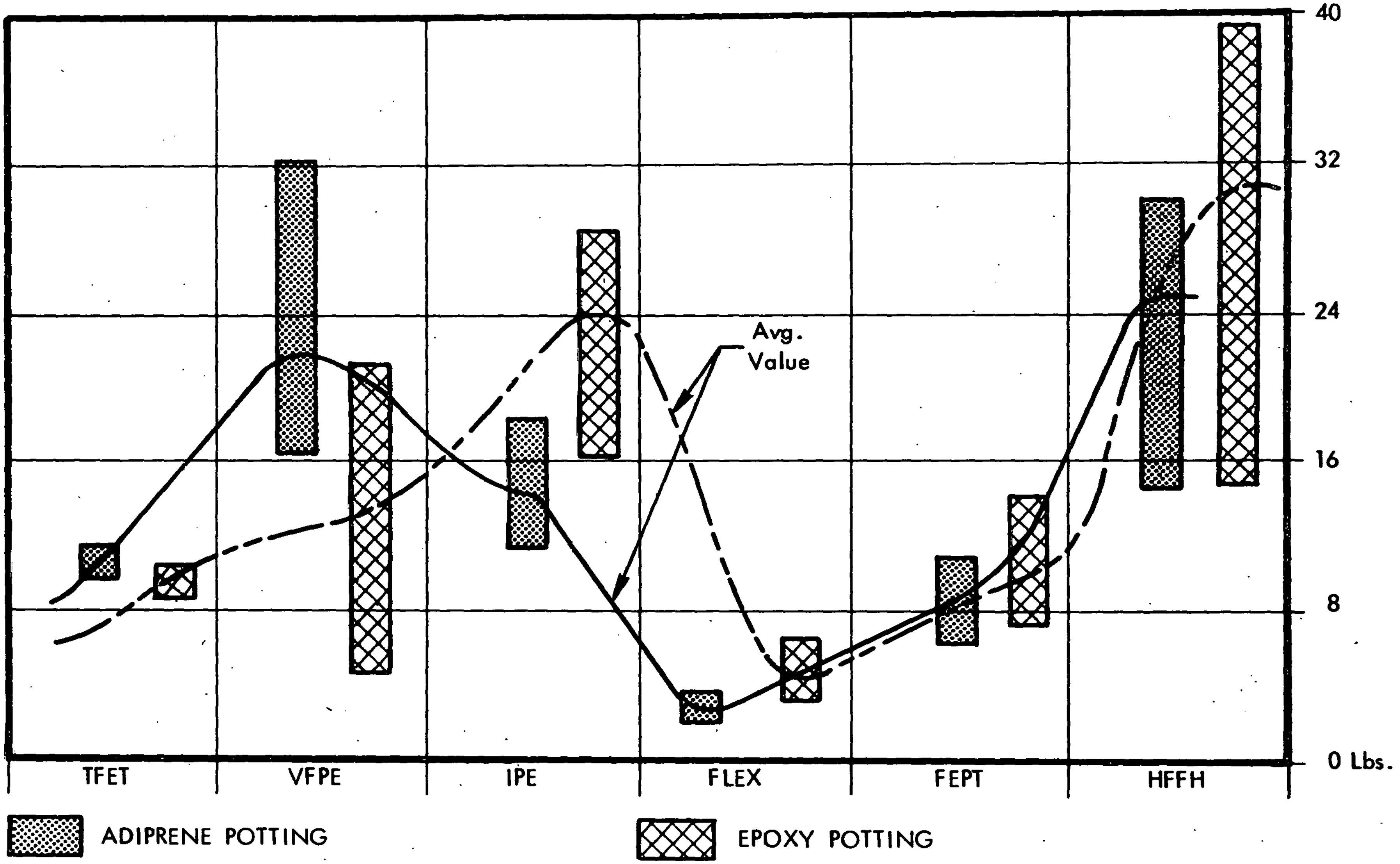


FIGURE 2. Specimens Pulled at Room Temperature

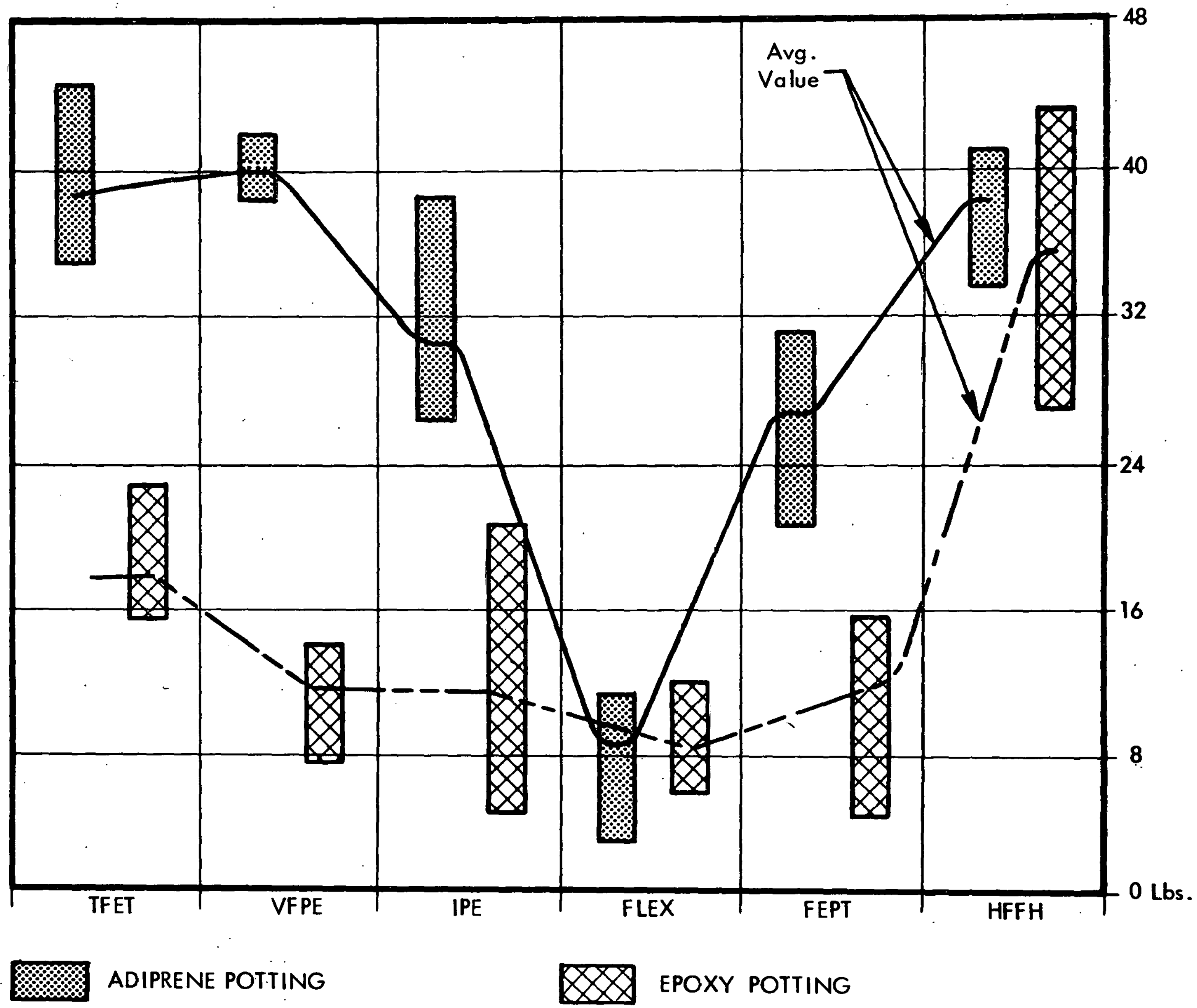


FIGURE 3. Specimens Pulled at -65^{0}F

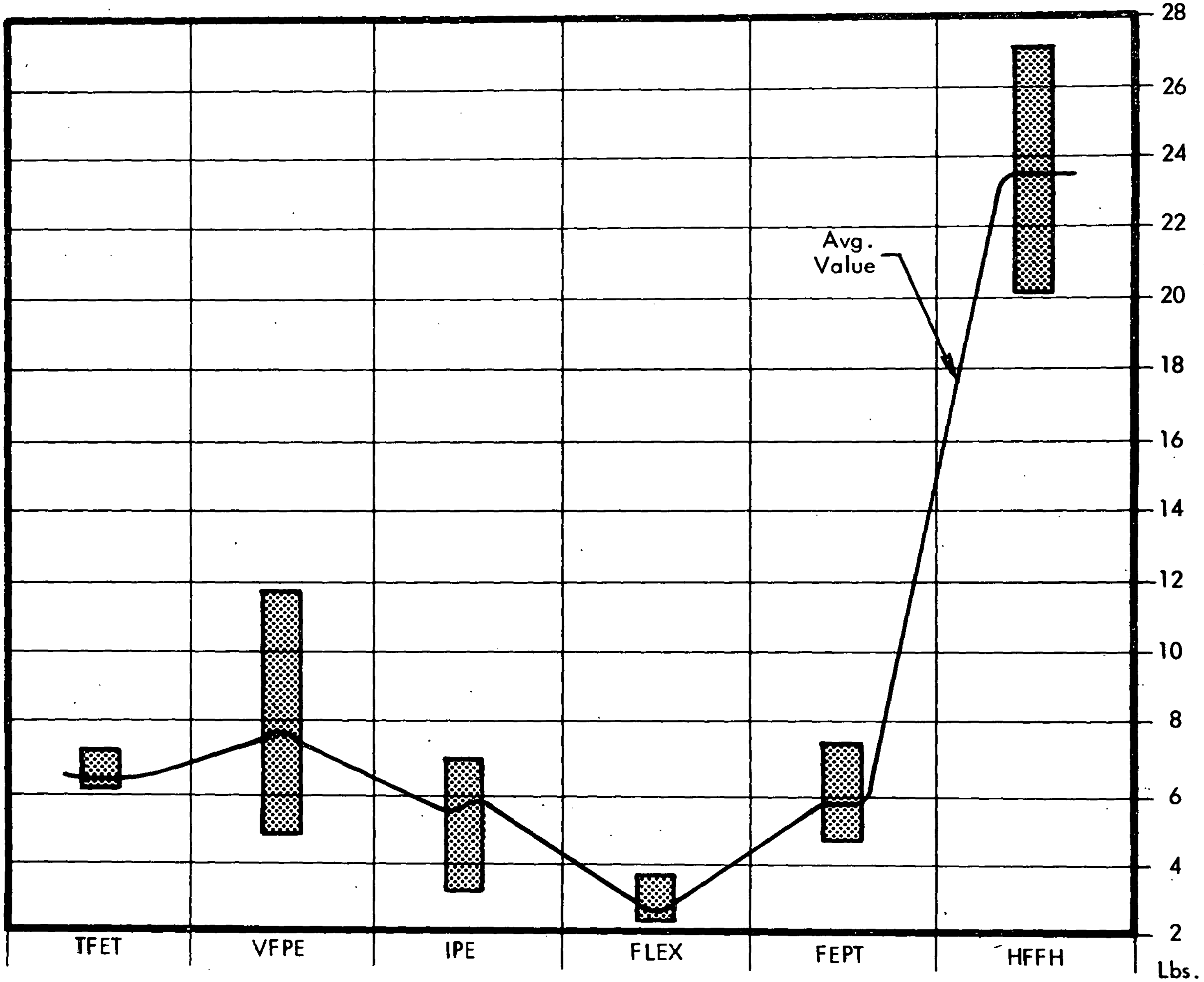
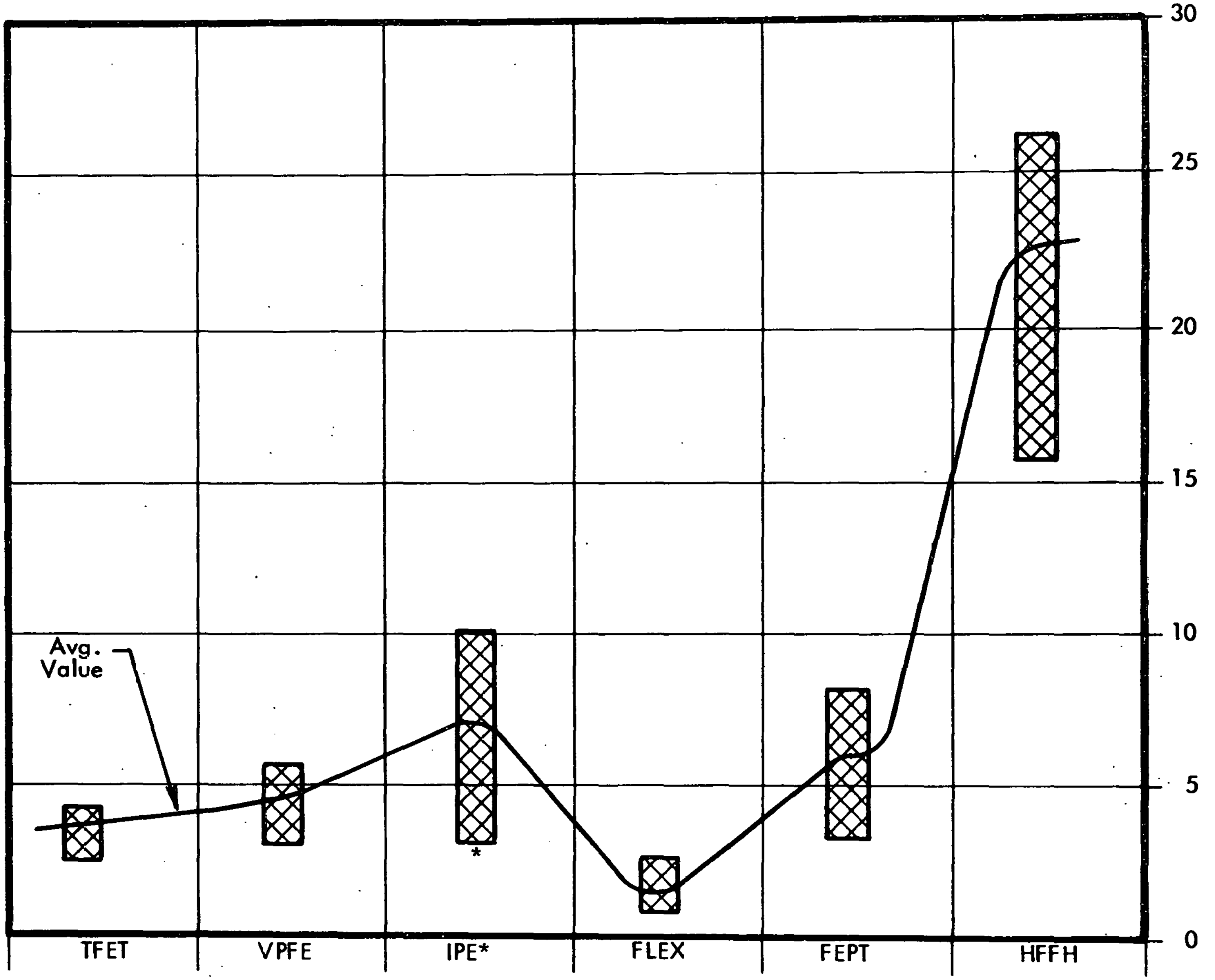
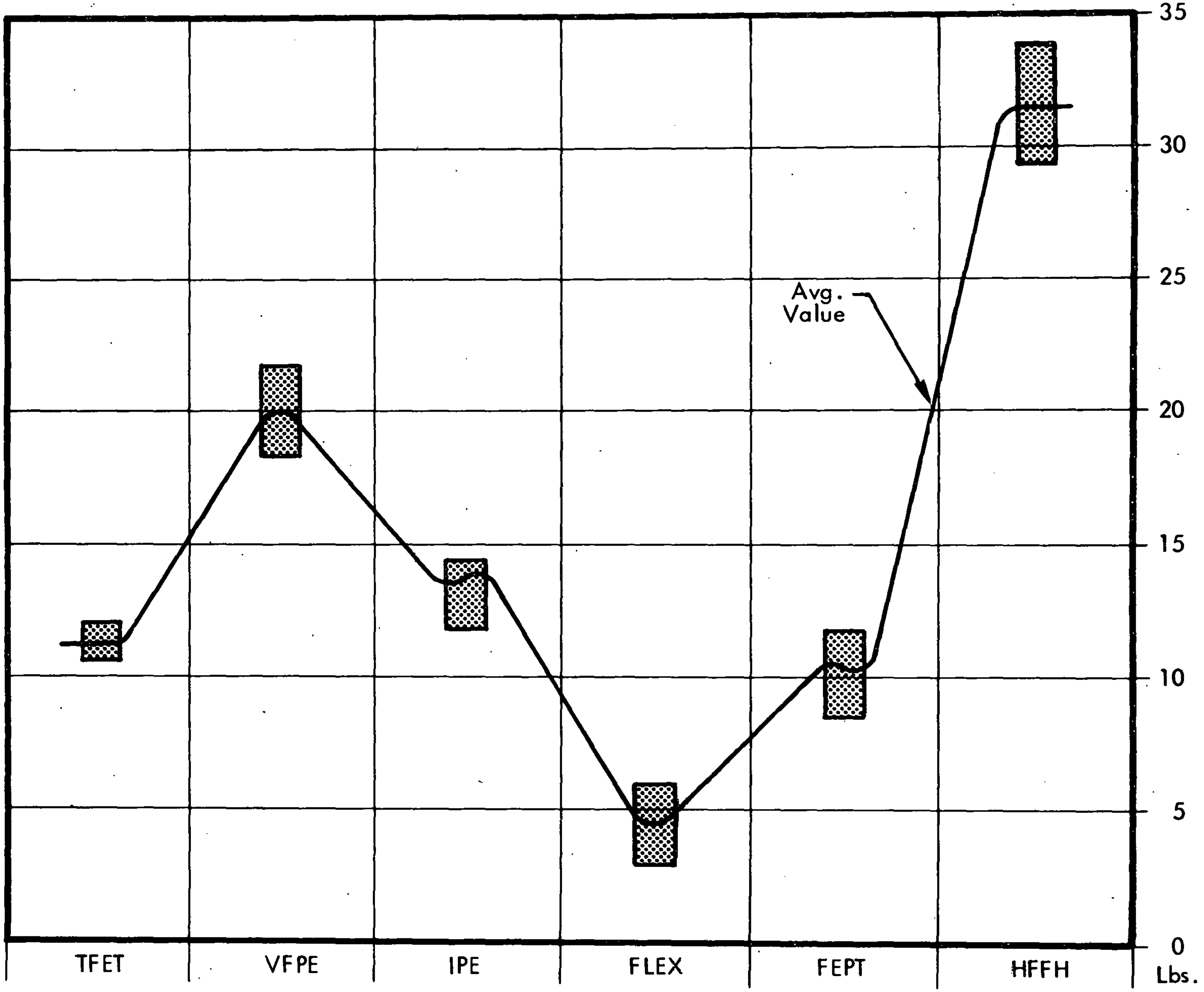


FIGURE 4. Adiprene-Potted Specimens Pulled at 200°F



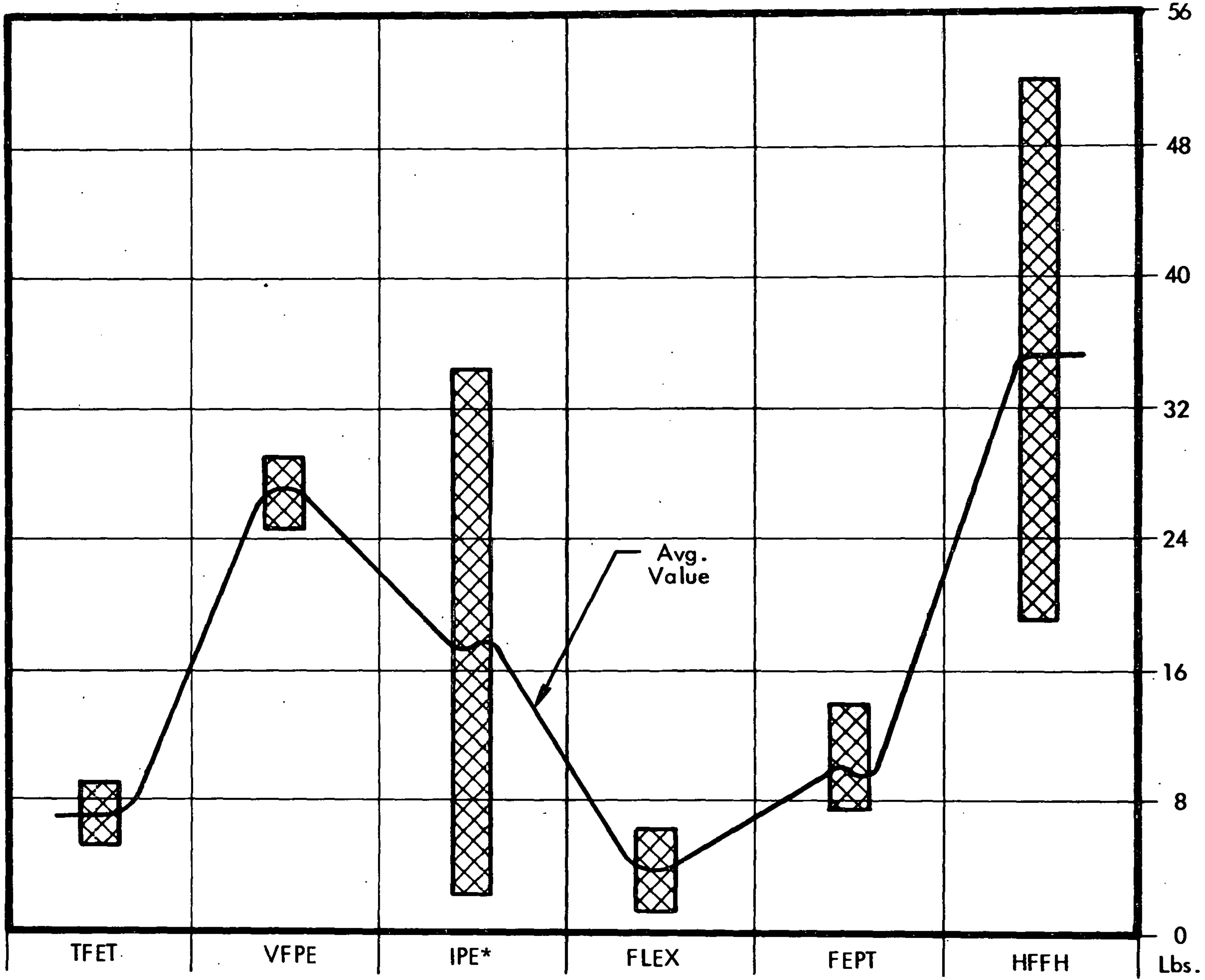
*Pulled at 250°F

FIGURE 5. Epoxy-Potted Specimens Pulled at 350°F



All specimens subjected to 3 cycles of 200°F to -65°F, pulled at room temperature.

FIGURE 6. Adiprene-Potted Specimens Pulled After Thermal Shock Conditioning



Specimens subjected to 3 cycles of 350°F to -65°F, pulled at room temperature.
*3 cycles of 250°F to -65°F

FIGURE 7. Epoxy-Potted Specimens Pulled After Thermal Shock Conditioning

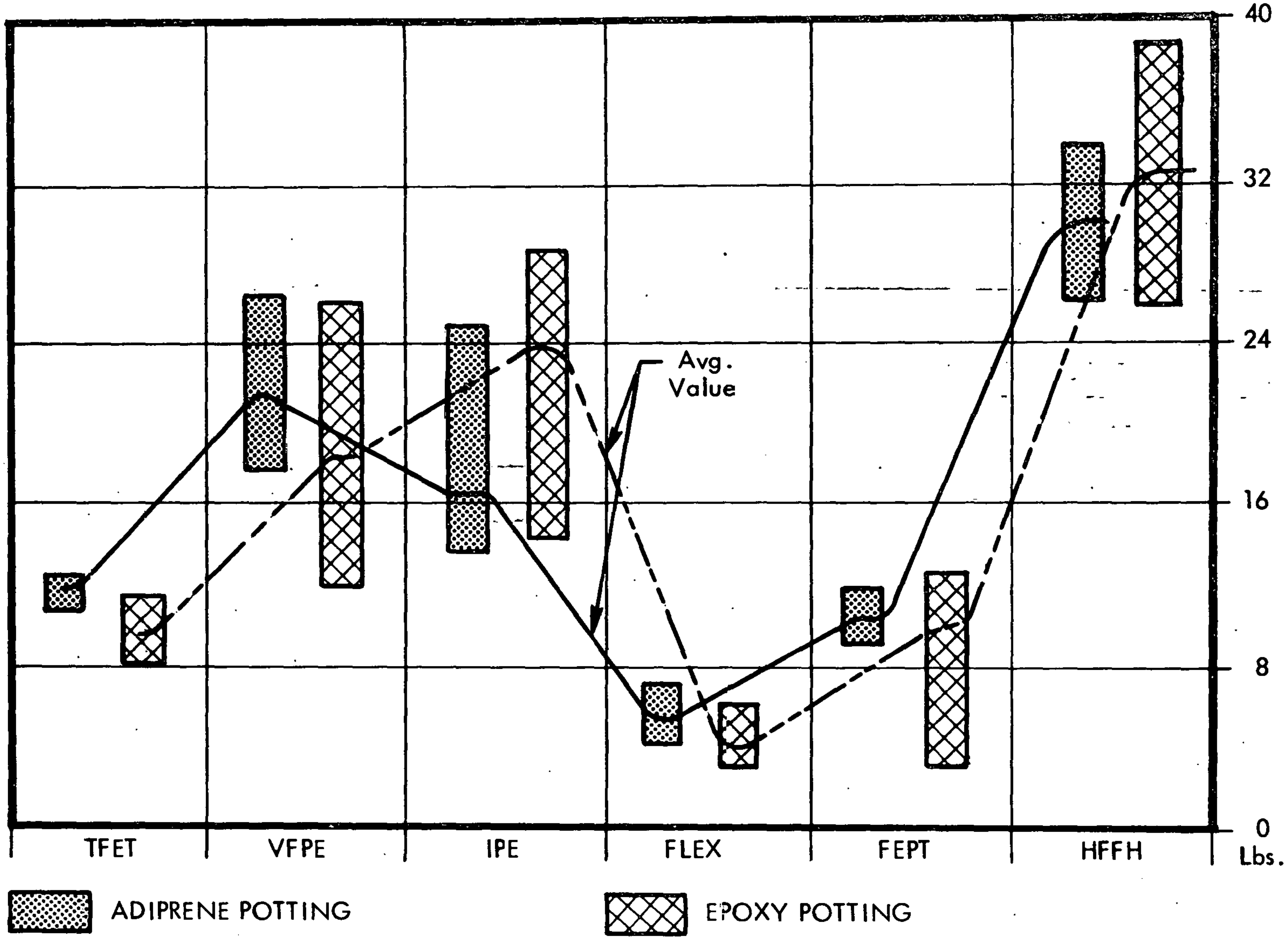


FIGURE 8. Specimens Pulled After Mechanical Shock Conditioning

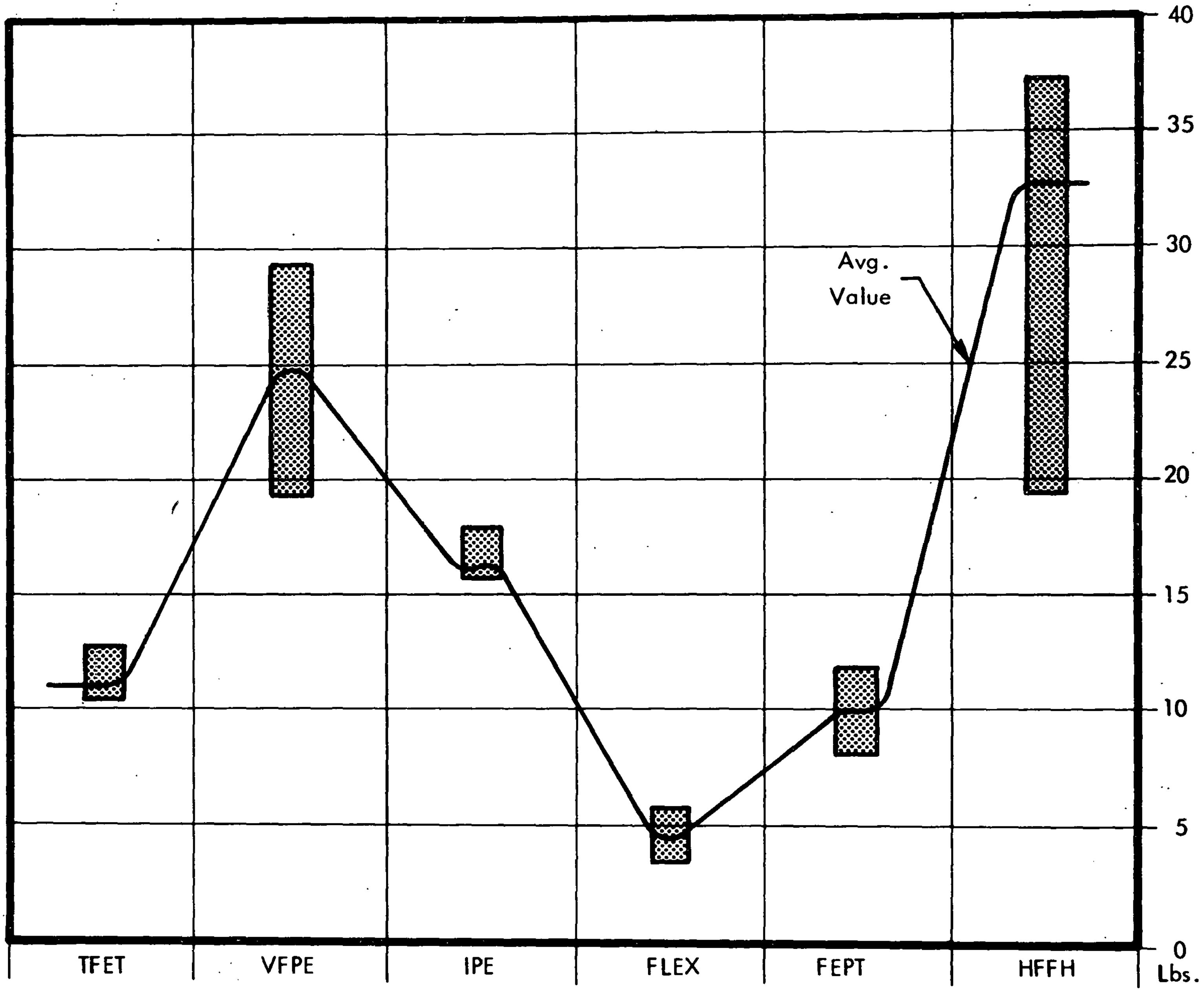


FIGURE 9. Adiprene-Potted Specimens Pulled at Room Temperature After Heat Aging for 96 Hours at 200°F

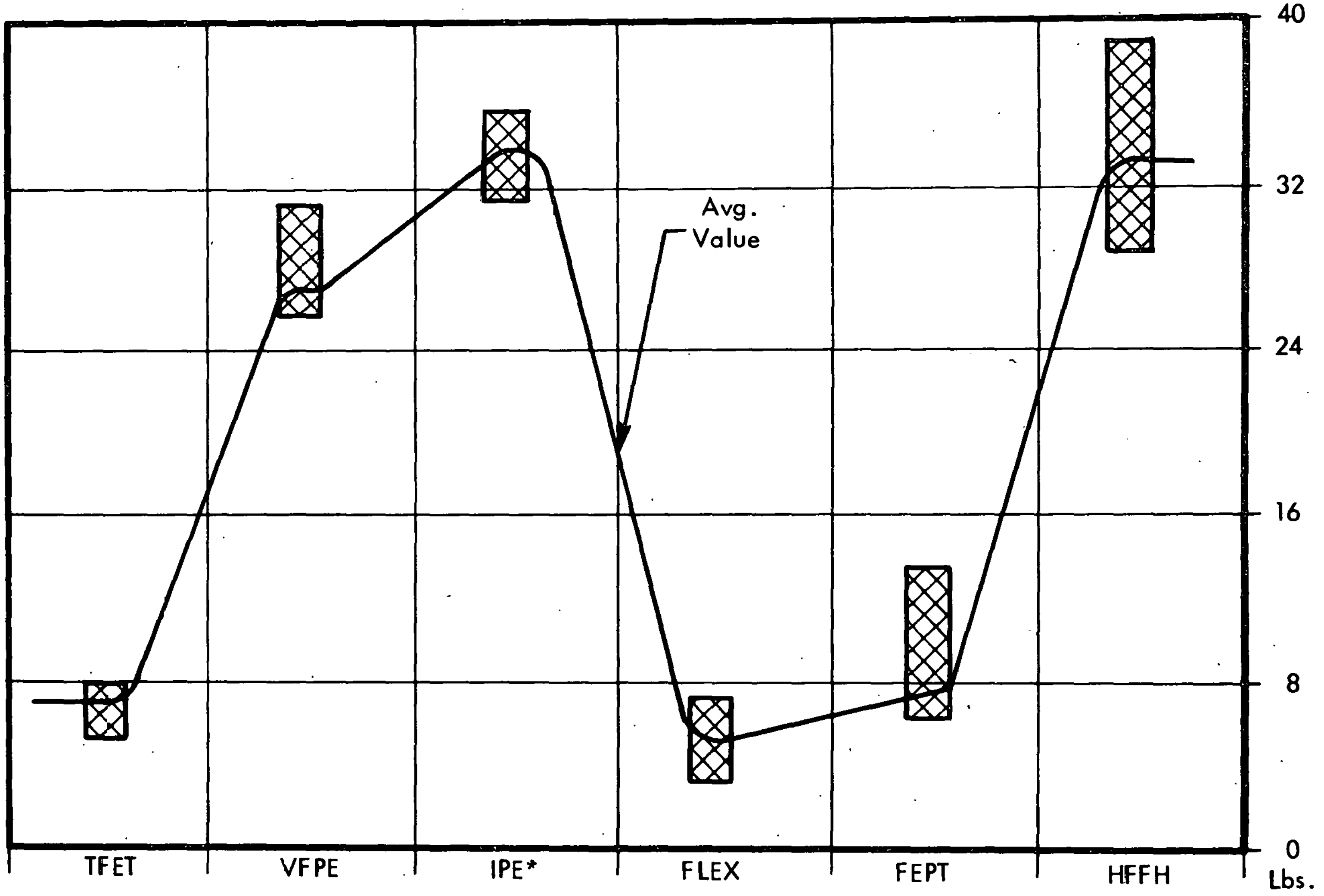


FIGURE 10. Epoxy-Potted Specimens Pulled at Room Temperature After Heat Aging for 96 Hours at 350°F

*Pulled After-96 Hours at 250°F

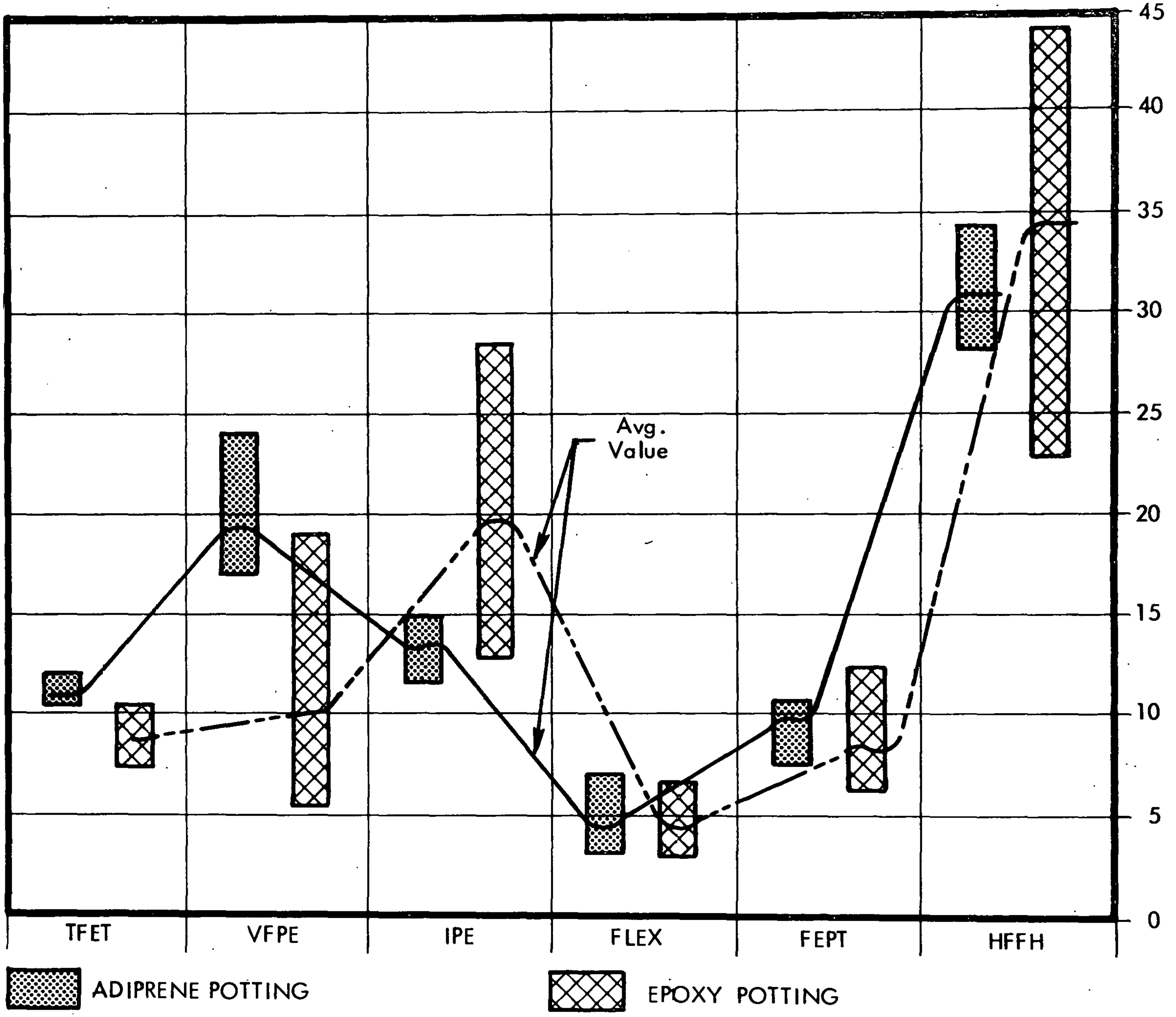


FIGURE 11. Specimens Pulled After Ozone Resistance Conditioning

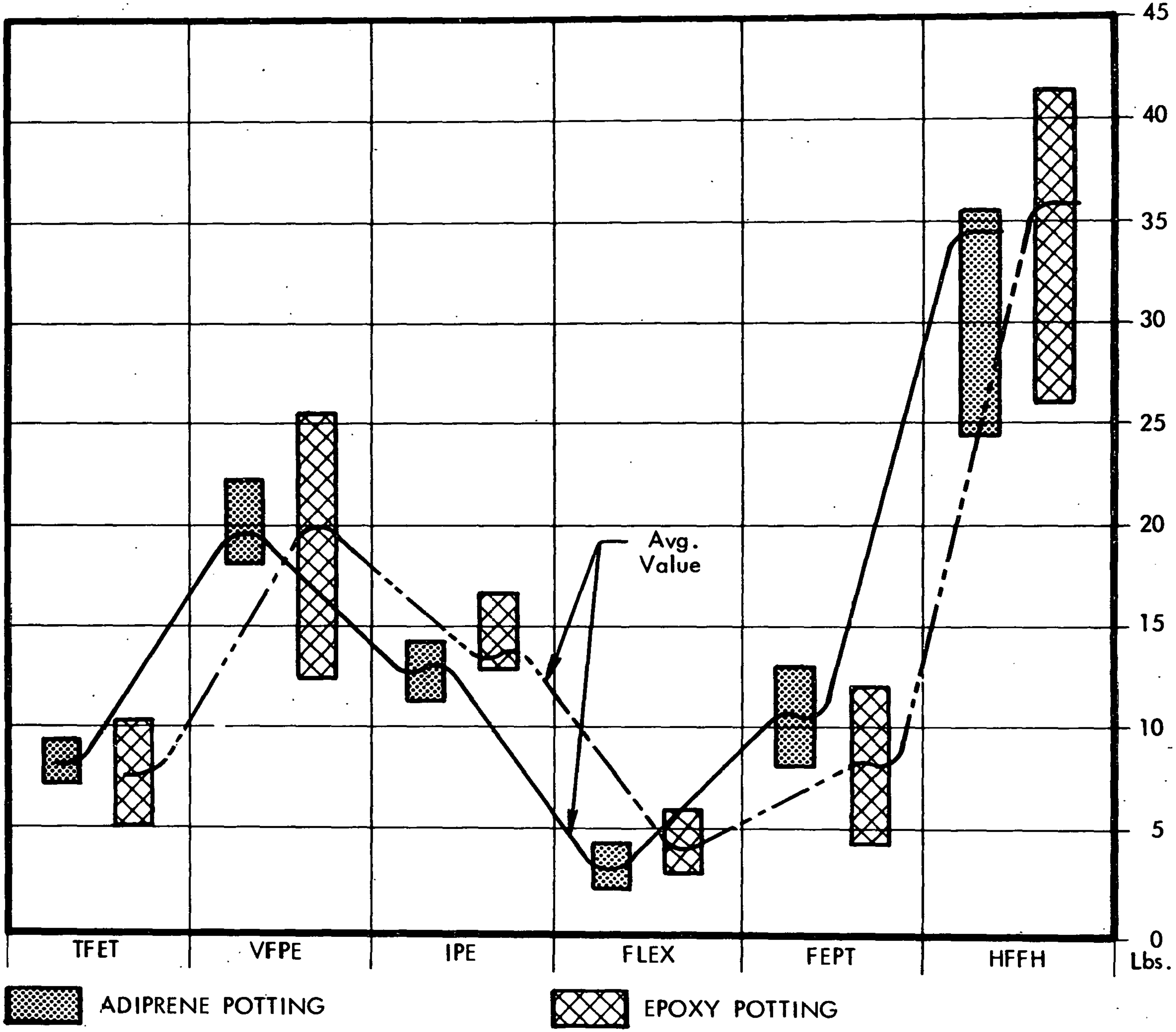


FIGURE 12. Specimens Pulled After Humidity Resistance Conditioning

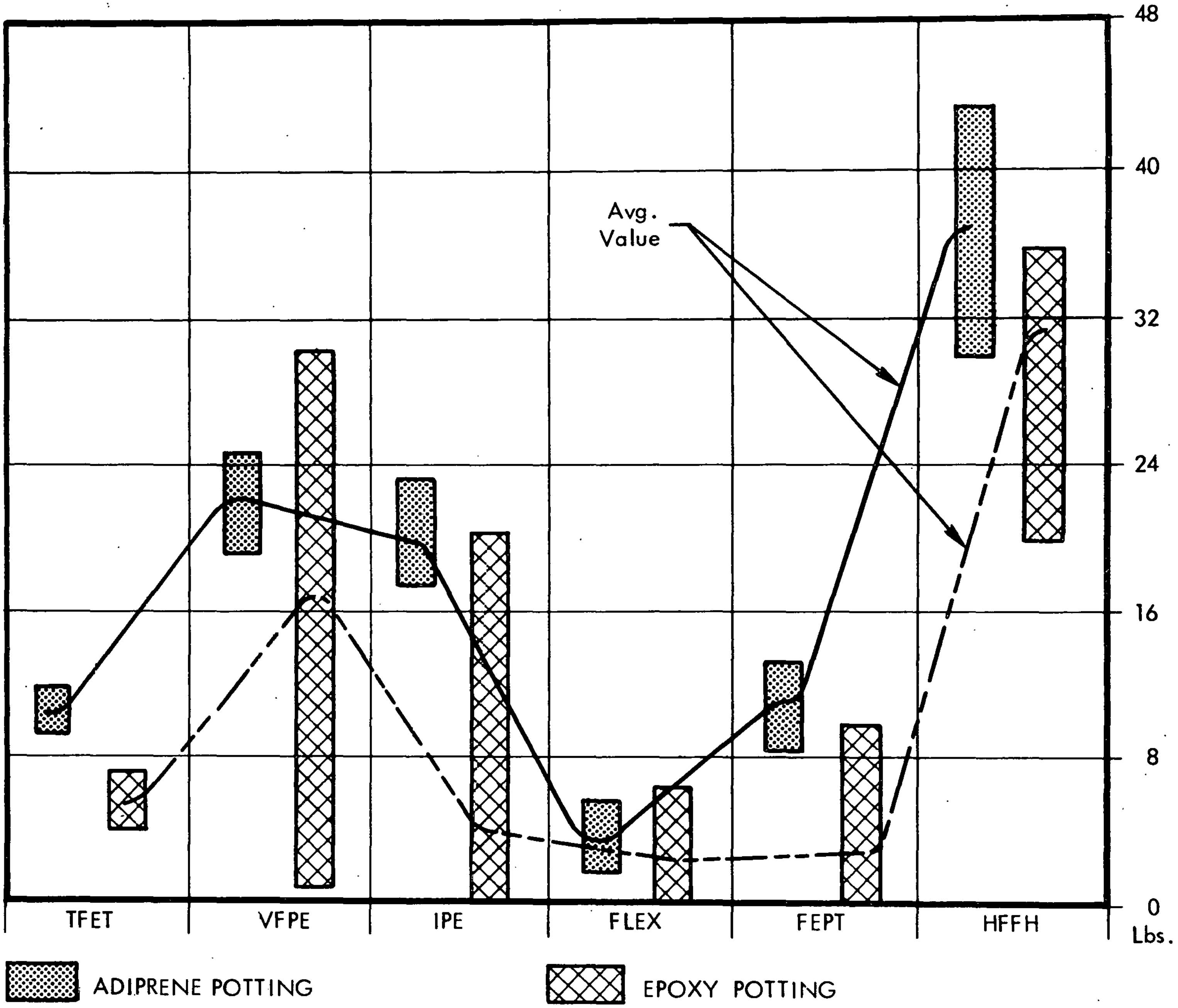


FIGURE 13. Specimens Pulled After Composite Environment Conditioning

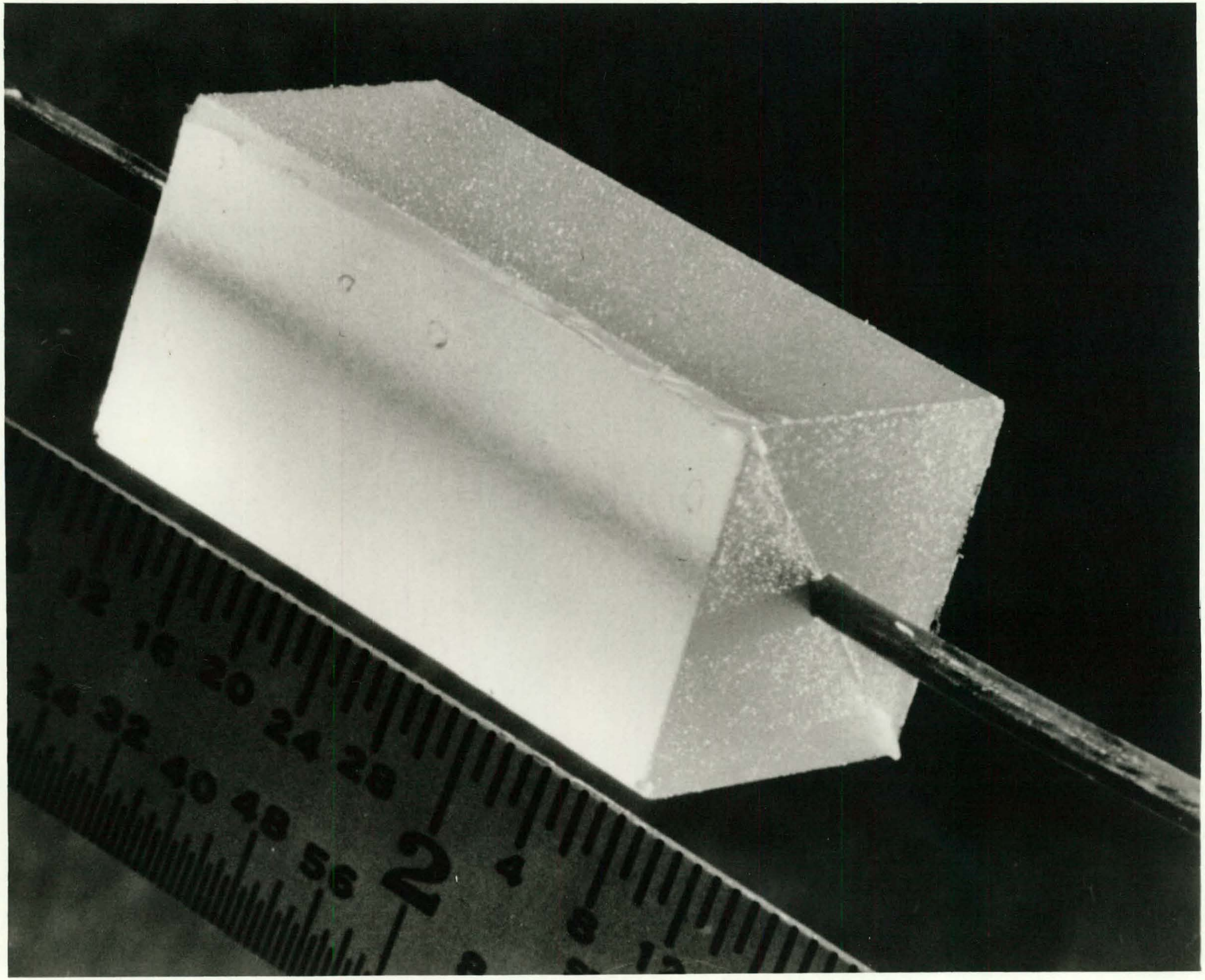


Figure 14. Potted Wire Specimen

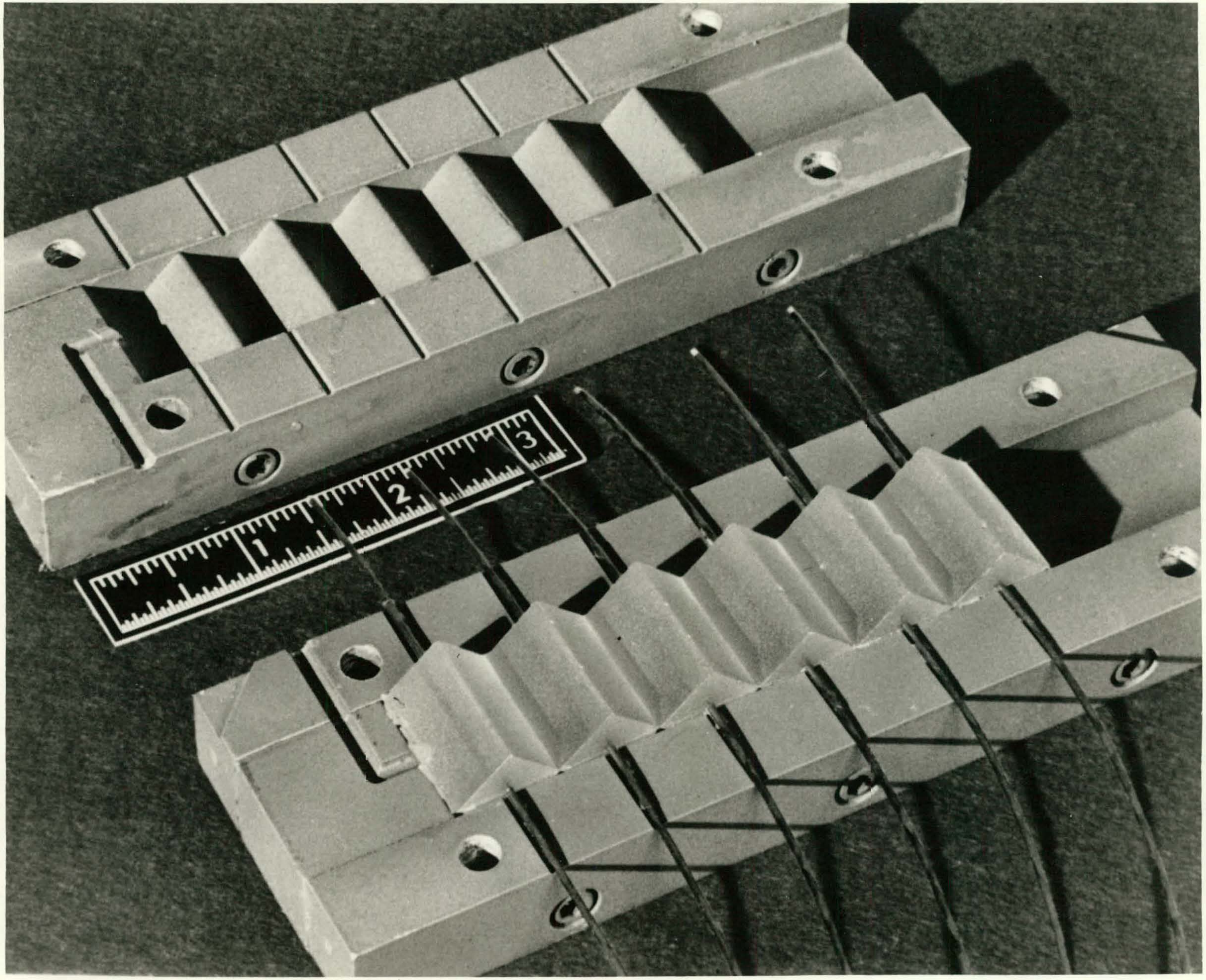


Figure 15. Potting Mold Fixture

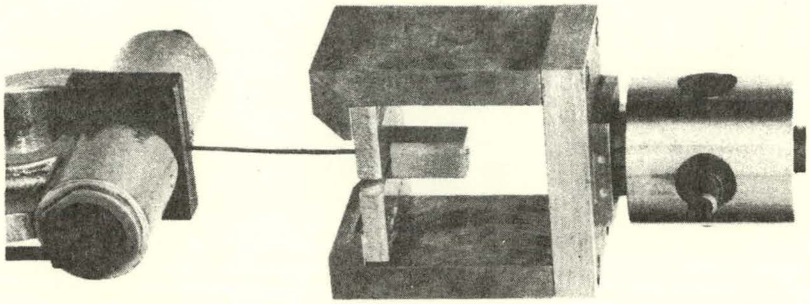


Figure 16: Specimen Mounted in Tensile Tester

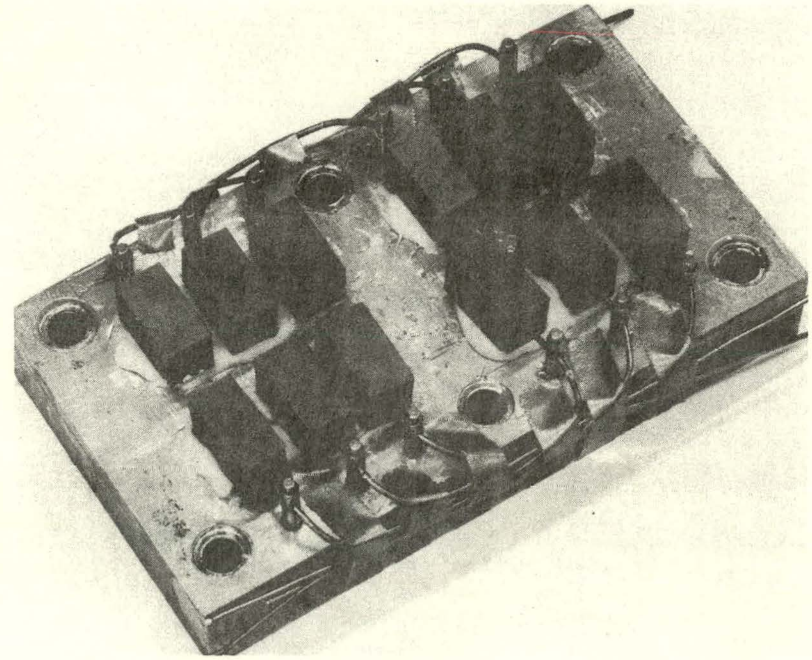


Figure 17: Specimens Mounted for Mechanical Shock

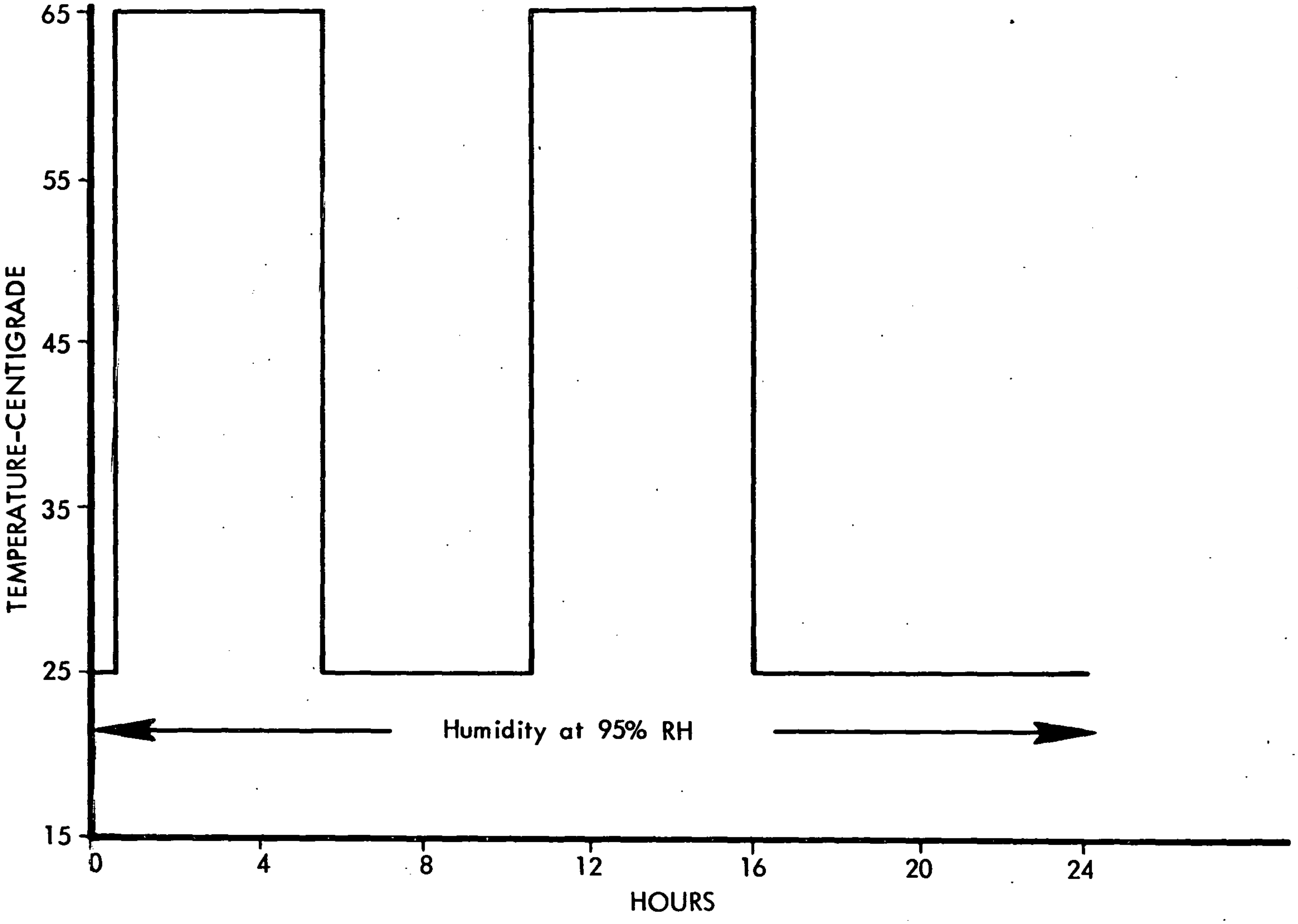


FIGURE 18. Humidity Resistance Test Cycle Profile

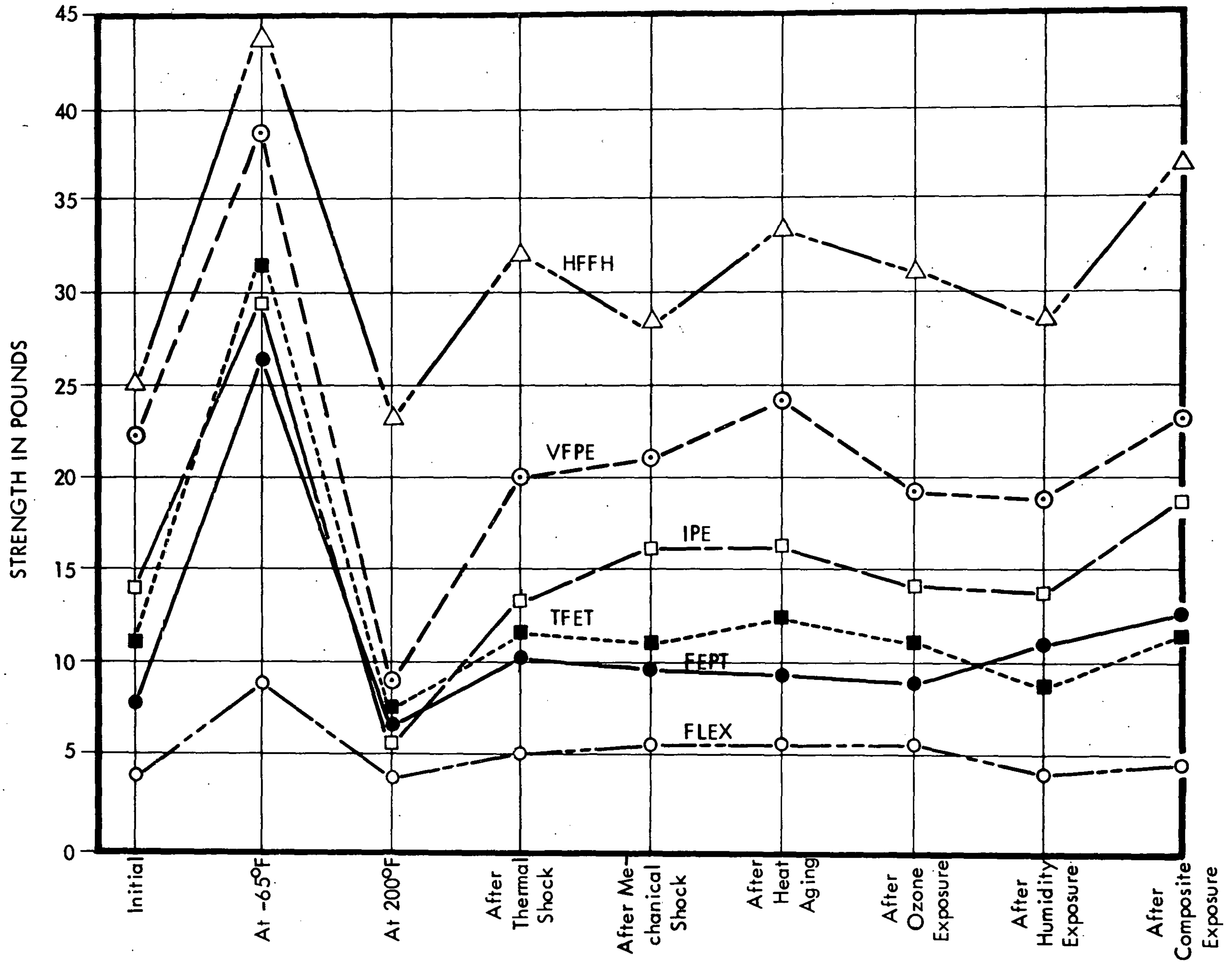


FIGURE 19. Bond Strength of Polyurethane-Potted Specimens

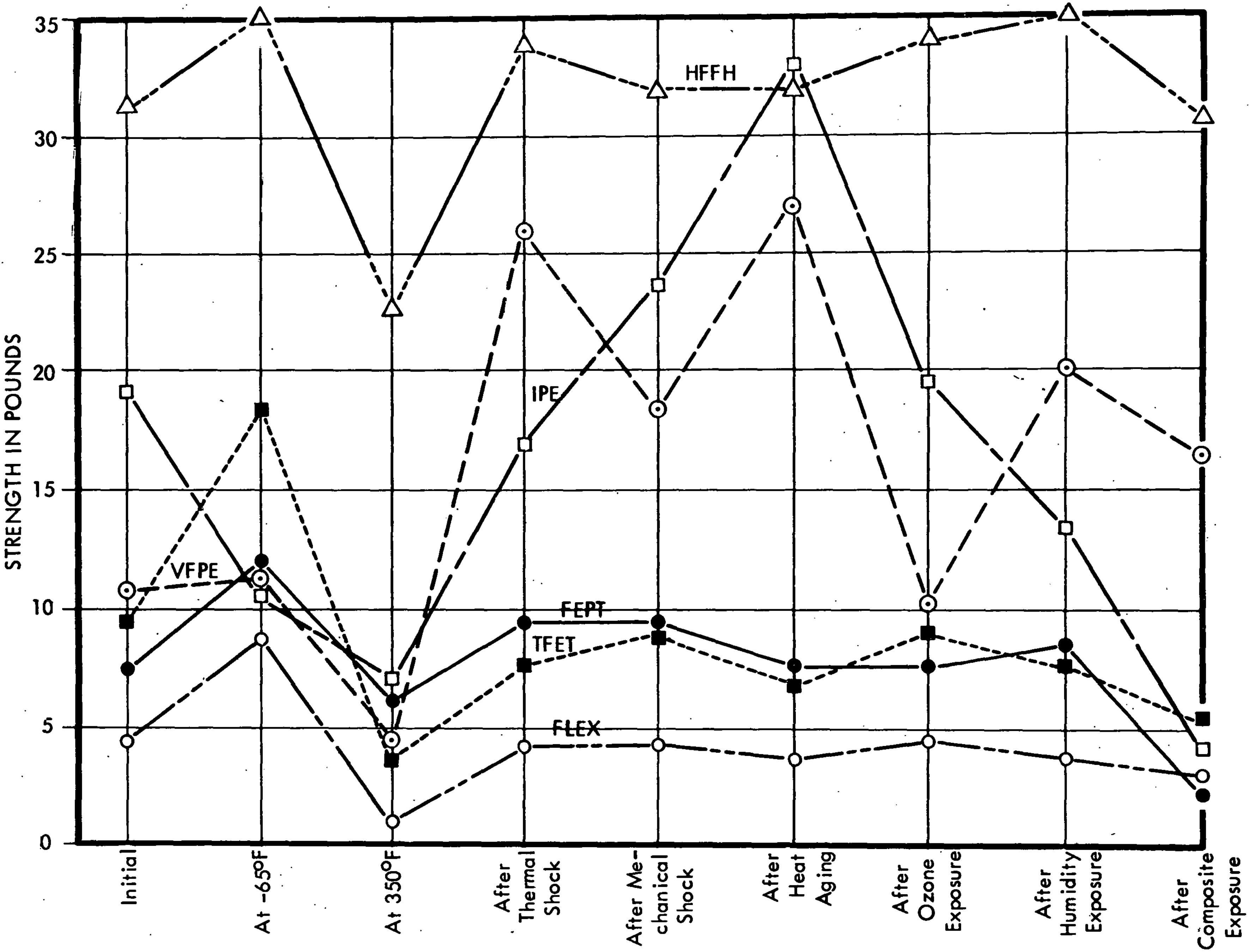


FIGURE 20. Bond Strength of Epoxy-Potted Specimens