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## **ABSTRACT**

Percon® 24, developed by Fisk Alloy Conductors, Inc., is a new cadmium free high strength high conductivity copper alloy developed especially for high strength wire and cable applications.

Percon® 24 meets the electrical and mechanical properties of ASTM B 624, NEMA WC-67 and all military specifications for "high strength alloy conductor".

Silver plated and nickel plated Percon® 24 and PD 135 were insulated with M22759/33 and /82 respectively. Tests were conducted to compare the performance characteristics of these two alloys. Copper wire samples were included in the tests for reference. Flex life, tensile strength and voltage drop tests of wire samples in an unconditioned state, and after exposure to thermal aging, thermal shock, and vibration were used as the indicators to compare performance. Additional tests were also performed to determine and compare Percon® 24's resistance or susceptibility to Red Plague.

Results of all tests demonstrate that Percon® 24 will provide equivalent long-term performance to PD 135 in high strength conductor applications.

## **INTRODUCTION**

Fisk Alloy Conductors Inc. has developed a new high strength cadmium-free copper alloy (Percon® 24) with mechanical and physical properties meeting the "high strength alloy" requirements specified in ASTM B 624, M22759, M81381, NEMA WC-67, M29606, etc. Each of these specs require the material to possess a 60 ksi (min) tensile strength, electrical conductivity of 85% IACS (min) and a minimum elongation of 6 or 8% depending on the specification.

Although none of these specifications is material specific, qualification of Percon® 24 for military or commercial aerospace wire and cable requires rigorous testing to ensure that the conductor material performs equally to currently accepted materials.

Currently, alloy C18135 (PD135) is the only accepted conductor material for high strength alloy conductor in military applications. Qualification or acceptance criteria for new conductor materials for military applications are not well defined, since there are no test procedures to qualify the performance of the conductor itself. There are many performance specifications for insulated wire, but the test procedures focus primarily on the performance of the insulation material and merely assume that it was applied over one of the accepted conductor materials.

Development of high performance military wire and cable resulted in numerous innovations in insulation materials and systems which have undergone rigorous performance testing before being accepted for military use. The innovation of new conductor materials has been infrequent. Copper, the standard conductor material, was most probably was accepted by default. PD135 was accepted as a high strength copper alloy, but its qualification process and data are not available. Aluminum was also qualified many years ago and its qualification process and data are not readily available. Conductor for a new category, "ultra-high strength copper alloy", was the most recent military qualified material and was approved approximately 10 years ago. Documentation of that test program and results is available, and the qualification program for Percon® 24 used it as a basis.

The qualification program for ultra-high strength alloy included tests of voltage drop, break strength and flex life, before and after conditioning by thermal aging and thermal shock.

Testing was conducted to compare the performance of 24 AWG Percon® 24 with 24 AWG PD135 and 22 AWG copper wire. Tests and conditioning environments similar to those used to qualify ultra-high strength conductor were also included in this investigation. A vibration environment to characterize conductor and crimp termination compatibility, a modified SAE AS4373 flex test and a comparison of propensity for Red Plague (silver plated wire) were also performed.

Voltage drop, tensile and flex tests were performed on wire and terminated specimens in the as-received condition, after thermal aging, thermal shock and exposure to vibration. Some tests were performed on terminated specimens in which the contact was applied to the wire after thermal aging (*re-terminated specimens*). Thermal aging and shock conditioning were performed at the rated operating temperatures of the wires.

Testing performance confirmed that Percon<sup>®</sup> 24 is comparable to PD135.

The results of this test program were forwarded to Naval Air Systems Command for review and acceptance of Percon<sup>®</sup> 24 as a high strength conductor alloy for military wire and cable applications.

### **DESCRIPTION OF TEST ARTICLES**

Fisk Alloy Conductors provided conductor samples of:

- 24 AWG silver plated (SP) Percon<sup>®</sup> 24 - 19/36 unilay
- 24 AWG nickel plated (NP) Percon<sup>®</sup> 24 - 19/36 unilay

Military QPL suppliers provided conductor samples of:

- 24 AWG SP-PD135 - 19/36 unilay
- 22 AWG SPC (copper) - 19/34 unilay
- 24 AWG NP-PD135 - 19/36 unilay
- 22 AWG NPC (copper) -19/34 unilay

A six mil extruded wall of cross-linked ethylene-tetrafluoroethylene copolymer (XL-ETFE) was applied to the 24 AWG silver plated alloy conductors per M22759/33 and to the 22 AWG silver plated copper per M22759/44.

A six-mil thick composite tape-wrap insulation was applied to the 24 AWG nickel plated alloy conductors per M22759/82 and to the 22 AWG nickel plated copper per M22759/92.

Termination contacts, when required, met the requirements of M39029/56-348 (MS27490-22D) for sockets and/or M39029/58-360 (MS27493-22D) for pins. All crimp terminations were attached using tools and positioners meeting the M22520 specification.

### **TESTING LABORATORY FACILITIES**

Raytheon Technical Systems, Indianapolis, Indiana was contracted to perform the specimen conditioning, diameter, weight, tensile, resistance and voltage drop measurements.

Conductor inspection, flex testing (using specimens prepared by Raytheon), Red Plague and other testing was performed at Fisk Alloy Conductors, Hawthorne, New Jersey.

### **SPECIMEN CONDITIONING**

Wire specimens were subjected to thermal aging, thermal shock and vibration to simulate environmental conditions that may affect conductor/wire performance. Unconditioned specimens were taken from as-received wire.

Specimens that required thermal aging were placed in an air-circulating oven for 1000 hours at the wire's specified operating temperature. Silver plated wire was aged at 200°C and nickel plated wire was aged at 260°C.

Specimens that required thermal shock were exposed to a total of 8 shock cycles. Each shock cycle consisted of soaking the specimens at the specific wire's operating temperature for one hour followed immediately by cooling to -55°C for one hour. The soak temperature for silver plated conductor was 200°C and 260°C for nickel plated conductor.

Specimens that required exposure to vibration conditioning were fixtured to simulate a functional application of the conductor/crimp termination. Test setup, conditions, monitoring and reporting conformed to MIL-C-39029 para. 3.5.10 and 4.7.11 and Method 2005 of MIL-STD-1344, test condition VI, letter J. A vibration duration of 8 hours in the longitudinal direction and 8 hours in the perpendicular direction was applied.

### **PROCEDURES, RESULTS AND DISCUSSION**

#### **Conductor Dimensions and Properties**

The conductor construction used for this investigation was 24 AWG - 19/36 lightweight Unilay. Conductor diameter, weight, DC resistance, lay length, break, tensile strength and elongation were measured to confirm that the material and conductor construction conformed to ASTM B624, NEMA WC67, and M29606 before insulating. Summaries of the conductor test results for the Percon<sup>®</sup> 24 samples are included in TABLES 1 and 2.

All conductor used for this investigation met the requirements of the applicable conductor and material specs.

TABLE 1 - SP-Percon® 24 Properties

	Spec Req.	SP-Percon® 24
Diameter (in)	0.0225-0.0244	0.0233
Weight (lb/mft)	1.33 min	1.42
DCR (Ω/mft)	28.4 max	23.87
Lay/Dir (in)	8-16L	0.333
Break (lb)	22.4 min	23.05
Tensile (psi)	60,000 <sup>(1)</sup>	61,785
Elongation (%) in 10"	6 min	9.5

Notes: Spec Requirements from NEMA WC-67 and M29606 except as noted.  
1 - ASTM B 624 requirement

TABLE 2 - NP-Percon® 24 Properties

	Spec Req.	NP-Percon® 24
Diameter (in)	0.0225-0.0254	0.0234
Weight (lb/mft)	1.33 min	1.42
DCR (Ω/mft)	30.1 max	26.3
Lay/Dir (in)	8-16L	0.333
Break (lb)	22.4 min	24.92
Tensile (psi)	60,000 <sup>(1)</sup>	66,798
Elongation (%) in 10"	6 min	8.9

Notes: Spec Requirements from NEMA WC-67 and M29606 except as noted.  
1 - ASTM B 624 requirement

### Insulated Wire Dimensions and Properties

Values for the wire diameter, conductor diameter, wire weight and DC resistance on the Percon® 24, PD135 and copper wires were within the required limits of M22759. Summaries of the results and M22759 requirements are included in TABLES 3, 4 and 5.

TABLE 3 - Wire and Conductor Diameter

Conductor Type	Diameter (in)	
	Wire	Conductor
24SP-Percon® 24	0.0366	0.0231
24SP-PD135	0.0369	0.0231
M22759/33 spec.	0.035-0.039	0.023-0.025
24NP-Percon® 24	0.0366	0.0231
24NP-PD135	0.0352	0.0229
M22759/82 spec.	0.034-0.038	0.0225-0.0254

TABLE 4 - Wire Weight

Conductor Type	Weight (lb/1000ft)
24SP-Percon® 24	1.89
24SP-PD135	1.88
M22759/33 spec.	2.0 (max)
24NP-Percon® 24	1.90
24NP-PD135	1.88
M22759/82 spec.	1.93 (max)

TABLE 5 - DC Resistance

Conductor Type	Resistance (Ω/1000ft)	
	Unconditioned	Thermal Aged
24SP-Percon® 24	22.17	24.29
24SP-PD135	22.14	25.36
M22759/33 spec.	28.4 (max)	N/A
24NP-Percon® 24	22.28	26.41
24NP-PD135	22.65	25.90
M22759/82 spec.	30.1 (max)	N/A

### Solderability

Solderability of the silver plated conductor specimens was determined in accordance with NEMA

WC67 (references ANSI/J-STD-002) without steam aging. All specimens exhibited 100% solder coverage.

### Voltage Drop

DC resistance measurements and voltage drop calculations were performed on specimens to determine the effect of the simulated environmental exposure on voltage drop across the crimp joints and on re-terminated specimens simulating "in-service" repairs.

Specimens (24 inches in length) with terminations crimped on both ends, from each wire group, were measured for DC resistance before and after exposure to thermal shock, thermal aging and vibration conditioning. Re-terminated specimens were also tested.

Voltage drop, based on a 100mA (0.100 amperes) current, were calculated from the DC resistance measurements using the following formula:

$$V = 100mA \times \frac{R(+)+R(-)}{2}$$

where:

- V = Voltage drop (at 100mA) of the wire sample with two crimp joints
- R(+) = DC resistance measurement
- R(-) = DC resistance measurement with reverse polarity

Pin probes were used to measure the resistance across the test specimens at the termination crimp joints (Figure 1). The pin probes were placed on the shoulder of the crimp barrels for the readings. For confirmation, the polarity of the milli-ohmmeter was reversed and the resistance reading repeated. Summaries of the resistance measurements and voltage drop calculations are shown in TABLE 6.

TABLE 6 - Voltage Drop

Conductor Type	Voltage Drop (millivolts)				
	Unc	T/Age	T/Shk	Vibr	Re-term
24SP-Percon® 24	4.98	5.00	5.14	5.16	5.04
24SP-PD135	5.14	5.18	5.23	4.95	5.20
24NP-Percon® 24	5.42	5.47	5.93	5.45	5.57
24NP-PD135	5.42	5.39	5.66	5.41	5.41

The results of silver plated specimens were consistently in the range of 5 millivolts and the nickel plated specimens were in the range of 5.5 millivolts. It should be noted that the voltage drop results include the electrical resistance of the 24 inch length of wire between the crimp contacts in addition to the resistance at the crimp barrel. The slightly higher conductor resistance for nickel would account for this trend.

In most cases, the voltage drop changed minimally after conditioning. The greatest change in voltage drop occurred after thermal shock, showing increases between 1.75% and 9.4%.

The performance of Percon<sup>®</sup> 24 and PD135 was considered to be comparable in the voltage drop tests.

### Crimp Tensile Strength

Tensile testing was performed to determine the effect of simulated environmental exposure on crimp pull-out strength. Specimens from each wire group were tested for crimp tensile strength in the as-received condition and after thermal shock, thermal aging and vibration. Additional sets of specimens, which had the crimp terminations attached after the wire was exposed to thermal aging, were also tested for crimp tensile strength.

Each specimen was attached to the tensile machine and pulled apart at a rate of 1 inch per minute to determine the force required to separate the conductor from the termination barrel. A summary of the crimp tensile results is shown in TABLE 5A and 5B.

Crimp tensile results were very consistent between both alloys. Unconditioned silver plated Percon<sup>®</sup> 24 and PD135 exhibited crimp strength results between 70 - 90% of the minimum required conductor break strength (22.4 lbs). Nickel plated conductors were lower than the silver plated versions, with crimp strength in the range of 56 - 74% of the conductor break strength.

The effects of conditioning were similar between Percon<sup>®</sup> 24 and PD135. Silver plated specimens generally exhibited increased crimp strength after thermal aging and thermal shock with a higher consistency in the results. Specimens exposed to vibration and re-termination generally exhibited a slight decrease in crimp strength.

The nickel plated specimens performed similarly to their silver plated counterparts in average crimp strength. However, after thermal shock, the nickel plated specimens exhibited much higher variability compared than the thermally shocked silver plated specimens.

TABLE 5A – Crimp Tensile Strength (Silver Plated)

Conductor Type		Load to Failure (lbs.)		
		min	max	avg
24SP-Percon <sup>®</sup> 24	Uncond.	15.18	20.32	19.04 <sup>(1)</sup>
24SP-PD135	Uncond.	15.85	21.13	18.72 <sup>(3)</sup>
24SP-Percon <sup>®</sup> 24	T/Aged	20.79	22.01	21.24 <sup>(1)</sup>
24SP-PD135	T/Aged	21.54	22.40	22.05 <sup>(1)</sup>
24SP-Percon <sup>®</sup> 24	T/Shock	19.78	20.57	20.21 <sup>(1)</sup>
24SP-PD135	T/Shock	20.16	21.72	21.01 <sup>(1)</sup>
24SP-Percon <sup>®</sup> 24	Vibration	15.10	19.89	17.59 <sup>(3)</sup>
24SP-PD135	Vibration	16.32	18.92	17.77 <sup>(1)</sup>
24SP-Percon <sup>®</sup> 24	Re-termin.	14.42	19.53	17.67 <sup>(3)</sup>
24SP-PD135	Re-termin.	15.79	19.24	16.95 <sup>(2)</sup>

Notes: (1) Conductors broke inside the crimp area for all samples  
 (2) Conductors completely pulled out of crimp barrel for all samples  
 (3) Some conductors broke inside the crimp area, some completely pulled out

TABLE 5B – Crimp Tensile Strength (Nickel Plated)

Conductor Type		Maximum Load to Failure (lbs.)		
		min	max	avg
24NP-Percon <sup>®</sup> 24	Uncond.	13.56	16.65	15.04 <sup>(2)</sup>
24NP-PD135	Uncond.	12.54	15.38	13.64 <sup>(2)</sup>
24NP-Percon <sup>®</sup> 24	T/Aged	20.28	21.61	21.02 <sup>(1)</sup>
24NP-PD135	T/Aged	20.85	21.85	21.41 <sup>(1)</sup>
24NP-Percon <sup>®</sup> 24	T/Shock	12.35	21.97	19.67 <sup>(3)</sup>
24NP-PD135	T/Shock	18.61	22.81	20.95 <sup>(3)</sup>
24NP-Percon <sup>®</sup> 24	Vibration	12.82	17.21	15.55 <sup>(2)</sup>
24NP-PD135	Vibration	11.46	15.62	13.91 <sup>(2)</sup>
24NP-Percon <sup>®</sup> 24	Re-termin.	18.37	21.49	20.21 <sup>(3)</sup>
24NP-PD135	Re-termin.	13.99	20.60	16.51 <sup>(2)</sup>

Notes: (1) Conductors broke inside the crimp area for all samples  
 (2) Conductors completely pulled out of crimp barrel for all samples  
 (3) Some conductors broke inside the crimp area, some completely pulled out  
 (4) Some conductors broke just outside the crimp barrel, some completely pulled out

It should be noted that the highest crimp strengths were exhibited after thermal aging. This trend held true for both plating and both alloy types. Thermal aging also decreased the variability between the specimens to the lowest level among the different conditioning treatments. Minimum and maximum crimp strengths varied between 4 - 6% for these specimens compared to range variations in excess of 40% after exposure to other conditioning. Additionally, the thermally aged specimens exhibited no conductor pullouts.

The performance of Percon<sup>®</sup> 24 and PD135 was considered to be comparable in crimp strength.

### Center-of-Wire Tensile Strength

Tensile testing was also performed to determine the effect of thermal aging on conductor break strength. Specimens from each wire group were tested for center-of-wire (conductor) break strength in the unconditioned and thermally aged conditions. Wire strippers were used to push back the insulation (without damaging the conductor) from the center of each specimen to create an approximately one-inch window prior to testing. Specimens were tested at a 1 inch per minute rate, and a 10 inch per minute rate. A summary of the tensile break strength results is shown in TABLE 6.

TABLE 6 – Conductor/Center of Wire Tensile Break Strength

Conductor Type		Tensile Rate	Maximum Load to Failure (lbs.)
24SP-Percon® 24	Uncond.	1"/m	22.56
24SP-PD135	Uncond.	1"/m	24.29
24SP-Percon® 24	Uncond.	10"/m	23.03
24SP-PD135	Uncond.	10"/m	24.57
24SP-Percon® 24	T/Aged	1"/m	22.70
24SP-PD135	T/Aged	1"/m	24.38
24SP-Percon® 24	T/Aged	10"/m	22.92
24SP-PD135	T/Aged	10"/m	24.55
24NP-Percon® 24	Uncond.	1"/m	24.90
24NP-PD135	Uncond.	1"/m	26.54
24NP-Percon® 24	Uncond.	10"/m	25.12
24NP-PD135	Uncond.	10"/m	26.77
24NP-Percon® 24	T/Aged	1"/m	24.68
24NP-PD135	T/Aged	1"/m	25.97
24NP-Percon® 24	T/Aged	10"/m	25.14
24NP-PD135	T/Aged	10"/m	26.00

All wire specimens broke within the stripped window in the tensile test. The average values for all the test specimens were above the M22759 minimum of 22.4 lbs.

Thermal aging seemed to have very little effect on the conductor's tensile strength. All specimens exhibited less than 1% change in break strength after exposure to temperature except for NP-PD135 (10 inch/min) which decreased by 3%.

The performance of Percon® 24 and PD135 was considered to be comparable in center-of-wire (conductor) tensile strength.

### Flex Life at Crimp Terminations

Flex fatigue testing was performed on specimens to determine the effects of environmental exposure on the flex life of the conductor at the crimp termination barrel. Specimens were axially flexed with an angle of ±60° from vertical, an oscillation rate of approximately 30 cycles per minute and a 2 pound load.

Terminated specimens were exposed to each of the conditioning environments prior to test. Re-terminated specimens were prepared from bulk wire that had already been thermally aged. Each specimen was mounted in the flex test fixture with the end of the contact barrel protruding approximately 1/8" above the mandrel center. This assured that the edge of the contact barrel was effectively the "mandrel" for the flex test. Testing was performed until failure of the conductor. A summary of the data for socket terminations is shown in TABLE 7.

Specimens with pin terminations were also tested for flex life. However, due to the short length of the contact and method of fixturing, large variability

and inconsistencies in flex life at pins resulted. Examination of the test in progress revealed that pin contacts had a tendency to oscillate with the flexing motion, which reduced the effective flex angle to varying degrees. Apparently this reduced flex angle resulted in inconsistencies and higher flex life for the pin specimens. Therefore, flex data from specimens with pin contacts were not used for this analysis.

Socket contacts, having longer length, allowed for more rigid fixturing that greatly reduced any oscillation. This assured better consistency of the applied flex conditions. The results from the sockets had much less variability and were used for the performance analysis.

TABLE 7 – Flex Life at Crimp Socket Terminations

Conductor Type		Cycles to Failure (avg. 3 specimens)
24SP-Percon® 24	Unconditioned	13
24SP-PD135	Unconditioned	16
22SPC	Unconditioned	16
24SP-Percon® 24	Thermal Aged	13
24SP-PD135	Thermal Aged	14
22SPC	Thermal Aged	13
24SP-Percon® 24	Thermal Shock	14
24SP-PD135	Thermal Shock	15
22SPC	Thermal Shock	16
24SP-Percon® 24	Vibration <sup>(1)</sup>	17
24SP-PD135	Vibration <sup>(2)</sup>	14
22SPC	Vibration	13
24SP-Percon® 24	Re-terminated	15
24SP-PD135	Re-terminated	19
22SPC	Re-terminated	17
24NP-Percon® 24	Unconditioned	15
24NP-PD135	Unconditioned	19
22NPC	Unconditioned	14
24NP-Percon® 24	Thermal Aged	13
24NP-PD135	Thermal Aged	15
22NPC	Thermal Aged	13
24NP-Percon® 24	Thermal Shock	13
24NP-PD135	Thermal Shock	19
22NPC	Thermal Shock	13
24NP-Percon® 24	Vibration	14
24NP-PD135	Vibration	19
22NPC	Vibration	13
24NP-Percon® 24	Re-terminated	15
24NP-PD135	Re-terminated	17
22NPC	Re-terminated	15

Note: (1) In one case, the socket broke during the flex cycling (data from remaining 2 specimens).

(2) In two cases, the socket broke during the flex cycling (data from remaining 1 specimen).

The results indicate that Percon® 24 exhibited slightly lower performance than PD135 in the unconditioned and re-terminated specimens, and comparable performance with the other specimens. The effect of the slightly lower flex life of Percon® 24 is considered to be minimal. Therefore the performance of Percon® 24 and PD135 was considered to be comparable in flex life at crimp terminations.

## Center-of-Wire Flex Life

Flex testing was performed to compare the flex life of Percon<sup>®</sup> 24 and PD135 conductor after insulating.

Flex test results have an inherently high variability. ASTM B 470 specifies a flex test for un-insulated wire and SAE AS4373 describes a technique for insulated wire, but neither specifies minimum flex life. Variability is also introduced by variations in testing machines and set-up. These tests basically evaluate the qualitative flex performance of wire and small differences in the results are not considered significant.

Unconditioned specimens from each wire group were flex tested. Specimens were mounted in the flex test fixture using the same conditions as the crimp flex tests but the insulated wire was placed between 0.250 inch diameter mandrels. The specimens were also attached to a low current circuit to detect conductor breakage in the event conductor failure occurred before insulation failure. All testing was performed until the failure of the conductor. A summary of the results is shown in TABLE 8.

TABLE 8 - Conductor Flex Life (Center of Wire)

Conductor Type		Cycles to Failure (data from 6 specimens)		
		Min	max	avg
24SP-Percon <sup>®</sup> 24	Uncond.	6994	10432	8670
24SP-PD135	Uncond.	3003	7347	5912
24NP-Percon <sup>®</sup> 24	Uncond.	4732	7323	6224
24NP-PD135	Uncond.	4268	6811	5811

The conductor and insulation failed simultaneously in all the test specimens. No instances were noted where the insulation was able to support the applied weight after failure of the conductor.

The performance of Percon<sup>®</sup> 24 and PD135 was considered to be comparable in center of wire flex testing.

## Modified SAE AS4373 Center-of-Wire Flex Test

SAE AS4373 Revision B Method 704 describes a two-step flex test that is an attempt to determine when conductor strand breakage actually begins. It first determines the number of cycles to catastrophic failure, then flexes additional specimens to a pre-determined number of cycles. The first step establishes a baseline flex life for the wire. The second step flexes additional specimens to 50%, 60%, 70%, etc., of the baseline value, the insulation in the flex area is removed, and the conductor is examined for strand breakage. The number of broken strands is then reported.

The SAE AS4373 test conditions were modified to parallel the other flex test procedures used in this investigation and to accommodate the existing test apparatus. The major differences were a  $\pm 60^\circ$  flex angle (versus  $\pm 90^\circ$  for SAE) and a 2 pound test weight yielding approximately 10% of the conductor's break strength (versus 20% for SAE). In essence, the principle of the test remains the same.

Unconditioned wire specimens of Percon<sup>®</sup> 24 and PD135 were flex life tested with the modified SAE test procedure. The average of the center-of-wire flex results for Percon<sup>®</sup> 24 and PD135 were used as the baseline results and two specimens of each wire type was subjected to flexing. Since conductor plating and insulation type may influence flex life, the silver plated and nickel plated conductor tests were evaluated separately.

The wire was attached to the test fixture in the same manner as the center-of-wire flex test. The electronic sensing circuit was also used in the event conductor failure occurred before the predetermined number of cycles. Specimens were flexed to 70%, 80% and 90% of the baseline then removed from the flex tester. Additional tests were also performed as necessary for additional data.

After flexing, approximately 2 to 2½ inches of insulation was carefully removed from the flex area of each specimen to expose the conductor. The conductor was then carefully untwisted to expose the inner strands and the broken strands were counted. The observed number of completely broken strands was reported. The results are shown in TABLES 9A and 9B.

TABLE 9A - Broken Strands - SAE Flex Test (Silver Plated)

Conductor Type	Number of Broken Strands at Pre-Determined Flex Cycles (Sample 1 / Sample 2)				
	50% (3645)	60% (4375)	70% (5104)	80% (5833)	90% (6562)
24SP-Percon <sup>®</sup> 24	0 / 0	0 / 0	0 / 0	0 / 0	0 / 0
24SP-PD135	0 / 0	0 / 0	1 / 0	4 / 0	N/A

Note: Baseline average of 7,291 cycles used for this test. (Average of 8,670 and 5,912 cycles from Center-of-Wire flex results)

TABLE 9B - Broken Strands - SAE Flex Test (Nickel Plated)

Conductor Type	Number of Broken Strands at Pre-Determined Flex Cycles (Sample 1 / Sample 2)			
	60% (3611)	70% (4213)	80% (4814)	90% (5416)
24NP-Percon <sup>®</sup> 24	N/A	0 / 0	0 / 0	0 / 1
24NP-PD135	19 <sup>(1)</sup> / 0	19 <sup>(2)</sup> / 0	0 / 0	19 <sup>(3)</sup> / 1

Note: Baseline average of 6,018 cycles used for this test. (Average of 6,224 and 5,811 cycles from Center-of-Wire flex results)

- 1 - During the predetermined flex run, one sample broke at 2,405 cycles.
- 2 - During the predetermined flex run, one sample broke at 1,266 cycles.
- 3 - During the predetermined flex run, one sample broke at 1,429 cycles.

SP-PD135 exhibited one broken strand in one sample after flexing 70% and 4 broken strands in one sample after flexing 80%. SP-Percon<sup>®</sup> 24 conductors exhibited no broken strands after flexing to 80% of the baseline, so an additional test to 90% was

performed. These specimens also exhibited no broken strands.

Complete wire failure was observed in some of the NP-PD135 specimens before completing the predetermined 60%, 70% and 90% runs. One broken strand was observed in the remaining 90% sample of NP-PD135.

One broken strand was observed in one of the NP-Percon<sup>®</sup> 24 specimens after 90% flexes. No other strand breakage was found in any of the other NP-Percon<sup>®</sup> 24 samples.

The performance of Percon<sup>®</sup> 24 and PD135 was considered to be comparable in the SAE flex test.

### **Susceptibility to Red Plague**

Red Plague corrosion on stranded silver plated conductor is due to the formation of copper corrosion products as a result of galvanic corrosion of the base metal at a break in the silver plating. It occurs in silver plated copper (and copper alloy) conductors due to the difference in electrochemical potential between copper and silver only if breaks or discontinuities, caused during manufacture or processing, exist in the silver plating. Under certain environmental conditions that may lead to this reaction, Red Plague may cause silver plated copper and copper alloy conductors to fail.

The Anthony and Brown "test" is sometimes used to determine a wire's susceptibility to Red Plague corrosion. As the test supplies the optimum conditions for Red Plague corrosion, some consider the "time required for the on-set of Red Plague" or the "number of Red Plague sites" as the measure. But if the electrochemical driving force between the two metals is sufficient, Red Plague can occur.

Results from the accelerated Anthony and Brown - Red Plague test demonstrated that silver plated copper alloys such as SP-Percon<sup>®</sup> 24 and SP-PD135, in addition to silver plated copper, are susceptible to Red Plague. Minor alloying additions in the high copper alloys do not appreciably change copper's electrochemical potential. Therefore the electrochemical driving force for this corrosion between copper and silver still exists.

Red Plague corrosion was observed on SP-Percon<sup>®</sup> 24, SP-PD135 and SP-Copper. The test exposure time for the initial appearance of Red Plague varied between the different lots tested, but there was no correlation to the conductor material. Visual examination of the specimens revealed that there was more conductor damage present in cases where Red Plague formed earlier. Some lots exhibited no corrosion after 10 days in test, very

little conductor damage was evident on that conductor.

Several observations on Red Plague were made:

- Most silver plated copper alloys, as well as silver plated copper, are susceptible to Red Plague. The alloying additions in most high copper alloys do not appreciably change the electrochemical potential of copper and their differences with silver are still sufficient to cause Red Plague corrosion.
- The onset of Red Plague in silver plated copper and copper alloys would seem to be controlled by workmanship of the conductor manufacturer, insulators and others that may compromise the integrity of the silver plating on the conductor.
- Red Plague corrosion (on silver plated copper or copper alloy) will take longer to occur on wire manufactured with good workmanship than on wire manufactured with poor workmanship. Silver plated copper, often considered "more susceptible" to Red Plague than silver plated copper alloys such as PD135 can be shown to be "less susceptible" depending on the workmanship of the samples, i.e. onset is controlled by workmanship.

### **CONCLUSIONS**

The performance of Percon<sup>®</sup> 24 has been demonstrated to be comparable to PD135.

It has been demonstrated that Percon<sup>®</sup> 24 meets the high strength conductor alloy requirements of military wire and cable.

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