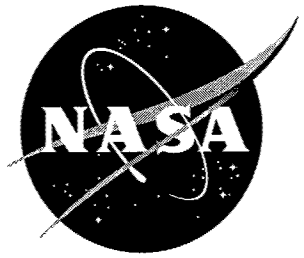

NASA Contractor Report 4774

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Contract NAS8–39983
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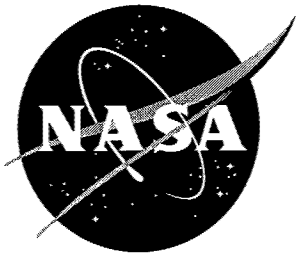

Test Report—Fault Current Through Graphite Filament Reinforced Plastic

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Prepared for Marshall Space Flight Center
under Contract NAS8–39983

April 1997

FOREWORD

This report describes fault current tests performed on graphite epoxy samples as a part of an investigation of electomagnetic effects on composite materials. This work was funded by NASA's Space Environments and Effects Program through the Electromagnetics and Aerospace Environments Branch of the Marshall Space Flight Center.

Mr. Steven D. Pearson is the Space Environments and Effects Program Manager and Technical Monitor assisted by Mr. Matthew B. McCollum for this contract, NAS8-39983.

Test samples were developed and provided by Mr.Thomas K. De Lay, of the Materials and Processes Laboratory.

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1. INTRODUCTION

The purpose of these tests was to determine the damage to samples of composite material when a current carrying wire is shorted to the surface of the composite material and to determine whether enough current can flow through the material to blow a fuse before damage can occur. Fault current tests were performed on special square samples of graphite epoxy materials. Some tests were made on single samples; others were made on joints between two samples. Each sample underwent resistivity testing before, and in some cases, after the fault current test.

2. SUMMARY OF RESULTS

Individual samples of graphite epoxy material had measured resistances of 0.1 to 0.2 ohms edge to edge. They could be expected to carry current up to 25 to 50 amps when a 5 volt line is shorted through the epoxy surface to the graphite filaments. However, tests show that when current exceeds approximately 5 amps, the graphite glows and the epoxy melts out at the shorted contact point. At higher current the epoxy burns with a spewing flame, and, in some cases, continues to burn several seconds after the current is stopped. At low voltages the epoxy outer coat acts as an insulator, and the shorting wire must be scraped across the surface to contact the graphite before significant current begins. At higher voltages, above 15 volts, the epoxy outer coat is easily broken without scraping resulting in a fire, and a rise in current occurs suddenly. When the current path includes joints between graphite epoxy panels, the higher resistance reduces the fault current to a lower maximum value. This current can easily be less than a power line circuit breaker limit. If the current is greater than approximately 5 amps, but less than the circuit breaker limit, fire will probably develop in the epoxy.

3. DESCRIPTION OF TEST SAMPLES

Samples consisted of six layers of Hercules IM7 graphite fiber mat in Hercules 8552 epoxy resin. Figure 1 shows the configuration and dimensions of the samples. The edges of the samples were sawed, and a one inch wide strip along opposite edges of the top surface was sanded to expose the conductive filler. Small spots near opposite edges of all samples were painted with conductive silver paint to facilitate resistivity measurements. On some samples the sanded surfaces near opposite edges were painted with 3/4 inch wide strips to provide a uniform contact to the filler. Two holes in each of the four edges allowed bolting edges of samples together so tests on joints could be made. Squares of Amoco T300 fiber in Thiokol TCR resin, Hercules AS4 fiber in Hercules 3501 resin, and a small sample of External Tank nose cone material, Cytec Rigidite graphite-phenolic prepreg, were also tested as single samples to determine their current carrying capability. The test configurations using Hercules IM7 samples are described below:

Single Samples -- A single sheet of material was used with only a silver painted spot or a silver painted strip to provide a good contact for a current outlet clamp.

Lap Joints -- Two single samples were joined with the one inch sanded surfaces mated. In some cases these surfaces were painted with conductive silver paint to provide a uniform, more conductive, contact. The samples were held together with electrically isolated bolts during tests.

Butt Joints -- Two samples with edges butted together were joined by an aluminum doubler plate bolted to the sanded strip on each sample. Some samples had conductive paint on the sanded surfaces. The aluminum doubler plate was replaced with aluminum foil mated to painted surfaces in one test. Bolts were electrically isolated.

4. DESCRIPTION OF TESTS

4.1 Resistivity Tests

Conductive silver paint was used to paint small spots on top and bottom sanded surfaces near the center of opposite edges. These spots allowed good contact by the resistance probe. Each square of material was measured to determine resistance. Resistance of each joint was also measured as it was assembled for test.

4.2 Fault Current Tests

A test fixture was developed to hold a section of enameled copper wire vertically at the end of a hinged arm. The high voltage side of the power supply was attached to this wire. The weight of the arm, which was approximately 2.2 ounces, held the end of the wire in contact with the sample. A variable power supply was used to provide up to 35 amps of current. Voltage levels to the wire were set at 5, 7.5, 10, 15, and 28 volts. The return was attached to the conductive painted strip or the small spot on the sample with a large alligator clip. The current was measured for each voltage when the high side was shorted to the top of the material. A different spot on the sample was used for each test. The shorting wire was scraped across the surface where necessary to break through the nonconductive layer of epoxy and make contact with the conductive graphite fibers. The effects during the test and the condition of the surface afterward were noted.

To test joints, the return was connected to the outside conductive paint strip or spot on one square, and the high side was shorted to the top of the other square.

5. RESULTS

Conductive silver paint was used to assure consistent conductivity through contacts to the GFRP. All samples had small spots painted near opposite edges to allow resistivity measurements to be made. Some samples had 3/4 inch wide strips painted along opposite edges. When the term "painted samples" is used it is referring to the latter configuration.

Individual test reports mention scraping through the nonconductive epoxy outer coat to make contact to the conductive graphite. Scraping consisted of moving the shorting wire laterally approximately one half inch and repeating along the same track until the epoxy was penetrated. This was indicated by a sudden rise in current.

Hot spots refer to points with some contact resistance and the greatest current density such as at the shorting contact, contacts at joints between samples, and at the outlet clamp. When smoke, glow, and fire occurred, it was always at these points.

Test data sheets may be found in Appendix A. The following paragraphs summarize test results. Tests # 1 through # 10 were performed on samples consisting of six layers of IM7 graphite fiber mat in Hercules 8552 epoxy resin.

Test # 1 -- Single sheet unpainted, sample # 6U -- Resistance from edge to edge was 157.1 milliohms. The test confirmed the nonconductive epoxy on the surface of the sample was hard to break through. When it did break through, the power wire contacted conductive carbon with low resistance to the return. The resulting current was over 20 amps and high enough to start glow and fire at the contact point even with a low supply voltage.

Test # 2 -- Single sheet painted, sample # 1P -- Resistance from painted strip to strip was 102.63 milliohms. Results were similar to test # 1 except at 5 volts the shorted current was low enough, 10 amps, to just allow glow with no fire. Any higher voltage produced fire in a short time.

Test # 3a -- Unpainted samples # 7U and # 9U, using a butt joint with an aluminum plate bridge across the joint -- The surfaces in contact were unsanded except for about one inch at each end. This resulted in a high pretest contact resistance of 6.6 ohms from sample to sample. The current flowed through a short to the surface of 7U and out through the edge of 9U. The high resistance made it more difficult to make contact through the nonconductive epoxy until voltage levels exceeded 15 volts. At 15 volts the current level did not exceed 5 amps. This is significant since no fire occurred. Five amps seems to be the limit of current through these GFRP samples without causing fire at the hot spots.

At 28 volts, high current caused fire to develop quickly. A blowing flame spewed from the contact point. The blowing was caused by outgassing from within the GFRP and added to the intensity of the flames. A tar-like substance melted out of the sample at hot spots. The tar-like substance seemed to bridge the joint at hot spots and decreased resistance as noted by measurement after the fault current test.

Test # 3b -- Unpainted samples # 7U and # 9U, using a butt joint with an aluminum plate bridge across the joint -- The surfaces in contact were sanded to expose graphite but were unpainted. The resistance from sample to sample was 856 milliohms. This relatively high resistance made it difficult to break through the nonconductive epoxy until 10 volts was exceeded. Current flowed through a short to the surface of # 7U and out through the edge of # 9U. Current of 5 amps at 10 volts and 15 amps at 15 volts caused glow, smoke, and some fire. At 28 volts fire occurred quickly at a hot spot at the outlet clamp as well as at the shorting contact point.

Test # 4 -- Painted samples # 2P and # 5P, using a butt joint with an aluminum plate bridge across the joint -- Painted edges were mated to the aluminum plate resulting in a low resistance joint. Sample to sample resistance was 127 milliohms. The shorting wire with 5 volts was shorted to a painted strip on sample # 2P. The outlet was connected to a painted strip on sample # 5P. This resulted in a current of 9 amps that caused glow and smoke but no fire or arc.

Other voltages were shorted to the GFRP surface and did not make contact to the graphite even with scraping until 15 volts was reached. At and above this voltage, smoke and fire quickly developed at the contact point and at the outlet clamp. There was no damage or evidence of arc at the painted GFRP to aluminum joints.

Test # 5 -- Painted samples # 3P and # 10P, using a butt joint with an aluminum foil bridge across the joint -- The aluminum foil was secured with silver paint between the foil and the painted strips on the samples. This gave a low resistance joint of 140.79 milliohms sample to sample. The current flowed through a short to the surface of # 3P and out through the edge of # 10P. With this low resistance the current was high, and fire with blowing flame developed quickly. The foil across the joint was not damaged which indicates it could be used to produce a well-bonded joint between GFRP surfaces.

Test # 6 -- Unpainted samples # 8U and # 9U, using a lap joint -- This test joined two samples through mating surfaces where only the graphite was conductive. This resulted in a high resistance of 932.2 milliohms between samples. This test was useful since low currents occurred when low voltages were shorted to the surface of # 8U. The low currents, up to 5 amps, did not cause fire or smoke. A current of 7.5 amps resulted in glow and smoke. Higher voltages and currents caused sudden fire and smoke from the shorting contact, the outlet clamp, and from the joint itself. Fire

persisted several seconds after the short was lifted. The joint showed evidence of a hot spot where a tar-like substance melted out of the GFRP.

Test # 7a -- Unpainted sample # 4U and painted # 5P, using a lap joint -- The painted strip on sample # 5P was mated to an unpainted, sanded strip on sample # 4U to produce another example of a poor joint. Resistance of the joint was 1.708 ohms. Current flowed through a short to the surface of # 4U and out through the edge of # 5P. At low voltages the current was low and no fire or smoke occurred until 5 amps was exceeded. At higher current levels fire was sudden and occurred at the joint as well as at the shorting contacts and outlet clamp. The unpainted half of the joint sustained damage, but the painted half only had black soot marks.

Test # 7b -- Painted samples # 4P and # 5P, using a lap joint -- This test was similar to 7a except the painted strips are used as the mating surfaces. This test at 5 volts produced 12.7 amps when the short was to a silver painted strip on sample # 4P. This current did not do damage until after 30 seconds when smoke occurred. Over 10 volts, which produced 24 amps, fire occurred suddenly at the shorting point and the outlet clamp, but there was no damage to the painted strips at the joint.

Test # 8 -- Unpainted samples # 6U, # 8U, and # 9U -- Three samples were connected with lap joints. The samples were sanded at their mating surfaces, but no conductive paint was used. The end to end resistance was 1.122 ohms. Current flowed through a short to the surface of # 6U, through 8U, and out the edge of 9U. With voltages less than 15 volts, the current was generally below 5 amps. This low current did not produce arcing or glow, and no smoke was seen until after one minute of contact. During this time the current increased somewhat and the connecting screws got hot even though they were isolated so no current flowed through them. When voltage was increased to 28 volts, the current rose to 30 amps with a quick arc and blowing flames. Insulation at the bolts melted, but the bolts never made contact with the GFRP. The bolts became much hotter than any part of the GFRP except at the shorting point where fire occurred.

Test # 9 -- Unpainted samples # 8U and # 9U, using a lap joint -- This test was similar to test # 6 except a 15 amp circuit breaker was placed in the high voltage side of the power line. The resistance through the samples was 544 milliohms. No fire or smoke occurred until the voltage reached 15 volts. Then the current jumped to 24 amps and lasted approximately 15 seconds before blowing the circuit breaker. Smoke and fire occurred at the shorting point and smoke at the outlet clamp during the 15 second period. At 28 volts the current jumped to 25 amps and again lasted 15 seconds before blowing the breaker. During the 15 seconds, fire with blowing flames occurred at the shorting point and outlet clamp. Smoke came from the joint. This test showed that considerable damage can occur to the graphite epoxy when a short occurs from a power line protected by a slow blow breaker or fuse.

Test # 10 -- Unpainted samples # 8U and # 9U, using a lap joint -- This test was similar to test # 9 except the 15 amp slow blow circuit breaker was replaced by an 8 amp regular breaker. The

resistance through the samples was 1.906 ohms. At 7.5 volts a small current was noted and the short was left to heat. The current grew to 8 amps and stayed between 7 and 8 amps for approximately one minute. The breaker did not blow, and a hot melted spot developed at the point of the short, but there was no fire, very little smoke, and only a small glow. At 10 volts the current grew to 10 amps and blew the breaker at approximately 5 seconds after slight glow and smoke. At higher voltages the breaker blew quickly with no fire and little smoke.

Corrosion Test -- Samples of GFRP, aluminum, silver painted GFRP, silver painted aluminum, and copper were placed in contact in a saltwater solution for two weeks to verify the position of GFRP in the galvanic series table. Aluminum was severely corroded at the GFRP to aluminum joint and slightly corroded at the silver painted GFRP to aluminum joint. The silver paint tended to flake off the GFRP after two weeks under water.

Special tests were performed on additional materials to determine differences in the effects from fault current. These tests are summarized below:

Special test # 1 -- Small sample of External Tank composite nose cone material made of graphite phenolic -- Fault current through this material produced a red glow but never burst into flame even when the maximum of 33 amps flowed through it.

A sample plate of lithium aluminum lightweight tank material was subjected to the same test. The shorting wire was immediately welded to the plate with no flame or sparks. The maximum current carried was 39 amps.

Special test # 2 -- Graphite epoxy composite made of Amoco 300 fiber with Thiokol TCR resin -- This sample burst into flame when 10 volts or more was shorted to it. The resulting current was approximately 30 amps.

Special test # 3 -- Unitape graphite epoxy made of Hercules AS4 fiber and Hercules 3501 resin -- The unitape has fibers running parallel rather than being woven into a mat as were all other composite samples. There were six double layers with alternate layers oriented 90° to each other. This material also burst into flame when greater than 10 volts was shorted to it. The resulting current was greater than 22 amps. The fire produced a thick oily smoke with no spewing of the flame as noted in earlier tests.

6. DISCUSSION

Most of the fault current tests were performed using samples consisting of six layers of Hercules IM7 woven graphite fiber mats in Hercules 8552 epoxy resin. Tests on individual samples showed that current above 5 amps would ignite the material at the shorting contact or at the exit point.

When joints were introduced, resistance was increased, and the maximum current resulting from a short circuit to the graphite epoxy was reduced. This condition could easily result in fault current lower than the circuit breaker limit and higher than the 5 amp ignition level. A poorly conducting joint could become one of the hot spots with melting epoxy, smoke, and possible fire. In all test cases the worst hot spot was at the shorted contact to the surface. During tests with higher current, the outlet clamp on silver paint would also smoke, glow, and sometimes burst into flame. The conductive joints where silver paint strips were used carried the current well even while the shorted contact and outlet clamp were burning. The silver paint to sanded GFRP makes a good contact when mated directly to other silver painted strips or through aluminum plates, or even through aluminum foil.

Special tests were performed on individual samples of Amoco T300 Fiber in Thiokol TCR resin and Hercules AS4 fiber in Hercules 3501 resin. Both samples ignited similar to the original test samples. A small sample of External Tank nose cone material, Cytec Rigidite graphite-phenolic prepreg, was tested and no fire occurred. This indicates that composite material made with high temperature phenolic resin can carry a significant amount of current without igniting.

Graphite is located near the low end of the galvanic series near copper and silver. Galvanic corrosion between GFRP and aluminum or even between silver and aluminum may present a problem for long term electrical bonds. Simple tests were performed by placing various materials in contact in salt water for two weeks. Placing GFRP and aluminum in contact in a salt solution caused severe corrosion to the aluminum and none to the GFRP. Silver painted aluminum in contact with GFRP did not corrode, but the silver paint tended to flake off after a few days under water. Silver paint on GFRP in contact with aluminum caused slight corrosion to aluminum and none to the silver paint.

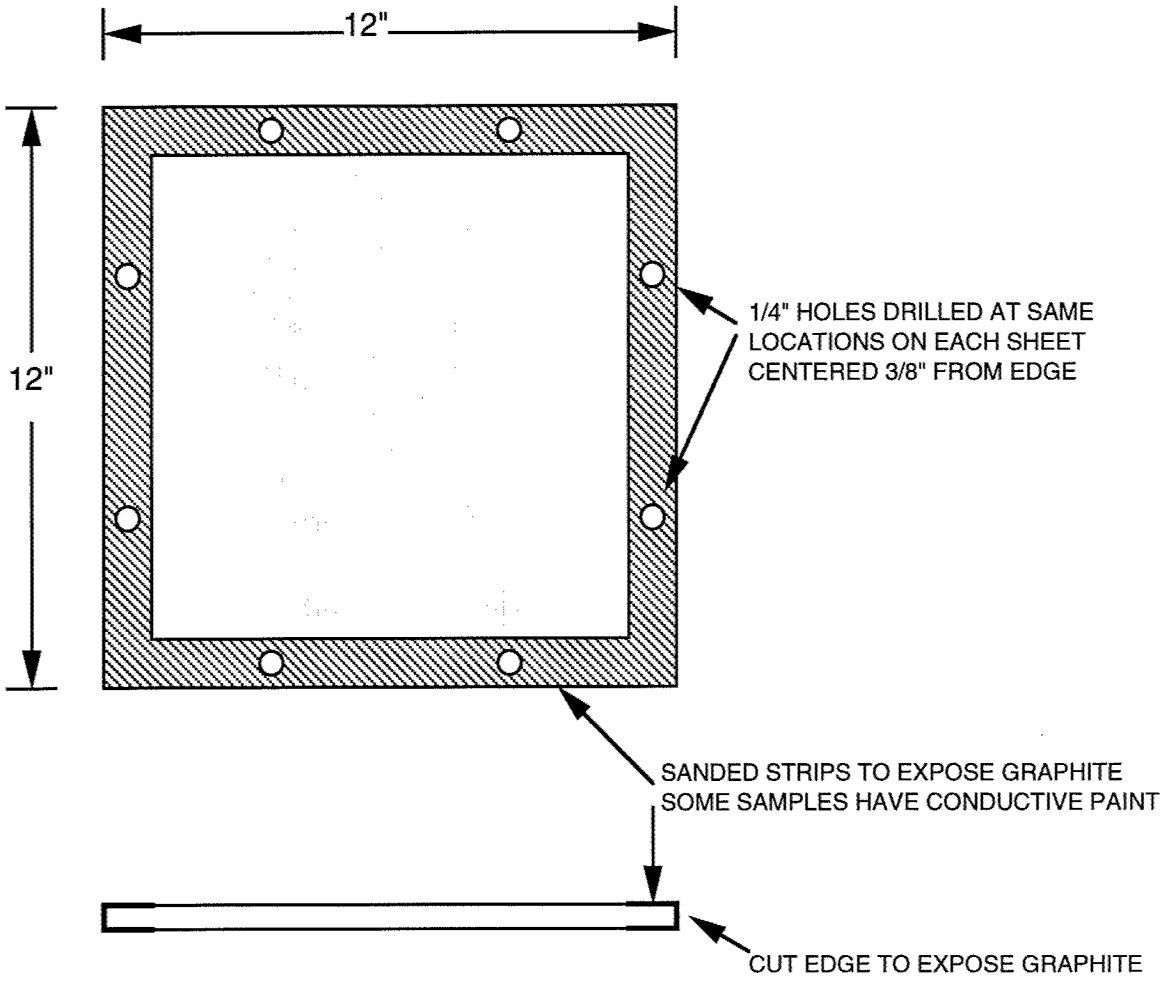

FIGURE 1-1 - TEST SAMPLE CONFIGURATION

APPENDIX A

TEST DATA SHEETS

TEST # 1

Sample # 6U					
	Single sheet, unpainted.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS WHILE SHORTED	RESULTS, CONTACT POINT & JOINT CONDITION
6U	spot to spot 157.10				
	Arc pit to edge after test				
	255.1	5	-	-	No arc after over 200 scrapes even on sanded edge.
	210.1	7.5	20	5.94	Arc after 5 scrapes on sanded edge, after 100 scrapes on unsanded edge. Starts with glow and builds to fire after 3-4 seconds.
	178.5	10	31	6.9	Glow after 2-3 scrapes, quickly turns to fire in 2 seconds. Flame blows 1-2 inches.
	185.2	15	31	7.9	Blowing flame within one second of 2-3 scrapes with new cut wire.
	175.9	28	32	9	Arc starts with any movement of wire on composite. Flame blows 2 inches. 1, 2, 3, & 5 second contacts look similar.
					Charred area of pits is .25 to .35 inches in diameter, slightly larger with longer contact time.

TEST # 2

Sample # 1P					
	Single sheet, painted				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS WHILE SHORTED	RESULTS, CONTACT POINT & JOINT CONDITION
1P	Spot to spot 102.63				
	Pit to edge after test 120	5	10	4.8	Very difficult to break through epoxy coat and oxidation on wire. Took over 100 hard scrapes even with fresh cut sharp wire. Light red glow in carbon. Takes several seconds to form puddle. No fire.
	132	7.5	22	5.8	Over 100 scrapes to break through epoxy. Bright red glow with near fire if left 2-3 seconds.
	101	10	30	6.3	Slight scrape breaks through epoxy at almost any point. Bright red glow. Fire after 1-2 seconds.
	104	15	31	6.2	Immediate fire after light scrape.
	89	28	32	8.1	Fire with explosive flame on first touch. Flame blows away from spot. Arc and burn at outlet clamp on silver strip also.
					Charred area of pits is between .25 and .35 inches in diameter no matter how much current. Will get larger with time. Black ring around pit up to 1/8 inch wide. Blackened area from blowing flame extends out to 1 inch from pit on high voltage tests.

TEST # 3a

Sample # 7U, 9U, and aluminum plate:					
	Butt joint, aluminum bridge, screws isolated.				
	Mating surfaces unsanded except 1 inch at each end.				
	Painted spots not in contact with aluminum.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS WHILE SHORTED	RESULTS, CONTACT POINT & JOINT CONDITION
Al. to 9U	1.202 ohms				
Al. to 7U	5.431 ohms				
7U to 9U	6.653 ohms				
		5	-	-	No arc with 200 scrapes even on sanded edge.
		7.5	-	-	No arc with 200 scrapes even on sanded edge.
		10	-	-	No arc with 200 scrapes even on sanded edge.
		15	5	14.64	Small red glow after 100 scrapes. Left on 20 seconds, dark circle grows. No fire or sparks.
		15	3.3	14.81	Smoke only for 20 seconds. Then slight glow for 10 more seconds.
		28	32	24.5	After 50 scrapes, sudden fire at scratch point and on outlet clamp on 9U. Smoke from one bolt. Left for 1 second.
					Repeated for 6 seconds, same result, flames blow 1-2 inches. Probably melted through bolt isolator. Al. bridge warm to touch.
	Repeat after arcs				
Al. to 9U	.544 ohms				
Al. to 7U	.768 ohms				
7U to 9u	1.322 ohms				
					After disassembly, bolt insulation had thin tar like substance on 3 out of 4. Al. plate had tar on same 3 of 4 places. Large tar spot (1/2 inch) on Al. plate from sanded strip on one end away from bolts. Tar on bottom of 7U below 28v touch points.

TEST # 3b

Sample # 7U, 9U, and aluminum plate					
	Butt joint, Al. bridge.				
	Screws isolated.				
	Sanded edges mated to Al.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
Al. to 9U	436				
Al. to 7U	397				
7U to 9U	856				
		5			No arc.
		7.5			No arc.
		10	5	6.8	Glow with smoke after several scrapes.
		15	15	14.3	Arc, glow, smoke, spewing smoke.
		28	31	19	Smoke, fire, spewing flame up to 2 inches. Burned silver off of outlet spot. No smoke at aluminum joint. 3 - 6 seconds.
		28	30	17.5	Flame spewed up to 3 inches. Board underneath scorched. Fire continued after contact lifted. Fire at outlet spot also. 12 seconds.
					Charred area of pits is 3/8 to 1/2 inches in diameter.
					No charring at aluminum joint or around bolts. Outlet spot is badly burned.

TEST # 4

Sample # 2P, 5P, and aluminum plate.					
	Butt joint, Al. bridge.				
	Screws isolated.				
	Sanded and painted edges mated to Al.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
Al. to 2P	51.8				
Al. to 5P	76.6				
2P to 5P	127				
		5	9	4.4	Glow and smoke on silver paint only. No arc with 100 scrapes on epoxy.
		7.5			No arc or glow after 100 scrapes plus 60 seconds on epoxy.
		10			No arc or glow after 100 scrapes plus 60 seconds on epoxy.
		15	25	8	Sudden arc and blowing smoke and flame after few scrapes with new cut wire. 100 scrapes in another location produced no arcs.
		15	25	8.4	Sudden arc and blowing flame with no scrapes. Left contact for 10 seconds and fire continued after lifting contact.
		28	26	9	Sudden flame blowing 3 inches Spark at outlet clamp. No smoke at aluminum plate or screws.
		28	26	9	Fire at contact point and at outlet clamp. Left 10 seconds and fire continued after disconnect.
					Char at contact points 3/8 inch in diameter. No char or evidence of arc at aluminum joint after disassembly.

TEST # 5

Sample # 3P, 10P, and aluminum foil					
	Butt joint, Al. foil bridge.				
	Screws isolated.				
	Sanded and painted edges mated to Al. foil.				
	Foil in three pieces bridging butt joint.				
	10P only has painted spot on outlet side.				
	Al. plate used for backing strength and is isolated from bolts, foil, and sample.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
Foil to 3P center end 1 end 2	80.65 102.63 91.63				
Foil to 10P center end 1 end 2	95.36 123.16 107.00				
3P to 10P	140.79				
		5	-	-	200 scrapes on epoxy, no glow or smoke.
		5	15.5	4.06	Contact to painted strip. Smoke after 1 min. Glow at 1.5 min. Outlet clamp warm. Took current well up to 1 min. (2 min. total)
		7.5	-	-	100 scrapes twice, no glow or smoke.
		10	24	8.38	1 scrape, quick arc, fire continuing for 6 seconds.
		10	24.5	8.38	Same, (14 sec.)
		15	31.5	9.2	2 scrapes, blowing flame, smoke at outlet.
		15	31.5	9.78	Blowing flame, smoke at outlet. Fire continued 6 sec. after lifting contact. Looks like tar boiling out and burning.
		28	34	8.17	Blowing flame, smoke at outlet. (6 sec.)
		28	33	9	Same. (15 sec.) Foil or plate not warm. No damage to foil.
		28	32.5	9.3	Aluminum backing plate removed, foil only. (6 sec.)
		28	31.9	9	Same. (15 sec.) No damage to foil. Outlet charred.

TEST # 6

Sample # 8U and 9U					
	Lap joint.				
	Screws isolated.				
	Sanded with unpainted edges.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
8U to 9U	932.2				
		5	0.5	4.98	200 scrapes on epoxy, left 2 min. Did not get hot or increase current.
		5	5.1	4.71	Contact to silver spot. Screws and silver spot got hot to touch. No glow or smoke. No charring of silver. (2 min.)
		7.5	1.7	7.41	200 scrapes. Occasional tiny glow for short periods . (120 sec.) Power supply pulsing on and off.
		10	1.5	9.93	200 scrapes plus 120 sec. Slight puffs of smoke.
		10	7.5	9.63	Glow, smoke, char. Rose to 9.5 amps after another minute. (3 min. total). Power supply still pulsing.
		15	30	13.5	50 scrapes, smoke, glow, high smoke output from joint. (12 sec.). Melted tar around one bolt. Bolt still isolated. Power supply O.K.
		28	31.8	13.2	Fire, blowing smoke and flame from contact and joint. (12 sec.)
		28	31.8	14	Fire, blowing smoke and flame. Fire continued after lifting contact. (6 sec.)
					Tar and scorched area around bolt on both top and bottom of 8U and 9U . Bolt still isolated, even though insulators melted to sample surface.

TEST # 7a

Sample 4U and 5P.					
	Lap joint, Screws isolated.				
	Sanded and painted edges.				
	One painted edge (5P) contacting unpainted edge (4U).				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
4U to 5P	1.708 ohms				
		5	-	-	No arc after 100 scrapes on epoxy.
		5	3.9	4.75	Contact to silver strip. No glow or arc, carries current O.K. (1 min.). Bolts got hot, but no electrical contact.
		7.5	-	-	No arc after 100 scrapes.
		7.5	1.8	7.36	Very small sparks after 150 scrapes. Made contact for more than 1 min. No glow or fire. Current grew to 2.5 amps at 2 min. Bolts and copper contact hot.
		10	10	9.32	30 scrapes produced glow, then blowing smoke and smoke around one bolt. (12 sec.)
		10	10	9.33	Glow and blowing smoke at contact and at joint near bolt. (25 sec.)
		15	30	10.6	Quick arc, glow, blowing smoke and flame at contact and at joint. (10 sec.)
		28	31	10.6	Quick arc, blowing flame, fire at contact and joint. Fire continues after lifting contact at 10 sec. and at 5 sec.
					Isolators melted to sample at joint. Damage to unpainted sample near bolts. Black area on painted sample. Bolts still had electrical isolation.

TEST # 7b

Sample # 4P and 5P.					
	Lap joint, Screws isolated.				
	Sanded and painted edges.				
	Painted edge (5P) contacting painted edge (4P).				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
4P to 5P	194				
		5	12.7	4.19	No arc or glow. Slight smoke at 30 sec. with contact on silver paint strip. No arc with 100 scrapes on epoxy or on sanded spot.
		7.5	13	6.6	No arc after 100 scrapes. After 200 scrapes thin smoke, glow at 10 sec.
		10	24	8.3	Quick arc, blowing smoke and flame. (10 sec.)
		10	25	8	Arc at first touch. Blowing smoke and flame. Fire at outlet clamp at 20 sec.
		15	30	9	Quick blowing flame. Smoke at outlet clamp.
		28	30.3	10	Quick arc, fire, blowing flames.
		28	30	10	Same, plus smoke at outlet clamp.
					No damage at all to painted strips at joint. Burns at outlet clamp, especially to side contacting epoxy, other side was to painted strip.

TEST # 8

Sample # 6U, 8U, and 9U.					
	Lap joints, Screws isolated.				
	Sanded edges.				
	Three samples, two joints.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
6U to 8U	0.648 ohms				
8U to 9U	0.560 ohms				
6U to 9U	1.122 ohms				
		5	0		No arc or glow after 100 scrapes on epoxy
		5	0.4	5	Light scrape on sanded area, No arc or glow.
		7.5	0		No arc or smoke after 100 scrapes on epoxy.
		7.5	1.6	7.43	Slight scrape on sanded area.
		7.5	5.2	7.17	Contact to silver spot. Screws hot. No smoke, slight smell. (2 min.)
		10	0		No smoke after 100 scrapes on epoxy.
		10	2.8	9.82	On sanded area, slight smoke.
			4.2	9.73	Current increasing after one min., slight smoke.
			4.8	9.69	Starts to char after two minutes. Smoke light, screws hot.
		15	8.8	14.43	Quick glow and smoke.
		28	30.3	18	Quick arc, fire, blowing flames. Insulation melting at bolts at joints.
					Insulation melted at one screw at each joint. Tar ran out of epoxy at hot spots. No fire at joint or at outlet clamp. Screws still isolated.

TEST # 9

Sample #	8U and 9U.				15 amp breaker in line
	Lap joints, Screws isolated.				
	Sanded edges.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
8U to 9U	544				
		5	0		No arc or smoke after 100 scrapes on epoxy.
		7.5	0		No arc or smoke after 100 scrapes on epoxy.
		10	0		No arc or smoke after 100 scrapes on epoxy.
		15	24	12.6	Quick glow and smoke. Drew 24 amps for approximately 15 seconds before blowing breaker.
		28	25	12.5	Quick arc, fire, blowing flames. Insulation melting at bolts at joints. Drew 25 amps for approximately 15 seconds before blowing breaker.
					Breaker was black 15 amp push button type from Skylab.
	1.73 ohms after test				

TEST # 10

Sample #	8U and 9U.				8 amp breaker in line
	Lap joints, Screws isolated.				
	Sanded edges.				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
8U to 9U	1.906 OHMS				
		5	0		No arc or smoke after 100 scrapes on epoxy.
		7.5	4 TO 8	7.24	Got small current after several scrapes. Left to heat for 3 minutes. Current rose to 8 amps without blowing breaker. Hot melted spot but no flame, small glow, little smoke.
		10	10.4	9.34	Smoke and hot spot slow to develop, but breaker blew after 5 seconds of 10 amp current.
		15	18	14.9	Smoke and glow. Breaker blew after 2 seconds.
		28	-	-	Breaker blew in milliseconds.
					Breaker was 8 amp toggle switch type. A 5 amp breaker of this type would probably protect this GFRP from fault current fire.

APPENDIX B

CORROSION TEST

APPENDIX B

CORROSION TEST

A simple test was performed to determine corrosion potential between GFRP, aluminum, copper, and silver paint. In one test a sample of aluminum was placed in contact with GFRP, silver painted GFRP in contact with the GFRP, silver painted aluminum in contact with aluminum, copper wire around all in contact with aluminum, GFRP, silver painted GFRP, and silver painted aluminum. This, along with a loose sample of GFRP one half painted with silver, was placed in a salt water solution. After two weeks the stack of samples was disassembled and inspected. Results were as follows:

1. There was no corrosion to the GFRP with one half silver painted.

2. There were some dark spots on the copper wire, but not at the contact points with any sample.

3. The silver paint was slightly brown at the contact between GFRP and silver painted GFRP, but there was no corrosion.

4. The silver paint had loosened in the water bath and tended to flake off the GFRP with hard rubbing.

5. The aluminum was severely corroded at the GFRP to aluminum contact, but there was no corrosion to the GFRP.

6. There was slight corrosion to the aluminum and none to the silver paint at the aluminum to silver painted aluminum contact.

7. Part of the aluminum samples corroded where they only contacted the salt water.

8. Aluminum corroded slightly where it contacted the copper wire. The silver paint easily flaked off the aluminum where it contacted only salt water.

APPENDIX C

SPECIAL TEST

SPECIAL TEST #1

Sample - ET Nose Cone Material					
	Cytec Rigidite Graphite-Phenolic Prepreg				
	Single sheet (1x4x3/16)				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS WHILE SHORTED	RESULTS, CONTACT POINT & JOINT CONDITION
ET NOSE	End to End				
	97 milliohms				
		15	31	2	Red glow, no fire or sparks.
		28	33	1	Red glow, no fire or sparks.
		28	33	1	Red glow, no fire or sparks.
Sample - Lithium/Al. Tank Material					
	Single Sheet				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS WHILE SHORTED	RESULTS, CONTACT POINT, & JOINT CONDITION
Lith./Al.	.02 milliohms				
		28	38	0	Welded wire to plate. No fire, glow, or sparks.
		28	39	0	Welded wire to plate. No fire, glow, or sparks.

SPECIAL TEST #2

Single Sample					
	Amoco T300 Fiber				
	Thiokol TCR Resin				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
Lightning sample 6	1.2 OHMS				
		5	0		No arc or smoke after 100 scrapes on epoxy.
		7.5	22	6.3	After 60 scrapes - small glow, smoke, dimple.
		10	30	8.3	Two scrapes - glow, fire in 2 sec., smoke at outlet clamp also.
		15	32	8	One scrape - burst into flame, 2 inch spewing flame.
		28	35	8	One scrape - burst into bright arc and flame at contact point and at outlet clamp.

SPECIAL TEST #3

Single Sample					
	Hercules AS4 Fiber				
	Hercules 3501 Resin				
	6 Double Layers of Unitape				
SAMPLE NUMBER	RESISTANCE MILLIOHMS	VOLTS APPLIED	AMPS	VOLTS DURING TEST	RESULTS, CONTACT POINT & JOINT CONDITION
Lightning sample 9b					
		5	0		No arc or smoke after 100 scrapes on epoxy.
		7.5	15	6.8	After 60 scrapes - glow, smoke, dimple.
		10	22	8.75	Ten scrapes - glow, smoke, also at outlet, tar smell.
		15	33	9	Three scrapes - glow, lingering fire at contact point, smoke at outlet clamp.
		28	35	8	Immediate smoke & non-blowing fire, thick oily smoke, lingering fire at contact point.

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13. ABSTRACT *(Maximum 200 words)*

Tests were performed to determine the damage to samples of composite material when a current carrying wire is shorted to the surface of the composite material, and to determine whether enough current can flow through the material to blow a fuse before damage can occur. Fault current tests were performed on samples of graphite epoxy materials. Samples consisted of six layers of IM7 graphite fiber mat in Hercules 8552 epoxy resin.

A variable power supply provided up to 35 amps of current. The high voltage side of the power supply was attached to a wire at the end of a hinged arm, and the low side was attached to the edge of the sample. To test joints, the return was connected to the edge of one sample, and the high side was shorted to the top of the other sample. Tests show that when current exceeds approximately 5 amps, the graphite glows, and the epoxy melts out at the shorted contact. At higher current levels the epoxy burns. At voltages above 15 volts the epoxy outer coat is easily broken, and fire, flame, and a rise in current occur suddenly.

When joints are introduced, resistance is increased, and the maximum current resulting from a short circuit to the graphite epoxy is reduced. This condition can easily result in fault current lower than the circuit breaker limit and higher than the 5 amp ignition level. The shorting contact and the joint become hot spots with melting epoxy, smoke, and fire.

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