SIMULATED ENVIRONMENTAL AGING OF CATV CABLE

Richard V. Barone
Project Manager Technical Center
Metallurgical Materials Division
Texas Instruments Incorporated

Abstract

Residual compressive stresses in CATV cable were measured using the parameter of aluminum shield removal force. Values for 0.412, 0.500, and 0.750 inch diameter CATV cables were measured for contact lengths of 2-1/2, 5 and 10 inches in the as-received condition. A series of time-temperature exposures ranging from ambient to 160°F and 15 to 1920 minutes were run on 0.500 inch diameter cable after which aluminum shield removal force measurements were made on specimens having a contact length of 2-1/2 inches. The rapid rate of decay at times and temperatures easily encountered in the field suggest that high compressive forces imposed during manufacturing for the purpose of minimizing moisture absorption, may exist for only a short time since environmental conditions may anneal out the residual stresses. Another fact of interest was that the center conductor/dielectric bond is chemical in nature and stronger than the plastic itself, whereas, the aluminum shield/dielectric bond is strictly mechanical in nature.

Introduction

The Community Antenna Television Industry has been characterized by continual technological advancement over a relatively short span of time. Characteristic examples include increased transmission distances, expansion of the carrier wave to the high UHF channels, reduced non-uniform attenuation of the signal, and reduced attenuation of the signal over the entire spectrum. Many of the improvements were directly attributable to improvements in the cable materials or the manufacturing method involved in making the cable. Arbuthnott[1] points out that prior to aluminum sheathing, jacketed foamed polyethylene cables were capable of picking up sufficient moisture through the jacket and into the foam insulation to cause excessive increases in signal attenuation. Increases could exceed 20% at Channel 13 in periods of less than six months. Aluminum sheathed cable eliminated transverse moisture penetration provided that the cable had no breaks. Connector improvements were also made to minimize any longitudinal moisture penetration at the dielectric/sheath interface. Manufacturing steps such as compressing the aluminum sheath tightly around the dielectric is also common practice and is claimed to minimize longitudinal moisture penetration and associated signal attenuation.

Background

Our interests focused on seamless aluminum shielded CATV cable with a foamed polyethylene dialectric as this constituted a major part of the market at the time of our investigation. This type is schematically illustrated in Figure 1. This material is manufactured by coextruding the center conductor made of either copper clad aluminum or copper and the foamed polyethylene. This combination is then inserted into an aluminum tube and the aluminum tube drawn down around the polyethylene and center conductor so that the dielectric is compressed and a tight, moisture prohibiting joint exists.

As a series of preliminary measurements to characterize fundamental cable properties, tests were performed to determine the bond strength of both the center conductor/dielectric and the dielectric/aluminum shield bonds. This was done using an Instron Testing Machine and the fixtures shown in Figure 2a and b. The fixture consisted of a die which would restrain the shield and dielectric while the center conductor was being pulled to determine the center conductor/dielectric bonding force and another die with a larger opening which would restrain only the aluminum shield so that the dielectric/shield bond could be determined.

Procedure

The initial series of measurements were made on a number of cables in the as-received condition made by different manufacturers to represent a characteristic cross section of the industry. Cables having an outside diameter of 0.412, 0.500 and 0.750 inches were tested. In addition, the contact length which was sheared was varied, i.e., specimens with 2-1/2, 5, and 10 inches of contact between the center conductor/dielectric and dielectric/aluminum shield were tested. This is schematically shown in Figure 3. Specimens from a manufacturer for each diameter with both copper clad aluminum and solid copper center conductor were tested if possible. The detailed specimen preparation is listed in Appendix I.

Results

The results of the initial series of tests are shown diagramatically in Figure 4 for the shield removal forces and Figure 5 for the center conductor removal forces. Individual test values, the maximum ones attained, are listed in Tables 1 and 2 respectively.

The nonlinearity of force for either the aluminum shield removal measurements or the center conductor removal force with respect to contact length indicate a mode of failure which is partially wavelike in character. However, both the shield and center conductor removal forces increase with increasing contact length as shown in Figures 4 and 5 so that there is a length factor involved. The increase in force with contact length is characteristic of a single event. Thus, there is a duality to the failure mode of both the shield removal and center conductor removal from the cable. Figure 6 is an illustration of the types of typical stress strain diagrams that resulted in either the shield removal or center conductor removal measurements.

Type I represents a characteristic plastic/metal bond separation. Note that the force measurement does peak followed by a relatively sharp drop in the stress. The initial portion of the curve was either smooth or contained minor perturbation steps which appear to be caused by small areas of the bond being broken. The stress then increases until the entire interface shears and the stress falls to a level necessary to overcome the friction drag of either the center conductor and the dielectric or the dielectric and the aluminum shield as they are being removed.

Type II behavior is typical of when a center conductor yields and fractures. This is essentially a tensile strength curve for the metal center conductor.

Bond Characteristics

The initial test observations of the center conductor removal and shield removal specimens illustrated that the nature of the bond between the center conductor and the dielectric and the dielectrical aluminum shield were significantly different. The shield was clean with virtually no dielectric adhering to it after the polyethylene and center conductor were removed from it.

This shows the bond to be mechanical and that friction is the prime retardant to hold the dielectric in contact with the shield. In contrast to this when the center conductor was pulled from the dielectric it had polyethylene adhering to it which shows the bond to be more than mechanical. This difference is attributable to the manufacturing in which the foam polyethylene is coextruded hot around the center conductor. This gives rise to the strong bond between the polyethylene and metal center conductor which must have been even stronger than the dielectric itself since fracture occurred within the polyethylene rather than at the polyethylene/metal interface. The aluminum shield/ polyethylene, on the other hand, appears strictly mechanical. It is formed cold by drawing the tubing around the polyethylene center conductor core so there is no chance for the dielectric to melt and adhere to the aluminum shield.

Atmospheric Exposure Tests

Cables which were left outside over the summer months (approximately seven months) were sampled and tested before and after exposure to see if any changes in the shield removal force had occurred. Typical values observed for Brand 1 for 0.412, 0.500, and 0.750 inches diameter cable using a 2.5 inch contact length are listed in Table 3. The trend to drop in value indicated that some form of relaxation had occurred in the cables. This led to the series of experiments to determine if the relaxation was due to thermal means. Preliminary tests on several cables heated to temperatures between 140°F and 160°F showed that the center conductor removal force was affected very little while the shield removal force dropped considerably. These results led to a series of experiments involving measurement of the shield removal force as a function of time and temperature in an attempt to quantify the relaxation of properties by artificially aging them through thermal exposure. For these tests, the Brand 1, 0.500 inch diameter with a 2.5 inch contact length was chosen as representative. Specimens were made and tested according to Appendix I after thermal aging at temperatures of 120°F, 140°F, and 160°F. These temperatures were chosen to cover the range of those which could be experienced in the field on a hot sunny day by a black jacketed cable. Thermal measurements of temperatures obtained at the Attleboro test site of a black jacketed cable reached 140°F on a day that was in the low nineties so that higher temperatures could be expected in many areas since Attleboro weather is temperate in nature.

The results of the aging tests are listed in Table 4 and plotted in Figures 7 and 8. The results follow traditional trends of a thermally activated process, that is a more rapid reduction of properties with increasing temperature. Shield removal forces also appeared to asymtotically approach a limiting value for each temperature so that after 240 minutes at temperature only minor reductions would be expected if longer exposures were encountered. It is interesting to note that if the initial properties of a CATV cable are known then a fair approximation of the temperature experienced by the cable could be estimated by measuring the shield removal force after environmental exposure.

One exception of reduced properties with increasing time at a given temperature was observed for the 1920 minute series for the 0.750 inch diameter cable. This may have been due to a slight temperature variations as the 1920 minute specimens were run at a different time from the other specimens.

The degree to which the shield removal force fell off after a relatively short exposure to temperatures which can be encountered in the field during the warmer months raises the question of the utility of using high reductions on the aluminum to induce high compressive forces on the dielectric. Inducing large compressive forces within the cable would intuitively require a larger expenditure of energy and thus be more expensive. Arbuthnott's gas leakage test work shows that high compressive forces are not necessary for moisture penetration inhibition. His test involved subjecting 5 foot long samples to a pressure of 5 psi at one end of the cable and collecting the gas which escaped at the other end of the cable. He reports that cables which experienced moisture penetration into cables (causing as much as 15% attenuation in three months of exposure) leaked at rates several orders of magnitude higher than properly made cable. This particular failure was caused in manufacturing by improper extrusion techniques. His work shows that lower shield compression forces (on the order of those measured on Brand 3) are adequate to provide low gas leakage rates if extruded properly during manufacturing.

Based on the simulated aging experiments it also appears that if large compressive forces are induced they will not be maintained if temperatures in the range of 140°F to 160°F are encountered. As previously mentioned, these temperatures are easily encountered in temperate climates including that of New

England if black jacketed. It also indicates that if the cable is installed near heat sources, e.g., chimneys, stacks, etc., similar relaxation would be anticipated.

Conclusions

1. The significance of the high stresses induced in the dielectric by some manufacturers in order to minimize longitudinal moisture absorption is questionable based on the literature available. The retention of the residual compression for long periods of time is doubtful since thermal relaxation induced by normal environmental exposure is capable of reducing the stress level in a relatively short time.

2. The center conductor/dielectric bond is chemical in nature and even stronger than the dielectric itself, whereas, the aluminum shield/dielectric bond is strictly mechanical in nature.

Acknowledgments

I would like to thank Frank Spexarth and John Fan for their comments and suggestions; Norman Hindley and Rene Langlais the principle technicians handling the experimental tests and Bob Laverdiere for the artwork.

Bibliography

1. Arbuthnott, Jack Jr., 18th Annual NCTA Convention Official Transcript, Rx: Cable Prescription for the Future National Cable Television Association June 22-25 1969 San Francisco Hilton p396-404.

TABLE 1

ALUMINUM SHIELD REMOVAL FORCE (POUNDS)

Manu-facturer	Dia-meter	Center Con-ductor	Specimen Length 2-1/2"	5"	10"
Brand 1	0.750	Cu/Al	150 (60)**	170 (34)	350 (35)
Brand 2	0.750	Cu/Al	120 (48)	260 (52)	372 (37)
Brand 3	0.750	Cu	17 (6.8)	9 (1.8)	15 (1.5)
Brand 2	0.750	Cu	134 (54)	260 (52)	390 (39)
Brand 1	0.500	Cu/Al	90 (36)	115 (23)	125*
Brand 3	0.500	Cu/Al	1 (.4)	2 (.4)	4 (.4)
Brand 1	0.500	Cu	80 (32)	148 (30)	200 (20)
Brand 2	0.500	Cu	82 (33)	160 (32)	250 (25)
Brand 1	0.412	Cu/Al	110 (44)	112*	112*
Brand 3	0.412	Cu/Al	15 (6)	22 (4.4)	30 (3.0)
Brand 1	0.412	Cu	138 (55)	175*	180*
Brand 2	0.412	Cu	96 (38)	176 (35)	182*

* Center conductor fractured prior to shield removal.

** Units of parenthesized figures are pounds/inch of contact length.

TABLE 2

CENTER CONDUCTOR EXTRACTION FORCE (POUNDS)

Manufacturer	Diameter	Center Conductor	Specimen Length 2-1/2"	5"	10"
Brand 1	0.750	Cu/Al	260 (104)**	315 (63)	320*
Brand 2	0.750	Cu/Al	310 (124)	375*	375*
Brand 3	0.750	Cu	260 (102)	280 (56)	400 (40)
Brand 2	0.750	Cu	320 (128)	440 (88)	500 (50)
Brand 1	0.500	Cu/Al	125*	125*	125 (12.5)
Brand 3	0.500	Cu/Al	120 (48)	128 (51)	138*
Brand 1	0.500	Cu	128 (51)	185 (74)	225 (22.5)
Brand 2	0.500	Cu	155 (62)	215 (86)	250 (25)
Brand 1	0.412	Cu/Al	130*	110*	112*
Brand 3	0.412	Cu/Al	81*	92 (18)	125 (12.5)
Brand 1	0.412	Cu	170*	180*	180*
Brand 2	0.412	Cu	150 (60)	235 (47)	307*

* Center conductor fractured prior to pulling out of the polyethylene.

** Units of parenthesized figures are pounds/inch of contact length.

TABLE 3

Aluminum shield removal force for 0.750 inch, 0.500 inch, and 0.412 inch diameter cable as-received and after aging for six months (average values).

Brand	Diameter inches	As Received pounds	Aged Six Months pounds
1	0.750	150	95
2	0.750	120	129
3	0.750	12	10.6
1	0.500	80	58
2	0.500	82	75
3	0.500	7.4	4.7
1	0.412	110	110
2	0.412	96	83
3	0.412	15	2.2

TABLE 4

Aluminum shield removal force as a function of time and temperature for Brand 1, 0.500 inch and 0.750 inch diameter CATV Cable (each value average of three tests)

		Aging Temperature (°F)		
		120	140	160
Diameter (Inches)	Time (Minutes)	Aluminum Shield Removal Force (Pounds)		
0.500	15	65	54	29
	60	51	46	15
	240	55	38	10
	960	50	34	8
	1920	51	33	6
0.750	15	77	64	39
	60	65	46	25
	240	63	47	23
	960	61	34	18
	1920	58.5	43	21

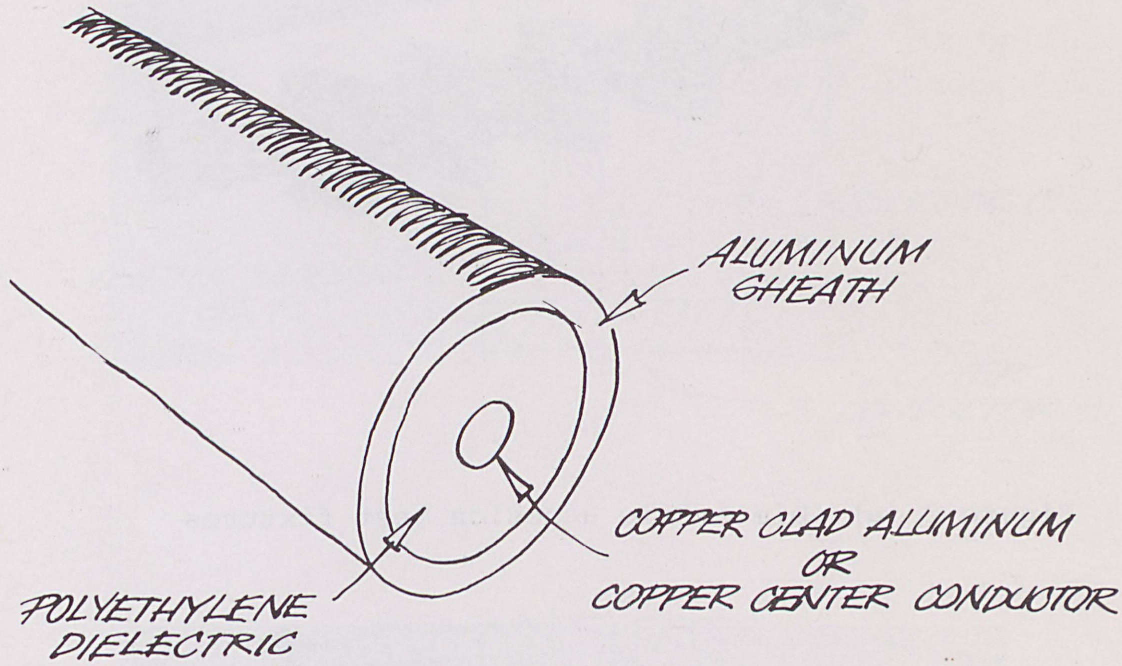

Figure 1. Schematic diagram of an aluminum shielded CATV cable with a foamed polyethylene dielectric.

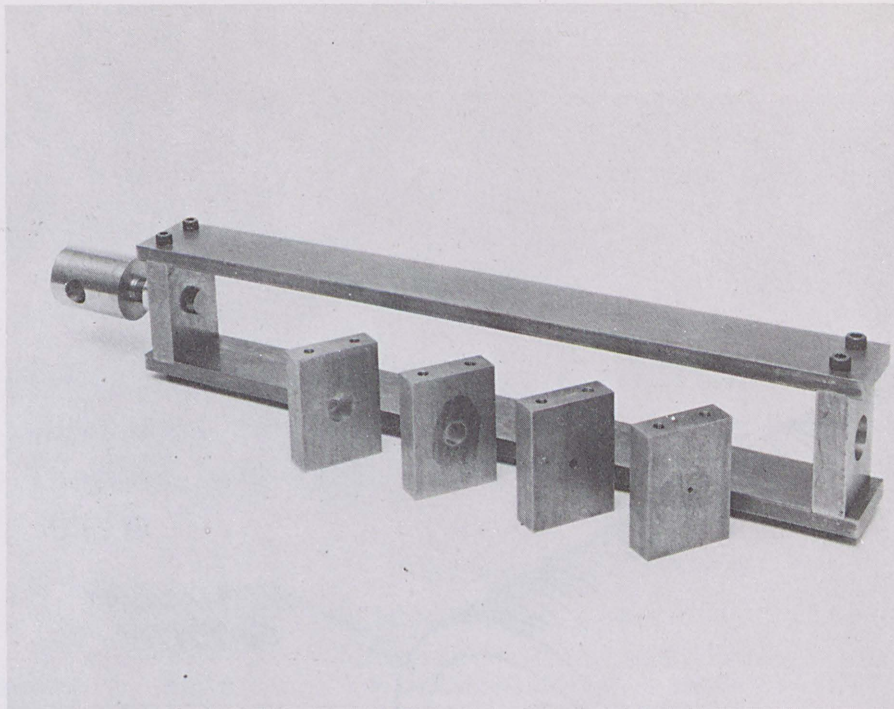

Figure 2 (a) Dielectric adhesion test fixtures

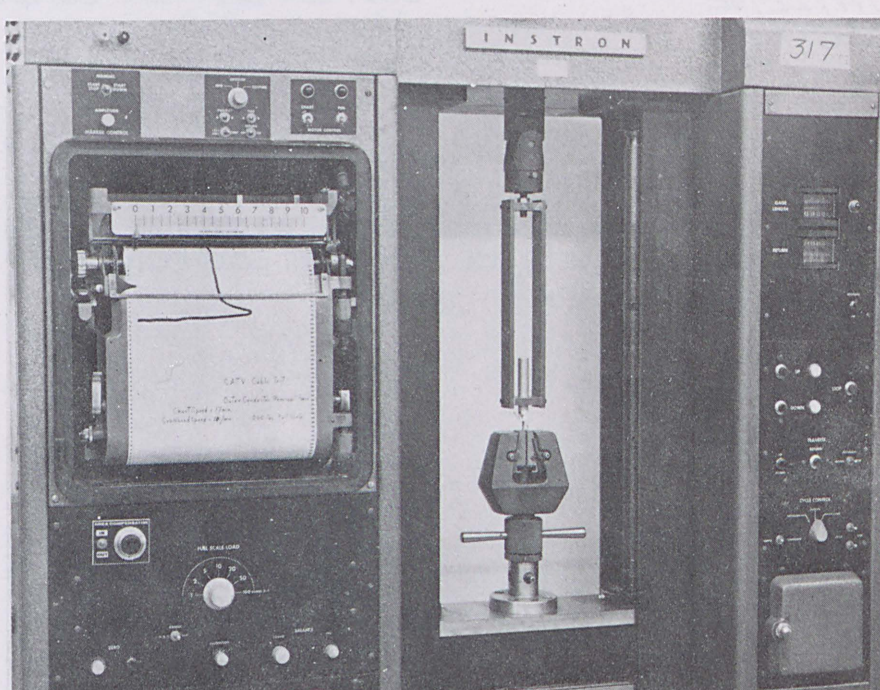

Figure 2 (b) Test fixture and specimen in position on Instron Tensile Testing Machine

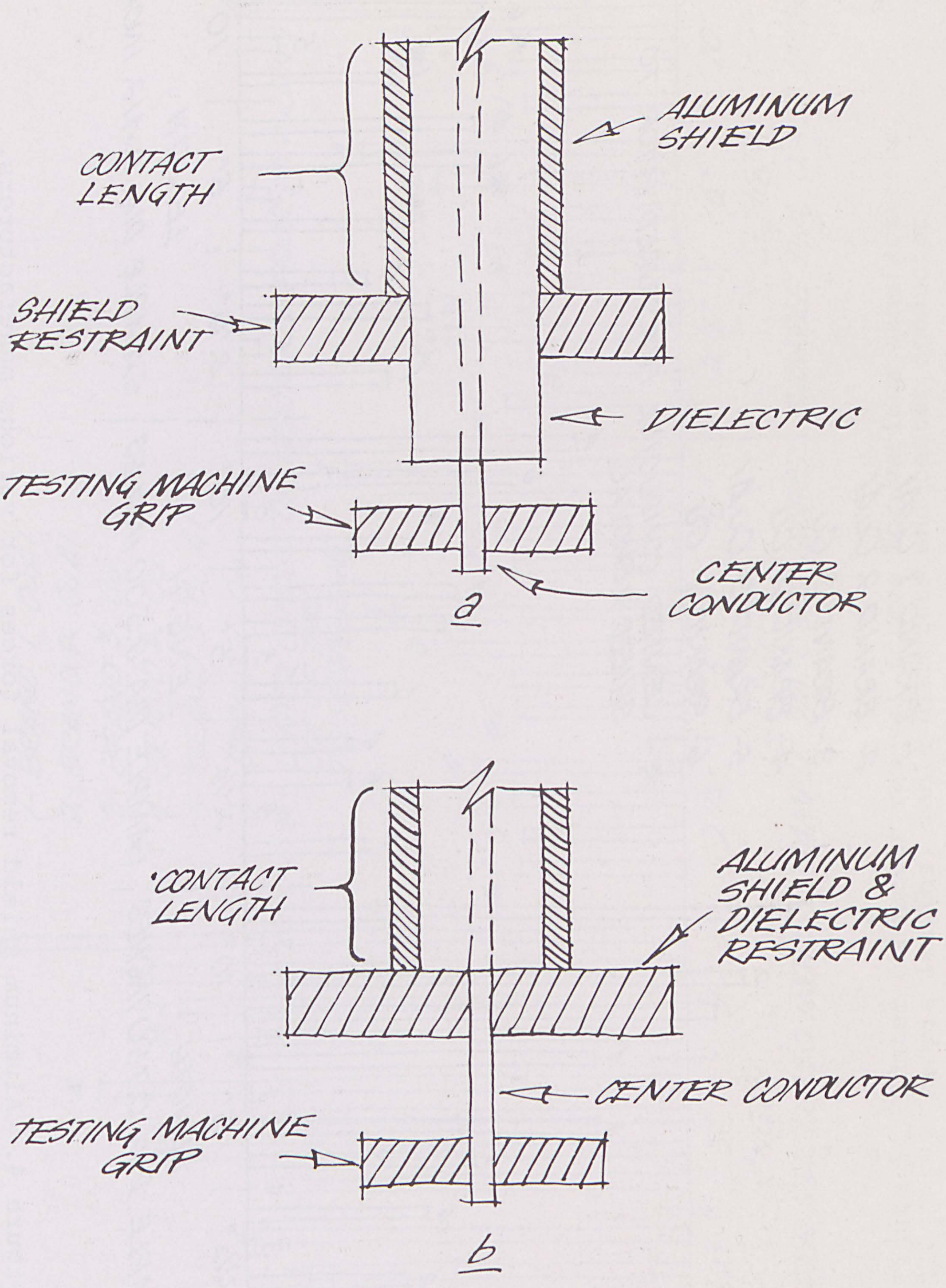

Figure 3. Schematic illustrating the fixture and specimen condition for (a) the shield removal force and (b) the center conductor removal force.

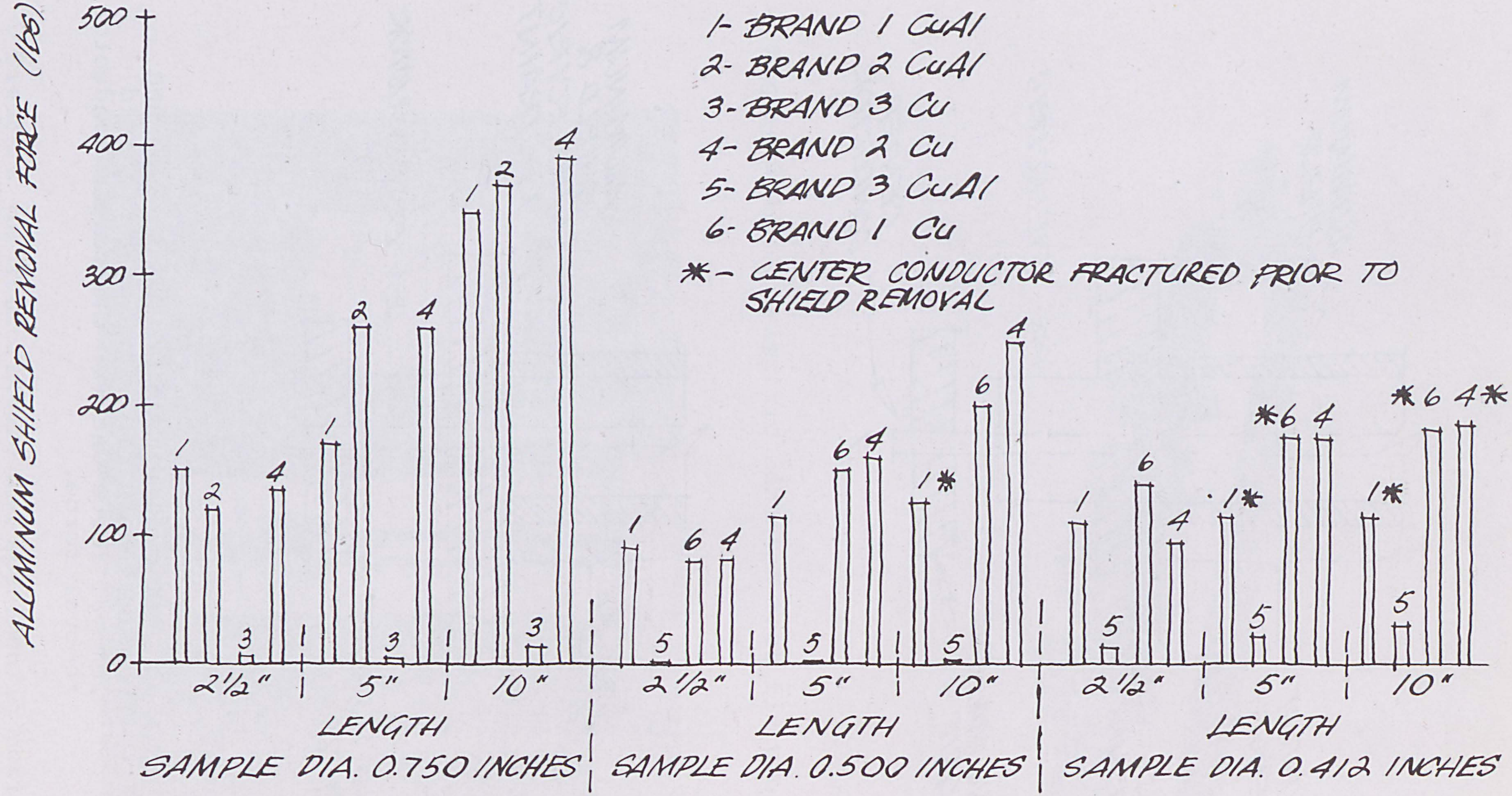

Figure 4. Aluminum shield removal forces for various manufacturers, sample lengths, cable diameters and center conductor materials.

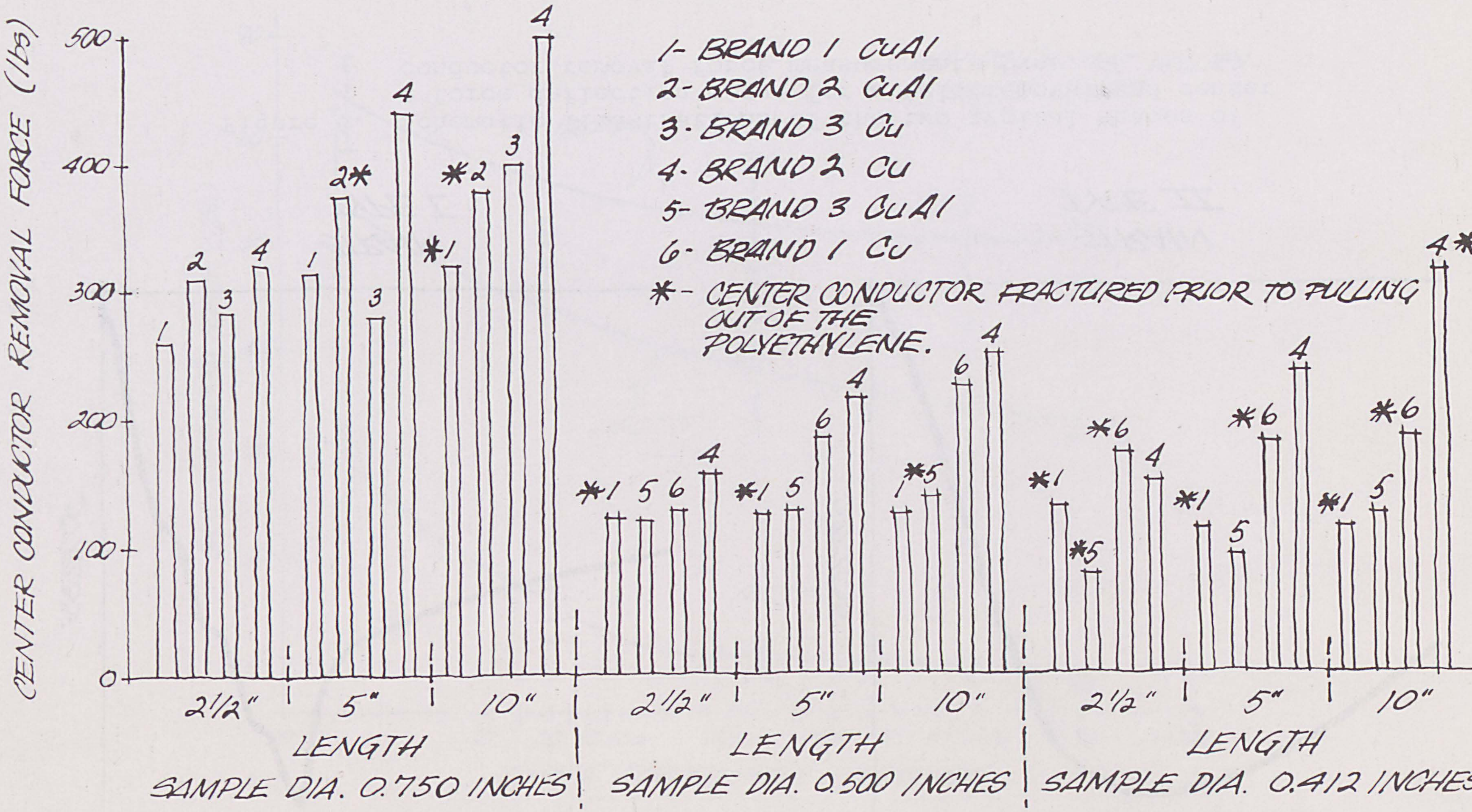

Figure 5. Center conductor removal forces for various manufacturers, sample lengths, cable diameters and center conductor materials.

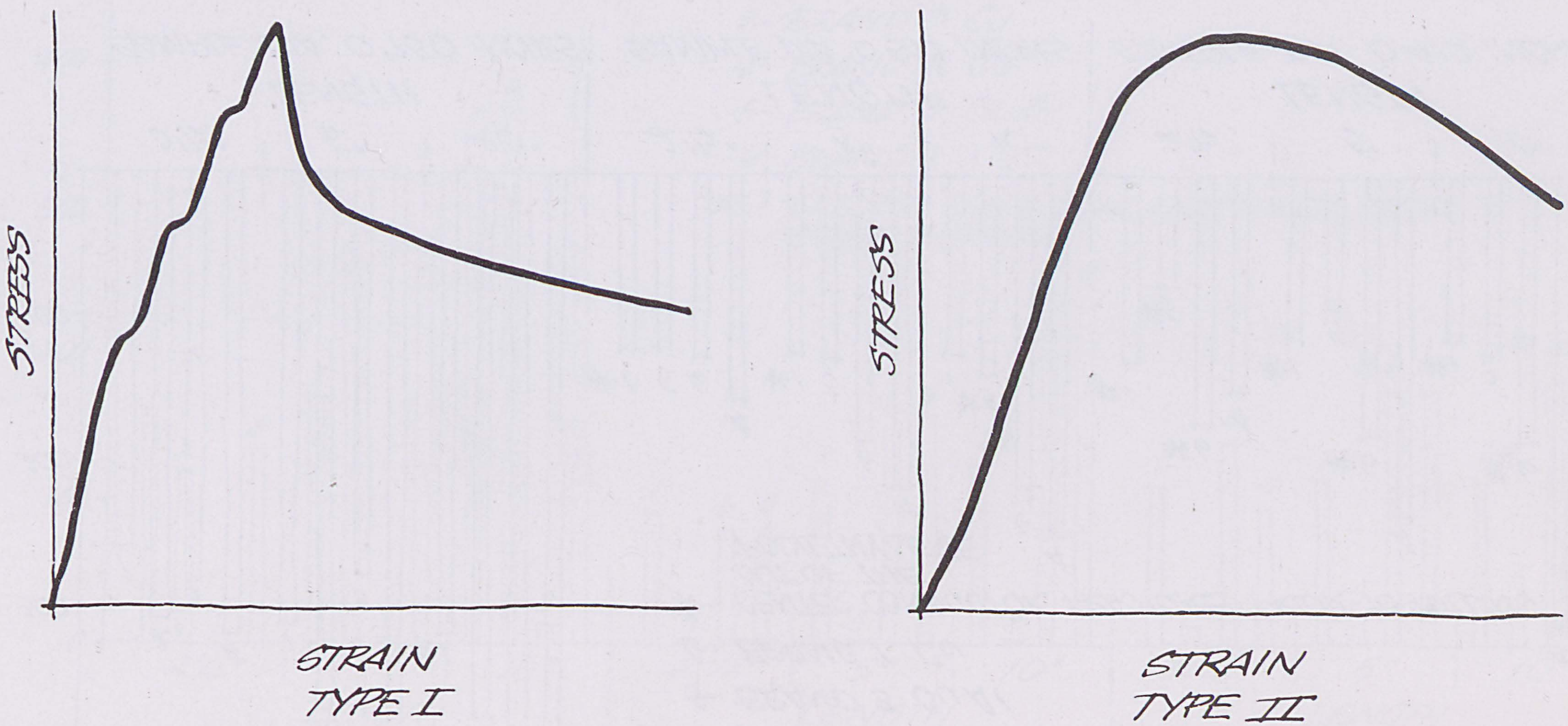

Figure 6. Schematic illustrations of the two typical shapes of a force deflection curve for shield removal and center conductor removal force measurements type.

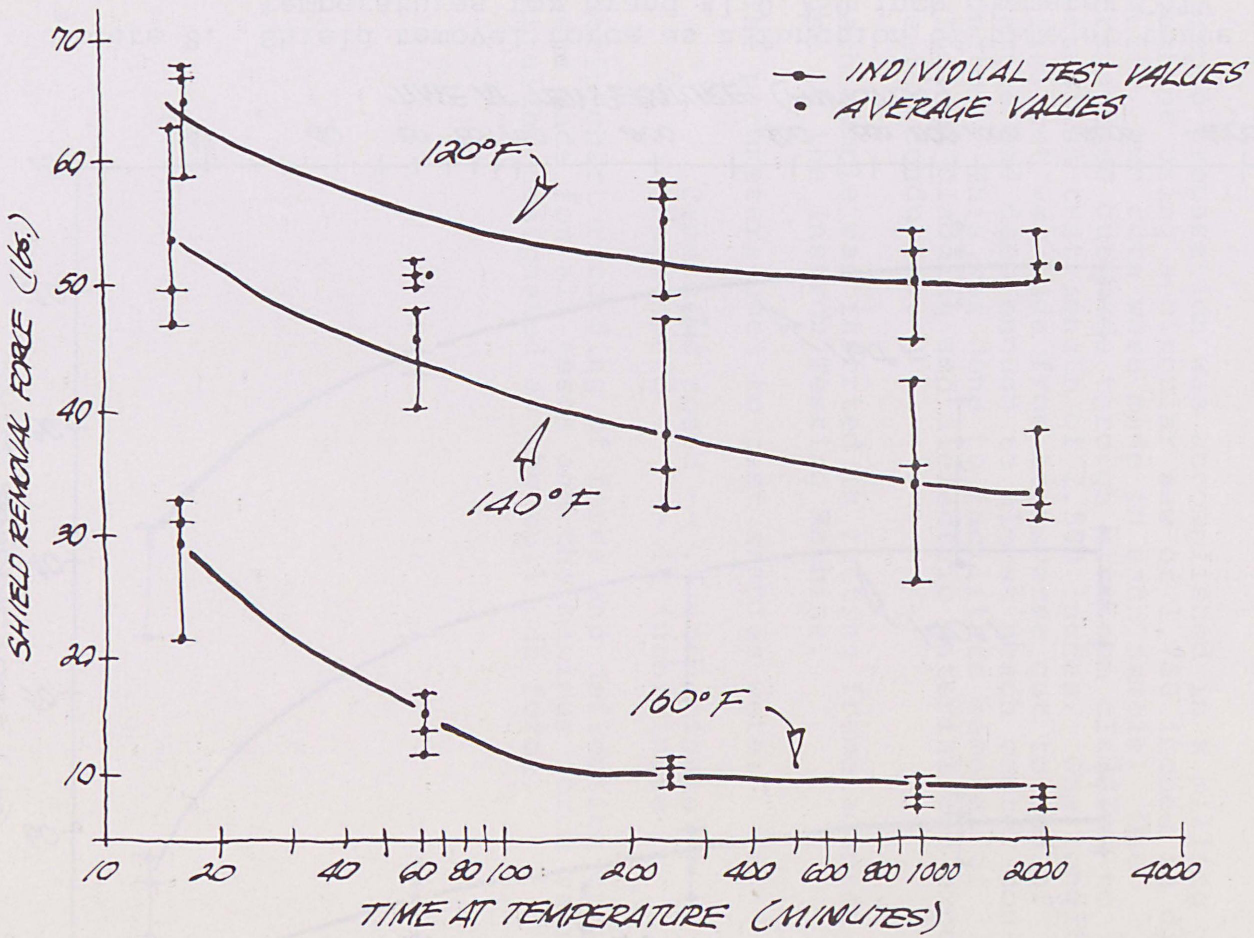

Figure 7. Shield removal forces as a function of time at three temperatures for Brand #1, 0.500 inch diameter CATV cable.

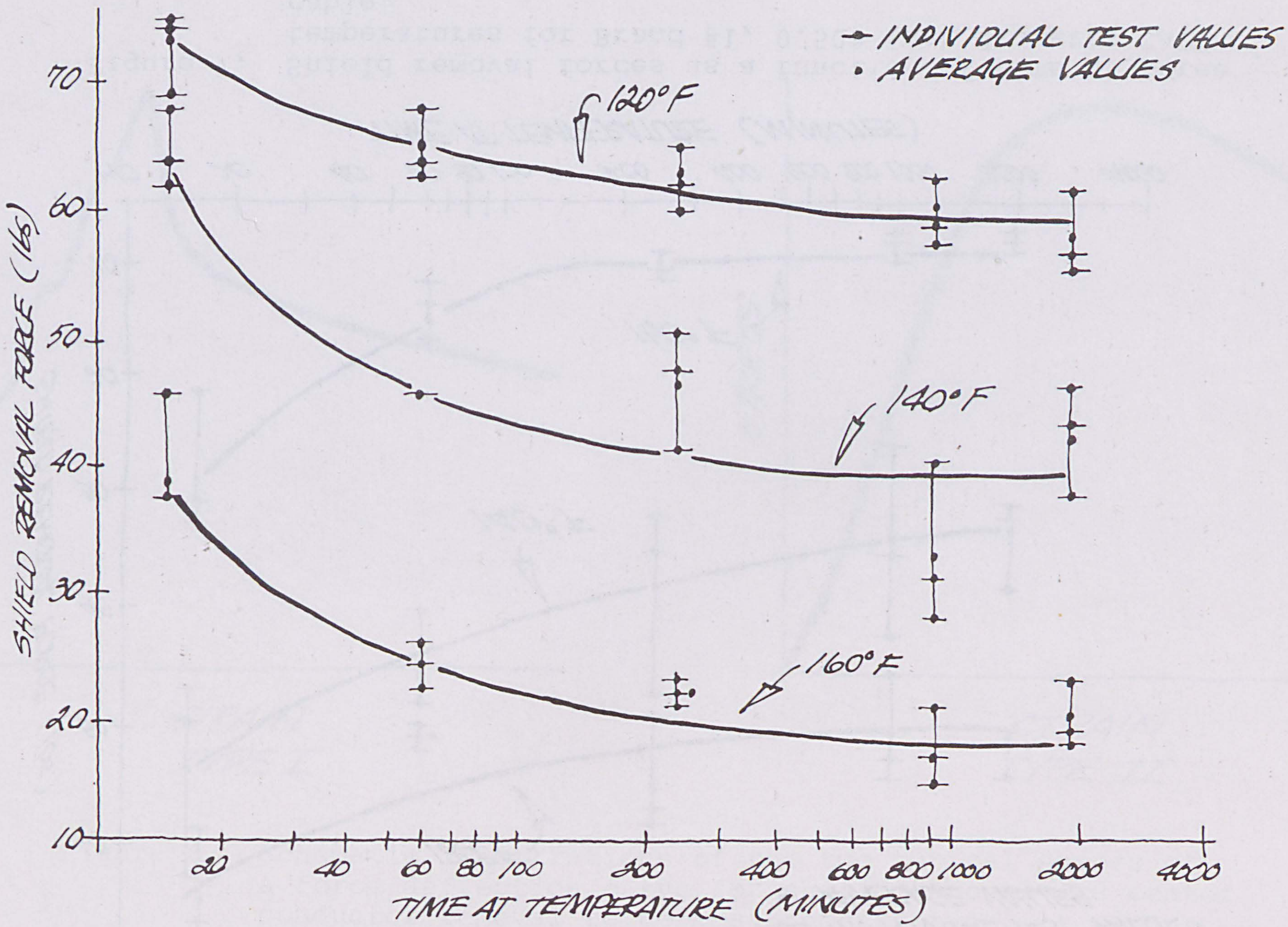

Figure 8. Shield removal force as a function of time at three temperatures for Brand #1 0.750 inch diameter CATV cable.

APPENDIX I

Standard Testing Method for Measuring Shield Removal and Center Conductor Removal Force for a 2-1/2 Inch Contact Length.

Each length of cable to be tested was cut into 4 inch lengths.

Sample preparation was accomplished in a milling machine using a circular saw of 1.750 inches in diameter, two cuts were made in each sample. One transverse cut made through aluminum cladding to establish test length of 2.500 inches. One longitudinal cut was made from transverse cut to end of sample and deep enough to almost reach center conductor. This was done to facilitate removal of aluminum cladding and dielectric material and expose center conductor.

Each sample was inserted in testing frame adapted for use in the Instron Testing Machine.

The parameters used to test samples were:

Crosshead speed	--	.5 inch/minute
Chart speed	--	10 inch/minute

Strip chart recording of force and deflection curves were made for all tests and the maximum force value attained designated as the pull out force.