DEPARTMENT OF THE NAVY
NAVAL WEAPONS SUPPORT CENTER
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P. Henderson

IN reply refer to:
10552/1
Ser 70523M/U91248
1.9 JUN 1991

From: Commanding Officer, Naval Weapons Support Center Crane
To: Officer in Charge, Strategic Systems Programs Office . (SP-24233)
Subj: FOLLOW-UP ANALYSIS TO ACCELERATED LIFE TESTING OF TR-333/BQN-25 HYDROPHONE AND TR-143/BQN-3 TRANSDUCER CABLES
Ref: (a) NWSCC ltr 10552/1 Ser 70523/U91170 of 29 Apr 91 Encl•

(1) Analysis of Accelerated Life Test Samples

1. Naval Weapons Support Center Crane (NWSCC) in conjunction with Texas Research Institute performed Accelerated Life Testing (ALT) of Navigation Sonar System equipment connectors as described in reference (a). After conclusion of ALT the test samples were shipped to NWSCC and submitted to the various analysis techniques described in enclosure (1).

2. The results of this analysis disclosed two potentially useful findings that should be addressed in any further development/test of nonconductive primers.

a. The element Silicon (Si) was found on the metal surface of the connectors primed with the BIW-1 and DGO-1 primer systems. Potential origins of the Si detected could be; (1) silicate fillers used in the primers, (2) silicone based release agents/ sealants used in molding/fabrication, or (3) sandblast grit material. If the Si element was present on the metal surface during primer application, a result of (2) or (3) above, it could be a potential source of primer to metal bond degradation.

b. The application thickness of the PR-420 on the NWSCC fabricated BIW-1 primed samples was 20 to 30 times thicker than that on the BIW fabricated BIW-1 primed samples. The bond on the BIW-1 fabricated samples remained intact during ALT testing while the bond on the NWSCC fabricated samples broke down at the PR-420 to BIW-1 interface. Fabrication of PR-420 sample coupons show that thicker samples require greater cure times and contain a greater number of voids.

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3. NWSCC point of contact is Mr. M. Mitchell, Code 70523M, telephone AV 482-1363 or commercial 812-854-1363, extension 4130.

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IN REPLY *CVCR To,
10552/1
Ser 70523fU91170

29APR 1991

From: Commanding Officer, Naval Weapons Support Center Crane
To: Director, Strategic Systems Programs Office (SP-24233)

Subj: ACCELERATED LIFE TEST OF TR-333/BQN-25 HYDROPHONE AND TR-143/BQN-3 TRANSDUCER CABLES

Ref: (a) NWSCC ltr 10552/1 Ser 70523/U91086 of 13 Mar 91

Encl: (1) Texas Research Institute Report 90344-706:SLA oi 12 Apr 91

1. Enclosure (1) contains a detailed report on Accelerated Life Testing (ALT) of TRIDENT Navigation Sonar System (NSS) cables performed by Texas Research Institute, Austin, Texas. Reference (a), a 'Lessons Learned' letter, was written prior to conclusion of ALT and should be utilized in any further testing.

2. Based on the observations and data contained in enclosure (1) Naval Weapons Support Center Crane (NWSCC) makes the following determinations:

a. The BIW-1 primer system exhibits the greatest potential toward alleviating the NSS cable debond problems. The BIW-1 primer system showed no degradation, in any sample, of the metal to BIW-1 primer bond and in three of the samples showed no degradation of the total bond system (metal to BIW-1 to PR-420 to polyurethane). This is significant because:

(1) the metal bond is the most difficult to obtain due to the mismatch of the physical properties of the bonding materials,

(2) the total bond system can be maintained intact.

The DGO-1 primer system displayed the second best bonding capability, but patches of debond were present in all DGO-1 samples. Both the DGO-1 and the BIW-1 primer systems exhibit a slower debond rate and longer time prior to initial debond.

b. Neither the epoxy or polyurethane backfill materials (Hysol, Chockfast, and PR-1547) provided a secondary water block. The metal to epoxy/polyurethane bond was broken in all but three samples. All backfill materials provided adequate reinforcement of the wire connections.

c. Extreme care must be taken in cable preparation in order to prevent cable to polyurethane debond.

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3. NWSCC makes the following conclusions/recommendations:

a. At the present stage, the BIW-1 primer system offers the best possible solution to the cable debond problem. However, further progress needs to be made in the BIW-1 to polyurethane bond. Boston Insulated Wire (BIW) has alluded that this bond has been improved.

The DGO-1 primer system, in order to offer a solution to the cable debond problem, requires further development that would eliminate the patches of debond that were present in all DGO-1 samples.

b. The cable debond reported in enclosure (1) should not be a problem if due care is taken in the cable preparation and molding stages, and peculiarities associated with these ALT tests are not present.

c. Alower modulus epoxy type material to reduce thermally induced stress fractures is necessary for the backfill to provide a secondary water block.

4. NWSCC point of contact is Mr. M. Mitchell. Code 70523M, telephone AV 482-1363 or commercial 812-854-1363, extension 4130.

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TEXAS RESEARCH INSTITUTE AUSTIN, INC.
A Texas Research International Company

90344-706:SLA
12 April 1991

To: Commanding Officer
Naval Weapons Support Center
Attn: Code 7052 (P. Henderson)
Crane, Indiana
47522-5070

From: Texas Research Institute Austin, Inc. (TRI/Austin)
Reliability Engineering Division

Shawn L. Arnett

Subj: Accelerated Life Testing of TR-333 and TR-143 Candidate Electrical Connectors

1.0 BACKGROUND

TRI/Austin, Inc. is tasked under NRL Contract No. N00014-89-C2431 to provide engineering support to NAVSEA, NRL-USRD, NWSCC, and other Navy activities in their efforts to improve the reliability of outboard sonar transducers, cables, and connectors. A recent task effort has involved the accelerated life testing (ALT) of 28 outboard electrical connectors intended for use with TR-333 and TR143 sonar transducers. The objective of the testing was to evaluate candidate designs which were developed to increase the service life reliability of metal backshelled electrical connectors. Specifically, these systems are intended to prevent, or inhibit, the rapid degradation of rubber-to-metal adhesive bonds caused by cathodic delamination (1]. Technical supervision was provided by NWSCC Code 7052 and contract support was provided by NRL-USRD.

Articles received for testing were metal connectors which were coated to provide the backshells a *non-conductive,* or hydrophobic, substrate for adhesive bonding of the cable boots. The mechanism of cathodic delamination requires a conductive bonding substrate, and affects many inorganic adhesive systems. Therefore, the use of a non-conductive and/or hydrophobic interfacial bond substrate should provide resistance to cathodic delamination.

Solid, non-conductive, glass reinforced epoxy (GRE) connectors were developed for use with some Fleet submarine sonar arrays to eliminate cathodic delamination failures [2,3]. The purpose for the ALT of the TR-333 and TR-143 candidate connectors was to determine if the cathodic delamination process can be inhibited by non-conductive or hydrophobic materials acting as a interfacial layer between the standard metal backshell substrate and elastomer boot. This report will describe the accelerated life testing, and subsequent failure analyses (autopsies), of candidate coating systems which were applied to metal connectors.

2.0 EXECUTIVE SUMMARY

Some of the significant findings which resulted from the ALT program included:

- The performance of the candidate coating systems showed improvements over the standard configuration connectors; although, each type exhibited failures with unique degradation mechanisms.
- The epoxy backfill encapsulations lost watertight sealing to the metal backshells in 21 of 23 units so configured.
- Deficiencies were identified with the adhesive bonding of one of the cable types with the molded boot elastomers on some test articles.

The candidate coating systems were provided by D.G. O'Brien, Inc. (DGO-1), L.L. Rowe Co. (LLR), BIW Connector Systems (BIW-1), and Conap Incorporated. The DGO-1 and BIW-1 systems are thick epoxy coatings (0.015 to 0.025 inches) which were applied to the backshells prior to boot molding. The LLR system is a polyphenylene sulfide resin coating which was also applied to the backshells prior to molding. The Conap system is a hard (96 Shore A) polyurethane molding compound, EN-4, bonded to metal backshells with an adhesive primer designated AD-1146C. Standard connectors were also tested which were configured with Products Research and Chemical Corporation's PR-420 rubber-to-metal adhesive primer and PR-1547 polyurethane molding compound.

The standard connectors all suffered failures of the adhesive bonding between the molded boots and metal backshells due to degradation of the PR-420 primer. Typically, the predominantly failed bond interface appeared to be the one between the primer and the metal substrate. It is probable that since the primer and polyurethane boot are both elastomers that they would develop a more compatible (crosslinkable) bond than the primer and the metal; especially since the metal is the generation site of reactive species detrimental to many organic bonding agents.

The DGO-1 coatings which failed all exhibited a combination of two degradation modes: 1) portions of the coating layer delaminated from the metal substrate; and, 2) the polyurethane boot debonded from portions of the intact coating. No adhesive primer was used to bond the DGO-1 coatings and boot moldings.

The LLR coating system failures were all characterized by delamination from the metal backshells. The coating and the polyurethane boot were bonded with PR-420 adhesive, and generally remained intact throughout the ALT.

The BIW-1 coatings did not delaminate from the metal substrate. Failures which occurred were initiated by PR-420 adhesive failure with the coating, which led to the debonding of the molded boot elastomer and the ingression of water into the connector.

The single sample of the Conap elastomer/adhesive system was observed at autopsy to have suffered complete debonding from the metal backshell, and the epoxy backfill seal with the backshell failed. Failure was not indicated by electrical testing because the polyurethane, pre-potted contact assembly performed as a compression gasket and prevented water ingression to the electrical conductors.

Eleven of 27 articles configured with South Bay Cable part number 1-PR-16 were observed to have adhesive bond deficiencies with the molded polyurethane boots. The cable jacket is made from a thermoplastic polyurethane compound; many of which are difficult to adhere to thermosetting polyurethane compounds and other elastomers.

Discussions pertaining to the test results, including possible failures`mechanisms and the applied environmental stresses, are summarized in section 8.0. Recommendations for improving the reliability of the connector configurations conclude this report.

3.0 TEST ARTICLE DESCRIPTIONS

The TR-333 transducer utilizes a MIL-C-24217 connector for cable attachment to the element, and a modified MIL-C-24231 (Portsmouth) connector for submarine hull penetration (both are three-contact configurations). The TR-143 transducer uses a MSSK2-CCP right-angle connector. Portsmouth connector backshells are Monel, and M24217 and MSSK series backshells are 316 stainless steel. Four vendors provided backshells or molded, pigtailed connectors for the evaluation. Table 1 shows the various configurations which made up the test matrix and Figures 1-3 are illustrations of the connector designs.

The candidate coating systems were provided by: D. G. O' Brien, Inc. of Seabrook, NH; BIW Connector Systems, Inc. (a division of BIW Wire and Cable Co.,) of Santa Rosa, CA; L. L. Rowe Co. of Woburn, MA; and, Conap Inc. of Olean, NY.

The system provided by D.G. O'Brien is referred to as the DGO1 priming system and is a light green, epoxy polymer coating, which they applied to M24217 and M24231 backshells and delivered to NWSCC for elastomer boot molding. An accelerated life test conducted by D. G. O'Brien, Inc. of this system was detailed in their Report No. ER 372 of March 1989. The coating systems subjected to ALT were applied to the test articles by a proprietary process in a thickness of approximately 0.015 inches.

The BIW system, referred to as BIW-1, is also a light green epoxy polymer applied by a proprietary process. BIW delivered both molded connectors and coated backshells which were molded to cables by personnel at NWSCC.

The L.L. Rowe system shall be referred to as LLR in this report, since they are the licensed distributor. The coating is a polyphenylene sulfide resin which is described in Westinghouse Patent No. 4,874,324. It was measured to be approximately 0.003 inches thick. Additional details regarding the connector's component configurations will be discussed in Section 7.0, which details the autopsy (failure analysis) results following the conclusion of the ALT.

A single sample (SIN 18) was configured with Conap EN-4 polyurethane molding compound bonded to a M24231 Monel backshell with AD-1146C adhesive primer.

The coatings were generally applied to the outer surfaces of the metal backshells, but there were distinctions. For instance, the BIW-1 coatings on the MSSK plugs were only applied to the lower portion of the backshell. PR-420 primer was applied over the coating and to the bare metal on the upper portion of the backshell. The M24217 and MSSK backshells were machined to provide a recessed area for the BIW-1 coating so that the final diameters of the plugs remained unaffected. And the entire length of BIW-1 was primed with PR-420. The DGO-1 coating on the M24231 backshells was terminated at the interface of the boot molding to prevent the enlarged diameter from affecting the plug fit in the mold. No primer was used to bond the boot to the DGO-1 coating. The L.L. Rowe coating was extended beyond the boot interface and was terminated at the shoulder of the backshell under the coupling ring. PR-420 primer was used to bond the boot and coating. Figure 4 shows the types of backshells and illustrates the configuration of the coatings and primers.

The connectors were each fitted with a standard receptacle or a machined, pressure-proof cap to make the configuration watertight during wet exposures to soak, thermal cycling, and hydrostatic pressure. The cables were sealed with molded polyurethane endseals to insulate the cable conductors from water during ALT. Other details pertaining to electrical measurements and test circuit configurations will be discussed in the following section.

Two types of cables were booted to the test articles. All MSSK-2-CCP and one M24231 (SIN 10) plugs were instrumented to a neoprene jacketed, armored coaxial cable designated by identification number 77C715486. The rest of the test articles were fitted to a thermoplastic polyurethane jacketed, two-conductor cable made by South Bay Cable Division of Consolidated Products Corp. of Idyllwild, CA., designated 1-PR-16.

4.0 ACCELERATED LIFE TEST PLAN

The ALT plan was based on a mission profile developed for Navy ballistic submarines [4], which has been used to establish environmental stress frequency and limits for laboratory testing. An activation energy of 13 kilocalories per mole was used to determine the acceleration factors provided by the test exposures. This was determined [5] to be a reasonable mean based on studies of the permeation of water through a variety of elastomers. The exposures used in the test are described below:

Exposure	Duration
70°C Saltwater Soak	350 Hours
Thermal Cycling (Saltwater) (66 to 6°C)	30 Cycles
Pressure Cycling (0-500 psig)	8 Cycles
Pressure Dwell (1000 psig)	45 Hours

These exposures are referred to as equivalent to a Fleet year of service for the test articles. Correlation between Fleet service and laboratory equivalent years (EY) is discussed later in this report.

Cathodic potential of -1.02 volts (dc) was applied to the ~ connectors during the soak and thermal cycling exposures, and controlled with an Aardvark Instruments model PEC 1A modular potentiostat. The test circuit is illustrated in Figure 5. The connectors were mounted to a 18 by 24 by 0.5 inch, stainless steel plate with cap screws. Wire attachment was made to connect the plate as the working electrode in the test circuit with the potentiostat. The counter electrode was a graphite plate with dimensions of 11 by 5 by 0.0625 inches. A saturated calomel (SCE) electrode was used as the reference electrode.

The thermal cycling was accomplished concurrently with the soak exposures by the use of an automated transport system which moved the test articles twice a day between hot and cold saltwater bathes maintained at a specific gravity of 1.023. The cold water exposure cycle was adjusted to a thirty minute duration, based on thermal equilibrium studies conducted previously [3].

5.0 DIAGNOSTIC TESTING AND INSPECTIONS

At the conclusion of each EY cycle, the connectors were tested for insulation resistance (IR) with a Model 1863 General Radio megohmmeter and 500 Vdc, unless lower voltages were required to measure low resistance. The diagnostic measurements were made with the connectors immersed in fresh water, and unmated to provide access to the electrical conductors. Contact-to-contact and contact-to-ground (water) measurements were made to monitor degradation and to identify failed connectors.

Visual inspections and non-destructive bond tests were also performed after each EY of ALT to compare the performances of the various coating systems. While the first indication of aging degradation was observed in the IR data, the initiation, propagation, and characterization of boot/coating debonding was considered the more significant measure of performance. Unfortunately, no viable non-destructive test methods have been identified for determining the extent of non-catastrophic debonding for booted electrical connectors. Visual observations and non-destructive pry tests of the rubber-to-metal interface were used to identify debonding, but these methods were ineffective in characterizing degradation in units with opaque boots and debonds longer than approximately 0.25 inches. Therefore, the IR measurements were used as the primary indicator of degradation and failure of the watertight insulation systems. As will be discussed later, however, resistance measurements can be misleading and do not necessarily characterize the rate of boot debonding and extent of water ingression.

6.0 PRELIMINARY AND INTERMEDIATE ALT RESULTS

The ALT test data is contained in Appendix A, plotted for each connector in log IR (ohms) versus time in equivalent years. One megohm was selected as the failure criteria for insulation resistance. Appendix B contains representative photographic reproductions depicting significant findings for each connector system. Table 2 lists the EY cycle exposures which each test article accumulated prior to failure, or at the conclusion of the ALT. Tables 3 indicates the initiation and propagation of debonding which was observed throughout the test. Table 4 indicates an estimated rate of debonding for each coating type undistinguished by backshell design. Figure 6 illustrates a plotted representation of time-to-initiation of debonding for each coating as a percent of population affected. The following section describes the autopsies of each of the failed and unfailed test articles.