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TESTING OF A FLAT CONDUCTOR CABLE BASEBOARD SYSTEM FOR RESIDENTIAL AND COMMERCIAL WIRING

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August 1974

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George C. Marshall Space Flight Center
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16. ABSTRACT

This report covers the results of extensive testing (mechanical, electrical, chemical, environmental, thermal, and analytical) of a flat conductor cable baseboard system for residential and commercial wiring. In all of the tests, Underwriters Laboratories (UL) Standards, UL Tentative Test Programs, or Accepted Engineering Practices were followed during test selection, test setup, and test accomplishment.

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TESTING OF A FLAT CONDUCTOR CABLE BASEBOARD SYSTEM FOR RESIDENTIAL AND COMMERCIAL WIRING

I. INTRODUCTION

As a spin-off of aerospace developed technology, the National Aeronautics and Space Administration (NASA) is applying flat conductor cable (FCC) technology to surface-mounted wiring systems for residential and commercial applications. Development of the surface-mounted wiring system is being accomplished by the George C. Marshall Space Flight Center (MSFC) under the sponsorship of the NASA Technology Utilization (TU) Office. The TU Office has the responsibility of providing the public sector with beneficial NASA-developed technology — of which FCC is one of many.

This report covers the testing of a logical portion of the total surface-mounted wiring system that is being developed and which, for purposes of definition, is called a "baseboard system." This baseboard system is intended for use with FCC and provides a surface-mounted, nonmetallic, protective covering with associated fittings; it offers a safe, aesthetically pleasing method for wiring at reduced overall cost to users, builders, and owners.

Many models of the baseboard system have been fabricated and assembled for exhibits in homebuilding shows, technical meetings, conferences, symposiums, etc. An actual, full-functioning installation was made in one of the MSFC conference rooms in early May 1974 and has been in continuous use since that time. The installation consisted of approximately 24 m (80-ft) of wired baseboard, with six standard receptacles, one switched receptacle, and two circuits of three-conductor, 12 AWG FCC.

II. HARDWARE DESCRIPTION AND USE

The baseboard system (Figs. 1 and 2) is composed of the following seven basic items:

Item	Drawing Number
Baseboard Front Cover	100368
Baseboard Back Channel	100369
Baseboard Outside Corner	50M75450-1
Baseboard End Caps (L, R)	50M75450-2
Baseboard Splice	50M75450-3
Baseboard Receptacle Box Cover	50M75450-4
Baseboard Receptacle Box with Hardware	50M75450-7, -8, -9

Note: Inside corners (see Figure 1) are accomplished by profiling the end of one of the intersecting front covers. The 2.44 and 3.66 m (8 and 12 ft) lengths of front cover are profiled at the factory, thus eliminating the need for on-site shaping.

The material used for manufacturing the protective covering and fittings (except the receptacle cover and receptacle box) is polyvinyl chloride (PVC), Goodrich GEON 8700A, gray, extrudible grade. The receptacle cover is vacuum formed PVC sheet material and the receptacle box is metal. The protective covering (back channel and front cover) tested was the extruded configuration which is for 5.08-cm (2-in.) width cables; with simple machining of the back channel, 6.35 cm (2.5 in.) wide cables can be adequately accommodated.

The baseboard system is for use with flat conductor cable in residential and commercial applications — homes, apartments, offices, stores, etc. It provides a safe and easy method for routing FCC throughout rooms and hallways. In addition to new structures, it will be of great benefit in renovating existing (old and contemporary) building and dwellings. The system, with or without receptacles, will easily house nine #12 AWG flat conductors of the proper size (see Table 1). Three additional #12 AWG flat conductors can be installed without undue difficulty. A typical #12 AWG, three-conductor FCC has three 0.3 by 10 mm (0.0125 by 0.4 in.) conductors housed within insulation that has outside dimensions of 0.6 mm (0.024-in.) thick by 5.08 cm (2.0 in.) wide. The cover and fittings are designed to snap onto the back channel but, if desired, PVC cement may be applied to appropriate spots to make disassembly a deliberate operation.

TABLE 1. WIRING CAPACITY

Conductor Size (AWG)	No. of Conductors
14	15
12	12

III. TESTING

Most of the testing accomplished was based upon a Tentative Test Program provided by UL (Melville, N. Y.) to Abt Associates (Cambridge, Mass.) on March 2, 1972. Additional, appropriate tests were made known during discussions with personnel of Quick Plastics (Jackson, Mich.), the manufacturer of the protective cover, and B.F. Goodrich (Cleveland, Ohio), the source of the GEON 8700A material. In all, sufficient mechanical, electrical, chemical, environmental, thermal, and analytical tests were determined to prove the worthiness of the baseboard system for the intended application.

A. Mounting and Assembly Test

1. Method. The receptacle boxes and baseboard back channel were mounted to various types of walls (sheetrock, wood, masonry) using ordinary fasteners appropriate for the type of wall. Scrap pieces of wood were used to position the parts at the correct height above the floor. Next, the cables (FCC) were routed, and standard duplex receptacles were connected in the receptacle boxes by using Amp Termifoil (Insulation Piercing) terminals. Appropriate lengths of the baseboard cover were then cut and snapped onto the back channel. Finally, the fittings (outside corners, splices, receptacle covers, end caps) were installed. Note: As discussed in Section II, a profiled end of the baseboard cover serves as an inside corner.

2. Results. Mounting and assembly of the protective cover and fittings were easily accomplished without any special tools or equipment. Removal of the fittings and cover was accomplished by intentionally lifting the lower flexible edge and applying an outward force sufficient to "unsnap" the attached part. If PVC cement had been used, a thin blade would have been used to separate the bond prior to "unsnapping" the part. Access to all electrical joints was made, and the removal or addition of cables (up to maximum) was possible.

B. Cable Installation Tests

1. Method. This test consisted of installing the number of wires (cables), as recommended in Section II, in straight lengths of baseboard mounted on a wall which traversed both inside and outside corners, at floor level. The number of wires (cables) is shown in Table 1.

2. Results. The conductors (three per cable layer) were installed in the protective covering without difficulty, both with and without receptacles. Also, as noted in Section I, many models of the baseboard system have been fabricated and assembled, and a large conference room was wired with the system in early May 1974.

C. Crushing Test Without Cables

1. Method. Two samples of the protective cover were cut to 15.2 cm (6 in.) lengths (both cover and back channel in the assembled position) and crushed between rigid flat metal plates which were wide enough to completely cover the baseboard sample. The crushing rate was at a speed of approximately 1.3 cm (0.5 in.) per minute with an Instron Testing Machine (Fig. 3). Figure 4 is a closeup view of the crush test setup. The crushing load was increased in uniform increments and released to observe the effect. This process was repeated at increasing loads until deformation and buckling occurred.

2. Results. The following results were obtained:

Crushing Force, N (lb)	Results
890 (200)	No deformation
2224 (500)	No deformation
3114 (700)	Very slight deformation (did not impair function)
4448 (1000)	Same as 3114 N (700 lb)
5338 (1200)	Definite deformation (snap-on action impaired)
6672 (1500)	Same as 5338 N (1200 lb)
7562 (1700)	Same as 5338 N (1200 lb)
8900 (2000)	Cracks at angles and lips

D. Crushing Test with Cables Installed

1. Method. This test was conducted in the same manner as described in Section III. C, except that three layers of cable (nine conductors) were inserted in the 15.2 cm (6 in.) long assembled protective cover, see Figure 5.

A very sensitive and reliable instrument was used to check for shorted or open conductors as the crushing force was increased continuously at a closing rate of approximately 1.3 cm (0.5 in.) per minute.

2. Results. Two samples were crushed without any of the conductors being shorted or opened. The test was stopped when the maximum capacity [44 480 N (10 000 lb)] of the machine was reached. Unlike round wire (which offers point contact in this type of test), FCC has a large plane area of contact. For samples of this size, a force of over 444 800 N (100 000 lb) would be required to short the FCC conductors.

E. Impact Test Without Cables

1. Method. This test was made to determine the effect of a sudden blow on the baseboard (assembled front cover and back channel). The apparatus in this test consisted of a weight, raised in a suitable guide tube, which was allowed to fall on the material resting on a flat steel plate (see Figure 6). Weights of 8.9 and 22 N (2 and 5 lb) with 3.2 cm (1.25 in.) diameter flat impact surfaces were used (see Figure 7). The baseboard was laid across the flat plate (Fig. 8) and the weight was raised to a predetermined height and allowed to fall freely on the baseboard. Each blow (impact) was made at a new location remote from the previous blow, or on a new sample. The test was repeated at various test heights and the results were recorded.

Failure was considered to occur when the baseboard cracked, seams opened up, or the part was deformed by more than 50 percent of its original overall flatwise dimension.

2. Results. The results of the 8.9 and 22 N (2 and 5 lb) impact tests are as follows:

Weight N (lb)	Height m (ft)	Results
8.9 (2)	0.61 (2)	Very slight strain marks
8.9 (2)	1.22 (4)	Very slight strain marks
8.9 (2)	1.83 (6)	Very slight strain marks
8.9 (2)	2.44 (8)	Slight strain marks
8.9 (2)	3.05 (10)	0.4 mm (0.016 in.) deep impression, no impairment to function
22.0 (5)	1.22 (4)	Same as 8.9 N, 3.05 m (2 lb, 10 ft)
22.0 (5)	1.83 (6)	Same as 8.9 N, 3.05 m (2 lb, 10 ft)
22.0 (5)	2.44 (8)	0.8 mm (0.031 in.) deep impression, no impairment to function
22.0 (5)	3.05 (10)	Same as 22 N, 2.44 m (5 lb, 8 ft)

F. Impact Test with Cables

1. Method. This test was conducted in a manner similar to that described in paragraph III. E, except that the weight was increased to 89 N (20 lb) with a 5.08 cm (2-in.) diameter flat impact face. The test was made to determine the effect of a sudden blow on the baseboard (assembled front cover and back channel) with three layers of cable (nine condectors) installed. A very sensitive electrical continuity instrument was used to check for shorted or open conductors as the impact was made.

2. Results. The 89 N (20 lb) weight was dropped from a height of 3.05 m (10 ft) more than 10 times without any conductors shorting or opening. The baseboard was permanently damaged with each blow.

G. Strength of Conduit Openings

This test was not applicable because, with recommended usage, no conduit or round wire clamps will be attached to the protective covering (front and back).

H. Dielectric Strength Test

1. Method. The thinnest portion of the protective covering was tested for dielectric strength by subjecting it to a high potential voltage for 1 minute. The probes used were about the size of #14 AWG round wire.

2. Results. There was no arcing or breakdown during the application of more than 2500 volts. The thinnest section was 1.5 mm (0.060 in.) which should theoretically withstand 48,000 volts.

I. Heating Test

1. Method. This test consisted of a heat run with three layers of FCC (nine conductors of size AWG 12). Six of the conductors were loaded at 20 amperes to produce the maximum heat loss per linear dimension to which the baseboard would be subjected in normal use.

The conductors were placed in the baseboard to simulate normal installation. A 9.1 m (30-ft) run of the baseboard was mounted to a plywood wall that had been painted with flat black paint. Both open ends of the baseboard were plugged to prevent ventilation. Below the baseboard was a 15.2 cm (6 in.) wide plywood shelf, assembled to simulate the baseboard mounted to a wall at the floor level (Fig. 9).

Thermocouples were cemented to the inside surface of the PVC back channel midway of the 9.1 m (30 ft) run at the top, center, and bottom. Thermocouples were also placed on the copper of the loaded conductors nearest the wall and between the back channel and the wall. Figure 10 shows the seven thermocouple wires exiting from the baseboard run. The tests were continued until maximum temperature rises were obtained.

2. Results. The following results were obtained by loading six conductors at 20 amperes until a steady state thermal condition was achieved. All thermocouples were installed midway of the 9.1 m (30-ft) run. Room temperature was 23°C (73.4°F).

Thermocouple Location	Temperature Rise, °C (° F)
Loaded Conductor Nearest Back Channel	
Top	25 (45)
Bottom	23 (41.4)
Inside Surface of Back Channel	
Top	22 (39.6)
Middle	14.5 (26.1)
Bottom	20 (36)
Between Back Channel and Wall	
Top	16 (28.8)
Bottom	15 (27)

J. High Current Test

1. Method. The same 9.1 m (30-ft) run of baseboard with three layers of cable (nine conductors), as noted in paragraph III.I, was used to simulate the heat effect when the circuits were loaded at the maximum ampere-minutes allowed for circuit breaker tripping and fuse blowing. Two ampere-minute settings were used: 40.5 ampere for 60 minutes, and 60 amperes for 2 minutes.

Six of the nine #12 AWG conductors were loaded. Thermocouples were attached to the two powered conductors nearest the back channel for measuring the two hottest spots.

2. Results. There was some buckling of the baseboard due to expansion caused by the heat. Function was not impaired and the baseboard returned to the installed position after the high current was removed. The temperature rises recorded are listed below; room temperature was 23°C (73.4°F).

Thermocouple Location	40.5 A at 60 min, °C (°F)		60 A at 2 min, °C (°F)	
Top Conductor next to Back Channel	103	(185)	67	(121)
Bottom Conductor next to Back Channel	94	(169)	64	(115)

K. Arcing Test

1. Method. This test was made to determine what effect an arcing, loose connection, or broken conductor would have upon the protective cover (assembled front cover and back channel). Flat conductor cable, #12 AWG, was used to create an arc inside the assembled baseboard. To make the arc, a short length of insulation was removed from a conductor and the conductor was nearly severed so that it would fuse and cause an arc when the voltage was applied. A resistance was placed in the circuit to limit the current to 40.5 amperes when 277 volts, 60 hertz, were applied.

2. Results. Three arcing tests were made with the duration of each being approximately 2 minutes. The baseboard was not damaged except for black spots [less than 1.3 cm (0.5 in.) in diameter] made on the inside of the cover by the arcing conductor.

L. Shrinkage Test

1. Method. A 0.3 m (1 ft) long baseboard sample was conditioned in a full-draft circulating air oven at a temperature of 82°C (180°F) for a period of 30 minutes. The sample was complete, having both back channel and front cover assembled in their relative positions. The sample was measured for overall length before and after exposure in the oven.

2. Results. The sample shrank 2.4 mm (0.094 in.) during the exposure. This was 0.78 percent shrinkage.

M. Deflection Test

1. Method. This test, essentially the same as described in ASTM D648-56, was made to determine the temperature at which a bar-shaped specimen of the PVC material would deflect 0.25 mm (0.010 in.) when the fibers are stressed at 45.5 and 182 N/cm^2 (66 and 264 psi). Two specimens [each 4.9 mm (0.193 in.) thick by 1.3 cm (0.5 in.) wide by 12.7 cm (5.0 in.) long] were prepared by laminating three thicknesses of the PVC material and machining.

2. Results. The temperatures to cause a 0.25 mm (0.010 in.) deflection were as follows:

Specimen	45.5 N/cm^2 (66 psi), °C (°F)		182 N/cm^2 (264 psi), °C (°F)	
1	74	(165)	65	(149)
2	70	(158)	65	(149)

These deflection temperatures equal or exeed the minimum allowed in UL Standard 651 for Rigid Nonmetallic Conduit.

N. Physical Properties Test

1. Method. This test was essentially the same as described in UL651 for Rigid Nonmetallic Conduit except for the different shape of the specimens. The test is a simple test of tensile strength before and after exposure. Ten 1.3 cm (0.5 in.) wide dog bone specimens were aged in a full-draft circulating air oven at a temperature of 113 ± 1°C (235 + 2°F) for a period of 168 hours (Fig. 11). The specimens were supported to prevent them from touching one another or the sides of the oven. After the aging process, the specimens were permitted to cool for more than 16 hours in still air before being handled. The specimens were then tested for tensile strength on a power driven machine provided with a device that indicated actual load at which the specimen broke (see Figure 12). The rate of separation of the grips holding the specimen was 2.5 cm (1 in.) per minute.

2. <u>Results</u>. The results of the tensile tests are as follows:

Specimen	Before Aging N/cm^2 (psi)	Specimen	After Aging N/cm^2 (psi)
21	3416 (4954)	1	3769 (5466)
22	3179 (4610)	2	3556 (5157)
23	3406 (4940)	3	3750 (5438)
24	3303 (4790)	4	3448 (5000)
25	3513 (5095)	5	3656 (5303)
26	3124 (4531)	6	3570 (5177)
27	3623 (5254)	7	3750 (5438)
28	3403 (4936)	8	3761 (5454)
29	3199 (4640)	9	3806 (5520)
30	3272 (4746)	10	3566 (5172)
Average	3344 (4850)		3663 (5313)

O. Light Exposure Test

1. <u>Method</u>. Seven samples of the baseboard were exposed to the light rom a xenon lamp for 200 hours at an intensity of one solar constant. The aboratory equipment used was a Spectrolab Solar Simulator Model X25. The ensile strength of the material was measured before and after the exposure.

2. <u>Results</u>. The following results were obtained:

	Before	After
Average Tensile Strength	3444 N/cm^2 (4850 psi)	3678 N/cm^2 (5334 psi)

P. Low Temperature Handling Test

1. <u>Method</u>. This test was conducted by exposing 0.76 m (2.5 ft) lengths f the protective cover (assembled cover and back channel) to a temperature of 35° C for a period of 5 hours. Each assembled sample was then dropped on a oncrete floor from a height of approximately 1.5 m (5 ft). For the first drop, he axis of the baseboard was approximately 45 degrees to the horizontal so hat the edge struck the floor first (see Figure 13). For the second drop, the xis of the baseboard was approximately parallel to the floor.

2. Results. There was no damage which would hinder the function of the baseboard. A small piece of the upper flexible fin (Fig. 14) did break off during the 45-degree angle drop. The flexible edge compensates for irregularities in the wall; it serves an aesthetic purpose and does not hinder the electrical or mechanical integrity of the baseboard.

Q. Flame Test

1. Method. Samples of the baseboard were mounted in a vertical position in an open front enclosure (Fig. 15). A 12.7 cm (5 in.) flame having a 3.8 cm (1.5 in.) blue cone was applied to each of the samples at a 20-degree angle from the vertical for a period of 1 minute. The flame was obtained from a Tirrill burner having a 16 mm (0.625 in.) bore and was located so that the cone was applied to the edge of the material. The flame was applied during three separate 1-minute periods with a 30-second interval after each application.

2. Results. None of the samples continued to burn after the flame was removed at the end of each 1-minute application, and there were no falling, burning particles. Figure 16 shows two samples after testing.

R. Extrusion – Process Test

1. Method. A 2.5 cm (1 in.) long sample (front cover and back channel) was cut from a length of baseboard and immersed in anhydrous acetone for 10 minutes.

2. Results. The sample showed some surface flaking which was not considered to be excessive.

S. Water Absorption Test

1. Method. Two clean, dry, specimens [15.2 by 5.08 by 0.16 cm (6 by 2 by 0.063 in.)] were weighed on an analytical balance and then immersed for 24 hours in distilled water at 23 ± 2°C (73.4°F). The specimens were then removed from the water, dried quickly with a clean piece of soft lintless cloth, and immediately reweighed.

2. Results. The following results were obtained:

Specimen	Weight Before mN (g)	Weight After mN (g)	Ratio
1	176.9 (18.0395)	177.3 (18.0750)	1.0019
2	176.8 (18.0260)	177.1 (18.0584)	1.0017

Both specimens showed less absorption than the maximum acceptable in UL651, Rigid Nonmetallic Conduit.

T. Identification Tests

1. Method I, Ash Content. Samples of the material, weighing approximately 68.6 mN (7 grams), were heated in porcelain crucibles over a modified Meeker burner for 1 hour. The samples were then heated in a muffle furnace maintained at 800° C (1472° F) for an additional 1 hour. The crucible and contents were then cooled in a desiccator and weighed, and the percent (by weight) of ash was calculated.

2. Results I. The following results were obtained.

Sample	Percent Ash
1	1.74
2	1.73

3. Method II, Specific Gravity. The specific gravity of two specimens was measured.

4. Results II. The specific gravity measurements were:

Sample	Specific Gravity
1	1.34
2	1.35

5. Method III, Infrared Spectrum Analysis. An infrared spectrogram of the material was made by using a Perkins and Elmer Model 521 Grating Infrared Spectrophotometer.

6. Results III. The spectrum obtained is considered representative of the material tested. The test results and a sample of the material tested are on file in the Materials Laboratory at MSFC for future reference.

IV. SUMMARY AND CONCLUSIONS

The test results documented in this report prove that the baseboard system is a safe and reliable method for routing and distributing flat conductor cable throughout rooms and hallways in residential and commercial structures. The mechanical, electrical, chemical, environmental, thermal, and analytical tests to which the baseboard and fitting were subjected were much more severe than what would be encountered in normal usage. In all of the tests, UL Standards, UL Tentative Test Programs, or Accepted Engineering Practices were followed during test selection, test setup,and test accomplishment.

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ED-2-71	Proposed Test Program for Measuring the Flexure Life of Flat Conductor Cable
ED-8-71	A Preliminary Study on the Possibilities of Electronically Controlling a Flat Conductor Cable Brazing Tool
ED-504	A Preliminary Study of Resistance Brazing Gold-Plated Flat Conductor Cable
ED-505	Thermal Analysis of Proposed Flat Conductor Cable Lamination Method
ED-510	Deflection Characteristics of Various Flat Conductor Cables
ED-512	Qualification Testing Report of Cable, Electrical Multi-Conductor Unshielded, Flat, Flexible, Copper Conductors, 200°C, for Use in the Apollo Telescope Mount (ATM) Program
ED-515	A Calculation of the Constriction Resistance of the FCC Individually Sealed Contact Connector Contacts
ED-516	Flat Conductor Cable Equipment and Techniques
ED-518	Tensile Tests of Flat Conductor Cable and Connectors
ED-525	A Mathematical Model Describing the Thermal Behavior of Flat Conductor Cable Under Load
ED-526	Periodical Current and Voltage Propagation on FCC
ED-527	Vibration Characteristics of Flat Conductor Cable

C. Internal Technical Reports (Concluded)

ED-529	The Flexure Life of Flat Conductor Cable
ED-530	Flat Conductor Cable Strength and Reinforcement Methods
ED-533	A High Voltage Tester for Flat Conductor Cable Insulating Film
ED-536	A Survey of Ground-Fault Circuit Interrupters for Use with Residential Wiring Systems
ED-537	An Assembly Tool for Terminating Flat Conductor Cable to a Plug
ED-539	Contact Resistance in the MSFC Individually Sealed Contact Connector for Flat Conductor Cable

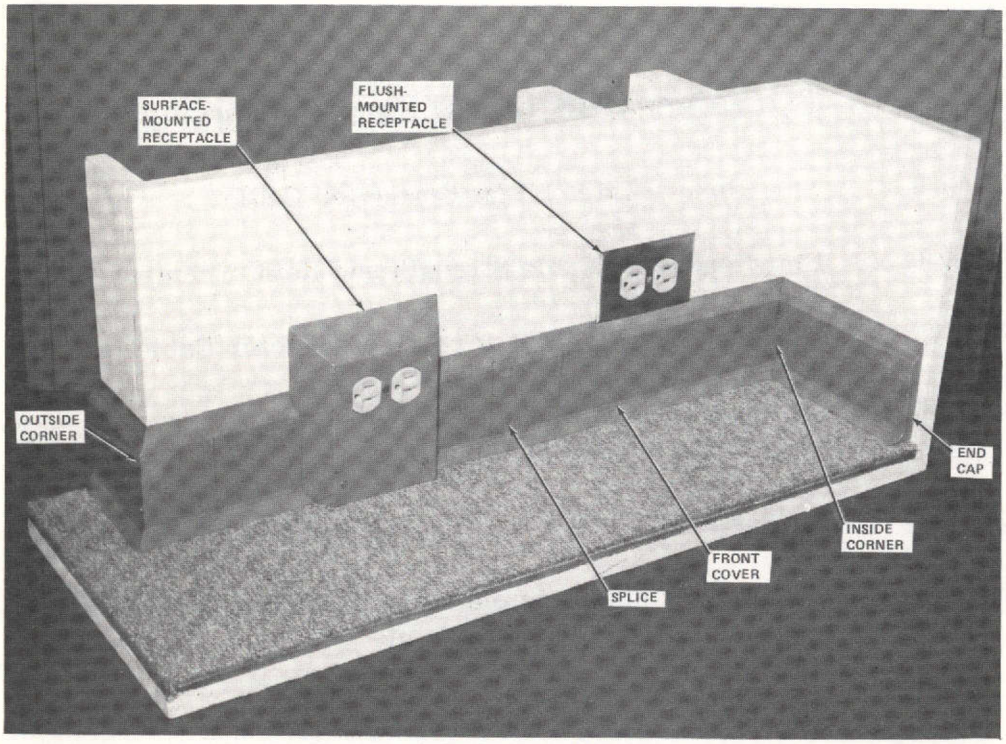

Figure 1. Baseboard system display. (Note: Flush mounted receptacle assembly is not included in this report.)

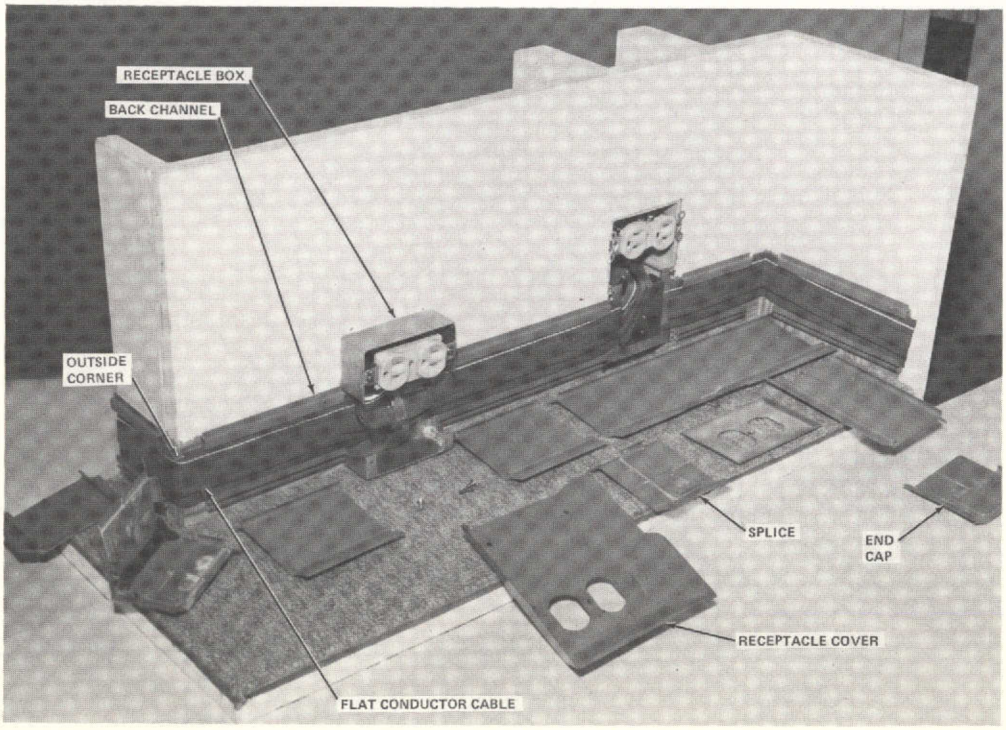

Figure 2. Unassembled baseboard display.

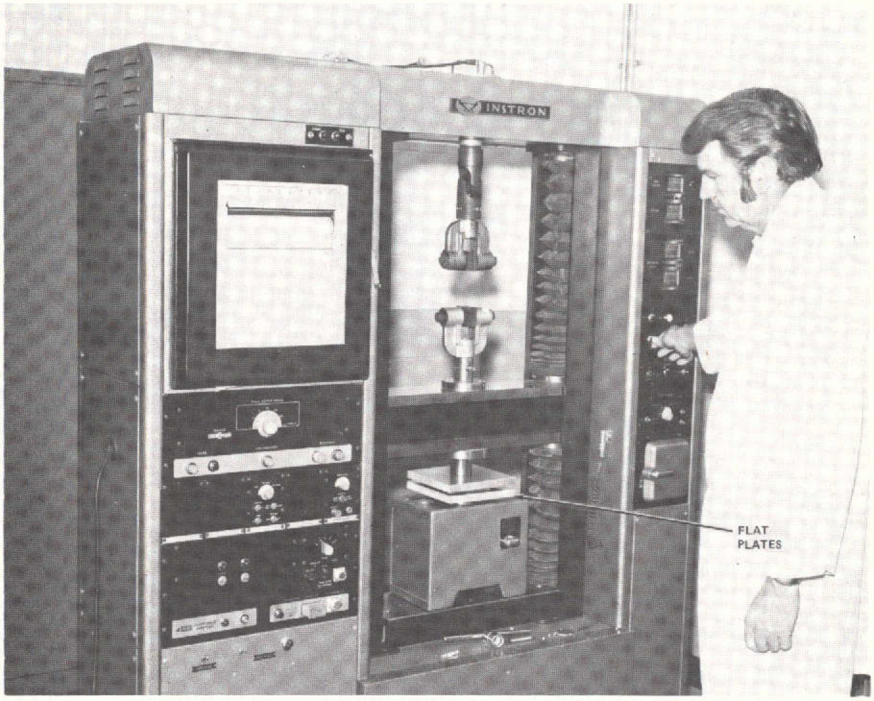

Figure 3. Instron Testing Machine with crush test setup.

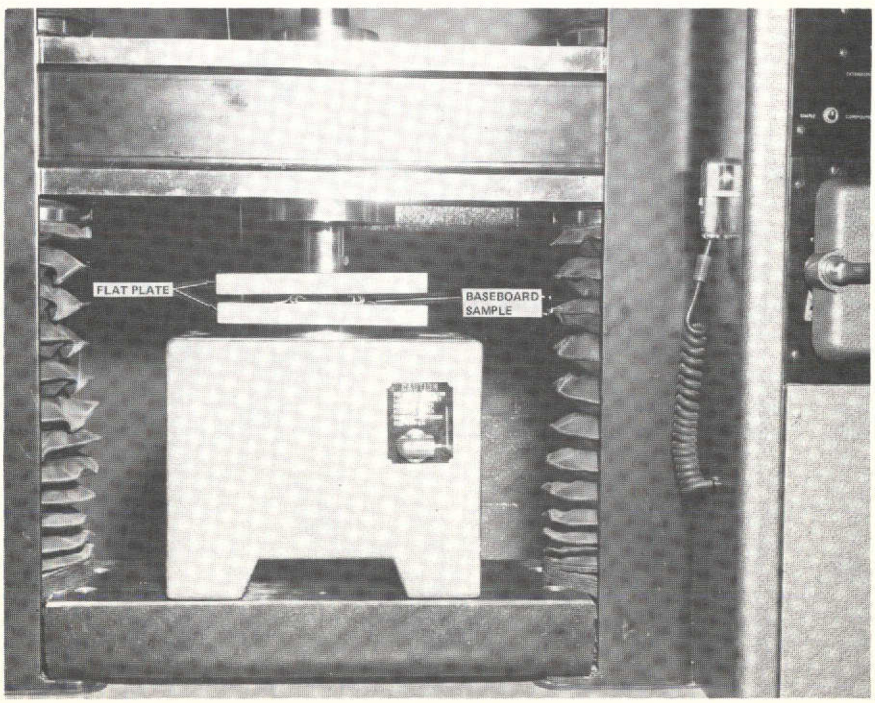

Figure 4. Crush test sample between flat plates.

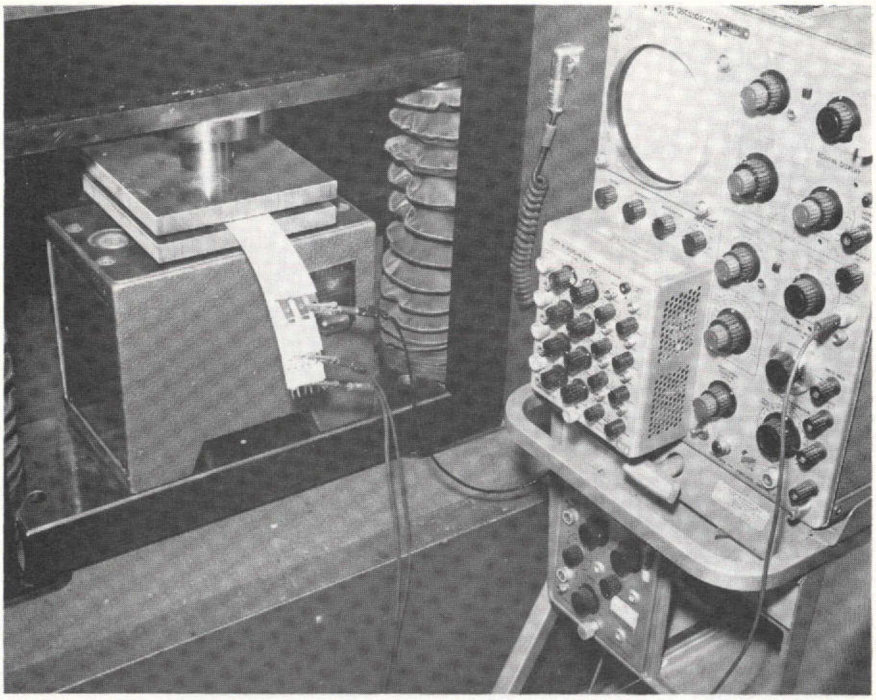

Figure 5. Crush test setup with cables.

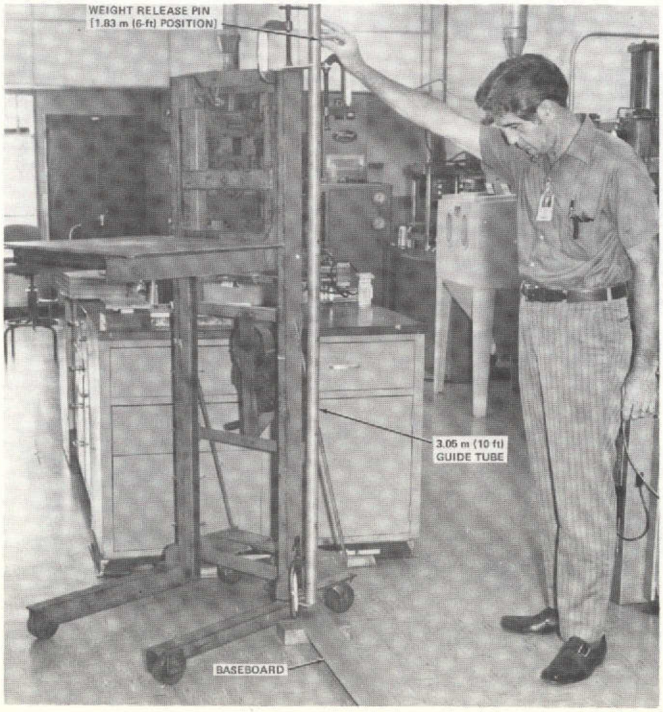

Figure 6. Impact test setup.

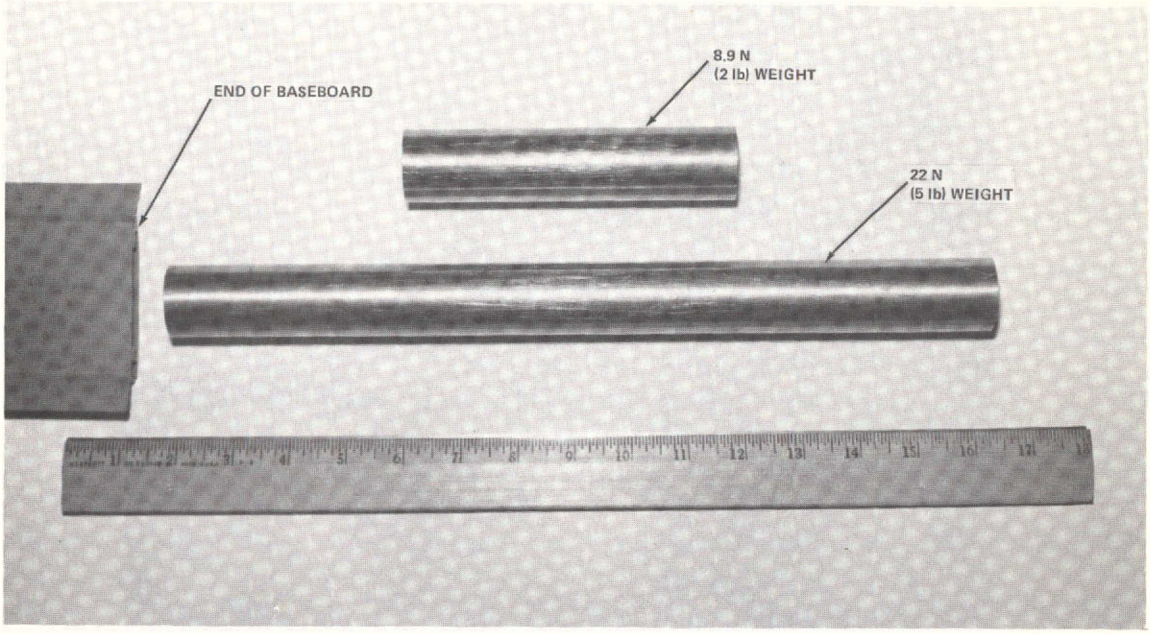

Figure 7. Impact test weights.

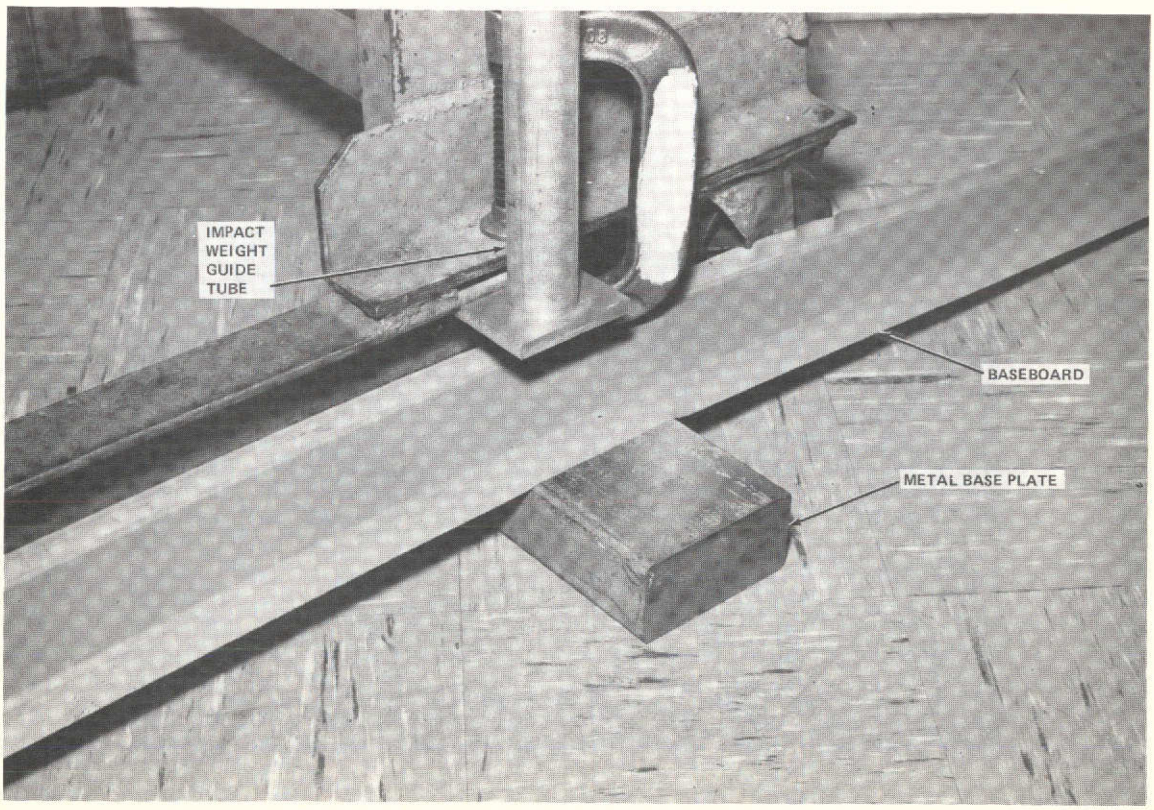

Figure 8. Baseboard in impact test position.

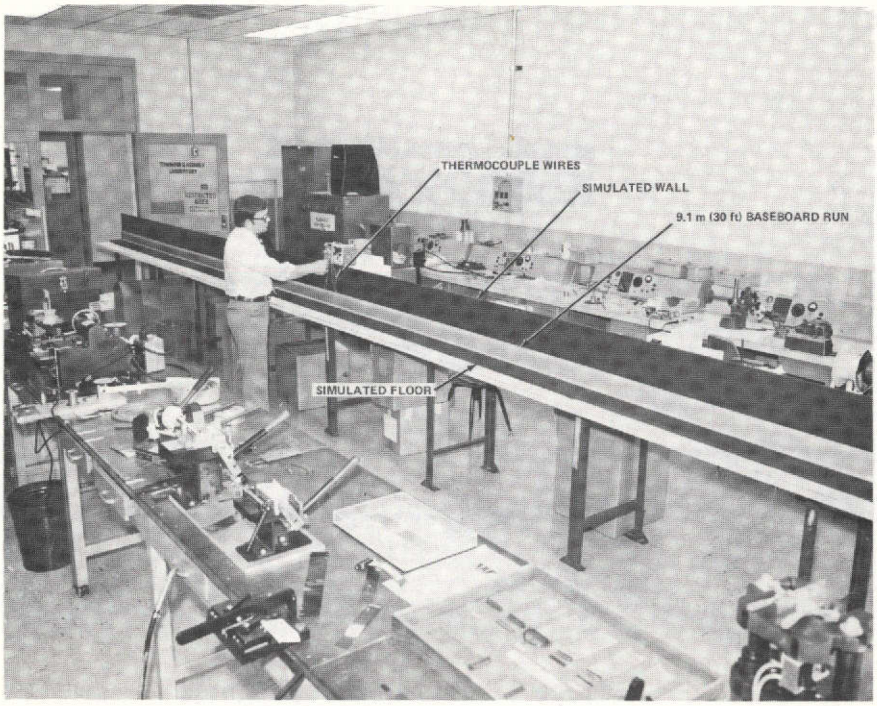

Figure 9. Heat test setup.

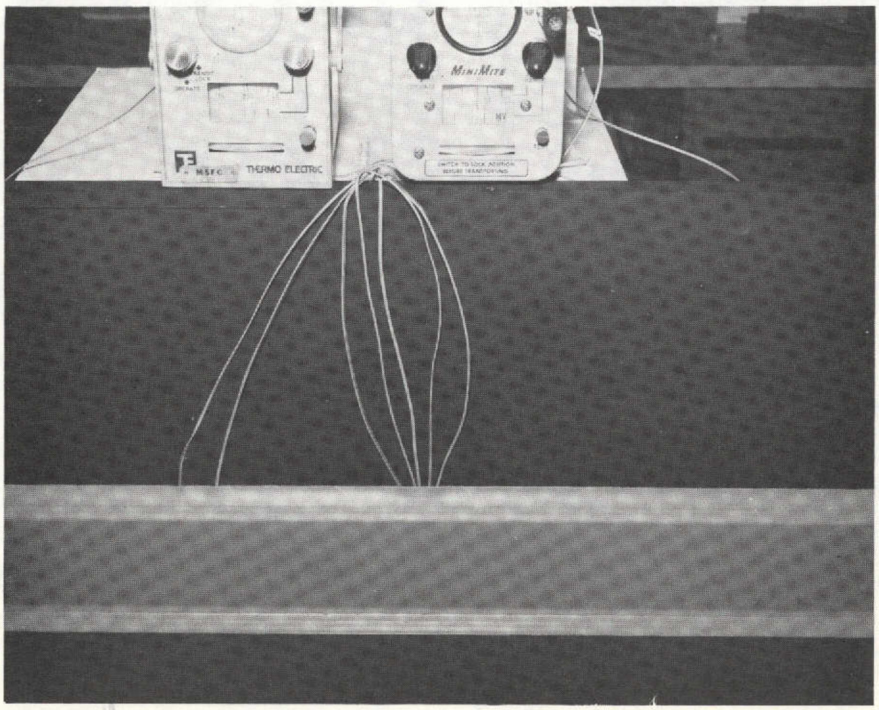

Figure 10. Heat test thermocouple wires.

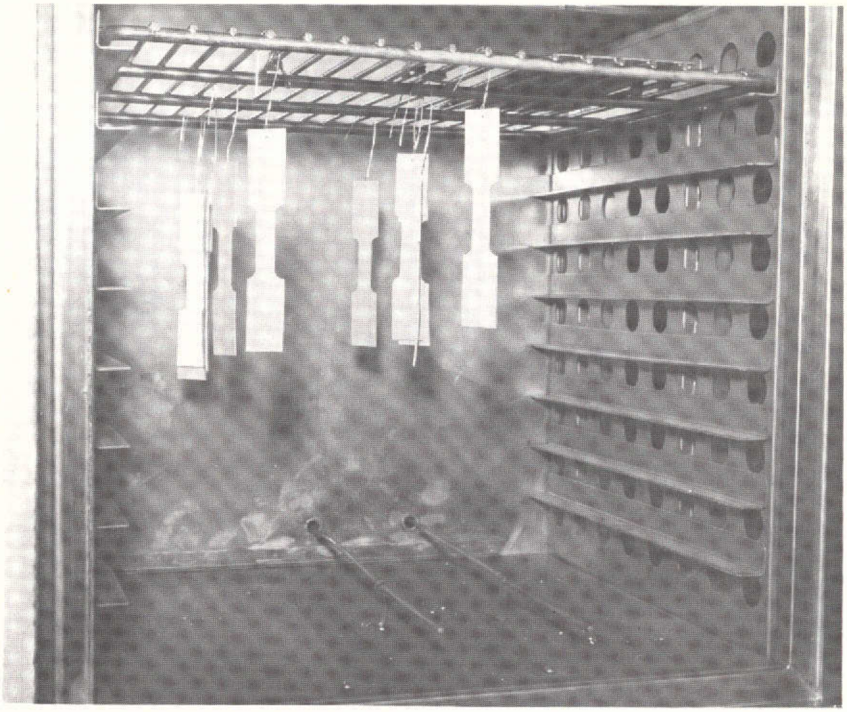

Figure 11. Aging specimens in oven.

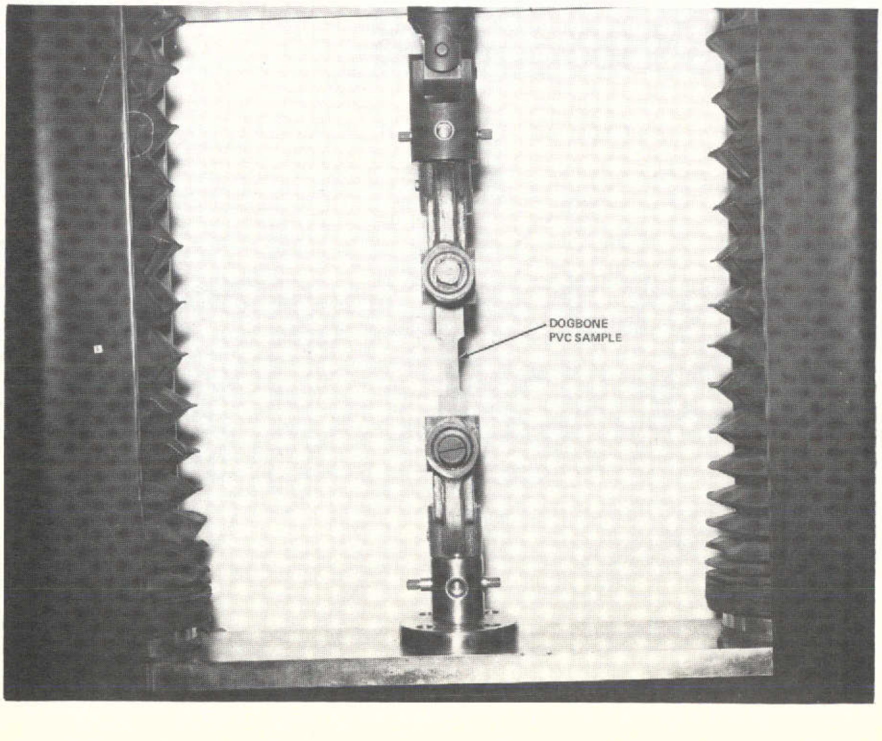

Figure 12. Tensile test setup.

Figure 13. Low temperature drop test.

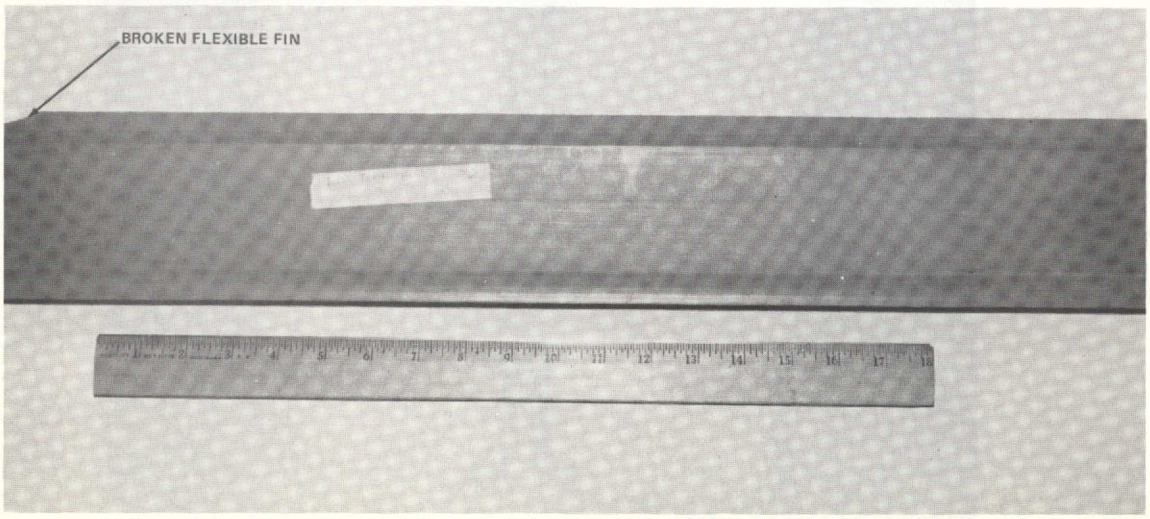

Figure 14. Low temperature dropped sample.

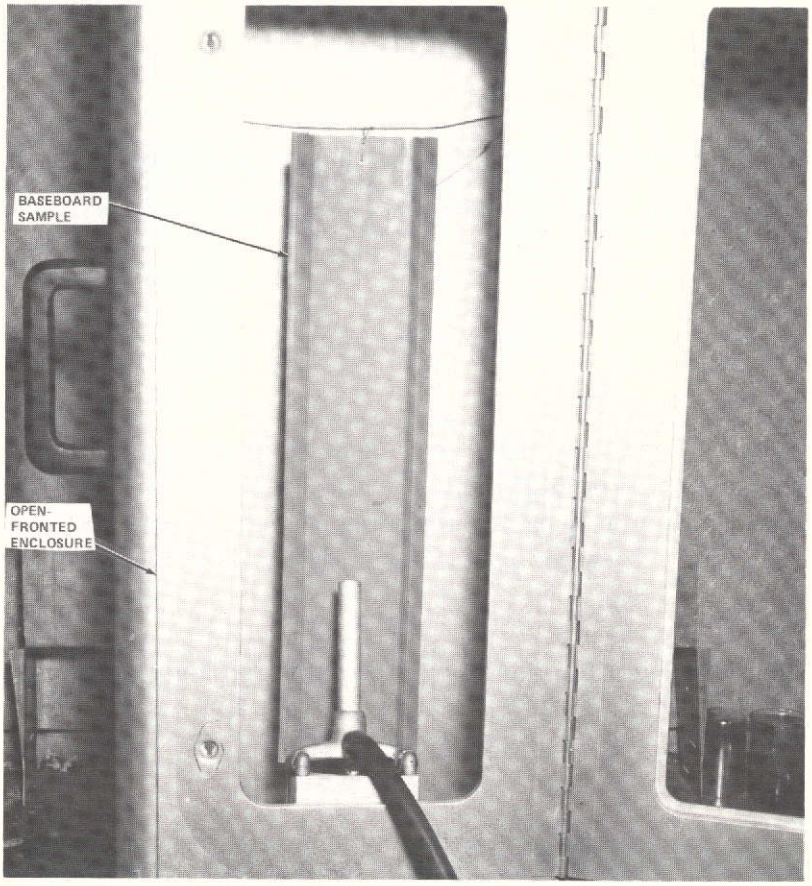

Figure 15. Flame test setup.

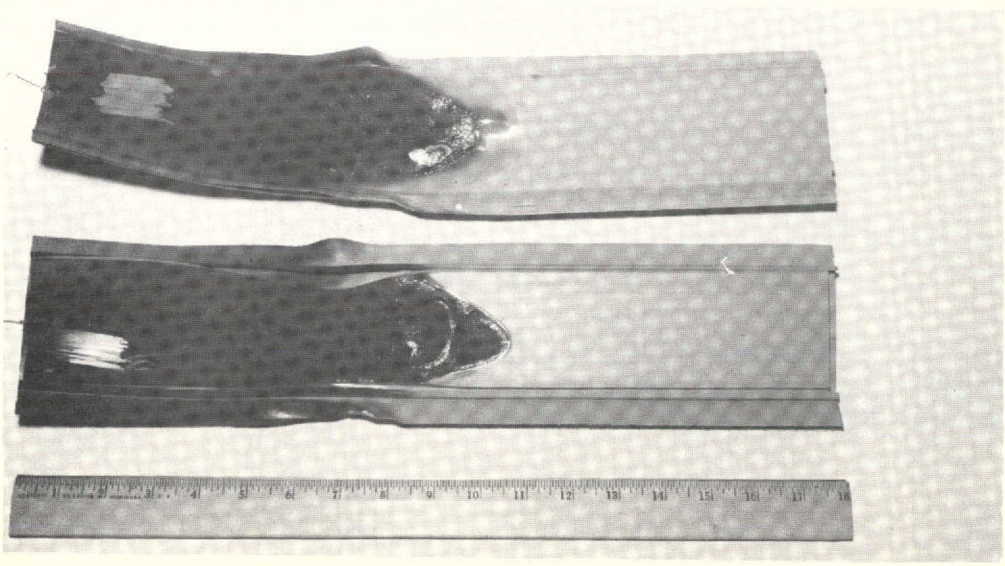

Figure 16. Flame test samples.

APPROVAL

TESTING OF A FLAT CONDUCTOR CABLE BASEBOARD SYSTEM FOR RESIDENTIAL AND COMMERCIAL WIRING

By James D. Hankins

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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