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Evaluation Of Composite Materials For Use On Launch Complexes

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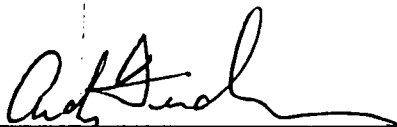
TEST REPORT

Evaluation of Composite Materials
for Use on Launch Complexes

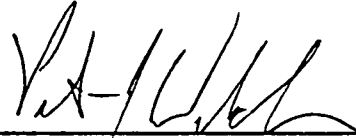
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ABSTRACT

Commercially available composite structural shapes were evaluated for use at Kennedy Space Center. These composites, fiberglass-reinforced polyester and vinylester resin materials are being used extensively in the fabrication and construction of low maintenance, corrosion resistant structures. The evaluation found that in many applications these composite materials can be successfully used at the space center. These composite materials should not be used where they will be exposed to the hot exhaust plume/cloud of the launch vehicle during lift-off, and caution should be taken in their use in areas where electrostatic discharge and hypergolic propellant compatibility are primary concerns.

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EVALUATION OF COMPOSITE MATERIALS
FOR USE ON LAUNCH COMPLEXES

1.0 INTRODUCTION

- 1.1 Recently there has been a significant amount of interest in the potential use of composite materials at Kennedy Space Center (KSC) and Cape Canaveral Air Force Station (CCAFS). Both Lockheed Space Operations (LSO) at KSC and General Dynamics Space Systems (GDSS) personnel at CCAFS have requested that the Materials Testing Branch (MTB) evaluate the potential applications of composite materials on the launch complexes.
- 1.2 The composite materials which were evaluated were the commercially available composites used for industrial structures. These are fiberglass reinforced resin materials.
 - 1.2.1 The Type P is a polyester resin based material.
 - 1.2.2 The Type UFR is a polyester resin based material with aluminum hydroxide added as a fire retardant.
 - 1.2.3 The Type V is a vinylester, epoxy methacrolate, based material.
 - 1.2.4 The Types P, UFR, and V, combine styrene, and other monomers and polymers as cross-linking agents to obtain desired physical properties.
 - 1.2.5 In addition to the composite materials, Type E which is a polyvinylchloride (PVC) material was also included in this evaluation.
- 1.3 The composite structural materials are produced by the pultrusion process. Unlike the extrusion process where the material is pushed through a die to form a structural shape, in the pultrusion process the glass fiber bundles or roving are pulled through a series of dyes. In this process the resin and protective veil are added, then the resin is heat cured before the solid structural member is drawn from the last dye.

- 1.4 Manufacturer's fabrication and repair guides recommend that the cutting, sawing, drilling, and other machinery operation on glass-filled composites be performed with carbide or diamond tipped tools. The fiberglass particles and dust can cause skin irritation, and should not be ingested. Protective clothing, gloves, goggles, and a dust mask should be worn by anyone doing extensive machining on composites. Assembly of composite structures can be performed with metal or composite fasteners or bonded with epoxy adhesives.
- 1.5 The manufacturers of these composite materials provide a great deal of chemical compatibility data. Therefore for this evaluation five basic criteria were selected, which were considered critical for use of composites in the ground support equipment and facilities at KSC. The five categories were electrostatics, flammability, hypergolic compatibility, ultraviolet light exposure, and launch environment exposure.

2.0 ELECTROSTATICS

Increasing attention is being given to the problem of static electricity because of its ability to initiate ordnance devices, ignite explosive atmospheres, and surprise workers performing critical tasks, causing undesirable consequences and injuries to occur. The triboelectric test device used to evaluate the electrostatic properties of the materials in this report was developed at KSC. It evaluates two distinct electrostatic properties of a material. One is the material's capability to develop a charge. This property is shown by the peak triboelectric voltage generated. The second property is the ability to discharge this surface electrical charge to a grounded frame.

- 2.1 The electrostatic tests were performed in accordance with the "Standard Test Method for Evaluating Triboelectric Charge Generation and Decay", MMA-1985-79.
- 2.2 The composite test specimens were approximately 7-inches square by 1/4 to 1/2-inch thick. The samples were conditioned for 24 hours and then tested at three different humidity conditions. The three sets of conditioning and test conditions were: 78° F/30%RH, 79° F/45%RH, and 86° F/80%RH. The test consisted of rubbing each test sample for 10 seconds with a foam backed felt Teflon rubbing wheel to triboelectrically generate the charge. The charged material was then placed in front of

the detector head which measured the surface voltage generated. This voltage was received by a digital storage oscilloscope which produced a display of voltage versus time as well as a digital readout.

- 2.3 The composite materials were considered acceptable for use at KSC if the electrostatic voltage generated by the triboelectric device decayed below 350 volts in 5 seconds.
- 2.4 The Electrostatic test results are presented in Table 1.

Table 1
Electrostatic Test Results
Volts

Test Conditions		78° F/30%RH	79° F/45%RH	86° F/80%RH
<u>Materials</u>	<u>Voltage</u>			
TYPE E	Peak	20680	23640	6530
	5 Sec Decay	18440	18930	4890
TYPE P	Peak	8160	13090	2760
	5 Sec Decay	5300	9550	960
TYPE V	Peak	1280	1380	200
	5 Sec Decay	770	740	<100

- 2.5 Only the Type V material passed the electrostatic acceptance criteria at 86° F/80%RH. None of these materials are considered acceptable in areas where electrostatic discharge is a concern.

3.0 FLAMMABILITY

A fire near the orbiters, payloads, ordnance materials, hypergols, or practically anywhere at KSC could potentially destroy millions of dollars worth of equipment and endanger hundreds of lives. To reduce the risk of fire, materials in controlled areas must decrease the probability of ignition to a minimum and restrict potential fires to well-defined isolated

areas. In evaluating the flammability of the composite materials the MTB conducted flammability test and performed, thermal gravimetric analysis of the materials.

3.1 Flammability tests were performed following the test specification - "Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion", NHB 8060.1b, Test No. 1, Upward Propagation Test.

3.1.1 Test Method - Using available material, 1-1/2 inch wide by 12 inch rectangular strips, 1/8 to 1/4 inch thick, were hung vertically in a fume hood. The sample's 1-1/2 inch wide bottom edge was located at least 3 inches from the base of the hood. The ignition source was an electrically ignited "Clearweld" igniter which produces a flame temperature of $2000^{\circ}\text{F} \pm 200^{\circ}\text{F}$ for a duration of 25 ± 5 seconds. The igniter was located 1/4 inch below the test specimen.

3.1.2 Acceptance Criteria - Materials shall be considered noncombustible, or self-extinguishing if, less than 6 inches of the sample is consumed, and the time of burning does not exceed 10 minutes. There shall be no sparking, sputtering, or dripping of flaming particles from the test sample. A failure of any one of three samples constitutes failure of the material.

3.1.3 Results - All of the materials tested (Type E, P, UFR and V) met the acceptance criteria for nonflammable materials. In all cases the flame extinguished upon removal of the ignition source, and the bottom of the specimens were slightly charred.

3.2 Thermal gravimetric analysis (TGA) was performed to assess the thermal degradation of the composites.

3.2.1 The TGA's were performed in nitrogen atmosphere, at 20°C per minute on 5 to 25 milligram samples.

3.2.2 Results - In the case of all four materials (Type E, P, UFR, and V) a weight loss of approximately 2 percent occurred by the time the materials reached 280°C (536°F). The Type P and UFR materials had lost in excess

of 10% by the time they reached 380°C (716°F), the Type V at 400°C (752°F) and the Type E at 330°C (626°F). The manufacturer's data indicates that the materials begin to breakdown and emit gas at 500°F.

- 3.3 Although non-flammable, these composite materials will be consumed in a fire, leaving only the glass fibers as a residue.

4.0 HYPERGOLIC COMPATIBILITY

Since hypergolic propellants are used in most launch vehicles and are often stored and transferred to the vehicle launch pad, it is essential that the composite materials be compatible with the hypergolic propellants.

- 4.1 The test samples were tested for compatibility with the following hypergolic fluids: Monomethyl hydrazine, nitrogen tetroxide, and hydrazine. Two separate tests were run on each sample of material.
- 4.1.1 The composite samples with a minimum of 2 sq. inches of surface area were placed on a watch glass and 0.5 ml of the appropriate hypergolic fluid was placed in the middle of each test specimen. The specimens were observed for 10 minutes in the configuration and monitored for temperature rise.
- 4.1.2 In the second test the samples were individually positioned over a glass beaker, and 1.0 ml of the appropriate hypergolic test fluid was placed in the middle of each test specimen. The specimens were observed for 2 hours in this configuration and monitored for reactivity.
- 4.1.3 The following four types of materials were tested: Type E, P, UFR, and V.
- 4.2 Acceptance Criteria: For the first test, the materials shall not ignite nor have a temperature rise greater than 5°F with either hydrazine or monomethyl hydrazine. For the second test, no gross reactivity of the sample is allowed.
- 4.3 The only material to fail any of the hypergolic compatibility tests was the Type V material which exhibited gross incompatibility with nitrogen tetroxide during the 2-hour exposure test.

5.0 ULTRAVIOLET LIGHT EXPOSURE

Samples of Type E, P, and V materials were subjected to ultraviolet (UV) light exposure and then examined and tested to evaluate the effects of the UV exposure. The composites were tested in conjunction with a roofing material exposure test.

5.1 The UV exposure was performed in accordance with the Test Method for Ultraviolet Aging, "Performance Testing of Roofing Membrane Materials" utilizing an Atlas Series C Weather-ometer.

5.1.1 The test specimens were subjected to up to 3800 hours of UV exposure from a xenon arc lamp. The black panel temperature was maintained at 80°C (176°F), which typically results in an ambient temperature of 60°C (140°F). The specimens were sprayed with water for 18 minutes every 2 hours.

5.1.2 One set of specimens was removed from the Weatherometer after 1500 hours of exposure and the remaining specimens were removed after 3800 hours.

5.2 The specimens exposed for 3800 hours were examined.

5.2.1 The Type E, PVC, material was originally dark gray in color. After 3800 hours all of the specimens were deformed, black on the UV exposure face, and the overall color changed from gray to olive.

5.2.2 The composite materials (Types P, UFR, and V) all reacted similarly. On the UV exposed face the surface was lighter in color, powdery, and a few of the veil fibers were exposed. The unexposed face was unchanged in appearance from the original reference specimens.

5.3 Three Point flexure tests were performed on the unexposed reference specimens, and the specimens exposed to UV in the Weather-ometer for 1500 and 3800 hours.

5.3.1 The tests were performed in accordance with the Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastic and Electrical Insulating Materials, ASTM D790-86.

5.3.2 The results are presented in Table 2 .

TABLE 2
FLEXURE TEST RESULTS

Maximum outer fiber stress (PSI)
Mean Value

Material Designation	Conditions		
	UNEXPOSED REFERENCE	1500 HOURS UV EXPOSURE	3800 HOURS UV EXPOSURE
E-2000 Series	11,190	13,410	12,760
P-2000 Series	64,880	65,060	65,540
V-2000 Series	76,540	75,240	71,720

5.3.5 There was no significant difference in the strength of the composite materials due to UV exposure.

6.0 THERMAL MECHANICAL ANALYSIS

Thermal mechanical analysis (TMA) was performed on three of the Types E, P, and V. A Dupont Model 1090 Thermal Analyzer system with a TMA module was used to perform the analysis.

- 6.1 The Type E material, PVC, showed signs of softening in the temperature range of 71.1°C to 83.5°C (160°F to 182°F). The softening or loss strength was indicated by the TMA probe penetrating or displacing the PVC.
- 6.2 The Type P material, glass filled polyester resin, showed signs of resin softening in the temperature range of 59°C to 94.1°C (139°F to 201°F). Design information indicates that the polyester resins undergo thermal distortion at 76.6°C (170°F).
- 6.3 The Type V material, glass filled vinylester resin, showed a physical/mechanical change in the range of 102.3°C to 111.2°C (216°F to 232°F). This corresponds with design guide information which indicates that the vinylester resins undergo thermal distortion at 99°C (210°F).

7.0 LAUNCH ENVIRONMENT EXPOSURE

- 7.1 Samples of the composite channel materials were exposed to the launch vehicle on Launch Complex 17A (LC-17A). The test specimens were placed at four locations illustrated in Figure 1.
 - 7.1.1 The first location, No. 1, was on the hand rail approximately 25 ft south of the vehicle centerline at the pad deck level (see Figure 2).
 - 7.1.2 The second location, No. 2, was on the handrail approximately 40 ft southwest of the vehicle and 7 to 9 ft below the pad deck level (see Figure 3).
 - 7.1.3 The third location was on a handrail approximately 150 ft west of the vehicle at the pad deck level (see Figure 4).
 - 7.1.4 The fourth location was on a west side handrail of the Mobile Service Tower (MST) approximately 22 ft above the pad deck (see Figure 5). The MST was rolled back approximately 150 yards west of the vehicle for launch.
 - 7.1.5 A test panel coated with a silicone rubber ablative material, Dow Corning Q3-6077, was located at locations No 1 and 3 to compare the severity of the launch blast with other exposure sites, such as, LC-39 and LC-40.
- 7.2 At location No. 1, five channels were mounted.
 - 7.2.1 The two end channels were Aickinstrut series 20E-1500 PVC material.
 - 7.2.2 The second channel from the left was Ackinstrut 20UFR-1500 fire retardant polyester.
 - 7.2.3 The center channel was a series 20P-2000 polyester material.
 - 7.2.4 The second channel from the right was a series 20V-2000 vinylester material.
- 7.3 At location No. 2, the following 4 types of Ackinstrut channel were installed:

	<u>TYPE</u>	<u>MATERIAL</u>
1.	20E - 1500	PVC
2.	20P - 2000	polyester/glass
3.	20P - 1500	polyester/glass
4.	20V - 2000	vinylester/glass

7.4 At location No. 3, the following 3 types of Ackinstrut channel material were installed.

	<u>TYPE</u>	<u>MATERIAL</u>
1.	20P - 1500	polyester/glass
2.	20P - 2000	polyester/glass
3.	20V - 2000	vinylester/glass

7.5 At location No.4, series 20E-1500 and 20P-2000 channels of the PVC and polyester/glass materials were installed.

7.6 The results are presented in Table 3.

TABLE 3
LAUNCH ENVIRONMENT EXPOSURE RESULTS

LOC No.	MATERIAL DESCRIPTION	RESULTS
1	ABLATIVE panel 20E - 1500 (PVC) 20UFR - 1500 20P - 2000 (polyester) 20V -2000 (vinylester)	Material Loss 0.041" average Severely Deformed and Burned Structurally Destroyed. Veil resin abraded and burned down into the glass veil.
2	20E - 1500 PVC 20P - 2000 (polyester) 20P - 1500 (polyester) 20V - 2000 (vinylester)	Channel Deformed from Heat Visibly Undamaged " " " "
3	ABLATIVE panel 20P - 1500 (polyester) 20P - 2000 (polyester) 20V - 2000 (vinylester)	Material Loss 0.0016" average Small Particle Impact Damage " " " " " " " "
4	20E - 1500 (PVC) 20P - 2000 Polyester	Visibly Undamaged " "

- 7.6.1 At location No. 1, (see Figure 6) the material loss in the silicone rubber ablative panel indicates the launch environment was slightly less severe than at the edge of the STS mobile launch platform (MLP) during a shuttle launch at Launch Complex 39 (LC-39). The two end channels of Type E, PVC, material were charred and severely deformed by the heat and blast pressure from the SRM's. The light weight channel, 20UFR-1500, was literally destroyed by the blast pressure. The 20P-2000, polyester, and the 20V-2000, vinylester, channels maintained their structural shape; however, the polymeric material was eroded and burned away down into the fiberglass veil.
- 7.6.2 At location No. 2, where the test specimens were protected from the direct blast exposure but were in the cloud of hot exhaust, both the Type P and V materials appeared undamaged. The Type E, PVC, channel was found to be significantly deformed by the exposure to the hot exhaust cloud (see Figure 7). This indicates that the exposure time was sufficient for the channel to reach the PVC softening temperature in the range of 77°C (170°F), the softening temperature for the polyester resins. At this location the Type P resin probably experienced a significant loss of strength and the Type V material may have also experienced some loss of strength.
- 7.6.3 At location No. 3 the materials probably experienced conditions similar to those at location No. 2. In addition they also experienced some small particle impact damage in the form of surface erosion. The particle impact damage may have been caused by particulate in the rocket exhaust blast, such as Martite and aluminum oxide. The Martite is the ablative material used on LC-17 and the aluminum oxide is an effluent from the SRM's exhaust.
- 7.6.4 At remote location No. 4 both the PVC and polyester materials were undamaged.

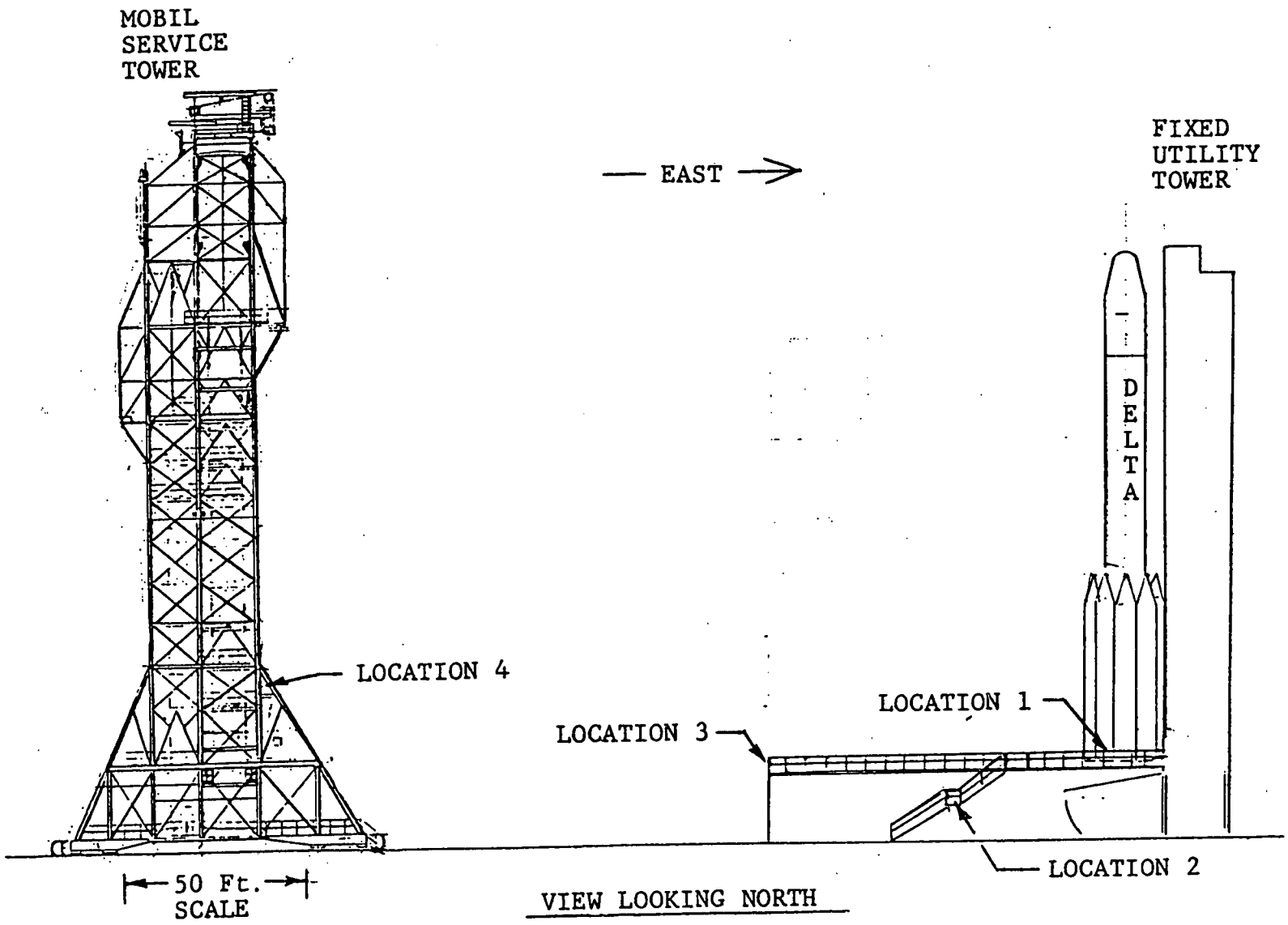


FIGURE 1

THE TEST LOCATIONS ON LAUNCH COMPLEX 17A ARE IDENTIFIED IN THE DRAWING.

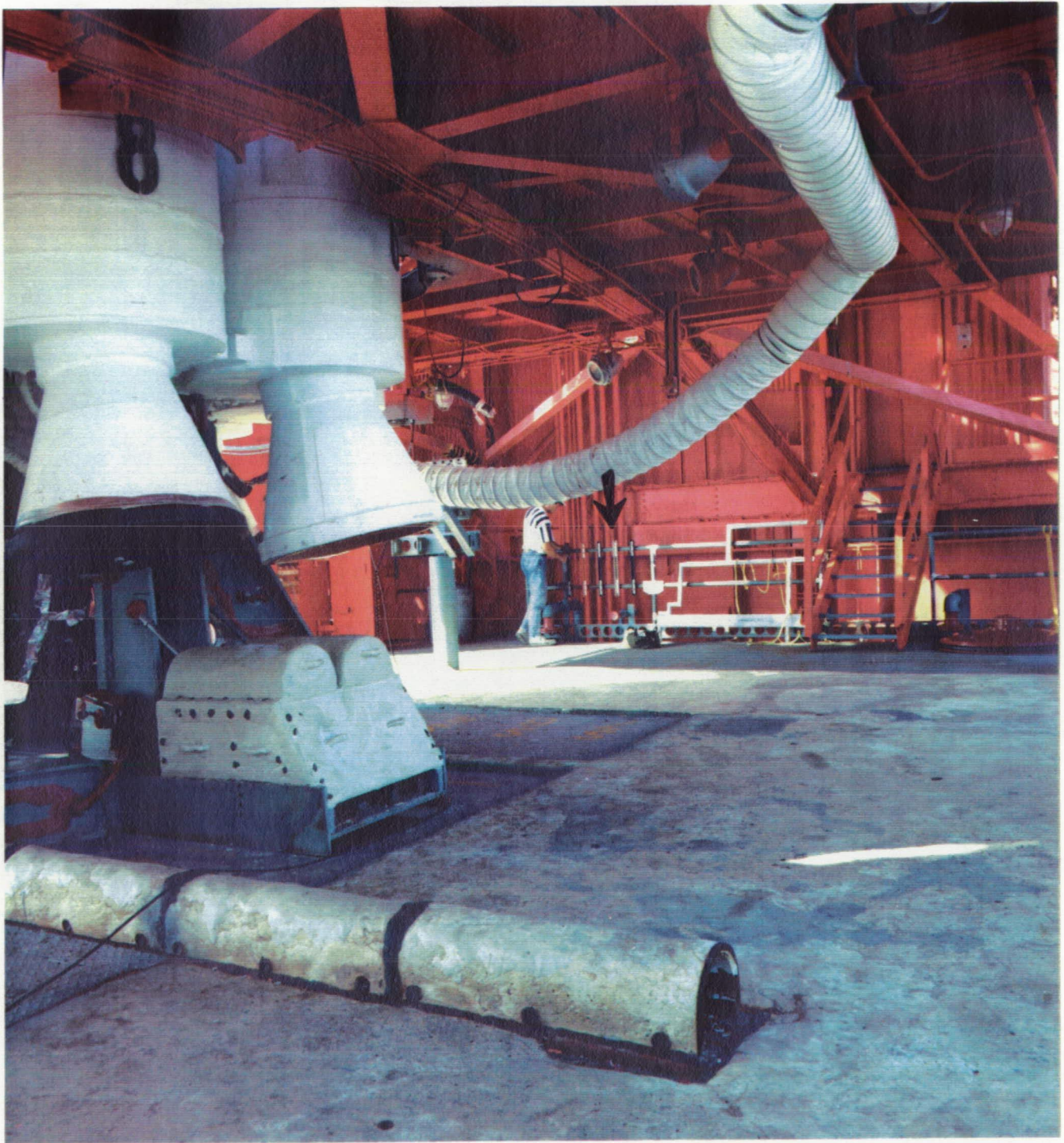


FIGURE 2

TEST LOCATION NO. 1 WAS ON THE HAND RAILS (ARROW) DIRECTLY SOUTH OF THE DELTA LAUNCH VEHICLE.



FIGURE 3

TEST LOCATION NO. 2 WAS ON THE SOUTH STAIRWAY HANDRAIL
SOUTHWEST OF THE DELTA LAUNCH VEHICLE. THE TEST SPECIMENS
WERE SHIELDED FROM THE DIRECT LAUNCH BLAST BUT ENGULFED IN
THE EXHAUST GAS CLOUD.



FIGURE 4

TEST LOCATION NO. 3, WAS ON THE WEST PAD DECK HANDRAILS
APPROXIMATELY 150 FT. WEST OF THE DELTA LAUNCH VEHICLE.

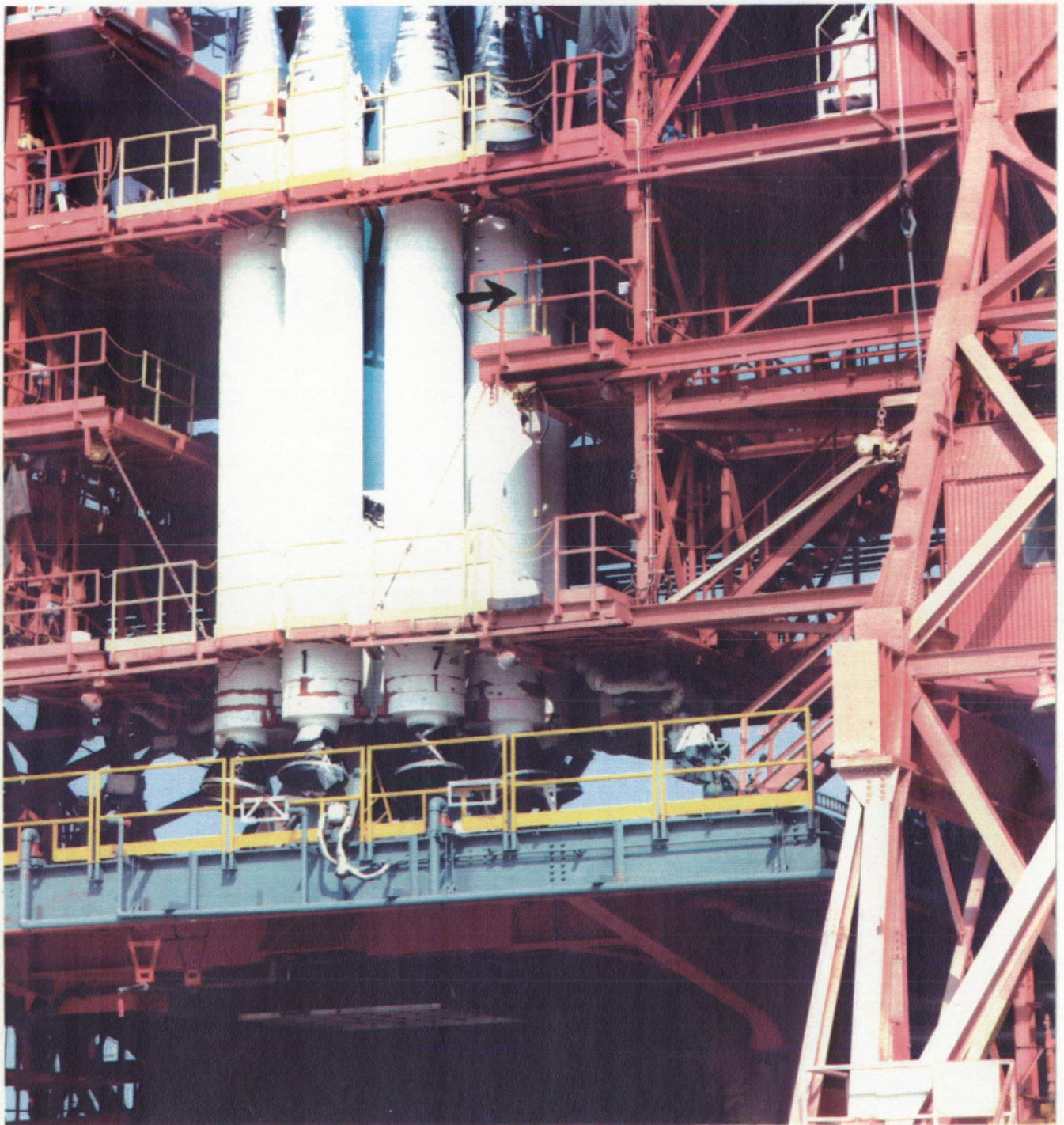


FIGURE 5

TEST LOCATION NO. 4 WAS ON THE MOBILE SERVICE TOWER WHICH WAS ROLLED BACK APPROXIMATELY 150 YARDS FROM THE DELTA VEHICLE FOR LAUNCH.

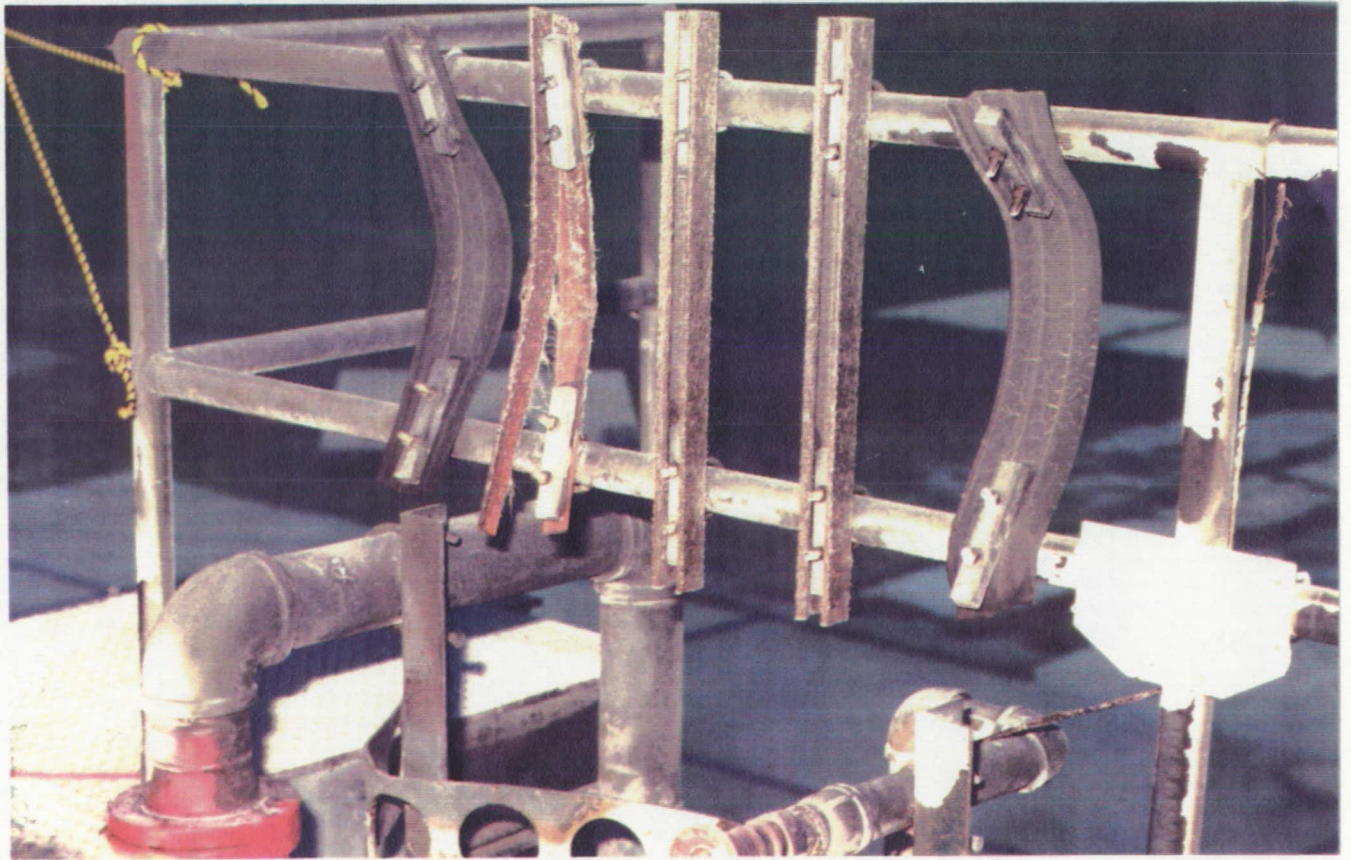
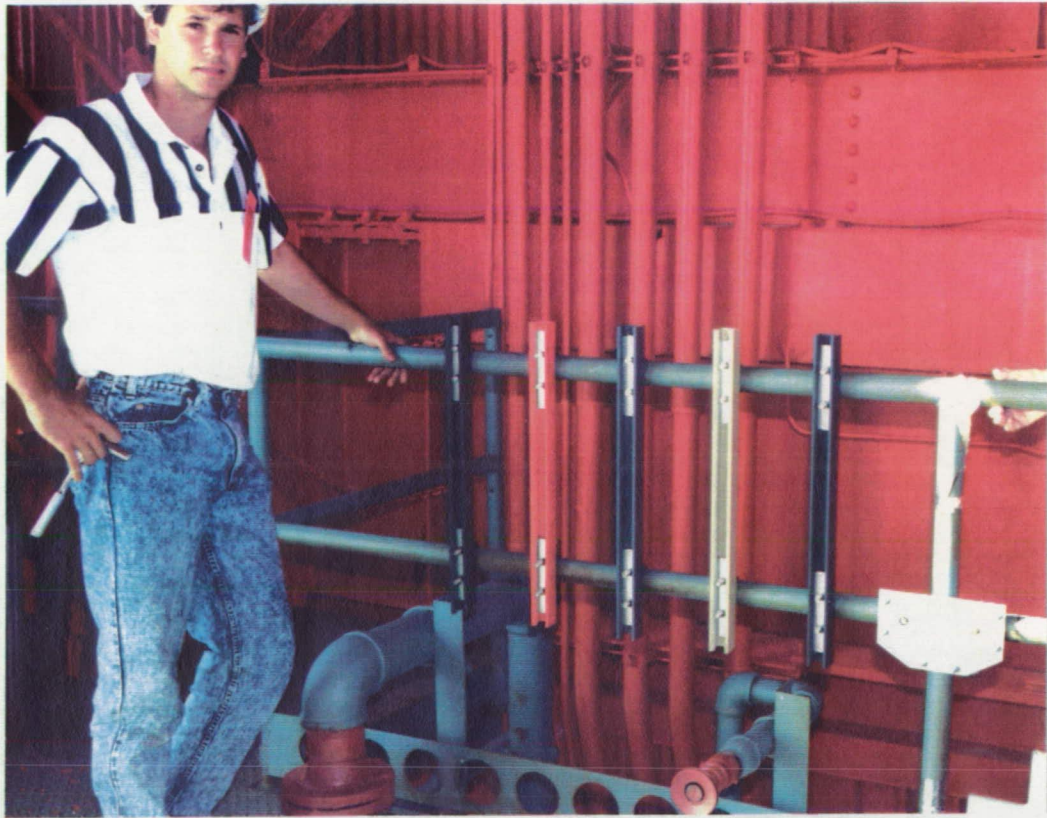


FIGURE 6

THE TEST SPECIMENS AT LOCATION NO. 1 ARE SHOWN BEFORE (TOP)
AND AFTER (BOTTOM) LAUNCH EXPOSURE.

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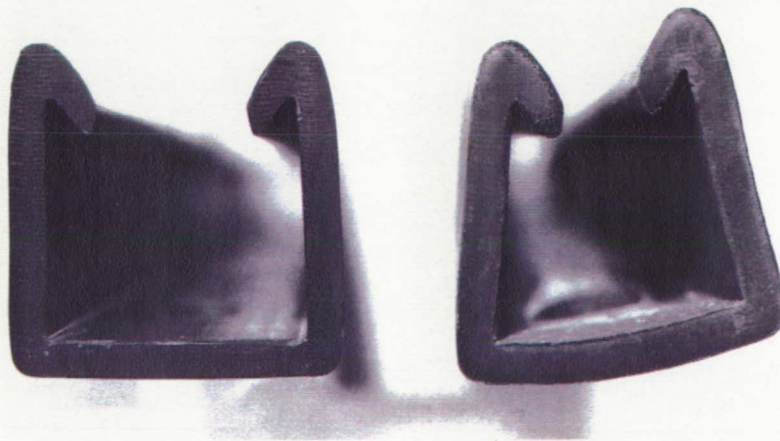


FIGURE 7

THE END OF THE TYPE E, PVC, CHANNEL AT LOCATION NO. 2 IS SHOWN (RIGHT) AFTER EXPOSURE WITH AN UNEXPOSED SEGMENT (LEFT). THE EXPOSED PVC CHANNEL HAS UNDERGONE THERMAL DEFORMATION.

8.0 DISCUSSION

- 8.1 These composite materials have been used extensively since the 1950's and 60's in tanks and vats for corrosive chemicals, in recreational marine craft, and in the automotive industry. More recent applications include low maintenance corrosion resistant structures and RF interference free structures. In the aerospace industry, the more "high tech" composites beginning with the epoxy/glass and epoxy/graphite materials were initially used in non-load bearing structural applications.
- 8.2 Before utilizing these materials for structural applications, several aspects of the materials should be considered such as; design criteria, potential operating environment, the veil material, and possible impact damage.

8.2.1 DESIGN CRITERIA

Manufacturer's design guides gives a factor of safety of 3 (33% of ultimate strength) for shear and a factor of safety of 2 (50% ultimate strength) for binding applications. It was noted that a more conservative value of 20 to 25% of ultimate strength was the design criteria for several resin/glass composites in outdoor applications with a functional life of at least 20 years. These conservative factors of safety in the range of 4 or 5 are caused by the phenomenon of "stress-rupture" of the composite's glass fibers under sustained loads. Under high sustained loads the ultimate strength of the fiberglass composites is gradually reduced by random rupturing of the fibers and debonding of the resin matrix material from the fibers.

8.2.2 HIGH TEMPERATURE ENVIRONMENT

Manufacturer's literature indicates that from 75°F (24°C) to 200°F (93°C) polyester composites experience a 48% reduction in strength. Vinylester composites are reported to have "considerable strength retention of properties in certain environments over 300°F"; but no specific data has been noted. When the questionable thermal characteristics of the composites are coupled with the long term stress-ruptured phenomenon of glass fiber composites, the wisdom

of using these materials where they will be exposed to high temperature launch environments is extremely questionable.

8.2.3 VEILS

The veil of a composite structural member is intended to provide an exterior layer of resin for environmental protection. The veil fiber cloth probably also provides a stress barrier, which prevents surface stress cracks from propagating into the load carrying fiber bundle and also prevents internal stresses from causing surface cracks.

8.2.3.1 The pultruded composite structural elements, channels, which were tested in this program all had fiberglass veils. Most of the structural shapes which are manufactured by other companies use Nexus[®] veils. Nexus[®] is a polyester fiber cloth.

8.2.3.2 In the case of the composite channels at Location No. 1, the resin was eroded and burned down into the fiberglass veil. With the Nexus[®]-veiled composites, the exhaust blast would probably burn through the veil down to the load carrying fiber bundle, because the Nexus[®] veil is a polymer just like the matrix resin.

8.2.4 IMPACT DAMAGE

In addition to particle impact erosion, which can be seen, these materials are susceptible to other forms of impact damage, which may go unnoticed. Impact from a large object may cause significant flexure of the structure. The flexure may result in the internal separation of the polymeric matrix from the reinforcing glass fibers and fiber breakage which weakens the structure but leave no external sign of damage.

9.0 CONCLUSIONS

- 9.1 Neither the polyester or vinylester composites meet the KSC electrostatics acceptance criterion. Caution should be exercised in the selection of these materials for applications where electrostatic discharge is a primary concern. The resins can be reformulated with some additives to meet this requirement.
- 9.2 The composites tested meet the flammability requirement of NHB 8060.1B; however, at elevated temperatures the resin matrix decomposes into combustible gases. This material except for the glass fibers will be consumed in an inferno.
- 9.3 The polyester resin composites meet the KSC hypergolic propellant compatibility requirements. The vinylester materials failed the nitrogen tetroxide exposure requirements.
- 9.4 Neither of the composites were degraded in the UV tests. However, it was noted that the manufacturers recommend a coat of urethane paint for long term outdoor usage of composites.

10.0 RECOMMENDATIONS

- 10.1 The polyester and vinylester/glass fiber composites can probably be successfully employed in the KSC industrial area and VAB areas, with the only major concerns being electrostatic properties for both materials and hypergolic propellant compatibility for the vinylester materials.
- 10.2 The polyester and vinylester/glass fiber composites are not recommended for use in launch pad areas where they will be engulfed by the launch vehicle exhaust plume/cloud during lift-off. The vinylester and other higher temperature composites have potential application above the 135 foot level of the Fixed Service Structure (FSS) at LC-39.

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16. Abstract Commercially available composite structural shapes were evaluated for use at Kennedy Space Center. These composites, fiberglass-reinforced polyester and vinylester resin materials are being used extensively in the fabrication and construction of low maintenance, corrosion resistant structures. The evaluation found that in many applications these composite materials can be successfully used at the space center. These composite materials should not be used where they will be exposed to the hot exhaust plume/cloud of the launch vehicle during lift-off, and caution should be taken in their use in areas where electrostatic discharge and hypergolic propellant compatibility are primary concerns.			
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