

# METALLIZED KEVLAR FOR UNDERSEA ELECTROMECHANICAL CABLES

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## ABSTRACT

As a result of the mismatch of the elongation characteristics of conductors and kevlar strength-members in undersea electromechanical cables, the Naval Air Development Center initiated an investigation of copper-coated kevlar. The metallized kevlar was developed to be used as both conductor and strength-member in e-m cables. Both kevlar 29 and kevlar 49 were evaluated. Three cleaning methods, two electroless coatings, and three thicknesses of electrodeposited copper were applied to each type of kevlar, resulting in twenty variations of material. Tensile tests and dc resistance measurements were made to determine the best process of metallization and best candidate copper-coated kevlar yarn for undersea cables. The effort resulted in strong, conductive kevlar and indicated direction for further development leading to the fabrication of metallized kevlar cables.

## INTRODUCTION

The development of small diameter kevlar electromechanical cables has been a continuing process at the Naval Air Development Center since 1973, and kevlar has replaced steel as the strength member in several sonobuoy cables. A recent development which shows promise of having application in underwater cables is the metallization of kevlar. Copper-coated kevlar has the potential to be both conductor and strength member in electromechanical cables; however, in the process of rendering the kevlar conductive, the tensile strength and flexibility of the kevlar must be preserved. An effort was undertaken to determine whether kevlar fibers could be made effective conductors while retaining their strength, as a first step toward developing an electromechanical cable using metallized kevlar.

## BACKGROUND

The availability of duPont Kevlar fibers has brought about a revolutionary change in the field of marine electromechanical cables. By using kevlar instead of steel as the strength member in cables, reductions in both

weight and size have been obtained without sacrificing strength, or conversely, stronger cables have been made in the same size.<sup>1</sup> Although the advantages of using kevlar in place of steel were significant, the transition was not always a simple one. Kevlar was susceptible to handling problems and abrasion, and early cables exhibited wide variation of breakstrength.<sup>2,3</sup> Awareness of the unique characteristics of kevlar, care in handling, and the availability of kevlar with various oil and waxed finishes have improved the consistency of kevlar cable properties and have raised the confidence with which they are used.

One problem which arose very early in the development of small kevlar marine cables was the incompatibility of the stress-strain characteristics of kevlar and those of the conductor.<sup>1,4,5</sup> Kevlar exhibits elastic elongation of 2 to 4 percent to break; whereas, copper conductors reach plastic deformation at small elongations (approximately 0.5 percent). In marine applications in general, the electromechanical cable is subjected to both a static tension load of 20 to 50 percent of ultimate strength and a dynamic loading caused by ocean waves. While the kevlar stretches and relaxes with the dynamic loading, the conductor, once stretched beyond the yield point, will buckle. Repeated cycling can cause severe z-kinking of the conductor and eventual loss of electrical continuity.

One solution to the incompatibility of the strength member and conductor elongations is to helically serve the conductor wires around a center nylon monofilament core, building elastic structural elongation into the design. This construction is being used in some single conductor/seawater return cables for sonar systems. A different possible approach to this problem is to coat the kevlar fibers with a conductive material, making the conductor an integral part of the strength member. Metallized graphite had been made by electrodepositing copper or nickel onto the conductive graphite, but since kevlar is nonconductive, the same technique had not been applied to kevlar.

Materials Concepts, Inc. (MCI), did some preliminary investigation which indicated that metallized kevlar could be produced through a process of precoating and electroplating. The Naval Air Development Center had MCI produce lengths of metallized kevlar varying a number of parameters in the metallization process to achieve a suitable combination for eventual use in underwater cables. The metallized kevlar samples were tested by the Naval Air Development Center for strength and conductivity.

#### DISCUSSION

The process of metallization of kevlar consisted of three steps: cleaning the kevlar of its finish to assure good bonding of the metal to the fibers, coating the kevlar with a conductive undercoat by an electroless, or autocatalytic process, and depositing a required thickness of copper onto the conductive fibers by an electrodeposition process. The variables that needed to be considered to evaluate metallized kevlar thoroughly included:

- a. Kevlar 29 vs. kevlar 49
- b. Denier of Fiber
- c. Type of finish on fiber
- d. Method of cleaning
- e. Type of precoat
- f. Thickness of copper coating

The differences between kevlar 29 and kevlar 49, as they affect cables, are the greater elongation and the lower cost of kevlar 29. Both are viable materials for underwater cables; therefore, it was considered important to use both in this investigation. In order to restrict the number of variations, a selection of 1420 denier kevlar 49 and 1500 denier kevlar 29 was made. These deniers are widely used for cables and each contain 1000 filaments, so comparisons could be readily made.

In order to select the type of finish and cleaning method, duPont was consulted. Type 965 kevlar 49 and type 964 kevlar 29 were selected as having a light oil finish which could be stripped away using Trichloroethane. Cordage or high lubricity finishes were considered more difficult to remove or adhere to, and duPont indicated that Kevlar without a finish was only supplied reluctantly on special request because the danger of damaging the fiber through handling was much higher. Three alternate approaches were chosen for the cleaning process. One method was to use Trichloroethane, as recommended by duPont; the second was to use a sodium hydroxide-trisodium phosphate cleaning solution that MCI normally used to prepare graphite fibers for coating (referred hereafter as the "standard" cleaning method); and finally, not to clean the kevlar at all,

which if it showed any promise, would eliminate a step from the metallization process.

Two types of undercoats were used - nickel and copper. It was anticipated that the nickel undercoat could be applied more rapidly and adhere better than copper, but that the copper undercoat might result in a better conductivity per weight ratio. The initial, or phase I, samples were to be electrocoated with a 1.0 micrometer thickness of copper, i.e., each of the 1000 0.0119 mm-diameter filaments in an end of 1420 denier kevlar 49 or 0.013 mm-diameter filaments in an end of 1500 denier kevlar 29 would have a coating of 0.001-mm thickness.<sup>6,7</sup> After the twelve varieties of the phase I samples, listed in Table I, were tested, the most promising combinations were selected for electrocoating with thickness of copper of 0.5  $\mu\text{m}$ , 1.0  $\mu\text{m}$ , and 1.5  $\mu\text{m}$ .

#### Phase I Samples

Each of the initial samples were 150 ft. in length and were provided to the Naval Air Development Center for testing. MCI reported difficulties in coating the kevlar 29 which were not experienced with kevlar 49. After the copper-undercoated samples of kevlar 29 (Type 964) had been made and did not appear to be of good quality, MCI consulted duPont who now recommended kevlar 29 (Type 962) as a "no finish" yarn. The nickel-undercoated kevlar 29 samples were made with the type 962 yarn and seemed to be much improved. The kevlar 29 samples with the copper undercoat were not repeated with the type 962 yarn. Table I summarizes the twelve phase I samples.

TABLE I: INITIAL SAMPLES OF METALLIZED KEVLAR

TYPE OF KEVLAR AND FINISH	CLEANING METHOD	UNDERCOAT	THICKNESS OF COPPER
KEVLAR 49 (TYPE 965) 1420 DENIER	STANDARD	NICKEL	1.0 MICRON
	NONE	COPPER	
	TRICHLORO-ETHANE	NICKEL COPPER	
KEVLAR 29 (TYPE 964) 1500 DENIER	STANDARD	COPPER	1.0 MICRON
	NONE TRICHLORO-ETHANE		
KEVLAR 29 (TYPE 962) 1500 DENIER	STANDARD NONE TRICHLORO-ETHANE	NICKEL	1.0 MICRON

Tensile tests were made on an Instron tensile machine with pneumatic grips. These grips were used previously in testing kevlar cables and were found to result in midspan breaks where split cylinder grips did not.<sup>3</sup> For yarn samples, a twist was required. Using a Twist Multiplier (TM), the twist in turns per inch was calculated from<sup>6</sup>

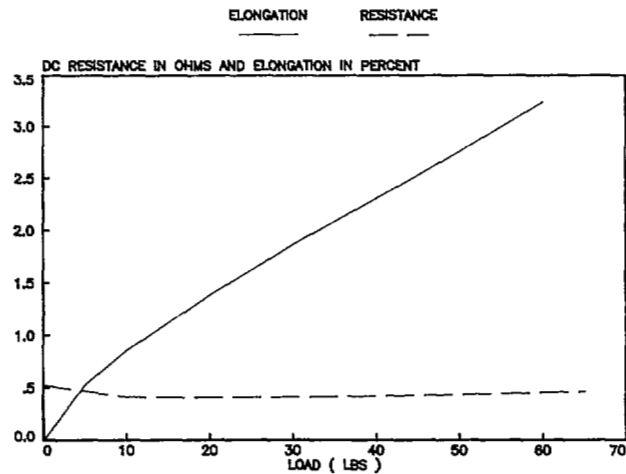
$$\text{Turns/in} = \frac{73 \times \text{TM}}{\text{denier}}$$

For an optimum twist multiplier of TM = 1.1, the turns/in for the 1420 denier should be 2.13 and for the 1500 denier should be 2.07. Both yarns, therefore, were twisted approximately 2 turns/inch for the 12-inch gage length tested. Although a 50% per minute elongation rate commensurate with duPont's yarn testing to ASTM D2256 was initially considered, a slower pull rate was required to obtain d.c. resistance measurements of the samples as they were tested. A pull rate of 0.5 inches/minute was used and d.c. resistance noted as load increased.

A typical result of the tensile tests is shown in figure 1. As the load increased the elongation became linear with tension until break occurred between 3 and 4 percent elongation. The d.c. resistance initially decreased rapidly as the sample came under tension and was at a minimum between 10 and 30 lbs. As tension increased further, the dc resistance began to increase slowly. The increase of resistance at the point of sample break was too rapid to measure. The sample mechanical integrity and electrical continuity were essentially interdependent. When the metallized kevlar sample broke, the sample became instantaneously an open circuit. That the dc resistance did not increase by an excessive amount under high loads (for example, at 50% or 80% of ultimate tensile strength) was encouraging for the eventual utility of metallized kevlar in cable applications.

Along with the metallized kevlar samples, a quantity of the untreated kevlar yarn was tested. The average breakstrength of the 1420 denier kevlar 49 yarn was 70.9 lbs. (from 11 breaks with minimum 64.0 lbs. and maximum 75.0 lbs.), the 1500 denier kevlar 29 (Type 964) yarn was 73.7 lbs. (from 11 breaks with minimum 70.5 lbs. and maximum 77.0 lbs.), and the 1500 denier kevlar 29 (Type 962) yarn was 69.3 lbs. (from 10 breaks with minimum 65.5 lbs. and maximum 71.5 lbs.). The average breakstrengths of the metallized samples (with 10 to 15 tests per sample) are shown in figure 2 as a percent of the raw kevlar yarn average breakstrengths. Overall, the metallized kevlar 49 samples had higher strengths than the kevlar 29 samples, but based on breakstrengths alone, it would be difficult to determine a best cleaning method. The standard method appears to be

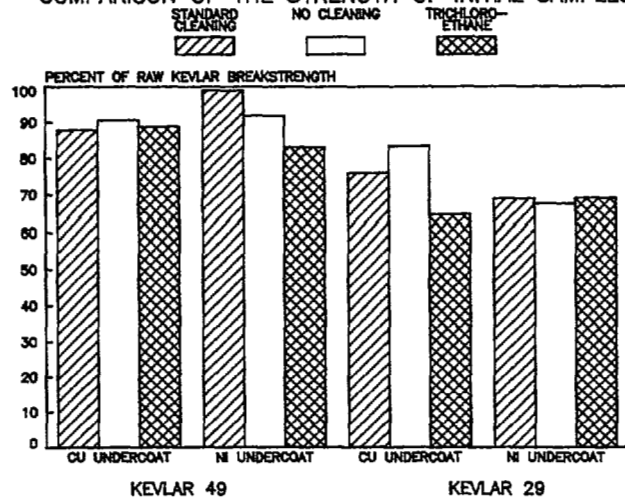
FIGURE 1: TYPICAL ELONGATION AND RESISTANCE CHANGE WITH LOAD ON METALLIZED KEVLAR



best for kevlar 49 with the nickel undercoat, but no cleaning shows some advantage for kevlar 49 and kevlar 29 with copper undercoats. The trichloroethane cleaning is the poorest method for kevlar 49 with nickel undercoat and for kevlar 29 with copper undercoat.

The average dc resistance of the samples are shown in figure 3. The measurements reflect the minimum values of resistance, usually under 20 lbs. tension. The kevlar 29 with copper undercoat shows that good adherence of the copper to the type 964 kevlar 29 was not obtained. Of the remaining samples, the most notable trend is for the resistance of the samples without any cleaning to be low. For the kevlar 29 with nickel undercoat, no cleaning gave the best results.

FIGURE 2: COMPARISON OF THE STRENGTH OF INITIAL SAMPLES



Considering both strength and resistance measurements, and further considering the advantage of simplifying the metallization process with the likelihood of eventual cost reduction, the preferred approach was not to clean the kevlar before applying the metallic undercoat. Undoubtedly, there are many areas for manufacturing techniques and choices of materials to be varied to obtain optimum or most cost effective methods of producing metallized kevlar, but the present study was directed toward obtaining a useful product with a very limited effort. The initial results demonstrated a 1420 denier kevlar 49 with over 90 percent of the strength of raw kevlar and a dc resistance of less than  $0.4\Omega/\text{ft}$ .

### Phase II Samples

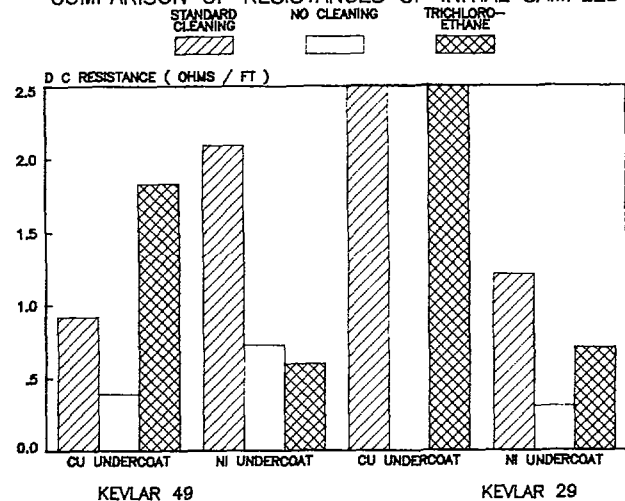
The second quantity of metallized kevlar was designed to evaluate the properties of various thicknesses of copper deposited on the kevlar. Although the variable of cleaning the kevlar prior to coating was eliminated, it was considered important to carry both kevlar 49 and kevlar 29 with the nickel and copper undercoats through this phase. The thicknesses of copper deposited on each 500 ft. long sample were  $0.5\mu\text{m}$ ,  $1.0\mu\text{m}$ , and  $1.5\mu\text{m}$ . The twelve variations are listed in Table II. These samples were subjected to separate tensile and conductivity testing.

The tensile tests performed on phase II samples were identical to those in phase I, i.e., the yarn was twisted at 2 turns per inch and pulled with a 12-inch gage length over pneumatic grips at 0.5 inches/minute. Twenty-five specimens of each sample were tested to break. Figure 4 shows the average breakstrengths of the metallized kevlar samples as a percentage of the raw kevlar strength. Three of the four types of kevlar-undercoat combinations with  $0.5\mu\text{m}$  of copper averaged over 90% of the kevlar

TABLE II: FINAL SAMPLES OF METALLIZED KEVLAR

TYPE OF KEVLAR AND FINISH	CLEANING METHOD	UNDERCOAT	THICKNESS OF COPPER
KEVLAR 49 (TYPE 965) 1420 DENIER	NONE	NICKEL	0.5 MICRON
			1.0
			1.5
		COPPER	0.5 MICRON
			1.0
			1.5
KEVLAR 29 (TYPE 962) 1500 DENIER	NONE	NICKEL	0.5 MICRON
			1.0
			1.5
		COPPER	0.5 MICRON
			1.0
			1.5

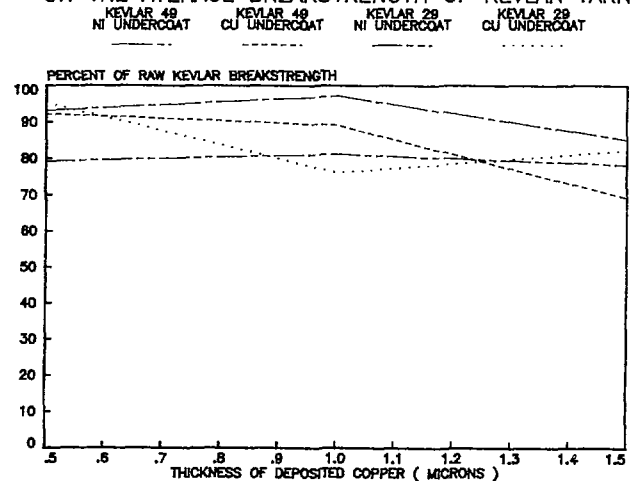
FIGURE 3: COMPARISON OF RESISTANCES OF INITIAL SAMPLES



breakstrength. Both kevlar 49 samples were also very strong with  $1.0\mu\text{m}$  of copper, with the nickel-undercoated kevlar 49 increased in strength to 97% of the yarn breakstrength and the copper-undercoated sample decreased to 89%. At the  $1.5\mu\text{m}$  copper thickness, both kevlar 49 samples have somewhat decreased strength. The kevlar 29 samples at  $1.0\mu\text{m}$  and  $1.5\mu\text{m}$  copper thickness are lower in breakstrength but consistent in the 76% to 81% range.

Figure 5 shows the results of dc resistance measurements on phase II samples. The  $0.5\mu\text{m}$  copper coverage was spotty in places and the best coverage was attained with the  $1.5\mu\text{m}$  thickness coating. The

FIGURE 4: THE EFFECT OF COPPER COAT THICKNESS ON THE AVERAGE BREAKSTRENGTH OF KEVLAR YARN

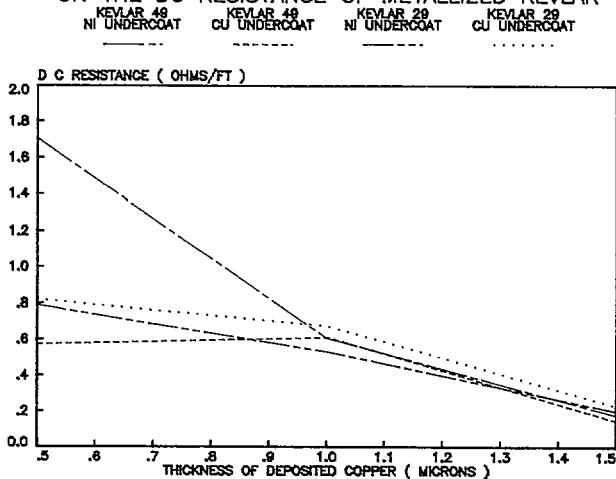


average dc resistance for the 1.0 $\mu\text{m}$  coating was 0.6 $\Omega$ /ft. and for the 1.5 $\mu\text{m}$  coating was less than 0.2 $\Omega$ /ft. From the perspective of dc resistance only, the 1.5 $\mu\text{m}$ -coated samples were the best and the most consistent, and the 0.5 $\mu\text{m}$ -coated samples the worst and least consistent. The phase II test samples were 6 ft. lengths, tensioned but not twisted. When three 6-ft. lengths of the 1.0 $\mu\text{m}$ -coated kevlar 49 (copper over nickel) were twisted together and tested, a dc resistance of 0.16  $\Omega$ /ft. was measured, whereas the untwisted samples of single end averaged 0.60 $\Omega$ /ft., which should yield 0.20 $\Omega$ /ft. for 3 ends. Just as twisting or braiding of kevlar fibers allow all the fibers to share the load, twisting the metallized fibers improve the conductivity of the bundle of fibers.

#### Further Evaluation

Considering the number of parameters involved in the metallization of kevlar, this initial study has indicated a number of directions for future work. Some additional observations should be mentioned. Although MCI eventually was successful in coating kevlar 29 with "no finish", kevlar 49 was reported to be easier to undercoat with copper than kevlar 29. It was also easier to coat kevlar 49 with copper than with nickel and easier to coat kevlar 29 with nickel than with copper. The 1.5 $\mu\text{m}$ -coated kevlar samples were stiffer than the 0.5 and 1.0 $\mu\text{m}$ -coated samples but certainly were flexible enough to be used in cables. The 0.5 $\mu\text{m}$ -coated kevlar samples showed a large proportion of yellow kevlar color indicating incomplete metallic coverage. Copper-coated kevlar was also found to be solderable using conventional techniques.

FIGURE 5: THE EFFECT OF COPPER COAT THICKNESS ON THE DC RESISTANCE OF METALLIZED KEVLAR



The copper content of a 1.0 $\mu\text{m}$ -coated 1420 denier kevlar 49 should be equivalent to an AWG 31 copper wire with approximately 0.133 $\Omega$ /ft. dc resistance or about 22 percent of the measured resistance, but the copper content of a 1.5 $\mu\text{m}$ -coated 1420 denier kevlar 49 should be equivalent to a copper wire between AWG 29 and 30 with approximately 0.1  $\Omega$ /ft. or about 50 percent of the measured resistance. It is apparent that some effort is still required to optimize the metallization process, especially to obtain a consistently complete coverage of each fiber in the kevlar yarn. This study, requiring, as it did, many variables to be examined, did not concentrate on quality control measures which can undoubtedly be utilized to achieve an improved end product.

The development of an undersea cable from metallized kevlar will not be without problems. It is not known whether the copper coating will withstand abrasion, act as a lubricating or protective surface to the kevlar, or be an irritant facilitating kevlar failure. Certainly, there are a number of prospective applications of copper-coated kevlar - as the strength-member-conductor of a sea-water cable, as the one-way electrical link to an LED-source for signals up a fiber optic link, and as strong, light-weight conductive members in multiple conductor array cables. The proposed continuation of this effort, therefore, will concentrate on producing a quantity of a single promising type of metallized kevlar with well-controlled strength and conductivity, fabricating insulated cables from the metallized kevlar, and testing these cables under cycle loading. For this purpose, kevlar 49 with either a copper or nickel undercoat appears to be the most promising candidate. A copper thickness between 1.0 and 1.5 microns will be sought to optimize strength and conductivity. With further work, the process of metallization should be capable of being improved significantly, making undersea cables of metallized kevlar practicable.

#### RESULTS

Twenty variations of metallized kevlar were fabricated and tested. The parameters varied including type of kevlar, method of cleaning, type of undercoating, and thickness of copper deposited on the kevlar yarn.

The precoat cleaning of kevlar was found to be of no advantage and sometimes detrimental to the metallization process.

Kevlar 49 (type 965) was better suited to the metallization process than kevlar 29 (type 964 or type 962).

No significant difference between nickel undercoating and copper undercoating was determined.

The uniformity of copper electrodeposited on the kevlar was better at the 1.0 and 1.5 micron thicknesses than at 0.5 micron.

Metallized kevlar samples were found to be capable of retaining more than 85 percent of the strength of the untreated kevlar while achieving low dc resistances.

#### CONCLUSIONS

Kevlar can be coated with copper through a metallization process that has the capability of producing strong, low-resistance metallized kevlar yarn.

The results of this investigation have laid the groundwork for and indicated the direction for the optimization of metallized kevlar for electromechanical cables.

Further effort is required to implement optimum application of conductive coating to kevlar and to fabricate cables from the metallized kevlar for dynamic testing.

#### RECOMMENDATIONS

The process of metallizing kevlar yarn should be improved to yield a well-controlled strong conductive yarn in quantity. The resultant metallized kevlar should be fabricated into insulated cables and tested under dynamic conditions of cyclic loading to evaluate their practicability for use as undersea electromechanical cables.

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Acknowledgement must also be made to Dr. Thomas Jones of the Naval Ocean Systems Center whose work with non-metallic conductors, graphite, and metallized graphite was the starting point for this effort in metallized kevlar.

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