NASA TECHNICAL MEMORANDUM

NASA TM X-53522

June 21, 1966

NASA TM X-53522

EVALUATION OF HIGH TEMPERATURE STRANDED HOOK-UP WIRE

By HAROLD J. MOORE, JR. AND JAMES H. DONNELLY
Quality and Reliability Assurance Laboratory

NASA

George C. Marshall Space Flight Center, Huntsville, Alabama

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

TECHNICAL MEMORANDUM TM X-53522

EVALUATION OF HIGH TEMPERATURE STRANDED HOOK-UP WIRE

By

Harold J. Moore, Jr.

and

James H. Donnelly

ADVANCED METHODS AND RESEARCH SECTION
ELECTRICAL TEST AND ANALYSIS BRANCH
ANALYTICAL OPERATIONS DIVISION
QUALITY AND RELIABILITY ASSURANCE LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TECHNICAL MEMORANDUM TM X-53522

EVALUATION OF HIGH TEMPERATURE STRANDED HOOK-UP WIRE

By

Harold J. Moore, Jr.

and

James H. Donnelly

George C. Marshall Space Flight Center
Huntsville, Alabama

ABSTRACT

This report presents the evaluation of selected wires and insulation for space vehicle and ground support equipment applications. The types of wire tested were tin coated copper with irradiated polyolefin insulation, a tin coated copper with irradiated crosslinked polyalkene and a jacket of radiation crosslinked polyvinylidene fluoride (Kynar), Teflon (TFE) insulated fine silver, Teflon insulated silver alloy, and Teflon insulated nickel-plated copper with a final plating of silver.

The test series of physical, electrical, environmental,and metallurgical analyses include measurements for flexibility, tensile strength, conductivity, insulation resistance, temperature resistance, corrosion resistance, etc.

"Workability" tests such as weldability, solderability, and strippability were performed to evaluate actual use conditions.

The conclusions and a survey of the test results will aid electrical personnel in selecting conductors and insulation materials for specific application.

NASA - GEORGE C. MARSHALL SPACE FLIGHT CENTER

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

LIST OF TABLES

TECHNICAL MEMORANDUM TM X- 53522

EVALUATION OF HIGH TEMPERATURE STRANDED HOOK-UP WIRE

SUMMARY

Tests to determine primary wire characteristics were selected in the areas of tensile strength, flexibility, conductivity, and general workability. Supplementary sampling tests were included to supply additional information usually required by procurement specifications.

Unless stated otherwise, on specific tests the wires evaluated are described in table 1.

Of the three insulation materials tested, Teflon (TFE), as expected, is superior in extremely high temperature applications. The irradiated Kynar polyolefin is sufficient for most high temperature uses and will withstand temperatures well above the normal 100° C applications.

The use of Teflon extruded insulation is limited by the inability of tin coating applications to withstand the Teflon extrusion temperatures which range up to 540° C. In space system applications using Teflon insulated wires, the copper conductors are plated with nickel or silver. The silver plating results in cuprous oxide or "Red Plague"; a condition generally recognized throughout the space industry. The silver over nickel over copper conductor was intended to overcome this corrosive condition, but environmental tests prove the corrosion continues to form and progress. Tin or nickel coatings are not subject to this electrochemical corrosion.

The use of Teflon over pure silver or silver alloy eliminates the formation of Red Plague and has excellent electrical characteristics. Limitations due to the higher costs and availability are the prime restrictions.

The strong bond between polyolefin and the conductor accounts for an increased flex life, a higher corrosion resistance, and, to some degree, less desirable strippability characteristics. Since the conductor has less contact with the outside environment, corrosion activity is reduced considerably. By contrast, Teflon does not bond readily, strips easily, but will permit exposure to corrosive atmospheres.

With proper consideration of design criteria and end use requirements, this report should aid in the selection of wire and insulation materials for space exploration systems. Knowledge of the advantages and limitations will prevent overspecifications and result in direct cost savings.

The performance rating chart in Section VI of this report is presented as a guideline summary only.

SECTION I. PURPOSE

This report contains the results of an evaluation of high temperature insulated hook-up wire for application to electronic space assemblies. Small gauge wire was included for application to slip-ring assemblies. The application required that the following characteristics be evaluated: tensile strength, flexibility, conductivity, and workability. Two wires of No. 20 and 22 AWG (for general purpose applications) were also evaluated to determine possible intermediate temperature range (150°C) capabilities. The types and sizes of wire evaluated are listed in table 1.

Table 1. Wire Description

Group Code	Wire Type	Conductor Composition	AWG Size	Insulation	Mfg.
G1	Silver Shield	Ag/Ni/Cu	22-19/36	Teflon	International Wire Co.
G2	Fine Silver	Ag	30-19/42	Teflon	Hudson Wire Co.
G3	44/0111/30-9	Sn/Cu	30-7/38	Kynar/ Polyolefin	Raychem Corp.
G4	Alloy 765	Ag Alloy	30-19/42	Teflon	ITT Mfg. Co.
G5	TRT 20 (19) U2	Sn/Cu	20-19/32	Polyolefin	Raychem Corp.

Note: Ag/Ni/Cu - Copper is plated with 40 microinches of nickel and 40 microinches of silver overall.

Ag - Silver, "Fine"

Sn/Cu - Tin coated copper

All wire insulations were applied by extrusion process.

SECTION II. TEST CONDITIONS AND EQUIPMENT

A. TEST CONDITIONS

Unless otherwise indicated in specific tests, standard laboratory test conditions were 24 (±2)°C temperature and 50 (±10) percent relative humidity.

B. TEST EQUIPMENT LIST

Name	Mfg.	Model No.
Megohmmeter	General Radio Co.	1862C
AC-DC-Hy-Pot	Peschel	Series H
Impedance Bridge	General Radio Co.	1608A
VTVM	Ballantine	643
Multimeter	Simpson	260
Wire Endurance Tester		85M01048
Temperature Chamber	Associated Testing Laboratories, Inc.	SLHB-5-CR/LC-1
Temperature Recorder	Bristol	1T500F-1B
Humidity Chamber	Tenney	Mite 3
Pull Tester	Dillon	Model M
Thermal Strippers	Ideal Industries	45-135
Differential Voltmeter	John Fluke	801B
Weld Head	Weldmatic	1032C
Weld Power Supply	Weldmatic	1048B
Pull Tester	Unitek	6-092-01
Force Scale (0-5 lbs.)	Chatillon	DPP-80
Force Gage (0-15 lbs.)	Weldmatic	F-918B
Microscope	Bausch and Lomb	
Solder Pot	Vulcan Electric Co.	1706T
Microscope	Kentron	AK-8
Research Metallograph	Bausch and Lomb	

SECTION III. EVALUATION TESTS

A. FLEXIBILITY TEST

1. Purpose. The purpose of this test is to determine the ability of the wires to withstand successive flexes and at what point fatigue failure will occur.

2. Test Items. Test samples were prepared of each type of wire with the exception of wire types G-1 and G-5. Flexibility characteristics of this wire size and composition were not considered pertinent to the evaluation. The test items and their particular configurations for this portion of the test program are tabulated in table 2.

Table 2. Flexibility Test Items and Configuration

Wire Type Code	Sample Length	Insulation Length	No. of Samples
G-2	7.75 cm (3 in.)	1.27 cm (1/2 in.)	20
G-3	7.75 cm (3 in.)	1.27 cm (1/2 in.)	20
G-4	7.75 cm (3 in.)	1.27 cm (1/2 in.)	20

3. Procedure. Individual test samples were mounted in the wire endurance tester as shown in figure 1.

The endurance tester subjects wire samples to a 90-degree bend cycle over a mandrel with a radius of 0.0635 cm (0.025 inch). Figure 2 shows the wire sample bent in the extreme 90 degree position. At the beginning of the test cycle the wire is completely vertical. A weight of 232 grams was suspended from the sample to maintain a tensile load during testing.

The wire sample under test was instrumented with a dc source to monitor the continuity of the wire during flexure. Thus, whenever continuity was lost, indicating fatigue had resulted in a wire break, the exact number of flexes could be noted. This resulted in some problems which are discussed in the test results of this section.

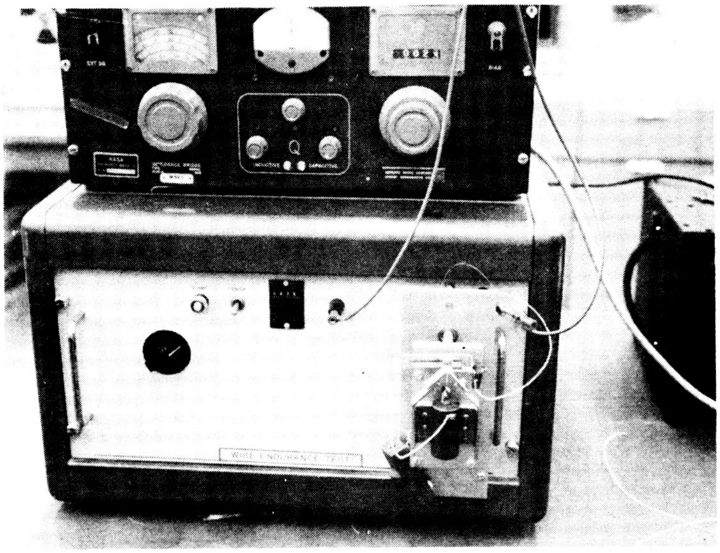


Figure 1. Wire Endurance Tester and Impedance Bridge showing Test Sample in Position

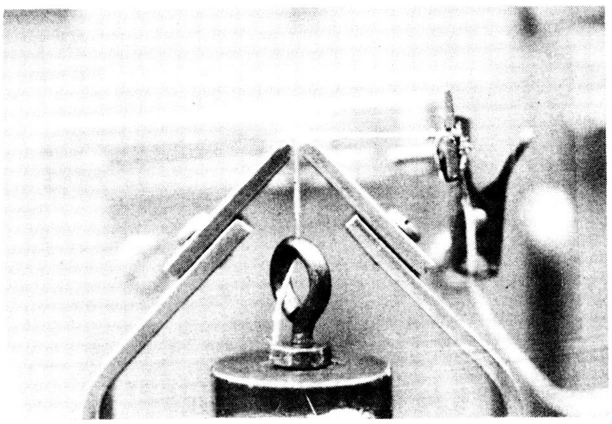


Figure 2. Wire Sample in 90 Degree Position of Flex Cycle

4. Test Results. Preliminary tests on the three insulated wires indicated a flex life greatly exceeding the specified number of flexes required. Careful stripping of the wires, however, showed that all strands were actually broken after this series of flexes, although continuity monitoring devices gave no visual or electrical indication of conductor breakage. Investigation revealed that during the manufacturing process or as the wire is thermally stripped, insulation is extruded between and/or bonded to the surface strands of the conductor. This prevented the attached weight from separating the broken strands. Figure 3 shows G-2 before flexing and figure 4 shows it after 2000 flexes. It can be seen that although the strands are broken, some in multiple places, the tight fitting insulation was sufficient to hold the strands in place. As a result of this characteristic, a test of strippability (the force required to pull the insulation from the conductor) was performed, the results of which can also be found in this section under 'Workability". Based on the results of this particular test, the amount of insulation remaining on the conductor in the final flexibility test configuration was selected as 0.635 cm (0.25 inch) above and 0.635 cm (0.25 inch) below the 0.0635 cm (0.025 inch) radius mandrel. In this manner the weight was sufficient to separate the broken conductor strands, giving a relatively accurate determination of overall flexibility.

One of the three insulated wires (G-2) failed to meet the specified number of flexes after being tested with only 1.27 cm (0.5 inch) of insulation on the wire as shown in table 3.

Table 3. Flexibility Test Results

Wire Code	Suspended Load	Flex Rate ±3 Cycles	Average Flexes to Failure
G2	232 grams	60/min	95
G3	232 grams	60/min	227
G4	232 grams	60/min	162

5. Summary. There are many parameters involved in determining why one wire is more flexible than another wire. Strand size and the number of strands that comprise the conductor are two important factors. Other factors affecting flex life are the type of

insulation and the metallic composition of the wire (in particular the work-hardening rate of the metal). Because the G-3 wire had a less flexible insulation and less strippability, it withstood approximately 1 1/2 to 2 1/2 times more flexes than the G-2 and G-4 wires.

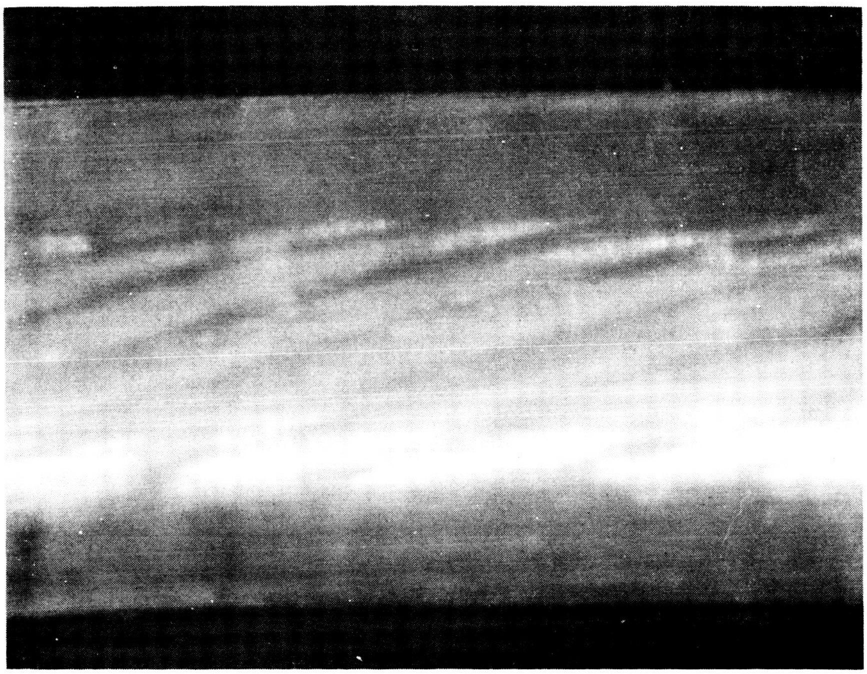


Figure 3. Fine Silver Wire Before Flex Testing

B. TENSILE STRENGTH

1. Purpose. The tensile strength test was performed to determine mechanical strength characteristics of the wires. The specimens were tested as composite wires (insulated) and also as bare conductors with the exception of G5.

2. Test Items. Five groups of five samples each were prepared in 45.7 cm (18.0 inches)lengths.

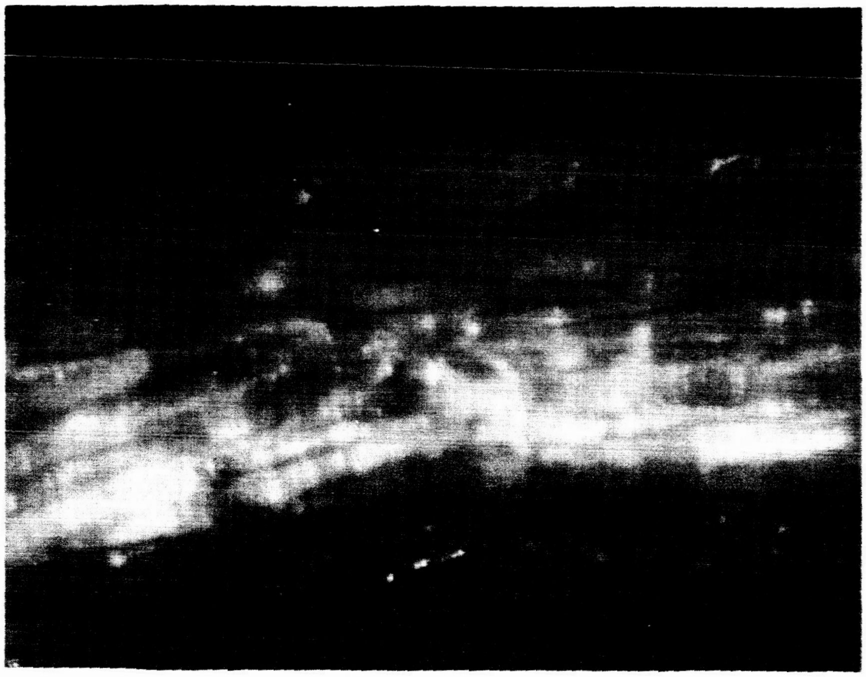


Figure 4. Fine Silver Wire After 2000 Flexures of 90 Degrees Over a Mandrel Radius of 0.0635 cm (0.025 inch)

Note the broken and deranged appearance of individual strands; also the manner in which the insulation retains the broken segments in intimate contact. This feature leads to erroneous indications of a greater flex life even with a test current (dc) of 250 ma through the conductor.

3. Procedure. Each specimen was wrapped one full turn around a 2.54 cm (1.0 inch) spool attached to the pull tester (figure 5) and stressed along the length axis until the conductor separated. The force required to break the specimen was recorded as F, and this along with a measurement of conductor diameter, recorded as D, was formulated to produce tensile strength in newtons per square meter (pounds per square inch).

4. Test Results. The results of tests and calculations along with the sample configuration are given in table 4.

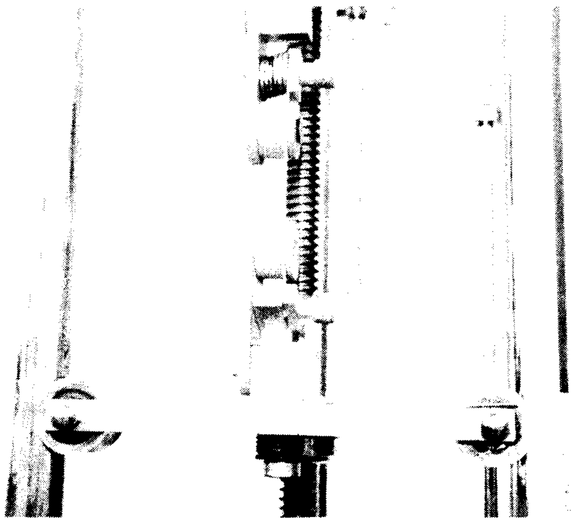


Figure 5. Wire Tensile Test

Table 4. Tensile Strength Tests

Wire Code	Wire Gauge	Size	Breaking Force (Insulated Wire)		Tensile Strength			
					Bare Conductor		Insulated Wire	
			N	lb.	$N/m^2 \times 10^8$	$lb/in.^2$	$N/m^2 \times 10^8$	$lb/in.^2$
G1	22	19/34	92.08	20.70	2.46	35,600	-----	------
G2	30	19/42	22.82	5.13	2.30	33,300	3.76	54,500
G3	30	7/38	29.36	6.60	1.87	27,100	4.46	64,700
G4	30	19/42	20.02	4.50	1.86	26,900	3.49	50,600
G5	20	19/32	124.47	27.98	-----	------	2.61	37,900

Tensile strength values were calculated using the cross-sectional area of the bare conductors.

5. Summary. Testing of the composite wire for ultimate tensile strength was considered to be the only method compatible with the results of associated tests. A pull test concerned with weldability presents data for evaluating uninsulated conductor tensile properties. Also, it was noted that the physical properties of insulation became a significant factor in any test of the mechanical or physical characteristics of insulated conductors. The test results in table 4 indicate approximately 60 percent increase in tensile strength when the wire is tested with insulation.

Three groups (G2, G3, and G4) have a specific requirement for a minimum tensile strength of 2.07×10^8 N/m^2 (30,000 psi). The only one of these three to meet this requirement, in the uninsulated configuration, was the G2 wire. The relatively fragile nature of the wire strands in the 30 gauge specimens prohibited any assessment of tensile strength based on pull testing of individual strands.

C. CONDUCTIVITY

1. Purpose. The purpose is to determine, with electrical and dimensional measurements, the quality of the stranded wires as a conductor of electrical current.

2. Test Items. Sample lengths (10 ft.) (3.048 m) of each wire, measured to an accuracy of 0.1 percent.

3. Procedures. Test procedures were based on Federal Specification J-C-98, Method 6021. The conductor dc resistance was measured to an accuracy of 0.5 percent ±1 milliohm and the cross-sectional area was calculated from optical measurements of individual strands. This, then, was formulated to result in a value of resistivity:

$\rho = \frac{RA}{L}$, where ρ = Resistivity
R = Resistance
A = Cross-sectional area
L = Length.

The basis of comparison was the reciprocal of 1.72×10^{-6} ohm-cm, International Annealed Copper Standard (I.A.C.S) of resistivity, arbitrarily selected as 100 percent conductive.

4. Test Results. Table 5 presents the results of measurements and calculations; temperature corrected to 20°C.

Table 5. Conductivity

Wire Group	Conductor Composition	AWG	Percent Conductivity
G1	Ag/Ni/Cu	22-19/34	93-98
G2	Ag	30-19/42	93-100
G3	Sn/Cu	30-7/38	90-95
G4	Ag Alloy	30-19/42	95-100
G5	Sn /Cu	20-19/32	85-90

5. Summary. The higher conductivity of the smaller wire (AWG-30) reflects the manufacturing efforts to retain current handling capabilities while reducing overall dimensions of the conductors. For general purpose applications (AWG 20-22), dimensional requirements are less stringent. The standard for current capability is based on dc resistance per unit length.

The G2 wire was somewhat lower in conductivity than expected. Silver is rated as approximately 104 percent conductive compared to the I.A.C.S. copper standard of 100 percent.

The alloying of silver is usually considered as compromising conductivity to enhance mechanical strength. The G4 wire (a proprietary silver alloy) retains a very high conductivity as compared to the other groups tested.

D. WORKABILITY

1. Weldability.

a. Purpose. The purpose of this test was to determine the weldability of wires G2, G3, and G4 to brass slipring

Table 6. Optimum Weld Schedule Parameters

	G2	G3	G4
Force	2.50 kg	2.27 kg	2.04 kg
Energy	22.0 watt-sec.	22.0 watt-sec.	24.0 watt-sec.

Deviation from these parameters results in the degradation of the quality of the welds.

(2) After the selection of the optimum parameters, qualification tests were performed, and in all cases excellent weld results were achieved. Also, in all cases the wire broke slightly away from the weld in the G-4 and G-2 wires and adjacent to the weld with G-3. Table 7 illustrates statistically the strengths and qualities of the different material combinations. These pull strengths are of bare conductor. Readout is given in kilograms of force except where noted.

Table 7. Results of Pull Tests on Welds and Conductors

	G-4	G-2	G-3
Maximum Pull Strength of Material kg	1.154	1.193	1.676
Minimum Pull Strength of Material kg	1.108	1.136	1.619
Pull Strength of Material, Average kg	1.136	1.153	1.637
Weld Strength, Average kg	1.079	1.120	1.520
Weld Strength, Percent of Material, Average	94.0	97.0	92.0
Standard Deviation	0.057	0.047	0.059
0.10 Percent of Weld Strength	0.108	0.112	0.152

blocks. The requirements are: acceptance to visual criteria as outlined in MSFC-STD-271 and a minimum weld strength of 1 kilogram.

b. Test Items. The wires specified above were cut into suitable lengths for welding. Dimensions of the brass slipring brush blocks were as follows: overall thickness of 0.266 (±0.0013) cm (0.105 ±0.0005 in.) with brush holder width of 0.076 cm (0.030 in.).

c. Test Procedure.

(1) The wires were cut to approximately 5.08 cm (2 in.) in length. One end of each sample was stripped approximately 1.27 cm (0.500 in.). The insulation of G-4 and G-2 (Teflon) was removed with a thermal stripper set at approximately 455°C (850°F). The wire G-3 insulation (Kynar) was stripped at 235°C (455°F) because higher temperatures left melted insulation smears along the conductor which were difficult to remove.

(2) Each stripped end was cleaned with a tissue saturated with ethyl alcohol and then inspected to assure that the lay of the strands was not disturbed and that all insulation was removed. Extreme care must be exercised when stripping G-4 as it has a tendency to birdcage readily. Birdcaging is the flaring or untwisting of stripped portions of the wire.

(3) The brass brush block was sanded and polished to the required tolerance. Surfaces were cleansed of contaminants by erasing and wiping with alcohol saturated tissue.

(4) Weld schedules were constructed using the standard opposed electrode configuration. However, the top electrode was grooved. It consisted of a Moly insert, tip size 0.076 cm (0.030 in.) diameter with a groove 0.033 cm (0.013 in.) diameter by 0.018 cm (0.007 in.) deep. The lower electrode consisted of a Moly insert, tip size 0.152 cm (0.060 in.) diameter. Pull testing was performed using the linear pull, or 180 degree configuration. The rate of pull was 8.9 cm (3.5 in.) per minute.

d. Test Results.

(1) Completed weld schedules pinpoint the necessity of an individual weld schedule for a specific material combination. Optimum parameters of both kilograms of force and energy were selected (table 6).

(3) Metallurgical examinations reveal a good weld bond. The strands of the wires appear to be fused together and a recrystallization is evident through the brass brush block. Figure 6 illustrates a recrystallized area in the brass and also a molten mass in the stranded silver wire. Some voids were noted in the G-4 wire. Increased magnification pinpointed the void area to be primarily between the strands of the wire (figure 7). The stranded, tinned copper had melted together well, and a narrower recrystallized band in the brass resulted in good welds (figure 8).

e. Summary. Weld tests on the three types of wires showed that all had excellent weldability. The pull strength of wire G-2 is more consistent than the G-4 or G-3. Also, the difference between average weld strengths and the average pull strength of the G-2 is less than that for G-4 or G-3. Other statistical analysis of standard deviation and weld strength percent of average strength of material reveals the superiority of the G-2 wire.

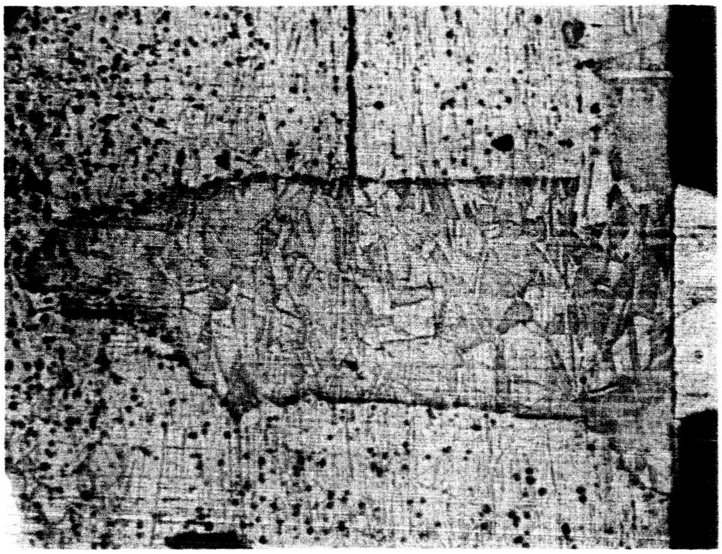


Figure 6. G-2 Stranded Wire Welded to Brass Brush Block. Transverse Cross Section. 96X.

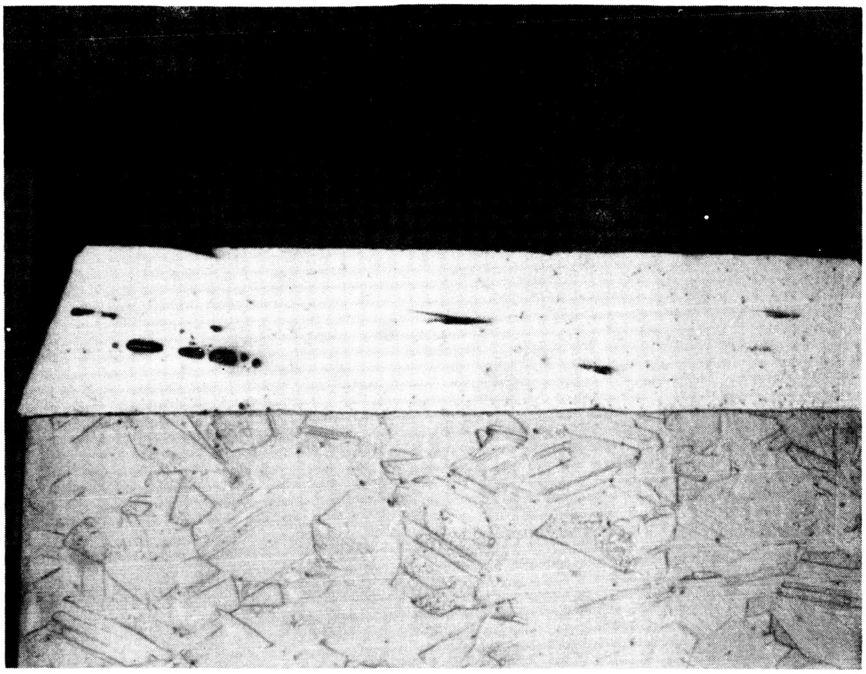


Figure 7. G-4 Stranded Wire Welded to a Brass Brush Block. Longitudinal. 150X

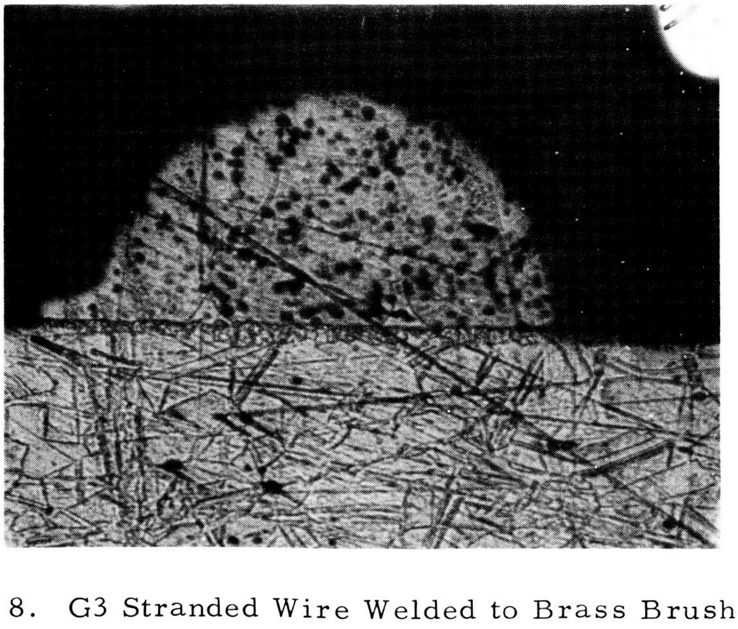


Figure 8. G3 Stranded Wire Welded to Brass Brush Block. Transverse. 156X

2. Solderability.

a. Purpose. The purpose of this test is to determine the extent of solder wetting action and shrinkback of insulation on the thermally stripped conductors.

b. Test Items. Four wires (G2 through G5), listed in table 8, were subjected to the solderability test.

Table 8. Solderability Test Specimens

Wire Code	Length	No. of Specimens	Thermal Stripped	Bend over Mandrel
G2	7.62 cm (3.0 in.)	3	0.95 cm (0.375 in.)	None
G3	7.62 cm (3.0 in.)	3	0.95 cm (0.375 in.)	None
G4	7.62 cm (3.0 in.)	3	0.95 cm (0.375 in.)	None
G5	12.7 cm (5.0 in.)	5	1.27 cm (0.5 in.)	90° 1.27 cm (0.5 in.) from stripped end

c. Test Procedures.

(1) The wires were cut to approximately 7.62 cm (3.0 in.) lengths and insulation stripped from one end approximately 0.635 cm (0.25 in.). The insulation of the G-4 and G-2 specimens was removed with the thermal stripper adjusted to approximately 455°C (850°F). The insulation on wire G-3 was removed at 235°C (455°F) because higher temperatures left melted insulation smears along the stripped conductors which were difficult to remove.

(2) Each stripped end of G2, G3, and G4 specimens was cleaned with alcohol, wiped with tissue and inspected to assure cleanliness from contaminants. G5 was not cleaned.

(3) The stripped wire (except G5) was dipped in mildly active liquid rosin flux 0.318 cm (0.125 in.) and then immersed in 60/40 Sn-Pb solder at 232°C (450°F) to a depth of 0.318 cm (0.125 in.) for 2 seconds. Ends were again cleaned with alcohol and wiped with tissue.

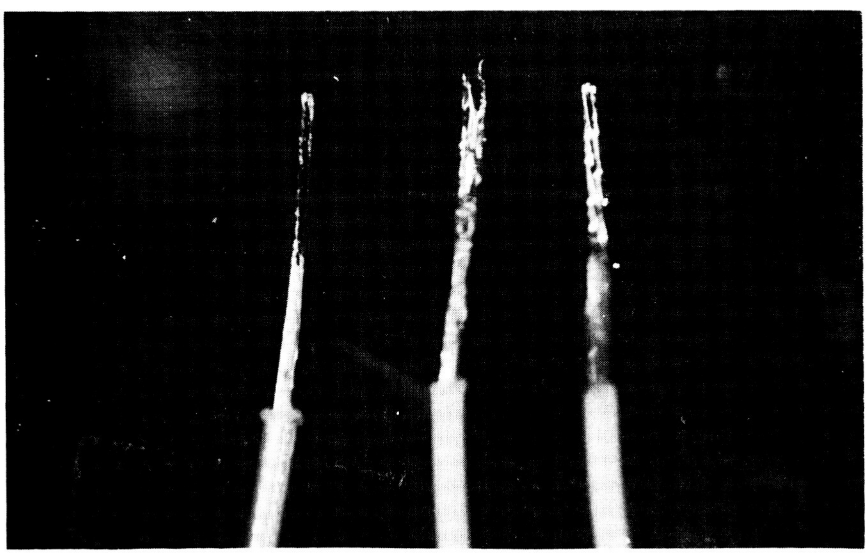
(4) G5 specimen was dipped in a solder pot with a temperature of 320°C (610°F) for 2 seconds to within 0.318 cm (0.125 in.) of the insulation then removed, inspected for solder coverage and measured again for insulation shrinkage.

d. Test Results.

(1) All the wires tinned properly and were considered excellent when normal procedures for cleaning and fluxing were used. This is illustrated in figure 9. However, it was difficult to strip G3 and G4 without "birdcaging" the conductor or disturbing the lay of the strands. This is illustrated in figures 9 and 10. No measurable shrinkback of the insulation was detected on G2 through G4 specimens.

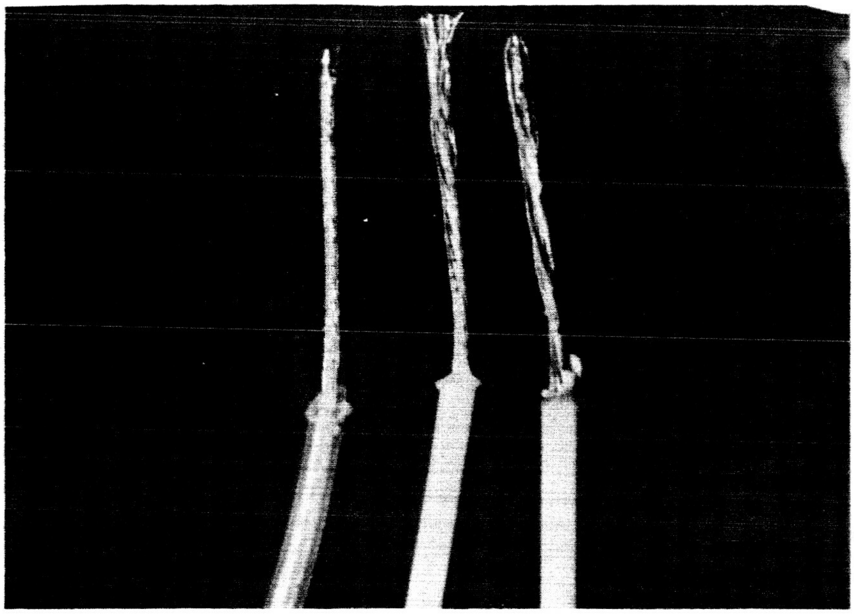
(2) The maximum shrinkback measured on the G5 specimen was 0.039 cm (0.0156 in.) and, considering that no cleaning or fluxing was employed prior to immersion in the solder pot, the solder wetting coverage was very good (figure 11).

e. Summary. All the wires exhibited very good solder wetting action. G2 shows the best overall characteristics of wetting and retaining the lay of the strands during stripping and handling operations. Insulation shrinkage is no problem with any of the types tested.



G2 G4 G3

Figure 9. Fluxed in Mildly Active Liquid Rosin Flux and Tinned 2 Seconds



G2 G4 G3

Figure 10. Attempted Tinning Without Fluxing

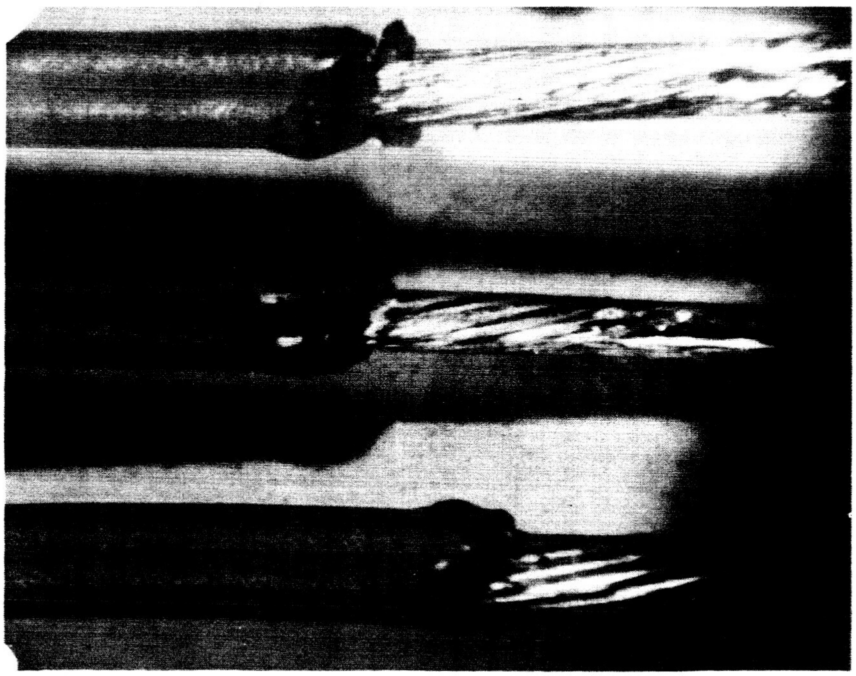


Figure 11. Solderability Specimen Configuration after Tinning

3. Strippability (Breakaway Force)

a. Purpose. Preliminary flexibility tests indicated the necessity for an additional test to detect adhesion to or bonding of the insulation to the stranded wire conductors of G2, G3, and G4 groups.

b. Test Items. Five samples of each group were cut to 3.8 cm (1.5 in.) lengths.

c. Procedure. Thermal stripping was employed (per MSFC requirements) to leave 0.635 cm (0.25 in.) of insulation on one end of each sample. The uninsulated end was then carefully inserted into a 0.038 cm (0.015 in.) hole located on a specially prepared jig. The jig was clamped into one side of the pull tester, positioned to place the protruding wires in the approximate location for clamping with the jaws of the other side and slight tension exerted to seat the insulation against the jig surface. Figures 12 and 13 illustrate the setup. The pull tester was then actuated and the force required to remove the 0.635 cm (0.25 in.) of insulation from the conductor was recorded.

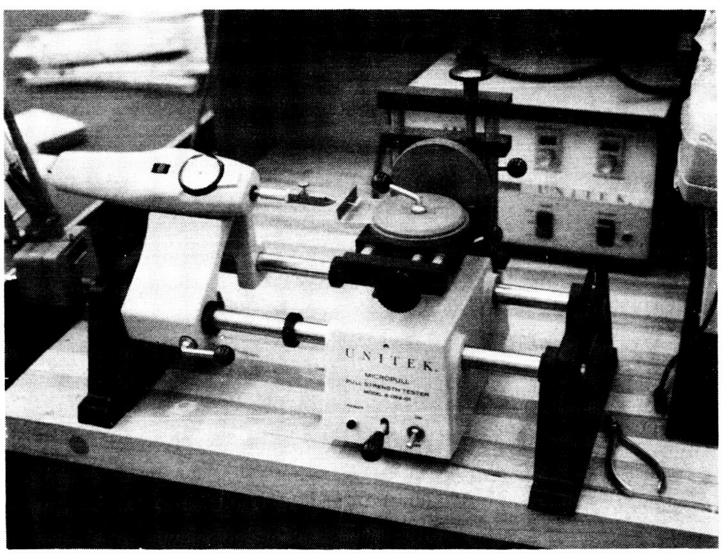


Figure 12. Test Setup For Strippability

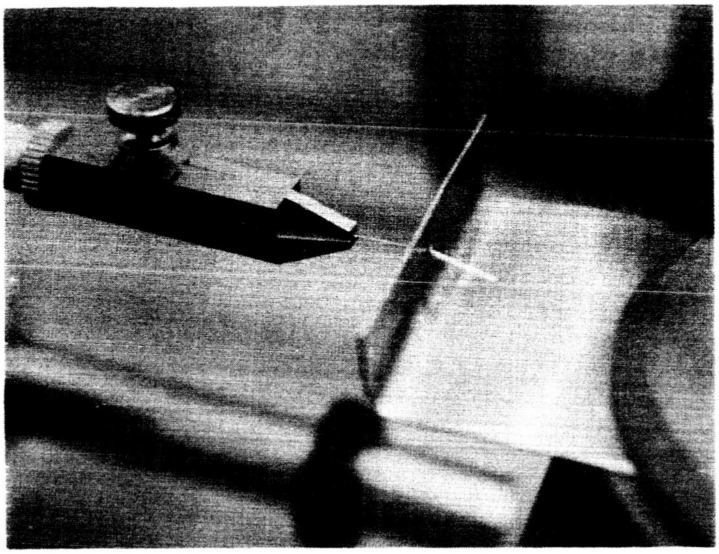


Figure 13. Closeup of Samples Positioned in the Pull Tester

d. Test Results. The maximum breakaway force per wire group was as follows:

Wire Group	Rate of Pull		Recorded Force	
	cm/min	in./min	N	Oz.
G2	7.62	3	3.34	12.0
G3	7.62	3	14.46	52.0
G4	7.62	3	2.78	10.0

e. Summary. This indicates a direct correlation with the results of the flexibility test (which was conducted using a 232 gram weight attached to one end of the stranded wire). The G3 wire required a force of four to five times that of the other groups to initiate slipping or stripping of the insulation from the stranded conductors. Many factors are involved such as tightness of the insulation, adhesion characteristics, and strand lay of the wire, but the only concern here was establishing a correlation with the three wire groups tested for flexibility.

E. METALLURGICAL EVALUATION

1. Purpose. The purpose of this evaluation was to determine if the wire samples supplied meet the required specifications. This was done by cross sectioning the wires and examining them to determine the following:

a. Number of conductor strands.

b. Overall diameter of the insulation.

c. Overall diameter of the conductor.

d. Diameter of the conductor strands.

e. Concentricity of the conductor within the insulation.

f. Thickness and uniformity of plating or coating.

2. Test Items. Six samples of each wire type, 3 inches in length, were prepared for metallurgical evaluation.

3. Procedure. Five specimens from each of the five samples were mounted for cross sectioning. Mounting was accomplished by supporting specimens in uncured bakelite preforms in which holes were drilled. These were placed in molds and potted with Castolite.

The mountings were then ground and polished. Photomicrographs were taken of the specimens with the metallograph Polaroid camera. Measurements made of the parameters of the wires included diameter of insulation, overall diameter of conductor, concentricity, and diameter of conductor strands. Coating thickness on the strands was measured on type Gl, G3, and G5 wires.

4. Results. Results of the measurements are given in table 9. Figures 14 through 19 are photomicrographs of the six types of wire. The tin plating on types G3 and G5 wire (tin plated copper) is very inconsistent and ranges from 0 to .00095 cm of thickness (figure 18b).

The plating on wire Gl, consisting of an outer layer of silver and an inner layer of nickel over copper is fairly consistent in thickness (figure 14,views b and c).

Table 9. Measurements on Cross Sections of Wires

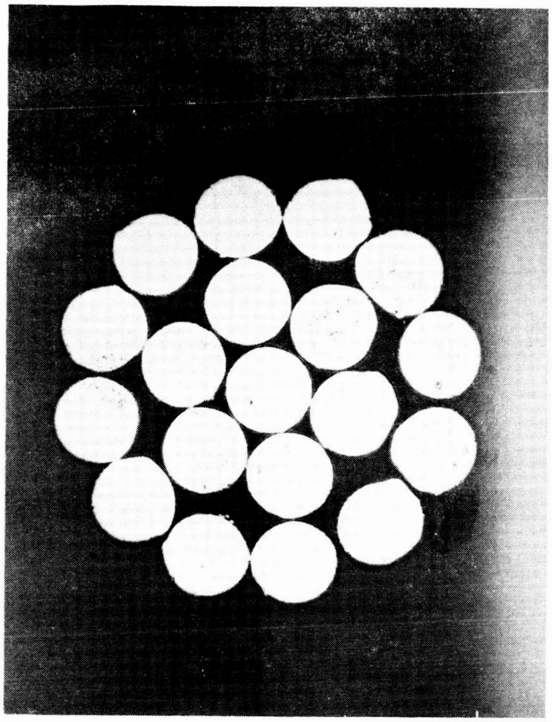
Wire Type	Insulation Diameter		Conductor Diameter		Strand Diameter		*Concentricity of Wire (%)	Plating Thickness	
	(cm)	(in.)	(cm)	(in.)	(cm)	(in.)		($cm \times 10^{-4}$)	($in. \times 10^{-4}$)
G1	-------		0.0842	(0.0331)	0.0168	(0.0066)	-------	1.6	0.6
G2	0.0806	(0.0317)	0.0361	(0.0142)	0.0073	(0.0028)	91.3	-------	
G3	0.0760	(0.0299)	0.0364	(0.0143)	0.0118	(0.0046)	91.2	**5.5	2.2
G4	0.0826	(0.0325)	0.0316	(0.0124)	0.0064	(0.0025)	89.2	-------	
G5	0.1486	(0.0585)	0.1012	(0.0398)	0.0216	(0.00850)	92.1	**8.0	3.13

* $\% \text{ Concentricity} = \frac{t_2}{t_1} \times 100$

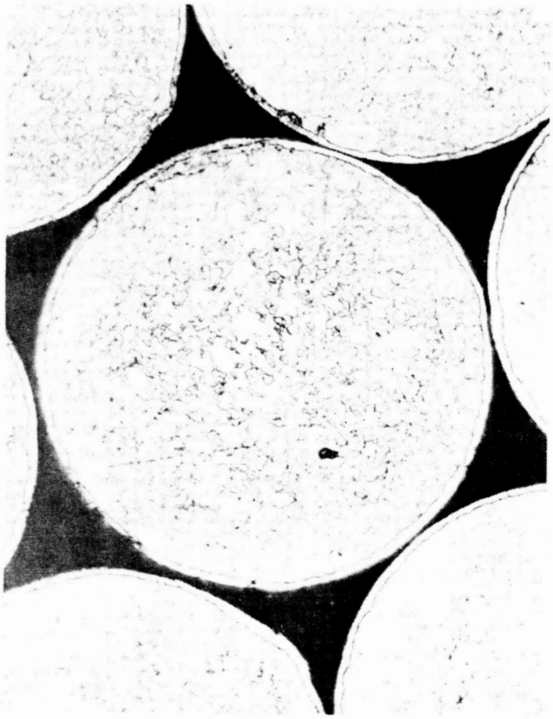
t_2 = minimum distance from conductor to outer surface of insulation

t_1 = maximum distance from conductor to outer surface of insulation.

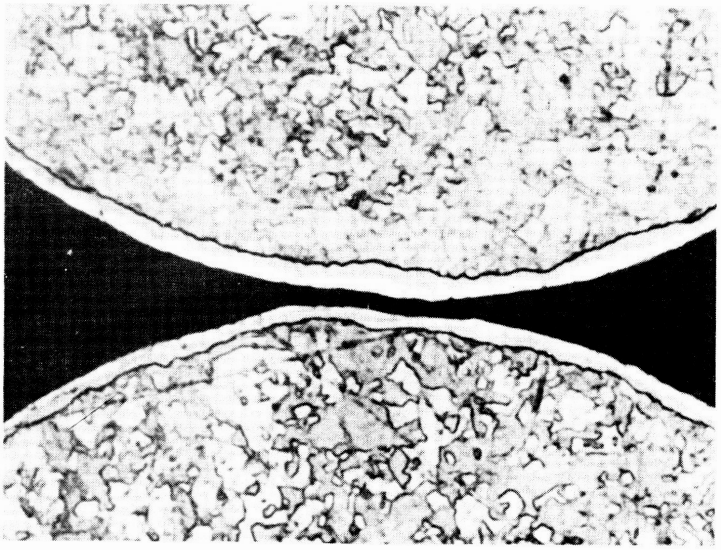
** Tin plating varied from zero to the maximum indicated.



A. Overall View of Wire - 50X

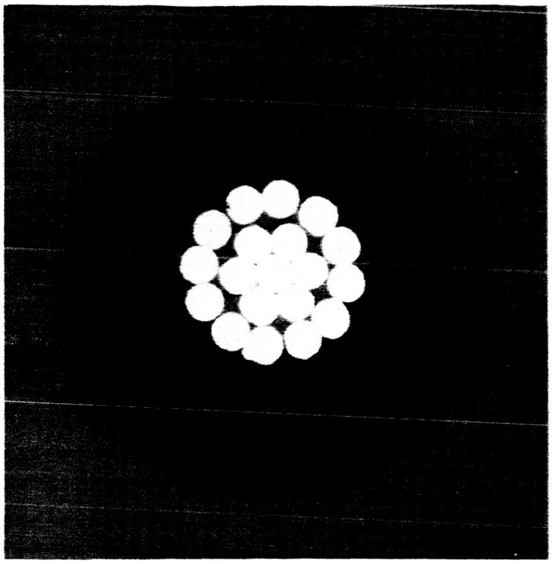


B. View of Individual Strand - 250X

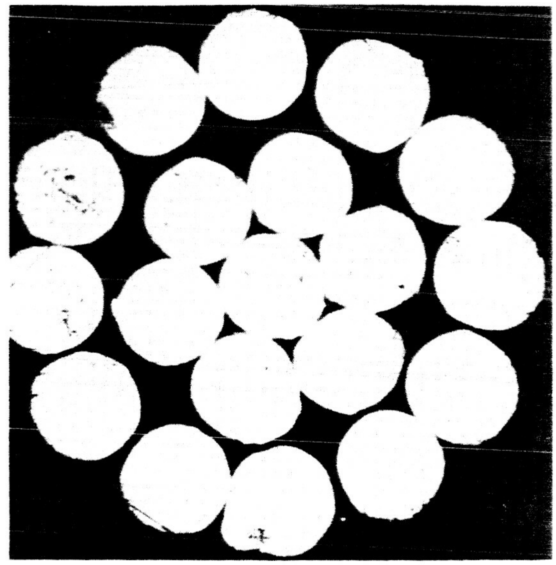


C. View of Silver and Nickel Platings - 1000X

Figure 14. Type G1 Wire Cross Sections

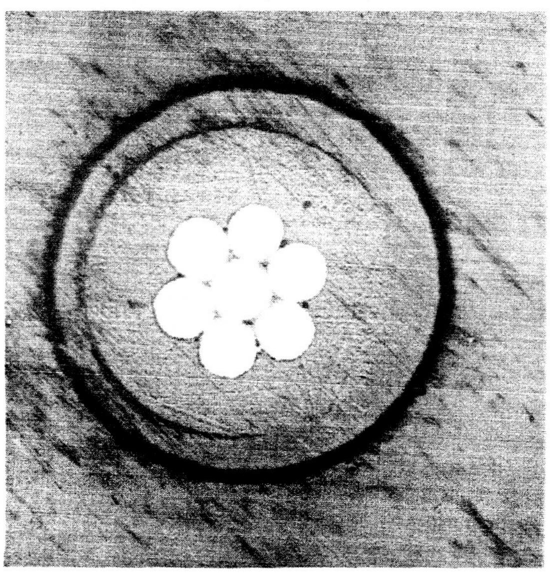


A. Overall View of Wire - 50X

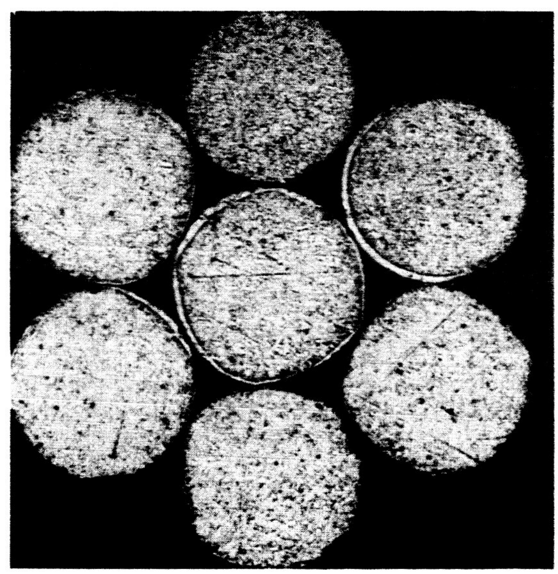


B. Overall View of Conductor Strands - 175X

Figure 15. Type G2 Wire Cross Sections

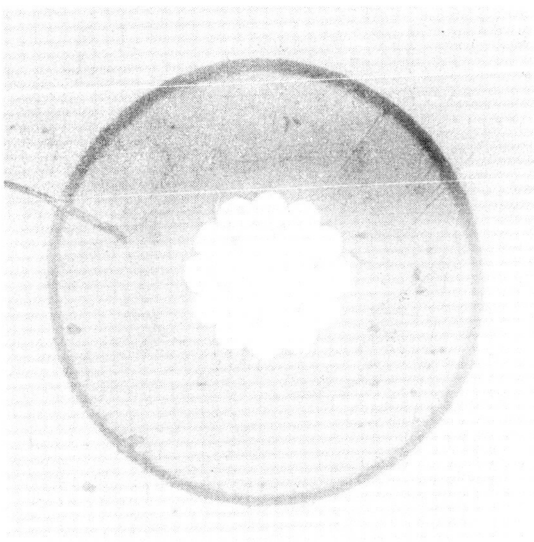


A. Overall View of Wire - 50X

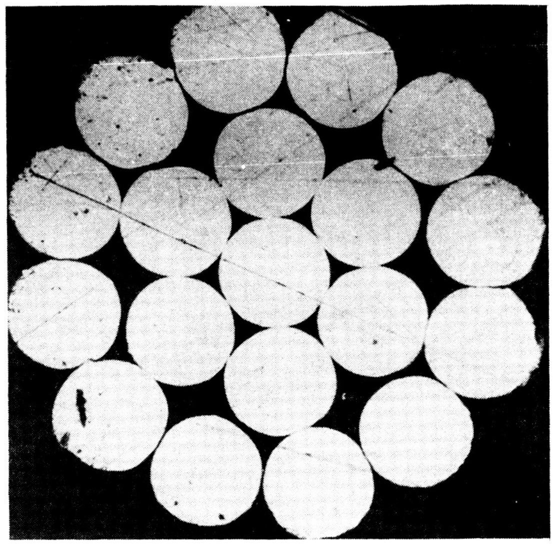


B. Overall View of Conductor Strands - 175X

Figure 16. Type G3 Wire Cross Sections

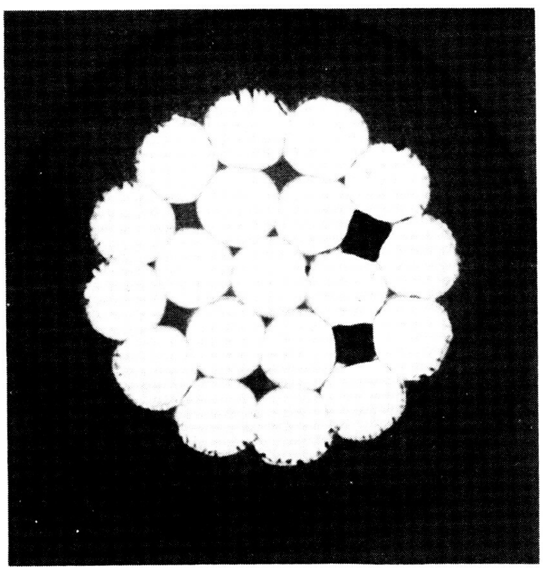


A. Overall View of Wire - 50X

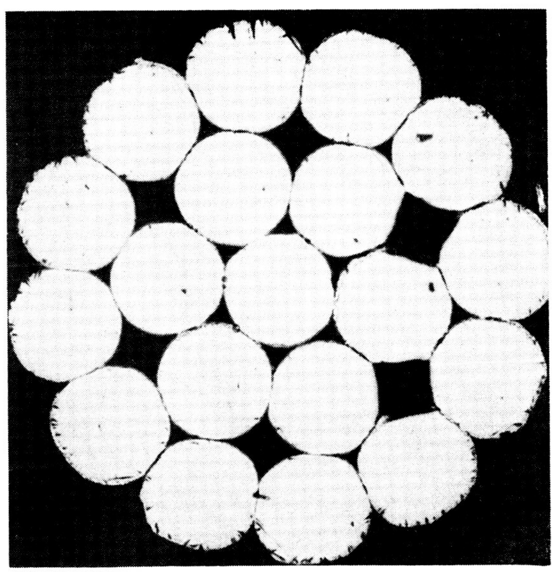


B. Overall View of Conductor Strands - 175X

Figure 17. Type G4 Wire Cross Sections

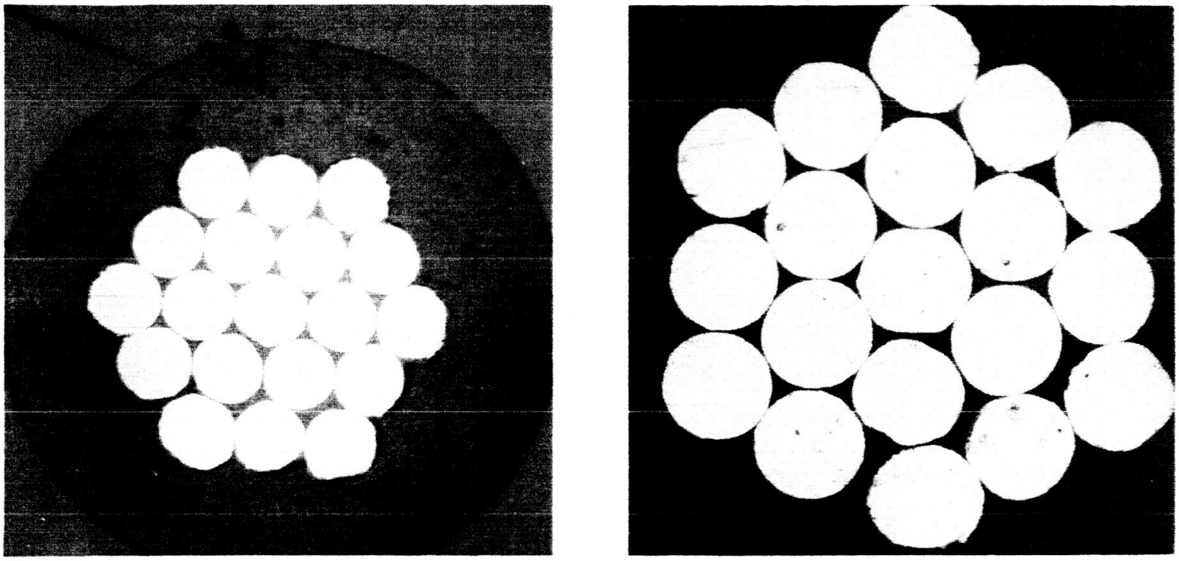


A. Overall View of Wire - 34X



B. Overall View of Conductor Strands - 60X

Figure 18. Type G5 Wire Cross Section



A. Overall View of Wire - 42X

B. Overall View of Conductor Strands - 60X

Figure 19. MIL-W-16878 Type B Wire Cross Sections

5. Summary. Five wire samples were received for metallurgical evaluation to determine if they meet required specifications. Specimens from each sample were mounted for cross sectioning.

As a basis of comparison with wire G5, a sample of MIL-W-16878 type B wire was mounted and cross sectioned. It can be observed in figure 19 that the quality and quantity of the tin coating is comparable to that of wire G5.

Evaluation of the cross sections showed all wires contained required number of strands and uniform strand lay. Insulation on wire types G2 through G5 was found to be of uniform thickness, and the concentricity was greater than the required 70 percent.

Plating thickness on type G1 wire was of uniform thickness and on types G3 and G5 varied considerably. The flat surface of the outer layer of strands is quite apparent even to the unaided eye. The tin coating appears to be smeared over these flat areas. Cross sectioning and viewing under a metallograph reveals these same irregular conditions (figure 20).

Figure 20. Bare Conductor of G5

SECTION IV. SELECTED SAMPLING TESTS

A. VISUAL AND DIMENSIONAL CHECKS

1. Microscopic Examination. The entire length of the sample wires was examined under a microscope from 7X to 30X. This optical examination was performed to detect minor surface defects, voids, and foreign particles contained or imbedded in the insulation. As a result of this examination, dark spots were revealed in and under the Teflon insulation on the G2 wire, and a subsequent chemical test determined the spot (or included foreign particle) to be nonmetallic. Electrical tests gave no indications of a compromising of the dielectric characteristics in these areas.

2. Conductor Diameter. Samples of the wires were gauged for overall dimensional variations (as received condition) using the hole gauge and micrometer caliper. Wire G2 could not be fitted through the hole gauge 0.0762 cm (0.030 in.), without excessive scraping of the surface. The maximum outside diameter measured on it was 0.0775 cm (30.5 mils). The minimum outside diameter measured was 0.0724 cm (28.5 mils). The maximum variation noted for G4 was from 0.0724 cm (28.5 mils) to 0.0813 cm (32 mils). The variations of wire G3 were 0.0724 cm (28.5 mils) to 0.0742 cm (29.2 mils) (table 10).

3. Test Lengths. Lengths of the wire received for testing were recorded (table 10). An accurate measurement (±0.1percent) of the sample length used in determining conductor resistivity was performed on each wire type also.

B. ELECTRICAL TESTS

1. Conditioning. Each type of insulated wire was immersed in tap water containing a wetting agent and constantly circulated for thermal equilibrium at 24°C for a 12 hour period. The two ends of each roll, or coil of wire, were wrapped together and supported above the water level to ensure that no moisture could readily penetrate the exposed, cut ends of insulation and stranded conductor.

At the end of 12 hours immersion, the wire was subjected to the high potential and the insulation resistance tests described in this section. There were no changes in the results compared to measurements taken before the conditioning.

Table 10. Selected Qualification Test Results

Wire Type	Visual Examination	Dimensional Examination	Length of Test Sample
G1	Inconsistency in plating	0.0792 ±0.0005 cm or 0.0312 ±0.0002 in.	(15.24 m) 50 ft.
G2	Nonmetallic black spots in portions of the insulation	0.0753 cm (Avg. 29.7 mils) 0.0724 cm (Min. 28.5 mils) 0.0775 cm (Max. 30.5 mils)	(9.144m) 1-30 ft. (0.9144 m) 10-3 ft.
G3	No voids or foreign particles	0.0737 cm (Avg. 29.0 mils) 0.0724 cm (Min. 28.5 mils) 0.07371 cm (Max. 29.2 mils)	(60.96 m) 200 ft.
G4	No voids or foreign particles	0.0754 cm (Avg. 29.5 mils) 0.0724 cm (Min. 28.5 mils) 0.0762 cm (Max. 32.0 mils)	(3.048 m) 1-10 ft. (15.24 m) 1-50 ft.
G5	No voids or foreign particles	0.145 cm (Avg. 57.1 mils) 0.1447 cm (Min. 57.0 mils) 0.1453 cm (Max. 57.2 mils)	(30.48 m) 100 ft.

2. High Potential (ac). This test was performed on insulated wires using the "wet electrode" configuration as shown in figure 21. A five percent salt solution (NaCl) formed the negative electrode and the stranded, coiled wire was the positive electrode. After the insulated portion of the wire was immersed in the solution, a 3 kilovolt rms potential was applied to the electrodes for 60 seconds. Electrical monitoring for excessive current leakage, arc-over, or breakdown gave no indication of failure of the four wire types tested (table 11).

3. Insulation Resistance (dc). This test was performed in the same (wet electrode) configuration and immediately following the Hypot test, except that the applied potential was 500 vdc from a megohmeter for 60 seconds, and then a measurement of the resistance of the insulation was recorded (table 11).

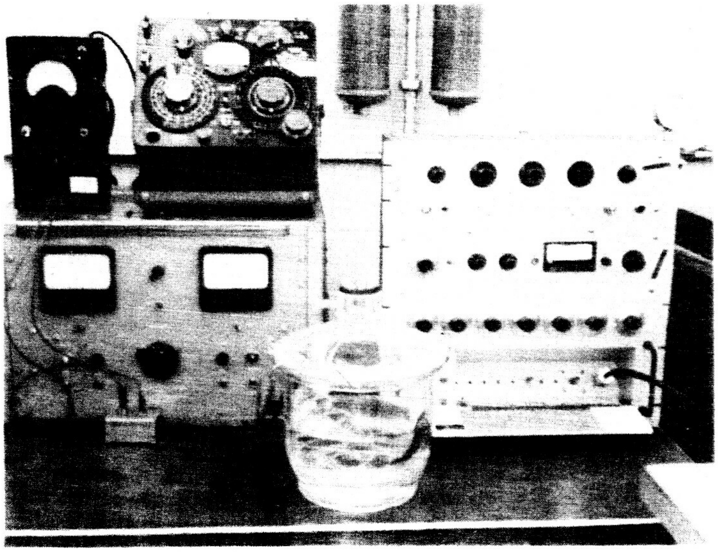


Figure 21. Test Configuration for High Potential and Insulation Resistance

Table 11. Electrical Tests

Type Wire	High Potential	Insulation Resistance (dc)	Conditioning Water Bath
G1	No Test	No Test	None Performed
G2	3 kv (rms) 1 minute no failure	10^6 megohms	12 hrs @ 24° C
G3	3 kv (rms) 1 minute no failure	10^5 megohms	12 hrs @ 24° C
G4	3 kv (rms) 1 minute no failure	2×10^5 megohms	12 hrs @ 24° C
G5	2.5 kv (rms) 1 minute no failure	5×10^5 megohms	12 hrs @ 24° C

C. ENVIRONMENTAL TESTS

These tests were selected to evaluate the insulation and conductor performance after subjection to relatively severe extremes of high and low temperatures, as well as humidity cycling and salt spray exposure. Methods for performing the tests were basically the methods of MIL-STD-202 and MIL-W-81044 with variations requested by the test personnel as necessary. Cold bend and heat resistance samples (3 of each type) were cut to 40.64 cm (16 in.) lengths and the corrosion test samples were cut to 10.16 cm (4 in.) lengths. Each sample had 1.27 cm (0.5 in.) of the insulation removed from each end.

1. Cold Bend Test.

a. Procedure. One end of the samples was attached to a mandrel and a weight was suspended from the other end. This arrangement was then installed in a temperature chamber and the temperature was reduced to -65° C (-85° F). This temperature was maintained for 1 hour and then the mandrel was turned to wind the wire samples on the mandrel three consecutive turns in each direction at a rate of one turn in 4 seconds. Still in the final, coiled configuration, the samples were removed from the chamber and allowed to return to room temperature. A visual inspection was performed and the coiled samples were then subjected to the Hypot test.

b. Test Results. No visible effects or dielectric failures were encountered as a result of this test.

2. Temperature Resistance.

a. Procedure. The wire samples were attached to a mandrel previously installed in the temperature chamber, and were then subjected to the high temperatures as indicated in table 12. Following the conditioning period, the mandrel was turned three complete revolutions in each direction (cw and ccw). With the wire still coiled on the mandrel, the setup was removed from the chamber and allowed to cool to room temperature (24°C). Visual inspection was performed and the coiled samples, with no obvious defects, were subjected to the high potential test.

b. Test Results. The performance of all types met or exceeded published continuous service temperatures. Efforts to evaluate

G3 and G5 at temperatures in excess of continuous service ratings presented some problems as shown in table 12 and figures 22 through 25.

c. Summary. The various results encountered during temperature testing may be summarized as follows:

Polyolefin insulated wires (with or without an outer jacket of Kynar) have a noticeable outgassing or volatilization at temperatures above 150°C. The volume and exact chemical nature of this volatilization was not established during the performance of this evaluation program. Any extension of temperature limit ratings for these wires would necessitate further study in this area. Adhesion of the polyolefin insulation to the surface of the mandrel is indicative of decomposition being generated by the higher temperature also. As a direct comparison to the temperature characteristics of Telfon, no special coating was considered for application to the mandrel to prevent adhesion. Consequently, some of the temperature failures of polyolefin were directly attributed to adhesion and subsequent rupture during removal of the coiled wire from the mandrel.

Removal of the insulation from the exposed samples of G3 and G5 reveals the tin coating has turned a dark, metallic hue, and in some areas the copper is readily visible as in figure 25. It should be noted that several of the high temperatures in table 12 exceed the manufacturer's established limits.

Table 12. Temperature Resistance Test Results

Wire Code	High Temperature Exposure					Continuous Service Temp. Rating
	150°C 4 hrs	175°C 24 hrs	215°C 4 hrs	225°C 4 hrs	250°C 1 hr	
G1						
G2					Pass all tests	200-260°C
G3	Pass all tests			Pass elect Fail color	Fail all tests	135°C
G4					Pass all tests	200-260°C
G5	Pass all tests	Fail visual	Fail elect & visual			125°C

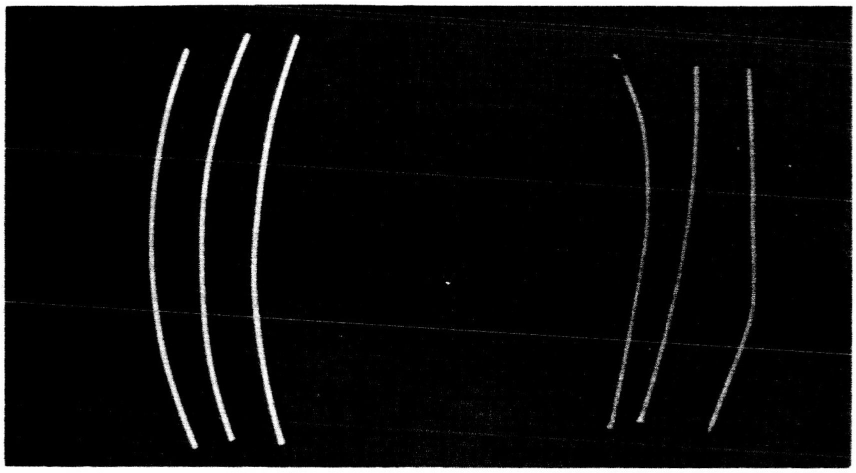


Figure 22. Temperature Resistance Test on G3

Samples on the left of the photo show G3 wire in an "as received" condition. Samples on the right show a brown discoloration from 4 hours of exposure at 225°C.

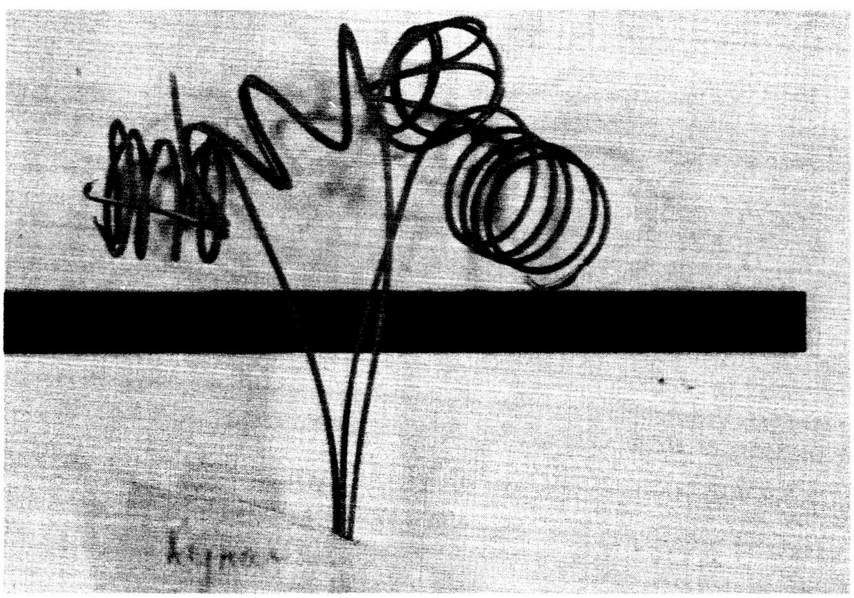


Figure 23. Temperature Resistance Test on G3

This shows the results of exposure to a temperature of 250°C for 1 hour. The stranded conductor of the wire is completely exposed where the coils were formed over the mandrel.

Figure 24. Temperature Resistance Test on G5

This view shows the G5 wire after exposure to a temperature of 215°C for a period of 4 hours. The ragged void just left of center is the results of adhesion to the wrapping mandrel.

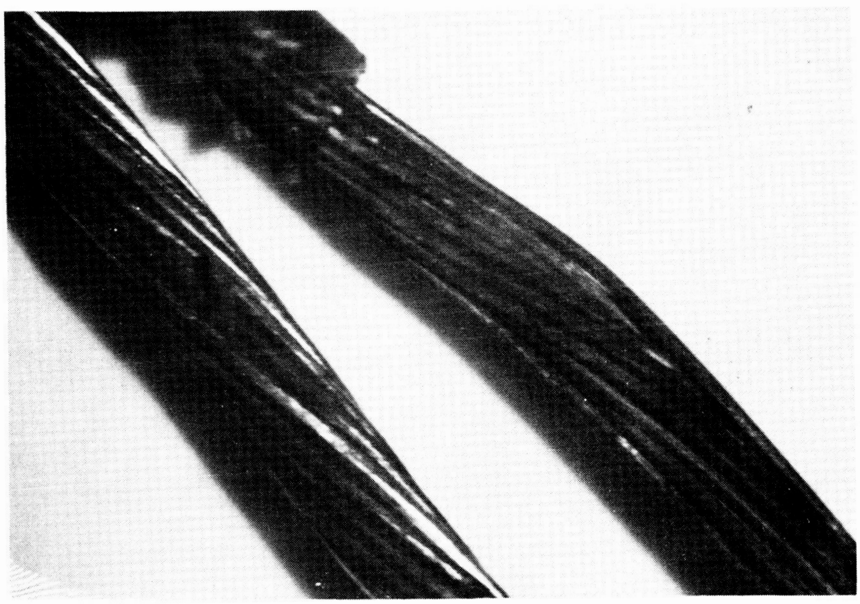


Figure 25. Temperature Resistance Test on G5

This close-up view (40X) shows the extent of discoloration of the stranded conductors (tin coated copper) after exposure to temperatures of 175°C for 24 hours and 215°C for 4 hours.

3. Flammability

a. Purpose. The purpose of this test was to determine relative capabilities of three types (or classes) of insulated wire to withstand exposure to direct, open flame.

b. Test Items. Lengths of each stranded wire were prepared as follows:

Wire Gage	Insulation	Teflon
20 AWG	Teflon	50.8 cm (20 in.)
22 AWG	Polyvinyl Chloride	50.8 cm (20 in.)
20 AWG	Irradiated Polyolefin	50.8 cm (20 in.)

The insulation was marked at 15.24 cm (6 in.) and 30.48 cm (12 in.) from the upper end.

c. Procedure. The flammability test procedure was conducted per MIL-W-16878 paragraph 4.4.2.7. The flame temperature was monitored as approximately 593°C (1100°F) at the tip of the inner cone. Application time was 30 seconds.

d. Test Results. The results were as follows:

(1) Teflon would not support combustion, but appeared to melt and exposed a blackened area directly over the flame for a total length of 3.18 cm (1.25 in.).

(2) The polyvinyl chloride burst into flames, dripped burning pieces, and extended this burned area a total of 7.3 cm (2.875 in.), plus melting 0.635 cm (0.25 in.) beyond the burned area.

(3) The wires with polyolefin insulation burst into flames and resulted in a white ash residue for a total length of 7.62 cm (3.0 in.) to 7.94 cm (3.125 in.).

e. Summary. Figure 26 shows the results of the 45 degree flammability test. None of the wires supported combustion after removal of the flame. The Teflon, as expected, was more impervious to the flame. No dripping or flowing was encountered during exposure of the polyolefin to the flame, but the measurement of the burned area on either side of the direct flame exposed portion approached the maximum allowed by specifications.

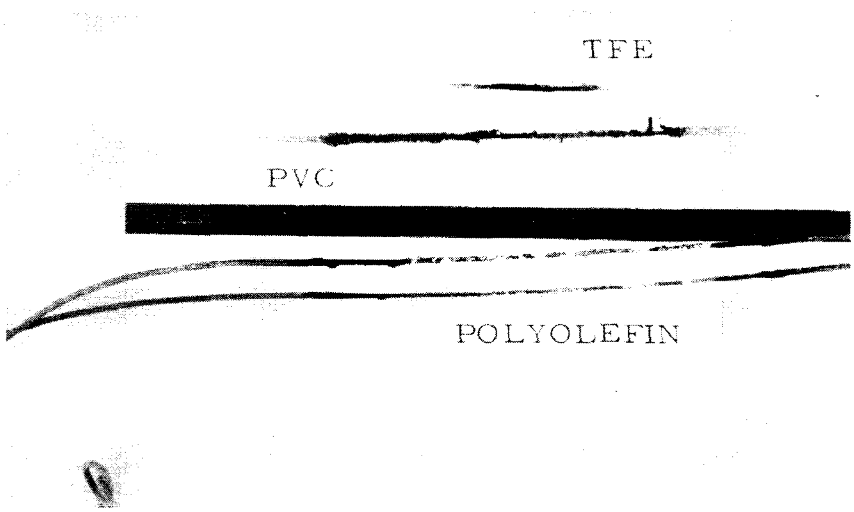


Figure 26. Results of a 45 Degree Flammability Test

4. Corrosion

a. Purpose. The corrosion tests were performed for a multipurpose reason. The salt spray test helps to determine the uniformity of metallic and nonmetallic coatings used as a protective coating. The temperature cycling test was conducted to determine the resistance of the insulation to the shock of repeated surface exposures to extremes of high and low temperatures for relatively short durations of time. The humidity test serves as an accelerated environmental test, accomplished by the continuous exposure of the specimen to high relative humidity at an elevated temperature.

b. Procedure. Forty test samples, 10.16 cm (4 in.) in length, were prepared from each wire group. These samples were divided into four groups of ten each for salt spray, temperature cycling, humidity, and laboratory control samples. Insulation, 1.27 cm (0.5 in.) thick, was thermally stripped from each end of each sample.

The tests were performed in accordance with MIL-STD-202C. The methods and conditions are as follows:

Salt Spray - Method 101B, Condition A, 20 percent salt solution.

Temperature Cycling - Method 102A, Condition C

Humidity - Method 103B, Condition B

c. Test Results. From the results of the salt spray test, all wires were tarnished to some extent. The only wire to show signs of corrosive strand breakage was the G-1 wire. Figure 27 is an example of the corrosive effect of copper chloride and Red Plague.

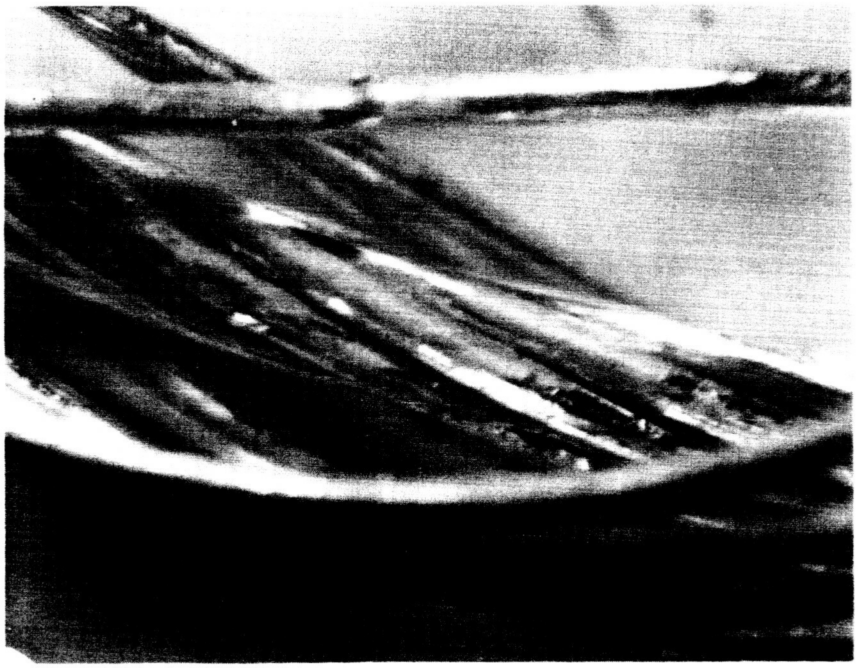


Figure 27. Strands of G-1 showing Green Deposit and Red Plague

Wires G-3 and G-5 showed some dark areas during the salt spray exposure. It was concluded that the dark areas are copper showing through an extremely thin, tin coating. The insulation on all wires was unaffected by this test.

The temperature cycling test showed only a loss of lustre or a tarnished appearance on all wires except G-4 which was discolored and Gl which again revealed scattered areas of Red Plague. Further examination of the G-4 wire showed that when the insulation was removed and the conductors separated, there was a black deposit in scattered spots along the entire length of wire examined. This black deposit was found to be nonmetallic. Figure 28 shows a section of the wire and the black deposit.

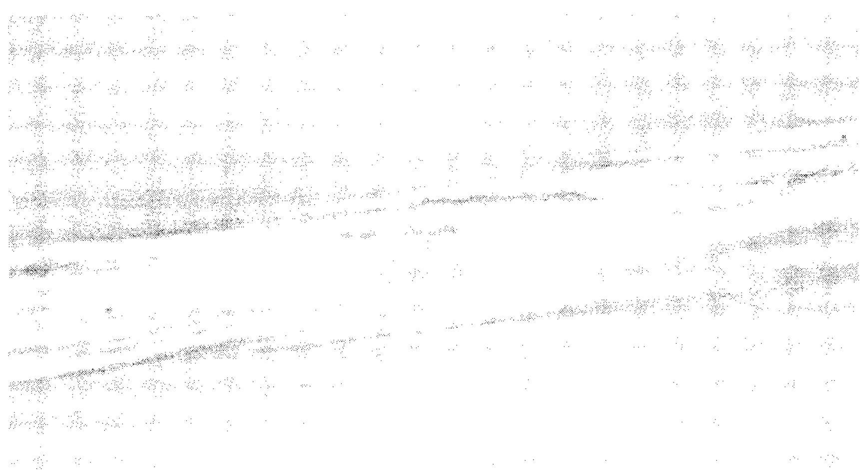


Figure 28. Section of G-4 showing Black Deposit

Examination of the wire showed no signs of corrosion. The insulation was unaffected by this test.

The results of the humidity phase of the corrosion test showed that all of the wires under evaluation tarnished to some extent. In addition, the tin coating on wire groups G-3 and G-5 turned dull. The only wire that corroded was the G-1 wire. Again, deposits were found along with evidence of Red Plague. The deposits appeared as bronze patches. Figures 29 and 30 show a bronze colored deposit and the beginning of Red Plague.

The insulation showed no detrimental effects due to the humidity test. There was no cracking or swelling. The wire samples subjected to the laboratory environment revealed microscopic evidence of Red Plague developing on the Gl wire. Wire groups G2 through G4 tarnished to a slight degree.

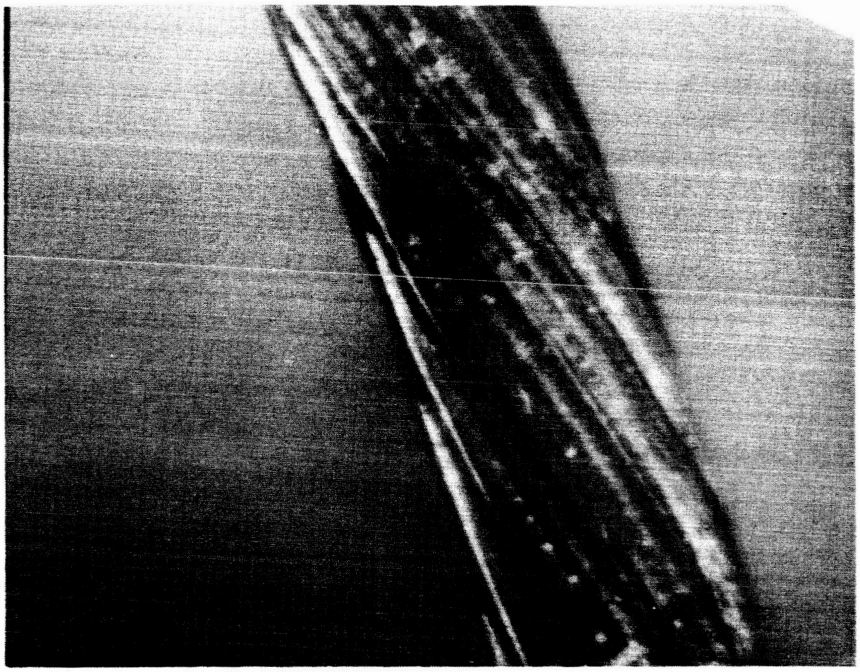


Figure 29. Humidity Test Specimen

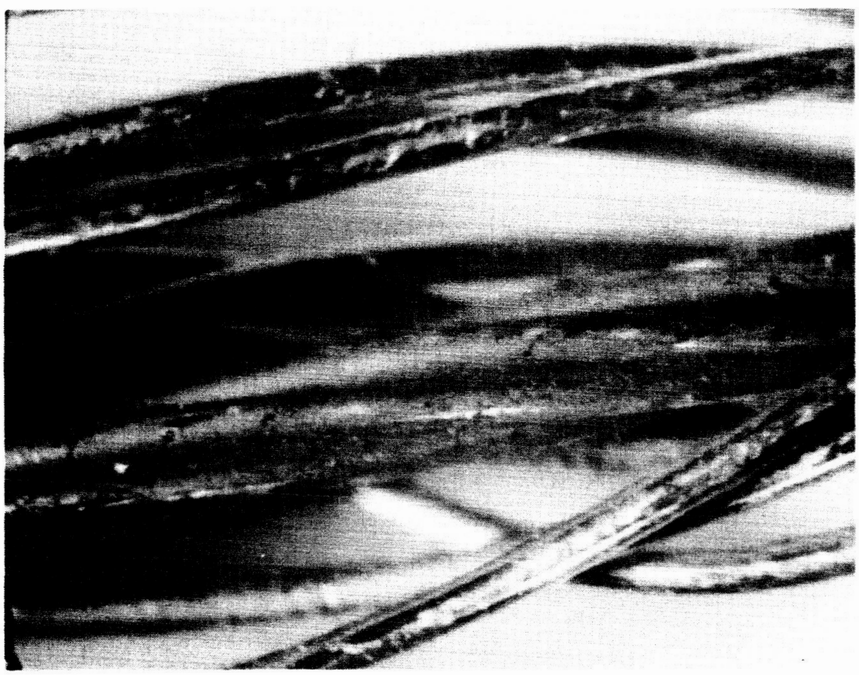


Figure 30. Humidity Test Specimen

d. Red Plague Summary. As reported in the test results, all conductors or conductor coatings exhibited a degree of tarnish or darkening at the exposed surfaces. This is due to the sulfur and other atmospheric contaminants normally present and will occur during "weathering" (without accelerated conditions) over a period of time. It is not destructive to the conductor.

The fine silver and silver alloy conductors had no corrosion beyond this tarnish level after exposure to the environmental conditions listed.

The tin plated copper had spots of dull red copper oxide on the stripped portion of the wire at each end. No cuprous oxide was found under the insulation. The oxidized portion on the stripped end was on spots with extremely thin, tin plating. This exposed copper to the test conditions and resulted in chemical oxidation. The resultant oxide acted as a passivator, inhibiting further oxidation below the wire surface. Therefore, progression of the corrosion did not occur with further exposure.

The Red Plague, resulting from electrochemical corrosive action, differs from the chemical oxidation in the bright orange-red color versus the dull red chemical corrosion. This is especially true in the earlier stages of corrosion when a galvanic effect is involved, resulting in a potential difference. The Red Plague is progressive, and oxidation continues until the protective plating becomes a hollow shell with complete destruction of the copper conductor from within.

Erosion takes place on the protective plating, starting with a small opening and continuing until strand separation occurs.

This is a brief explanation of the corrosive action on type G1 wire. The nickel barrier was placed between the silver and copper to prevent this galvanic action which has occurred many times on silver plated copper. Test results prove there was no appreciable reduction in the incidence of occurrence.

The silver (even increased to 68 microinches thickness) and nickel have sufficient openings through cracks, breaks, or pores to allow entrance of an electrolyte. This completes the circuit and, with the small anode and large cathode area, produces the inevitable accelerated corrosive action through oxidation-reduction.

The nonbonding characteristic of Teflon allows free access of the atmosphere to the wire under the insulation. Upon stripping the wire, the Red Plague was found in random areas throughout the samples.

SECTION V. CONCLUSIONS

A. OMISSION CONSIDERATIONS

Many tests were excluded to conserve time and manpower. No solvent resistivity determinations were made since each chemical solvent has its individual reaction and rating systems. Chemical tests should be performed using chemicals likely to be in contact with or exposed to the insulation during specific applications.

Again, depending on the application, several additional tests should be performed. These may include abrasion resistance, notch sensitivity, etc. Care should also be exercised in considering the wire gauge when comparing test results. As most customers know, hook-up wire is not always available in the gauge, strand number, protective coating, and insulation desired. Such was the case in procurement of samples for this evaluation.

B. SUMMARY

Polyvinyl Chloride (PVC) has been used successfully for many years for wire insulation. Most of its properties are known and accepted when the temperature requirements are not excessive. When the temperature requirements are above 100°C, many engineers and designers automatically specify Teflon; a special purpose insulation which has established a permanent position in the extra high temperature range (250°C).

This report establishes the characteristics of some conductors and insulation materials that may be used to bridge the large gap between Teflon and PVC. A brief summary of the findings is shown in the following paragraphs and in table 13.

1. <u>Teflon Insulated Wire.</u> For high temperature applications, above 135°C operational, Teflon insulation is unsurpassed. It has excellent electrical properties, good physical properties, and good workability. Where magnetic properites are not a factor, it may be used over nickel plated copper conductors.

The use of Teflon in conjunction with silver plated copper, even with nickel barrier, creates a destructive corrosive effect on the wire, even though the Teflon, chemically, plays no part in the reaction. The insulation is expensive, as are the silver and silver alloys.

2. Irradiated Kynar Insulated Wire. For operational temperatures up to 135°C, Kynar insulation performed exceptionally well. It has good electrical properties, good physical properties, and presents no workability problems. In spite of the poor conductor strand dimensional consistency and plating continuity, no adverse effects were noted in the electrical properties. It also suffers no destructive corrosion damage in adverse environmental conditions. It is relatively inexpensive as a high-temperature wire.

3. Irradiated Polyolefin Insulated Wire. This is considered a general purpose wire with the additional advantage of an operational temperature up to 125°C. It has good electrical and physical properties, good workability, and is relatively inexpensive. Corrosion resistance is good since the tin-copper does not form a galvanic couple under the conditions tested.

Table 13. Comparative Performance Ratings Based on Tests for General and Specific Applications

Test Groups	Test								
	Outer Dimensional Consistency	Conductor Strand Dimensional Consistency	Flexibility	Tensile Strength (30,000 psi min)	Workability * (welding, soldering)	Conductivity (90% min.)	Performance per Temperature Rating	Dielectric Qualities	Corrosion Resistance
G1	G	G	No Test	No Test	Vg	Vg	-55°C E 250°C	Vg	P
G2	G	E	P	Vg	E	E	-65°C E 250°C	Vg	Vg
G3	E	P	Vg	Vg	Vg	G	-55°C E 135°C	G	G
G4	F	G	G	Vg	Vg	Vg	-55°C E 250°C	Vg	G
G5	G	G	No Test	No Test	G	G	-55°C Vg 125°C	G	G

E - Excellent - Greatly exceeds minimum requirements
Vg - Very Good - Exceeds minimum requirements.
G - Good - Meets minimum requirements
F - Fair - Varies above and below minimum requirements
P - Poor - Does not meet minimum requirements
*Minimum requirements based on applicable specifications or test criteria.

G3 and G5 design rated to 135°C maximum and perform very well to 150°C.

SECTION VI. REFERENCES

A. SPECIFICATIONS

1. Military

MIL-W-16878D- Wire, Electrical, Insulated, High Temperature

MIL-W-5086A - Wire, Electrical, 600-volt, Copper, Aircraft

MIL-W-81044 - Wire, Electric, Crosslinked Polyalkene Insulated, Copper

MIL-I-16923D - Wire and Cable, Hookup, Electrical, Insulated

2. Federal

QQ-W-343 - Wire, Electrical and Non-Electrical, Copper, (Uninsulated)

J-C-98 - Cable and Wire, Insulated; Methods of Sampling and Testing

B. STANDARDS

1. Military

MIL-STD-202C Test Methods for Electronic and Electrical Component Parts

2. Marshall Space Flight Center

MSFC-STD-271

Fabrication of Welded Electronic Modules

3. National Aerospace Standard

NAS-703 Wire, Electrical, Insulated, Copper, High Temperature, Hookup and General Purpose (for 200°C service)

C. OTHER PUBLICATIONS

Capson, H. R. and F. L. Laque, Corrosion Resistance of Metals and Alloys, Reinhald Publishing Corp., New York, N. Y., 1963

DISTRIBUTION

INTERNAL

R-ASTR-DIR, Dr. Haeussermann
R-ASTR-EA, Mr. Smith
R-ASTR-E, Mr. Fitchner
R-ASTR-EE, Mr. Rosinski
Mr. Hardage
Mr. Swords
R-ASTR-ES, Mr. R. Aden
Mr. G. Barr
R-ASTR-N, Mr. Moore
Mr. Wojtalik
R-ASTR-ND, Mr. Swearingen
R-ASTR-G, Mr. Mandel
R-ASTR-GS, Mr. Kelley
R-ASTR-I, Mr. Hoberg
R-ASTR-P, Mr. Angele
R-ASTR-PS, Mr. Willis
R-ASTR-PE, Mr. Van Orden

R-QUAL-DIR, Mr. Grau
R-QUAL-J, All Project Engineers
R-QUAL-OT, Mr. Dendy
R-QUAL-RE, Mr. Brown
R-QUAL-Q, Mr. Brien
R-QUAL-A, Mr. Henritze
R-QUAL-AE, All Project Engineers
R-QUAL-AA, Mr. Penny
R-QUAL-AAA, Mr. Calhoun
R-QUAL-AAT, Mr. Lynch
R-QUAL-AAM, Mr. Knadler (50)
R-QUAL-OCP, Mr. Krone (6)
R-DIR, Mr. Weidner
R-P&VE-DIR, Dr. Lucas
R-TEST-DIR, Mr. Heimburg
R-RP-DIR, Dr. Stuhlinger
R-ME-DIR, Mr. Kuers

I-DIR, Gen. E. O'Connor
I-I/IB-MGR, Mr. James
I-V-MGR, Mr. Rudolph

EXTERNAL

Mr. Douglas Delve
NASA Headquarters
ORQA-KR
Washington, D. C.

Mr. John Stokes
Goddard Space Flight Center
Greenbelt, Maryland, Code 323.2

Mr. Ralph Latta
Manned Space Flight Center
Houston, Texas
Mailing Symbol AR

Chief: Bureau of Ships
Washington, D. C.
Attention: 621A2A2

Mr. R. Convertino
Systems Engineering Division
Ames Reserach Center
Moffet Field, California 94035

Mr. A. Gahn
Ames Reserach Center
Moffet Field, California 94035

Scientific and Technical Information
Facility (25)
Attn: NASA Representative (S-AK/RKT)
P. O. Box 5700
Bethesda, Maryland

DIR
DEP-T
I-RM-M
MS-H
MS-IP
MS-IL (8)
MS-T (6)

APPROVAL

EVALUATION OF HIGH TEMPERATURE STRANDED HOOK-UP WIRE

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.

John Knadler, Chief
Electrical Parts and Manufacturing Analysis Section

for Robert G. Penny, Chief
Electrical Test and Analysis Branch

Richard M. Henritze, Chief
Analytical Operations Division

for Dieter Grau, Director
Quality and Reliability Assurance Laboratory