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SACRAMENTO PLANT

REPORT NO. RN-TM-0418

DEVELOPMENT OF THE FLAME-SPRAYED ALUMINUM CONCEPT FOR
CONDUCTIVE COOLING OF XE ENGINE-MOUNTED ELECTRICAL CABLES

NERVA Program

Contract SNP-1

26 JANUARY 1967

AEROJET-GENERAL CORPORATION

SACRAMENTO, CALIFORNIA

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RN-TM-0418

26 January 1967

CLASSIFICATION CATEGORY	
<i>Unclassified</i>	
<i>SK Yoder</i>	<i>2-26-67</i>
CLASSIFYING OFFICER	DATE

REON TECHNICAL MEMORANDUM

DEVELOPMENT OF THE FLAME-SPRAYED ALUMINUM CONCEPT FOR CONDUCTIVE COOLING OF XE ENGINE-MOUNTED ELECTRICAL CABLES

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CONTENTS

	<u>Page</u>
I INTRODUCTION	1
II CONCLUSIONS AND RECOMMENDATIONS	1
A. Convective Cooling	1
B. Conductive Cooling	1
III DISCUSSION	2
A. Convective Cooling	2
B. Conductive Cooling	3
1. Epoxy Bonded Material	3
2. Flame-Sprayed Material	6
C. Additional Work	23
REFERENCES	24
APPENDIX A	A-1

FIGURES

	<u>Page</u>
1 Comparison of Cable Temperatures, Bonded & Unbonded to Vessel Surface	4
2 Flame Spray Experiments to Determine Effectiveness of Fillet Application	8
3 Flame Spray Experiments to Determine Effectiveness of Fillet Application	9
4 Vacu-Blast Section Blasting Recovery System	11
5 Vacu-Blast Section Showing Blast Control Valve, Abrasive Return Hose, and Gun Body	12
6 Grit Blasting Experiment to Determine Proper Grit Blast Abrasive Particle Size	14
7 Grit Blasting Experiment to Determine the Relative Effects on Grit Particle Size and Pressure	15
8 Rear View of Thermocouples Embedded in Demonstration Specimen	17
9 Demonstration Specimen Prior to Grit Blasting and Flame Spray Coating	18
10 Demonstration Specimen After Grit Blasting and Prior to Flame Spray Coating	19
11 Application of Nickel-Aluminide Bond Coating	20
12 Application of A54 Aluminum Powder Fillet Material	21
13 View of Fillet Application Using Sphereodized Aluminum Powder	22

I. INTRODUCTION

This report was prepared to document the development of the conductive cooling concept proposed for the XE engine-mounted metal-sheathed cables, encompassing the period from April, 1964 to October, 1966. The report describes the various concepts considered and the results of tests conducted to demonstrate the practicability of each method. The flame-sprayed aluminum concept, currently specified for use on XE-1, is the culmination of this development effort.

II. CONCLUSIONS AND RECOMMENDATIONS

The investigation into various methods of convective and conductive cooling of engine-mounted sheathed cables can be summarized with the following conclusions.

A. CONVECTIVE COOLING

Analysis indicates that the method proposed to cool sheathed cables in steel conduits utilizing hydrogen gas is possible but not practical because of the excessive flows of hydrogen gas required.

B. CONDUCTIVE COOLING

Test results from the investigation into the use of metal-filled, epoxy-based material for thermally bonding sheathed cables to the pressure vessel indicated that the material was not suitable for XE engine use. However, since the tests conducted on NRX/EST were made under less than ideal conditions and the cables were not attached to the surface of the vessel prior to the application of the filler material, the test results are inconclusive. Retest of the method was not planned for the NRX-A5 test because of the promising results from the concurrent flame spray aluminum bonding tests.

Test results from the investigation of flame-sprayed aluminum as a means of thermally bonding sheathed cables to the pressure vessel indicated that the flame-sprayed material achieved a good metallurgical bond with the pressure vessel and could be applied with satisfactory results.

Additional investigation is in process for the application of this method to various materials other than aluminum, as well as perfecting the method to optimize the material buildup and provide a professional appearance.

III. DISCUSSION

Concern over the need for cooling instrumentation cables on the XE engines was expressed by the Instrumentation Department as early as April, 1964 in a series of memoranda (References 1-5) that attempted to define the XE cable cooling requirements based on the predicted heating rates and the XE engine environment. The work performed at that time barely skimmed the surface of the problem but did point out that a serious problem existed and that considerably more investigation was required.

A. CONVECTIVE COOLING

By mid 1965, with a better definition of the XE engine configuration and environment, the problem of cable cooling was again taken under consideration. A convective cooling approach was proposed which utilized two hydrogen cooled cable conduits. Thermal analyses were conducted on this approach (References 6 and 7) with the results (Reference 8) indicating that hydrogen flows of 0.4 lb/sec would be required for each of the conduits. This hydrogen flow requirement was considered to be excessive and the investigation was redirected to consider alternate cooling methods.

B. CONDUCTIVE COOLING

Since the cryogenically cooled engine presents an ideal heat sink, a conductive cooling approach was considered (Reference 9) which took into account an upgrading of the maximum temperature limits of the swaged cable (Reference 10), a reduction in cable quantities, and a reduction in the size/mass of each cable. The results of this study indicated that conductively cooled cables would be capable of surviving the anticipated XE engine environment if the cables could be adequately heat sunk to the pressure vessel over approximately one-third of the pressure vessel length through the high radiation area. Figure 1 shows the comparative cable temperature distribution for both unbonded and bonded cables along the length of the NRX pressure vessel. Since the conductive approach for cooling cables appeared practical, an investigation was initiated to determine a suitable cable bonding material.

1. Epoxy Bonded Material

Because of its successful use for heat sinking engine-mounted transducers during the NRX-A2 and NRX-A3 tests, an 80% silver-filled epoxy (Eccobond) was proposed as a suitable thermal conductive material for providing an adequate thermal path for cable cooling. In a subsequent meeting (Reference 11) to explore this heat sinking technique, materials representatives expressed concern over the use of Eccobond epoxy because of the probability of shrinkage and fractures occurring which would result in thermal path discontinuities. A substitute binder material (Polyurethane) was suggested which has a known radiation tolerance level and can be manufactured into a metal-filled paste with thermal properties comparable to Eccobond. An immediate decision was required as to whether the conductive cooling approach was practical. Work was initiated to test the proposed epoxy base material on the NRX/EST test.

Figure 1

Comparison of Cable Temperatures, Bonded and Unbonded to Vessel Surface

A thermal analysis was conducted (Reference 12) to determine the minimum acceptable thermal conductivity of the proposed metal-filled Polyurethane mixture consistent with an allowable operating temperature limit for the material of 660°R which is 100-200°R below the maximum temperature limit of Polyurethane.

Based on the calculated thermal conductivity values obtained, three different Polyurethane formulations were prepared (Reference 13) to be used for thermal conductivity tests and for testing on the NRX/EST engine. Because of time limitations the tests were conducted concurrently so that results of the thermal conductivity tests were not available in time to precede the NRX/EST test.

Sample lengths of the metal-sheathed swaged cables were prepared and attached to the surface of the NRX/EST pressure vessel (Reference 14) using three different Polyurethane mixtures. One cable sample was bonded with Thermon, a commercially available, high thermal conductivity material, used by WANL and LASL for heat sinking engine-mounted transducers. The test was noninstrumented and was used to visually determine whether the Polyurethane mixture could survive the radiation environment without shrinkage, fractures, or separation from the pressure vessel. The effort on NRX/EST was limited to only that activity which would not interfere with the NRX/EST test schedule. With the hardware involved, and the limited time available, proper curing cycles of the bonding materials could not be effected which resulted in a less than optimum test condition.

The results of the test (Reference 15) indicated that all but one of the samples separated from the pressure vessel and fell from the engine. The remaining sample was examined later and, except for several small local areas that remained bonded, was also found to be separated. The results of the test are not entirely conclusive since the mixtures could not be properly cured and bonded to the surface. Metal clamps on braid tie-downs normally

would be used to mechanically attach the cables, with the thermal material merely serving to provide good thermal paths from the cable to the vessel wall. However, the samples installed on NRX-A5 were not mechanically attached which may have induced separation from the wall.

The prepared Polyurethane mixture samples were also subjected to tests to determine the thermal conductivity of each formulation. The results of the tests indicated that the thermal conductivity values obtained were one order of magnitude smaller than required and two order of magnitude lower than anticipated.

Based on the preceding test results it was concluded that the metal-filled epoxy-based material was not suitable for use on the XE engine. Although the test conducted on NRX/EST was made under less than ideal conditions, no plans were made to retest this method on the NRX-A5 engine because of the promising results obtained during the concurrent flame-sprayed material bonding tests.

2. Flame-Sprayed Material

Concurrent with the investigation of the use of organic materials for heat sinking purposes, the use of metallic materials was also being investigated. One of the first attempts in this area was the attachment of the steel sheathed cables to the pressure vessel wall by means of aluminum soldering. This method appeared practical when used on sample pieces of aluminum but when the method was attempted on a massive piece of aluminum, heat was conducted away from the work zone so rapidly that a solder bond could not be achieved without resorting to a very high temperature heat source. In any metallic bonding method the primary concern is to keep the temperature of the pressure vessel below its annealing temperature which is approximately 810°R. If this temperature is exceeded during the bonding operation, the strength characteristics of the pressure vessel may be altered resulting in possible failure of the pressure vessel.

However, the fact that the aluminum pressure vessel does conduct heat rapidly makes possible the use of a high temperature heat source of short duration. The possibility of applying flame-sprayed aluminum as a heat sink material was investigated.

The flame-sprayed aluminum approach was demonstrated in the laboratory by performing a simple flame spray test utilizing an 8- by 36-inch segment of a previously burst pressure vessel. Fifteen lengths of 1/8-inch diameter sheath cable were attached to the surface of the test sample using the steel braid tie-downs of the type that were used previously on the NRX engine tests. A total of 14 thermocouples were attached to the surface of the test plate to monitor temperatures throughout the test. After 12 minutes of continuous flame-spraying, resulting in a buildup of material far in excess of actual requirements (Figures 2 and 3 and cross-section view, Appendix A), the maximum temperatures observed did not exceed 780°R. In actual application excessive material buildup and prolonged heating would not occur, and the large mass of the pressure vessel, with the excellent heat conductive properties of aluminum, would ensure lower temperatures and a greater margin of safety. Additional material tests were performed which indicated that no material changes were evident and that the flame spray method provided an excellent metallurgical bond to the surface of the pressure vessel (see Appendix A).

The preliminary flame-spray tests, although quite successful, did point out the need for additional investigation into the methods of cable attachment. The flame spray application is preceded by a grit blasting operation that serves to clean and roughen the surface for better adhesion of the sprayed aluminum. The grit blasting operation tends to loosen the steel braid tie-down straps so that excessive cable movement occurs during the flame spray operation, which results in the excessive buildup of aluminum required to firmly encapsulate the cable.

Figure 2

Flame Spray Experiments to Determine Effectiveness of Fillet Application

Figure 3

Flame Spray Experiments to Determine Effectiveness of Fillet Application

In an attempt to solve this problem, stainless steel foil clamps were tested with unsuccessful results. The difference in thermal expansion of the two materials caused separation of the clamps from the surface during the flame spray operation. The problem was successfully resolved by resistance welding a 10 mil aluminum foil shaped in the form of a "U" clamp over the cables to the aluminum surface.

The solution of one problem often introduces another. In this instance the repeated welding of the aluminum foil deposited aluminum oxide on the copper welding electrode tip. The oxide creates a high resistance between the electrode and work piece resulting in periodic expulsion (arcing) of the clamp material. This expulsion pits the pressure vessel surface and literally destroys the weld clamp. One way to avoid this occurrence is to continually redress the electrode tip which is time consuming and does not entirely eliminate the problem. A satisfactory solution was reached by electro-depositing a thin film of copper on the work side of the clamp. This film (0.0006 - 0.001 inch thick) completely eliminates the oxide buildup and permits continuous weld operation without expulsion.

The need for a grit recovery system became apparent during the grit blasting operations. Grit blasting in a noncontrolled area is dirty and can be hazardous because of high speed grit glancing from the surface. A commercially available suction blasting system called Vacu-Blast, manufactured by Dri-Honing Corp., Belmont, California, completely satisfied the requirements for this operation. This system is unique in that it has an abrasive reclaiming system that air washes, separates, and screens the abrasive to the required size which is important to maintain a uniform bonding condition. The system is portable with a 95 to 98% reclaiming system and is suitable for use in nearly all work areas. The system is shown in Figures 4 and 5.

NOTE: PLEASE USE TOP PART NOS WHEN ORDERING PARTS,
LOWER NO. FOR REFERENCE ONLY

Figure 4

Vacu-Blast Section Blasting Recovery System

Figure 5

Vacu-Blast Section Showing Blast Control Valve, Abrasive Return Hose, and Gun Body

The first flame spray tests were unsuccessful. Two problems occurred; the inability to obtain a satisfactory bond to the base material and the inability to control the flame spray pattern. This resulted in separation and excessive buildup of the fillet material respectively. It was subsequently determined that a true metallurgical bond could be obtained by first applying a precoat (0.005-in.) of nickel-aluminide, which is self-bonding through a synergistic, exothermic reaction. The fillet material consists of a 99% spheroidized aluminum powder which should be applied to the precoat within the three hours after the precoat operation to insure good bonding.

The problem of spray pattern was resolved by providing the spray gun with an attachment that introduces a high velocity air jet into the flame. The jets were set to converge the spray pattern at approximately 3-inches in front of the nozzle producing a narrow spray pattern that could be aimed as desired. This spray pattern proved to be the most satisfactory method of applying the material in lieu of masking, which does not appear practical at this time.

Additional tests were conducted to determine the optimum grit material and size and the blast pressure for the surface preparation operation. Figures 6 and 7 show some of the results of these tests.

Based on the successful results of the previous tests, preparations were made to conduct a demonstration test to illustrate the necessary processes to attach the sheathed cables and to demonstrate that the operation was not detrimental to the structural integrity of the pressure vessel. The demonstration was conducted with representatives of NRX Projects, XE Projects, Instrumentation, Materials, Thrust Chamber, and the Test Site (NRDS) present.

Figure 6

Grit Blasting Experiment to Determine Proper Grit Blast Abrasive Particle Size

Figure 7

Grit Blasting Experiment to Determine the Relative Effects on Grit
Particle Size and Pressure

A large section of the pressure vessel was obtained for the demonstration. Since the specimen would be subjected to a materials test after the demonstration, considerable care was taken in cutting the section to preclude material property changes in the test specimen. Thermocouples were embedded in the test specimen as shown in Figure 8 to provide data of the maximum temperatures attained.

The prepared specimen with the cables attached is shown in Figure 9, and the prepared surface after grit blasting is shown in Figure 10. Figures 11, 12, and 13 show an application of the nickel-aluminide precoat, a closeup of the hand-held aluminum flame spray gun, and a buildup of the flame-sprayed material, respectively.

The results of the test indicated a successful attachment of cables to the aluminum surface. The temperature monitors indicated that a maximum temperature of 718°R was attained which was lower than experienced in the first test since the aluminum test sample was considerably larger. A test section was removed from the sample and subjected to materials examination tests. The results of these tests are reported in Appendix A. Process Specification AGC 90161 was prepared to control the metal spraying process (Reference 16).

Based on the results of these tests it was decided to incorporate this method of cable bonding on the XE-1 engine and NRX-A6. In addition, to fully evaluate this method under test conditions, a nuclear irradiation test is planned in conjunction with the NRX-A6 test. A network of cables and thermocouples will be flame sprayed to the pressure vessel surface. The effectiveness will be determined by monitoring the internal temperature of both bonded and unbonded cables.

Figure 8

Rear View of Thermocouples Embedded in Demonstration Specimen

Figure 9

Demonstration Specimen Prior to Grit Blasting and Flame Spray Coating

Figure 10

Demonstration Specimen After Grit Blasting and Prior to Flame Spray Coating

Figure 11

Application of Nickel-Aluminide Bond Coating

Figure 12

Application of A54 Aluminum Powder Fillet Material

Figure 13

View of Fillet Application Using Sphereodized Aluminum Powder

C. ADDITIONAL WORK

Based upon test results, the flame spray application appears to be sound functionally and mechanically. Areas that require further investigation, such as application on other materials and a refinement of the process to perfect the material buildup and provide a professional appearance are currently in process.

REFERENCES

1. Memorandum 8204:0076I, E. R. Sita to W. E. Durkee dtd 22 April 1964.
Subject: Cooling Requirements for XE Engine Transducers and Cables.
2. Memorandum J. D. Hankowski to E. R. Sita dtd 6 August 1964. Subject:
Gamma Heating Rates in Swage Cables to be Used in the XE Engine Tests.
3. Memorandum W. R. Westmore to E. R. Sita dtd 15 September 1964.
Subject: Thermal Analysis of Pressure Transducer Model 170-9 and
Swage Cables to be Used in the XE Engine Tests.
4. Memorandum W. R. Westmore to E. R. Sita dtd 22 September 1964.
Subject: Addendum to Thermal Analysis of Pressure Transducer Model
170-9 and Swage Cables to be Used in the XE Engine Tests.
5. Memorandum 7461:M0204, D. E. Swartz to J. L. Smith dtd 21 October 1964.
Subject: Instrumentation and Wiring Cooling Requirements, XE Engine.
6. GWA 134287, W. P. Gilles to K. Sato dtd 9 August 1965. Subject: XE
Instrumentation Cable Thermal Analysis.
7. GWA 151069, W. P. Gilles to K. Sato dtd 28 September 1965. Subject:
XE-1 Kit Engineering Design (XE Instrumentation Cable Thermal Analysis).
8. Memorandum 7411:M0401, D. T. Buchanan to W. P. Gilles dtd 27 October
1965. Subject: Preliminary Thermal Analysis of Swaged Instrumentation
Cables and Pressure Transducer Tubing.
9. Memorandum 7761:M4185, G. L. Fluke to D. E. Swartz dtd 19 November 1965.
Subject: Swaged Cable Temperatures in XE-1 Environments.
10. Technical Memorandum RN-TM-0329 dtd 7 Apr. 1966. Subject: Evaluation
and Testing of Engine-Mounted Metal-Sheathed Cable Assemblies.
11. Meeting on 9 December 1965. Called by W. A. Sutter to Discuss Heat
Sinking of Cable on Pressure Vessel.
12. GWA 151076, W. P. Gilles to K. Sato dtd 31 January 1966. Subject:
XE-1 Kit Engineering Design (XE Instrumentation Thermal Analysis.)
13. GWA 151086, W. P. Gilles to C. W. Funk dtd 13 December 1965. Subject:
NRX-A5 Kit Engineering Design.
14. Memorandum 7761:M4202, W. P. Gilles to R. K. Swain dtd 28 December 1965.
Subject: NRX/EST Material Samples Test.

REFERENCES (cont.)

15. Memorandum D. T. Buchanan to K. Sato dtd 12 May 1966. Subject: Trip Report - Investigation of Thermon T-63 Bonding Material for XE Instrumentation.
16. AGC Process Specification 90161, Metal Spraying Process, Instrumentation Cable Installation.

APPENDIX A

*EFFECTS OF FLAME SPRAYED ALUMINUM ON THE NERVA PRESSURE VESSEL WALL

I. PROBLEM

A heat conductive adhesive is desired for cable bonding in order to keep the cable wire thermally cool. Excessive heating of the cable wire degrades insulation and continuity of the cable circuits. By bonding the cable to the pressure vessel outside surface with a heat conducting adhesive, such as flame sprayed aluminum, the cable can be cooled since the inner wall of the pressure vessel is exposed to temperatures approaching that of liquid hydrogen. A solution to the problem using flame sprayed aluminum as an adhesive was proposed by the REON Instrumentation Department.

II. APPROACH

The process selected was developed by the REON Instrumentation Department assisted by Metco, Inc., of Los Angeles. The instrument cables are attached to the pressure vessel surface by spot welding, and the surface is cleaned by vacuum grit blasting using 40 to 60 mesh aluminum oxide. A vacuum process is necessary, since the job must be done at the NTO site and all grit used must be contained to prevent contamination of the area. Vacuum grit blasting is followed by an aluminum nickel interface to facilitate bonding. This interface is applied by an oxyacetylene wire-fed flame spray torch. This interface is followed by a fillet of aluminum applied with an oxy-hydrogen powder-fed flame spray torch. Thermocouples were attached at critical points to measure the temperature rise caused by the flame spray operations. Photographs of the process are shown in Attachment (a).

*Originally issued as Memorandum 66-184 by REON Materials Department 7720.

III. RESULTS

With constant torch movement the thermocouple measured temperature rise experienced was less than 180°F, 260°F total. Nominal torch distances for the interface and aluminum fillet applications are 6 and 3 inches respectively.

A sectioned specimen pictured in Attachment (a) was chilled by exposing only the inner face of the pressure vessel wall to liquid nitrogen. This test showed no separations.

A Rockwell B hardness survey and a Rockwell B microhardness survey taken over a critical cross section of the substrate showed no significant variation. The hardness ranges were 59 to 62 and 63 to 73. Data are shown in Table I and Table II.

Tensile strength gradient was investigated by machining 1/8" x 3/8" throat tensile specimens from the pressure vessel section; 2 specimens were taken adjacent to the cable attachment point and 2 specimens were taken 1/2" away from the cable attachment. These specimens were cut transverse to the direction of the cables. Tensile tests of these specimens showed no significant variation across the pressure vessel wall. These data are listed in Table III.

Photomicrographs of the one thick cross section showed no abnormal variation in grain size or structure. These photographs are shown in Attachment (b).

IV. RECOMMENDATIONS

Since the results of the above tests are favorable and indicate that no strength loss of the pressure vessel will occur because of flame spraying, the REON Materials Department recommends that the aluminum flame spray method for attachment of instrument cables to the pressure vessel exterior wall be considered for use and further tested by full scale evaluation involving gamma heating.

V. ATTACHMENTS

- a. Photographs of Flame Spraying Operation and LN_2 Chilling.
- b. Photomicrographs of Pressure Vessel Cross Section under Point of Cable Attachment.
- c. Table I - Rockwell B Hardness Traverse Taken on Cross Section of Pressure Vessel Wall.
- d. Table II - Rockwell B Microhardness Traverse Taken on Cross Section of Pressure Vessel Wall.
- e. Table III - Tensile Data from Specimens Machined from Pressure Vessel Wall.

Photographs of Flame-Spray Operation and
Simulation of Liquid Nitrogen Chilling

Flame Spray Operation Using Aluminum Nickel Wire
and Oxy-Acetylene Torch

Simulation * of Liquid Nitrogen Chilling of Pressure
Vessel Section with Instrument Cables Attached by Flame-Sprayed Aluminum

* For photographing, water was substituted.

Photomicrographs of Pressure Vessel Cross
Section under Cable Attachment Point

100X-Keller's Etch
Showing area directly under
point of attachment. Alumi-
num nickel interface is at
the top of photograph.

100X - Keller's Etch
Showing area 1/2 inch away
from interface.

These two photomicrographs show no significant difference in grain size and micro-structure; therefore, no change in tensile strength due to flame spraying should be expected.

TABLE I

Rockwell B Hardness Traverse Taken
on Cross Section of Pressure Vessel Wall

<u>Inches from Cable</u> <u>Attachment Point</u>	<u>Rockwell B</u>
.079	59
.136	60
.216	62
.315	62
.433	61
.532	61
.650	62

Total width of cross section: .70 inches

TABLE II

Rockwell B Microhardness Traverse Taken
On Cross Section of Pressure Vessel Wall

<u>Inches from Cable</u> <u>Attachment Point</u>	<u>Converted</u> <u>Rockwell B</u>
.003	64.5
.006	67.0
.009	66.0
.012	68.5
.015	69.0
.020	67.0
.040	67.0
.060	73.5
.080	73.0
.100	65.5
.200	65.5
.300	66.0
.400	70.0
.500	63.0

TABLE III

Tensile Data from Specimens Machined
from Pressure Vessel Wall

<u>Specimen</u>	<u>Tensile, Ksi</u>	<u>Yield, Ksi</u>	<u>% Elongation</u>
T-1 (Top)	44.2	34.8	9.3
T-2 (Top)	42.9	39.3	7.8
B-1 (Bottom)	42.5	38.7	7.1
B-2 (Bottom)	42.6	39.7	7.1

Sketch Showing Orientation of Specimens in
Relation to Attached Cables