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Development of Shipboard Electrical Cables with Compacted-Strand, Copper-Clad Aluminum Conductors

DEVELOPMENT OF SHIPBOARD ELECTRICAL CABLES WITH COMPACTED-STRAND, COPPER-CLAD ALUMINUM CONDUCTORS

By

Ernest W. Fisher

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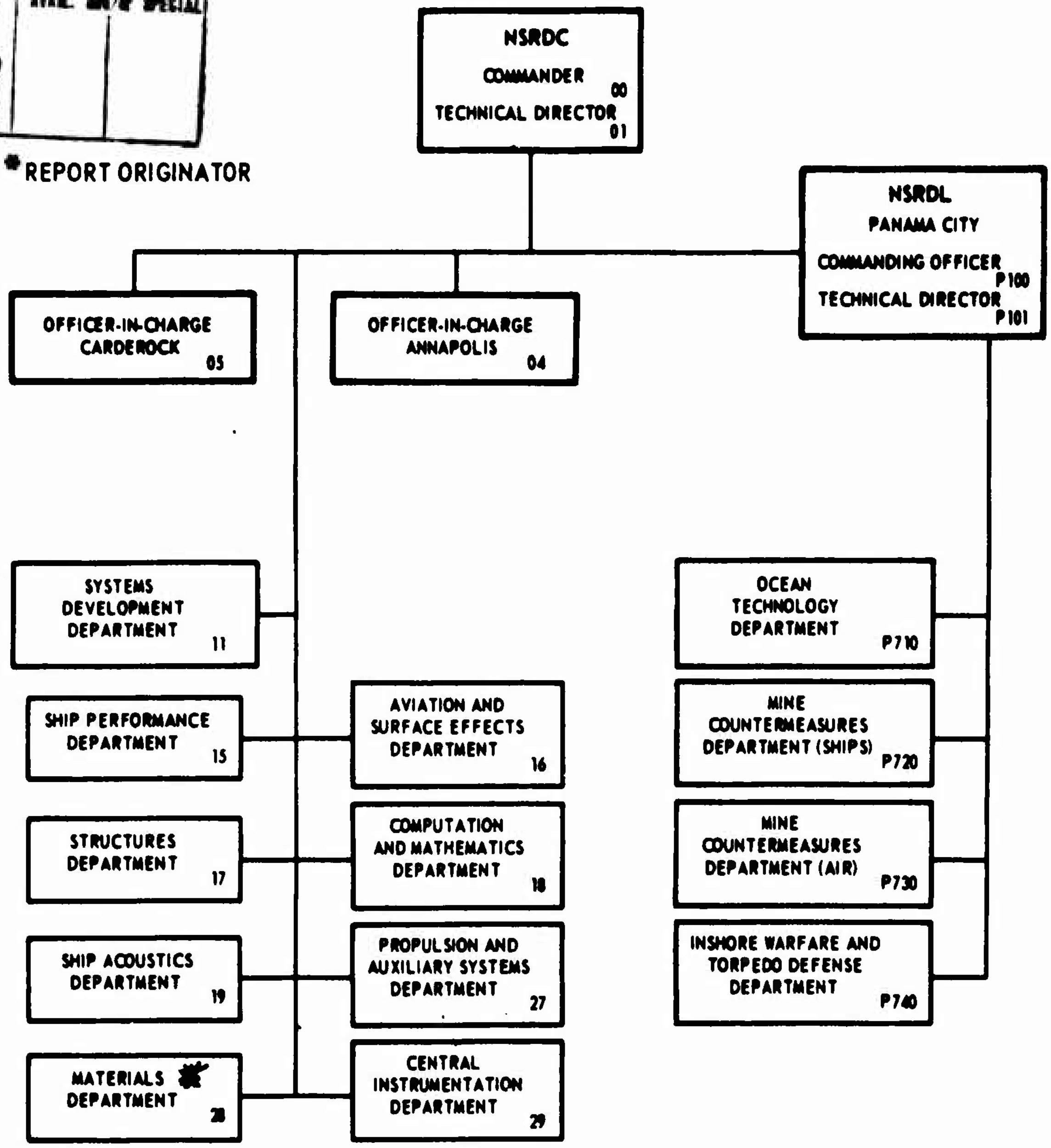

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ABSTRACT

Copper has been preferred as the conductor material for shipboard electrical cables because of its high electrical conductivity in comparison with that of most other metals. However, it is fairly expensive, and problems of supply which are becoming serious under ordinary conditions might become acute in times of national emergency. Therefore, alternate conductor materials are being investigated.

A sample of power cable, incorporating conductors of compacted 20% copper-clad aluminum strands, has been investigated in the laboratory. Results indicate that such conductors are unacceptable as direct substitutes for copper conductor in general shipboard power service but might be employed in more limited service, such as in intraspace power cables.

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DEVELOPMENT OF SHIPBOARD ELECTRICAL CABLES WITH COMPACTED-STRAND, COPPER-CLAD ALUMINUM CONDUCTORS

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INTRODUCTION

Copper is preferred as a conductor material for shipboard electrical cables because of its high electrical conductivity compared to all metals except silver, which is very expensive and scarce. However, copper is fairly expensive and is presenting increasingly serious supply problems which could become acute in times of national emergency. In anticipation of the occurrence of such a crisis, the Navy has been seeking an alternate conductor material which would conserve copper and also satisfy the requirements for cables made with copper conductors, at a cost no greater, and if possible less, than that of copper.

Specifically, the requirements to be satisfied by a cable incorporating conductors of the alternate material are:

- A reduced amount of copper.
- A cost no greater, or less, than that of the corresponding present standard cable.
- Compatibility with standard Navy copper lug terminals.[1]
- Current-carrying capacity equal to that of the present standard cable, having an overall diameter held within the limit set by the specification.[2]
- A cable no heavier, and if possible lighter, than the comparable copper-conductor cable.
- Installation cost no greater, or perhaps reduced.
- Capability of meeting all requirements of the specification.[2]

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[1] Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

- No appreciable increase in cable stiffness over that of standard cables of the same type.

APPROACH

A logical alternative conducting material is aluminum; however, its conductivity, although comparatively high, is only about 60% that of copper, so that for the same conductivity, aluminum conductors must be much larger in diameter than those made of copper. Also, special aluminum lug terminals must be installed on the cable for two reasons:[1]

- Aluminum expands more than copper with temperature rise and tends to flow under compression by the copper lug terminal, resulting in loose connections after the junction undergoes temperature cycling.

- Aluminum-copper junctions in humid environments are subject to severe electrolytic corrosion.

Both conditions are likely to occur in shipboard service.

As another alternative, a cable sample incorporating conductors made with 20% copper-clad aluminum strands was procured from a major manufacturer. It was considered that this combination of conductor materials would be free from the objectionable features of aluminum alone and that the cable might satisfy all the requirements listed above. To obtain maximum conductivity with a cable diameter within the dimensional limit of the specification,[2] the conductor strands were tightly compacted by the manufacturer. This sample has been subjected to a comprehensive laboratory investigation, with results detailed in this report.

PROCEDURES

Although the laboratory evaluation was comprehensive, certain tests such as jacket physicals were not performed because they were not considered pertinent to the objective of the investigation. The procedures employed were as follows.

- Construction and dimensions of sample. A specimen was visually examined, and dimensional measurements were made in accordance with paragraph 4.8.1 of the specification.[2] A specimen 26 feet long was weighed.

- Resistance of conductors. A specimen, 25 feet long, was measured on a Kelvin bridge in accordance with paragraph 4.9.1

of the specification.[2] To obtain a uniform current density in the conductors, the strands of each conductor were soldered together at the ends and potential measurements were made between copper wire bands wrapped around the conductors 6 inches from the current connections.

- Current-carrying capacity. The apparatus, conditions, and measuring methods employed in this procedure were the same as those prescribed by paragraph 4.8.11 of the specification,[2] except that the specimen was 25 feet long and measurements were made at several conductor current values, the maximum being the current-carrying capacity of standard Navy Cable of this type under the test conditions.[3]

- Effect of heat cycling on connections. Standard Navy CLS lug terminals of appropriate size were installed on the cable ends and torqued to a value previously determined to be sufficient to satisfy the pull-out requirements of the specification.[4] With the specimen installed in the apparatus specified in paragraph 4.8.11 of the specimen,[2] sufficient current was passed through the conductors to raise the lug temperature to 125°-130° C.* The specimen was allowed to cool to room temperature and lug-to-cable voltage-drop measurements were made in accordance with paragraph 4.3.3.1(a) of the specification.[4] This cycle was repeated twice.

- Effect of vibration on connectors. Standard Navy CLS lug terminals of appropriate size, tightened to the same torque value as for the heat cycling specimen, were installed on specimens of the sample and vibrated in accordance with paragraph 4.3.2 of the specification.[4] Appropriate measurements of the direct-current and lug-to-cable voltage drop were made in accordance with paragraph 4.3.3.1(a) of the specification.[4]

- Cold-bend performance. This was determined in accordance with paragraph 4.8.5 of the specification.[2] A 19-inch-diameter mandrel was employed.

- Bending force. The force required to bend a specimen 180° around a 19-inch-diameter mandrel, in a direction opposite to its natural set, was measured.

- Longitudinal watertightness: determined in accordance with paragraph 4.3.8 of the specification.[2]

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*Abbreviations used in this text are from the GPO Style Manual, 1967, unless otherwise noted.

- Dielectric strength. A specimen was subjected to a dielectric proof test in accordance with paragraph 4.9.2 of the specification.[2]

- Insulation resistance: measured in accordance with paragraph 4.9.3 of the specification[2] at an applied potential of 250 vdc.

- Capacitance and power factor. Measurements were made on a General Radio type 1680A automatic capacitance bridge.

- Accelerated service performance: determined in accordance with paragraph 4.8.14 of the specification.[2]

- Gas-flame performance: determined in accordance with paragraph 4.8.13 of the specification.[2] To determine whether the conductor strands would rupture and molten aluminum exude from the cable, a failed specimen was subjected to the gas flame for an additional 3 hours without applied voltage.

- Drip test. The tendency of components to drip from the cable at elevated temperatures was investigated in accordance with paragraph 4.8.7 of the specification.[2]

RESULTS

- Inspection and dimensions. The overall diameter of the cable exceeds the specification[2] limit by 10 mils. The diameter over the outer layer of glass-tape conductor insulation measured about 0.035 inch greater than the specified[2] nominal value. Dimensions, cable weight data, and notes on construction are detailed in table 1.

- Conductor resistance. Measurements at 20° C are as follows:

Conductor	Resistance ohm/1000 ft
A	0.0700
B	0.0699
C	0.0701

Table 1
Dimensions and Construction of Sample

Nominal Type: TSGA-150	Manufacturer Code A
Individual Conductors	
Number of conductors.	3
Strands (20% copper-clad aluminum), left-hand (LH) lay. Strands tightly compacted to fill interstices between strands. Sealed with mastic sealer, code B.(1)	37
Diameter over stranded conductor, in. (average)	0.433
Conductor cross-sectional area, circular mils	230,000(1)
Diameter over outer insulating glass tape, in. (average) Separator over conductor and insulation - consisted of 2 layers of clear polyester tape, 0.001-in.-thick by 1-in.-wide, butt wrapped, right hand (RH) lay. Insulation consisted of silicone rubber glass (SRG) tapes: 4 layers, 0.007-in.-thick by 1-in.-wide, wrapped with 1/16-in. gap over 2 layers, 0.010-in.-thick by 1-in.-wide, butt wrapped, RH lay.	0.592
Diameter over insulation and separator, in. (average)	0.593
Grouped Conductors	
Cabling: Three insulated conductors cabled with asbestos cords in core and valleys and watersealed with mastic compound, code C(1)	
Length of lay of conductors, in.	13 LH
Conductor identification: outer layer of SRG tape stamped with letters at about 1/2-in. intervals. One conductor marked "A," another "B," third conductor unidentified.	
Diameter over grouped conductors, in.	1.250
Diameter over binder tape, in. Binder tape: glass-reinforced asbestos paper, polyester backed, 0.010-in.-thick by 2 1/2-in.-wide, 9/16-in. lap, RH lay.	1.275
Manufacturer's identification: 1/3-in.-wide cream-colored tape marked "(Mfr Code A and address) 1963 to Navy Spec MIL-C-2194D 0016226 FT."	
Diameter over jacket, in. Jacket was black polychloroprene. Outer surface was smooth and circular.	1.525
Jacket thickness, in.	Maximum 0.132 Minimum 0.096 Average 0.139
Diameter over armor, in. Armor made up of 0.0125-in.-diameter aluminum strands, 15 strands per carrier, 24 carriers, 3 1/3 picks per in., one over one under weave, aluminum-painted.	1.575
Average weight of cable per foot, lb	1.73
Weight of standard TSGA-150 cable per foot, lb	2.40[3]
Weight reduction of sample over standard TSGA-150 cable, %	28

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(1) Manufacturer's data

- Current-carrying capacity. Temperature measurements were made at conductor current values of 75, 105, 140, 180, and 216 amperes rms in each conductor. The highest value is the normal current-carrying capacity of standard TSGA-150 cable at the ambient temperature maintained.[3] All measurements were made after the temperatures had been stable for at least 1/2 hour. The data are plotted in figure 1.

- Effect of heat cycling on connectors. A-C voltage-drop measurements were made, employing a Ballantine model 310A electronic voltmeter, from a point on the center line of the lug terminal behind the screw to a copper wire band wrapped around the conductor 1 inch from the lug. All measurements were made within 30 seconds after power was applied to minimize conductor heating. The designations (A1, A2, etc) indicate lugs at opposite ends of the same conductor. The data are detailed in table 2.

Table 2
Effects of Heat Cycling on Connections

	Potential Drop, RMS MV, Lug-to-Conductor at 80 Amperes						
	Lug						Ambient Temperature
Reading	A1	A2	B1	B2	C1	C2	° C
Initial	2.40	1.95	2.95	2.35	1.80	2.05	28
After 1 cycle	2.25	1.85	3.15	2.30	1.95	1.90	25
After 2 cycles	3.35	1.95	4.00	3.00	2.00	2.05	25
After 3 cycles	2.55	2.05	4.45	3.05	2.05	2.30	25

- Effect of vibration on connections. Potential measurements were made at room temperature with a d-c millivoltmeter between points similar to those described for heat cycling except that the wire bands were located 1/2 inch from the lug terminals. The data are presented in table 3.

- Cold bend. Two specimens were dissected and examined after bending. No evidence of displacement or damage to the cable components was noted.

Table 3
Effect of Vibration on Connections Potential

Reading	Drop, D-C MV, Lug-to-Conductor at 80 Amperes Sample			
	1	2	3	4
Initial	0.88	0.95	0.85	1.15
After vibration per specification[4]	0.91	0.90	0.87	1.12

- **Force.** The force required to bend two specimens of the cable 180° around a 19-inch-diameter mandrel was determined to be: 45 pounds for sample 1 and 52 pounds for sample 2. The average bending force was 48 1/2 pounds, and the average bending force for standard TSGA-150 is about 60 pounds.

- **Watertightness.** There was no longitudinal water leakage through any of the three specimens subjected to 25 psi water pressure for 6 hours.

- **Dielectric proof test.** The specimen withstood an applied potential of 5 kilovolts, 60 Hz for 1 minute without breakdown.

- **Insulation resistance.** The data calculated from measurements made on a specimen 24 feet long, employing a General Radio model 1230A amplifier electrometer with 250 vdc applied, are presented in table 4.

Table 4
Insulation Resistance Data

Insulation Resistance, Megohms - 1000 Feet Temperature of Specimen: 21° C			
Phase A to Others and Armor	Phase B to Others and Armor	Phase C to Others and Armor	All to Armor
538	524	474	174

- Capacitance and power factor. Capacitance and power factor, measured at 1000 Hz on a specimen 24 feet long, are recorded in table 5.

Table 5
Capacitance and Power Factor Data
Temperature of Specimen: 21° C

	Phase A to Others and Armor	Phase B to Others and Armor	Phase C to Others and Armor	All to Armor
Capacitance, µf/1000 ft	0.233	0.231	0.231	0.470
Power factor, %	8.2	8.4	8.3	8.9

- Accelerated service. The specimen failed because two jacket temperature readings exceeded the limit values of the specification;[2] the highest value measured was 154° C at 32° C ambient. There was no exudation of components as defined by the specification.[2]

- Gas-flame performance. All specimens failed in the gas flame. Failures in all cases consisted of insulation breakdowns of a single conductor to the armor. Examination of two failed specimens revealed no evidence of damage to the conductors. The data are presented in table 6.

Table 6
Gas-Flame Performance

Sample	Time to Failure min.
1	30
2	37
3	58
4	46
5	71

- Examination of the failed specimen subjected to the gas flame for an additional 3 hours without voltage applied disclosed evidence of complete alloying of copper and aluminum and extreme embrittlement, a result considered normal under the conditions[5] and illustrated in figure 2. However, no molten metal had exuded from the conductors.

DISCUSSION

The basic premise for determining the feasibility of substituting alternate conductor materials for copper in shipboard electrical cable conductors is that a cable incorporating these alternate materials must be completely interchangeable with the corresponding copper conductor cable and satisfy all the requirements of the specifications[2,4] covering that cable.

The sample evaluated failed to satisfy two specified[2] requirements (discussed below).

GAS-FLAME PERFORMANCE

Examination of two specimens after insulation breakdown in the gas flame revealed no damage to the conductors. However, at the point of insulation breakdown of one specimen (located by electrical testing), a large hole in the conductor insulation, estimated to be about 1 sq in. in area, was discovered. The edges of this hole presented a jagged appearance which seemed to indicate tearing of the insulation tapes. It is considered that the tearing might have been caused by expansion of the conductors in the flame since aluminum at high temperature expands about 50% more than copper. Also, at some places along the rough edges of the insulating tapes, the presence of what appeared to be some carbonized material was noted. Since the composition of the strand sealer (code B) is unknown, it is considered possible that this material could have exuded through the tape and carbonized in the gas flame, resulting in insulation breakdown.

Examination of the failed specimen which was exposed to the gas flame without applied voltage for an additional 3 hours revealed a slight amount of melting but no exudation of the metal of the conductors through the insulation. However, apparently complete alloying of the two metals and extreme embrittlement of the conductor occurred, a result which is considered typical[5] (see figure 2). At points on the specimen exposed to the flame, the conductors could be easily broken in the hands alone and short pieces of the strands broken with the fingers. It is thought likely that if a considerable length of the cable, particularly one of the smaller sizes, should lose its support during a shipboard fire, the weight of this unsupported length might fracture and open circuit the conductors even if no insulation breakdown occurred.

ACCELERATED SERVICE

It is considered that the accelerated service failure due to excessive sheath temperature may be connected with the dimensional deviations from specified[2] values noted under Results. From the measured diameter over the conductor insulation, it was calculated that the measured diameter over the grouped conductors is about 30 mils less that the theoretical value required to round out the cable. Furthermore, since this latter measurement is made with a tape, any accentricity of the group would tend to show a measured value of this diameter as greater than its actual value. A comparison of these data was made with those from reports of three previous investigations of copper conductor cable of this type. This comparison indicated that standard cables are ordinarily filled out to make the diameter measurement from 10 to 100 mils greater than the minimum theoretical value.

Observation of the cable end tends to confirm that the cable is not sufficiently filled; the insulation of one of the conductors, instead of being tangent to the binding tape, makes intimate contact with it over a considerable arc of its periphery so that the binding tape and conductor insulation appear embedded in the jacket. Observation also confirms that the thinnest areas of the jacket (which varies atypically in thickness but is still acceptable) are located directly over this conductor. It is thought possible that this unusually large area of intimate contact of the conductor insulation with the binding tape created a highly conductive thermal path from conductor to jacket which could account for hot spots on the outer surface of the jacket. Further evidence for this was produced by cutting through the jacket of the specimen at the points where the measuring thermocouples were located. It was found that the thermocouples measuring acceptable temperature values were located over the valleys and that those measuring the inordinately high values were located directly over a conductor, where the jacket measured much thinner than its average value.

CONCLUSIONS

The sample fails to satisfy the requirements of the specification[2] in the following respects:

- Accelerated service performance.

- Gas-flame performance.

- Copper-clad aluminum conductors of this type are unacceptable as substitutes for copper conductors in cables which must satisfy the requirements of the specification.[2]

RECOMMENDATIONS

It is recommended that copper-clad, compacted-strand aluminum conductors be considered unsuitable for use under specification MIL-C-2194E(SHIPS). It is further recommended that consideration be given to using this type of conductor in intraspace power cables.

FUTURE WORK

A laboratory investigation of the knuckling and short-circuiting of the conductors of 1SWA cable is in progress and a report on this is being written.

TECHNICAL REFERENCES

1 - Miller, William E., "How to Make Aluminum-Copper Connections," Electrical Construction and Maintenance Magazine, Feb 1969
2 - Mil Spec MIL-C-2194E(SHIPS), 31 Jan 1968
3 - "Cable Comparison Guide," NAVSHIPS 250-660-23, 1964
4 - Mil Spec MIL-E-13366C(SHIPS), 7 Feb 1958
5 - Freiling, Gerald H., "Copper-Clad Aluminum Wire-a New Electrical Conductor Material," Wire and Wire Products Magazine, Jan 1967

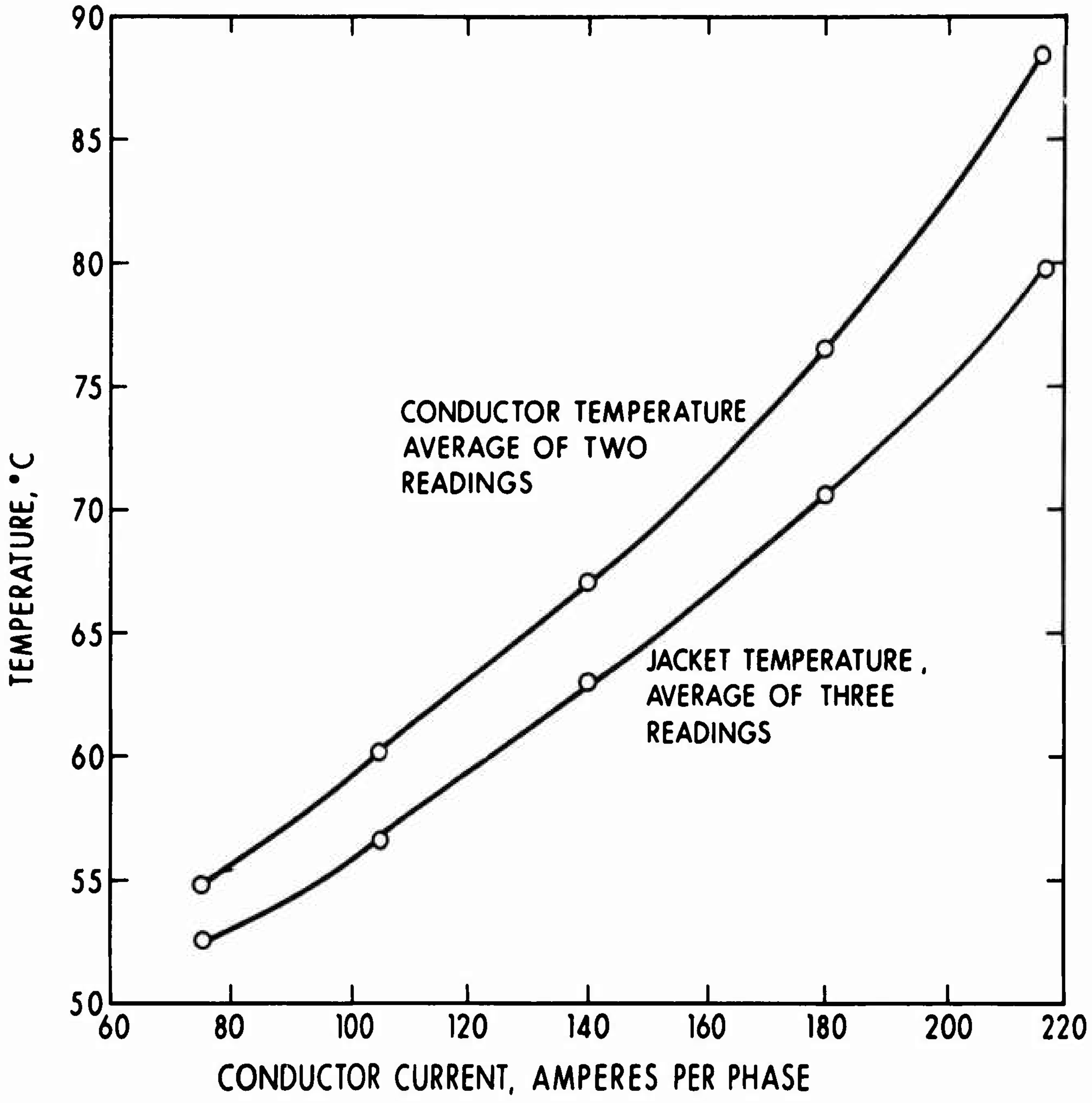

Figure 1
Temperature Versus Conductor Current
TSGA-150 Type Cable With 20% Copper-Clad
Aluminum Compacted-Strand Conductors
Ambient Temperature: 50° C
Measuring Current 60 Hz

Top: Conductor (partially dismantled) after insulation breakdown in gas flame.
Middle and Bottom: Conductors after 3 hours in gas flame without voltage applied.

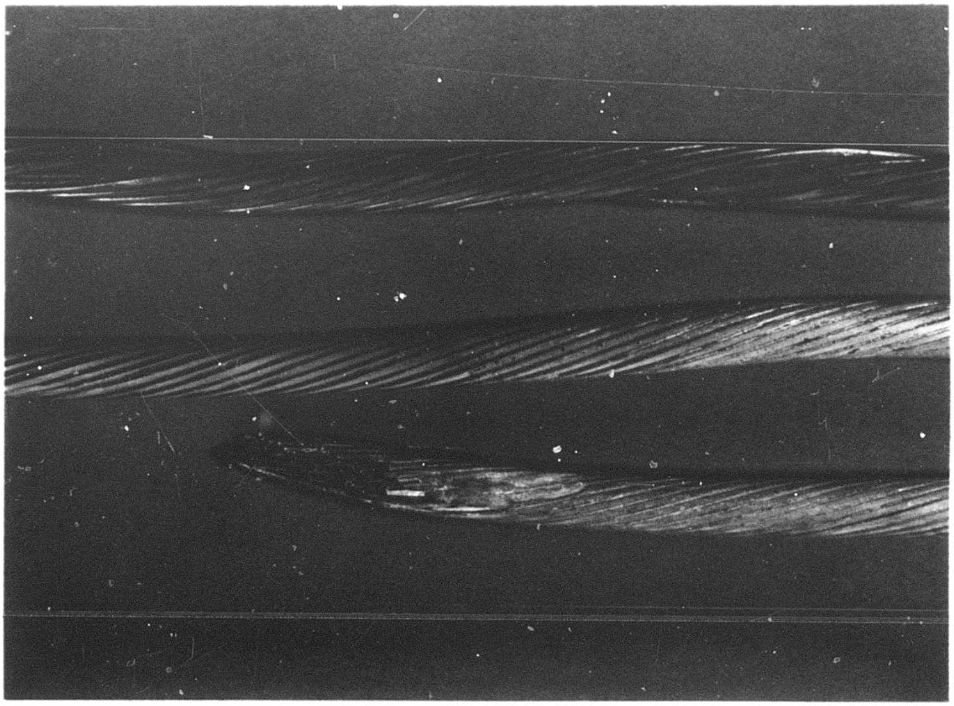

Figure 2
Effect on Conductors of 3-Hour Exposure of Cable to Gas Flame

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Copper has been preferred as the conductor material for shipboard electrical cables because of its high electrical conductivity in comparison with that of most other metals. However, it is fairly expensive, and problems of supply which are becoming serious under ordinary conditions might become acute in times of national emergency. Therefore, alternate conductor materials are being investigated. A sample of power cable, incorporating conductors of compacted 20% copper-clad aluminum strands, has been investigated in the laboratory. Results indicate that such conductors are unacceptable as direct substitutes for copper conductor in general shipboard power service but might be employed in more limited service, such as in intraspace power cables.

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