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# DESIGN AND DEVELOPMENT OF A COMPOSITE BATTERY BOX FOR CORROSION CONTROL FOR MARINE CORPS VEHICLES

J.J. Reilly and L.J. Buckley, Ph.D.  
Air Vehicle and Crew Systems Technology Department (Code 6064)  
NAVAL AIR DEVELOPMENT CENTER  
Warminster, PA 18974-5000

J.E. Merritt and C.R. Avletti  
A & M ENGINEERING, INC.  
Silver Spring, MD 20904

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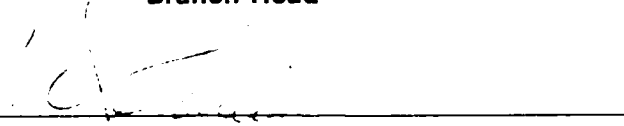
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<p>A fiberglass/epoxy composite material and the vacuum bag molding process were used to replace an existing steel battery box for the Marine Corps MK-48 ground vehicle. This item has been plagued with corrosion problems that directly impacts operational readiness, reliability, and life cycle costs. Quality control, chemical resistance, and mechanical tests were performed after selection of an appropriate material and process. Design and fabrication of several battery boxes has shown a weight savings of 13.2 kg (29.1 lbs). Six composite battery boxes were delivered to the Marine Corps (Quantico, VA) for field testing.</p>					
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J.J. Reilly and L.J. Buckley, Ph.D.  
Air Vehicle and Crew Systems Technology Department (Code 6064)  
NAVAL AIR DEVELOPMENT CENTER  
Warminster, PA 18974-5000

J.E. Merritt and C.R. Avletti  
A & M ENGINEERING, INC.  
Silver Spring, MD 20904

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## INTRODUCTION

Military vehicles are confronted by extremely corrosive environments that can adversely affect their performance. The operational readiness, reliability, and life cycle costs associated with these vehicles are significantly impacted by corrosion. Considerable efforts are expended each year on corrosion maintenance labor and materials to preserve and extend the life of these vehicles. Other sizable efforts are performed to develop and design these vehicles with inherently corrosion-resistant materials to reduce the amount of maintenance required while in service. The work described in this report relates to these latter efforts.

Corrosion of ground vehicle battery trays and compartments has been a particularly serious problem in the Marine Corps. The typical battery used by the Marine Corps is the lead-acid type having a sulfuric acid electrolyte. The battery case and its adjacent areas continue to be subject to the corrosive action of the electrolyte despite protective paint systems and drain hole provisions. Fumes and spillage of battery acid solution initiates and accelerates corrosion of these metallic parts, necessitating their repair or replacement. In particular, the steel battery box on the Marine Corps MK 48 ground vehicle has been very susceptible to corrosion attack. Figures 1 and 2 show photographs of the existing steel box and the existing composite lid, respectively. Also, a diagram of the battery box assembly is depicted in Figure 3.

The specific approach selected was to substitute the steel box with a polymer-matrix composite. Several suitable polymeric matrices and reinforcement fibers can be used to fabricate corrosion resistant battery compartments and trays. The candidate material, however, in addition to being chemically resistant to sulfuric acid ( $H_2SO_4$ ), must be resistant to gasoline, hydraulic fluid, engine oil, and salt water. Service temperatures ranging from  $-40^{\circ}C$  to  $60^{\circ}C$  ( $-40^{\circ}F$  to  $140^{\circ}F$ ) and mechanical loadings as high as 113 kg (250 lbs) of static force on the battery case cover are also requirements that are to be integrated into the replacement battery box design. The materials and process are to be selected to minimize costs when the box moves into production.

## SELECTION OF MATERIALS AND PROCESS

The initial step in designing a corrosion-resistant battery box is to select a material system and a processing technique that will meet both the mechanical property and chemical resistance requirements in a cost-effective manner. Various processing techniques such as injection molding, compression molding, stamp molding, resin-transfer molding, contact molding, pressure-bag molding, vacuum bag molding, etc., were considered for this application. Injection molding, compression molding, and stamp molding were each eliminated due to the relatively high tooling costs associated with these processes. Note that the tooling cost was a major factor since low production volumes were anticipated. Resin-transfer molding and contact molding were not considered because of their limitations on fiber content (typically less than 35% by weight). This left pressure bag molding and vacuum bag molding as processing candidates. Both of these processes utilize single mold, composite tooling (either male or female), are amenable to room-temperature curing, and allow high fiber fractions for good mechanical properties. Both processes are also very similar. However, the tooling cost associated with pressure bag molding is slightly higher than that of vacuum bag molding because the tooling must be strong enough to withstand the applied pressure. For this reason, the vacuum bag molding process was selected. A diagram of vacuum bag molding is shown in Figure 4.<sup>1</sup>

After the process was selected, it was necessary to select the specific material system. The three generic resin systems primarily used in vacuum bag molding are polyesters,<sup>2,3</sup> vinyl esters,<sup>2,3</sup> and epoxies.<sup>4,5</sup> However, the Marine Corps<sup>6</sup> requested that the final material meet a military specification. This factor was included to facilitate future composite battery box procurements. It was learned that

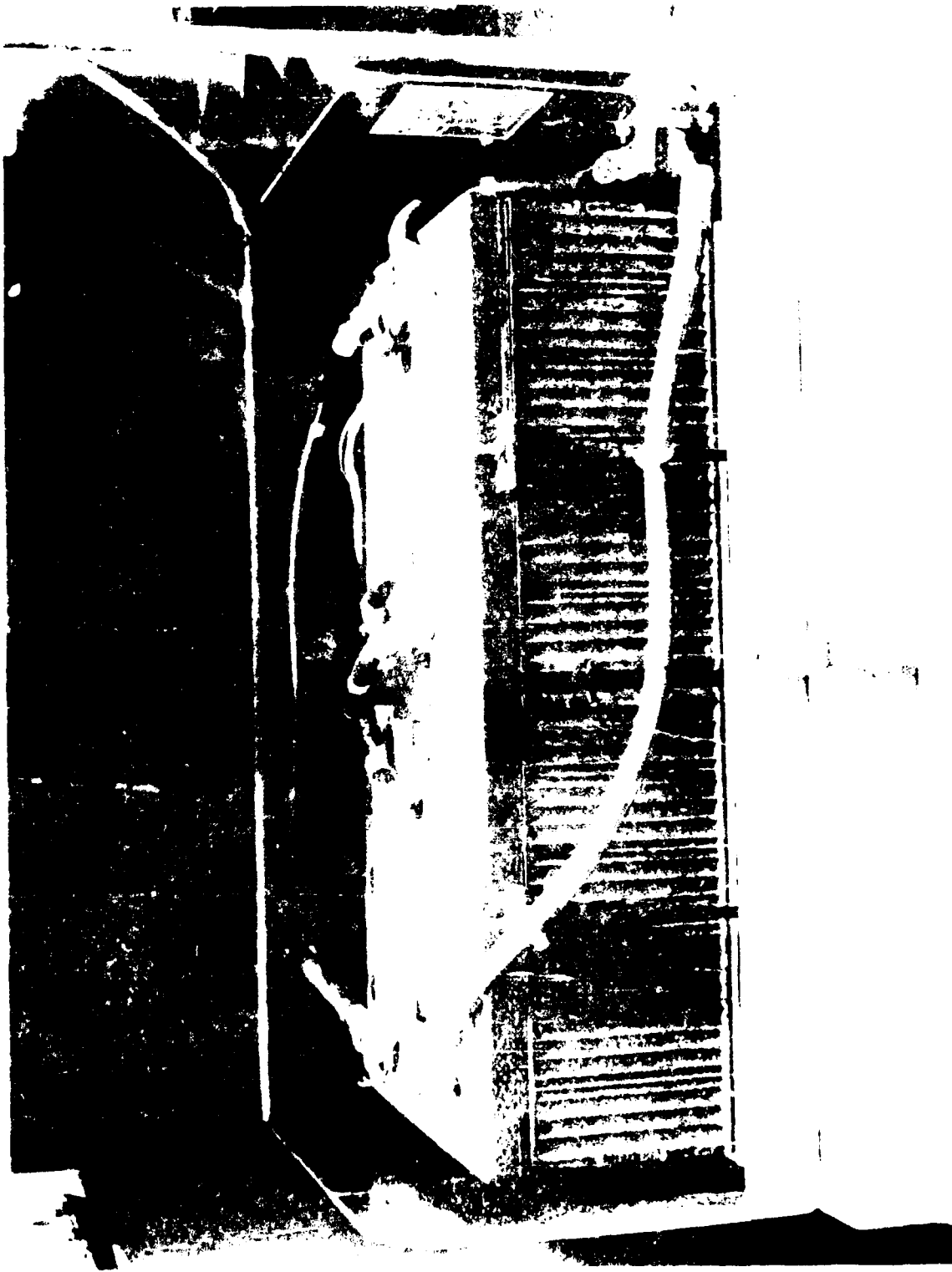


Figure 1 Photograph of Existing Steel Battery Box.

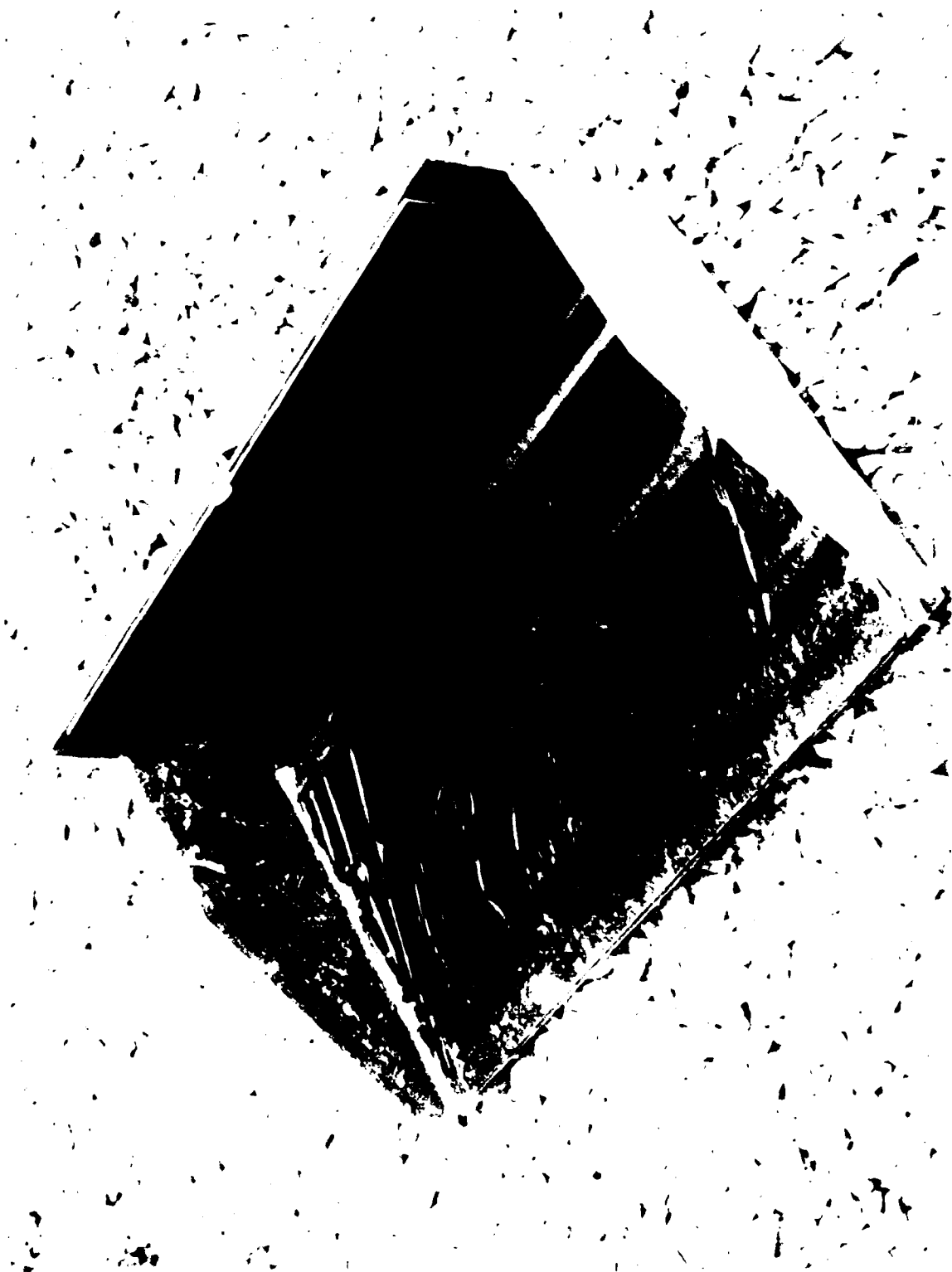


Figure 2. Photograph of Existing Composite Battery Box Lid.

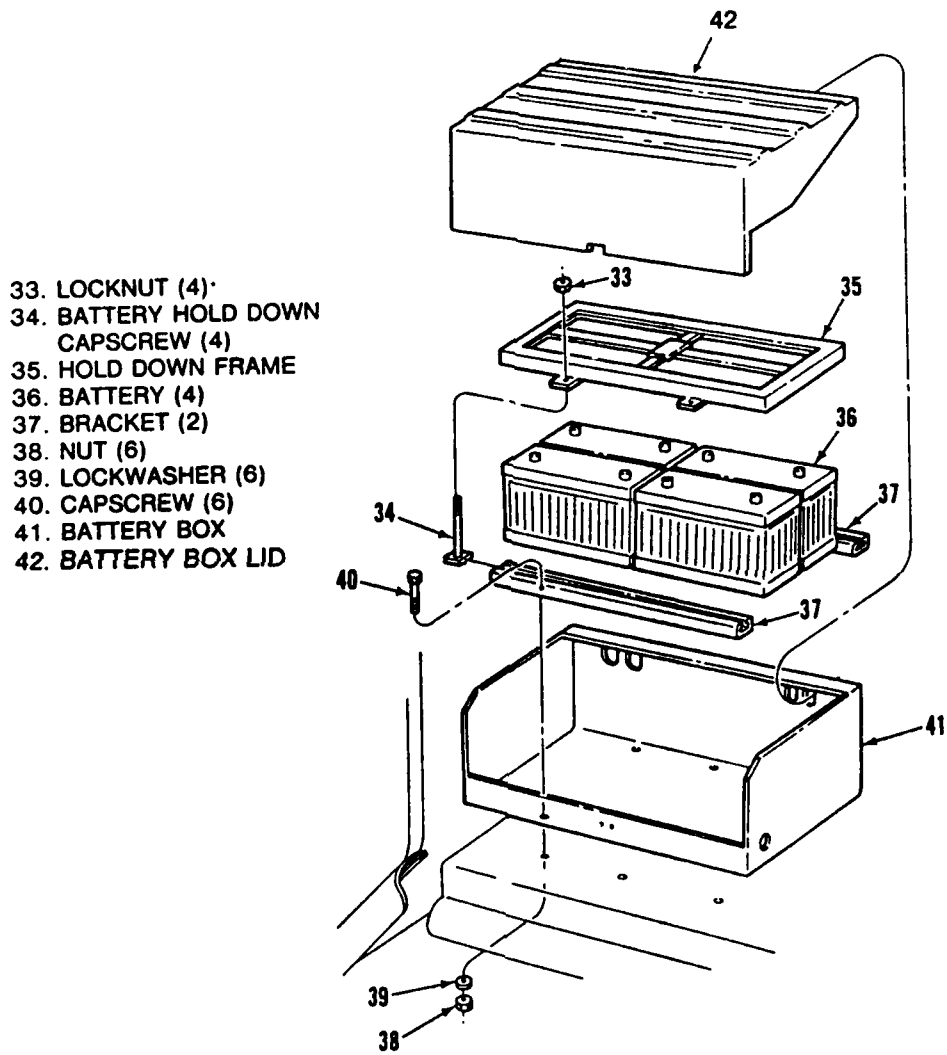


Figure 3. Diagram of Battery Box Assembly.

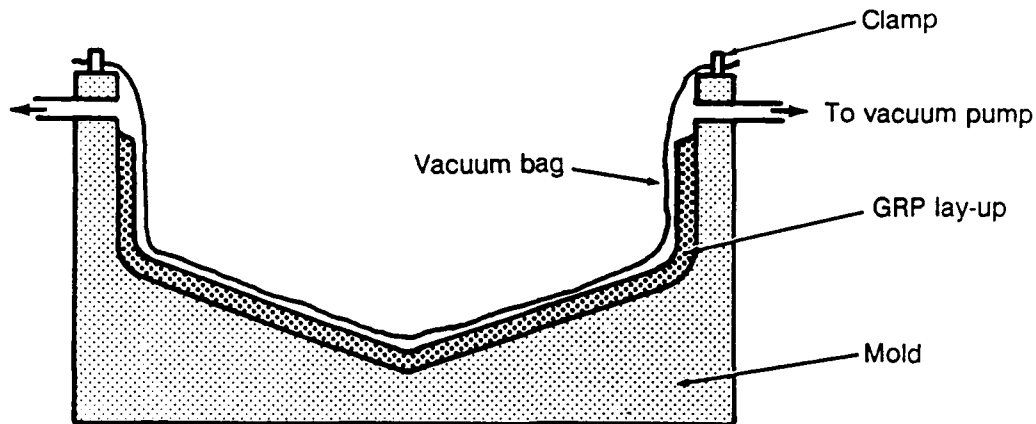


Figure 4. Vacuum Bag Molding Process.

MIL-R-7575C, Low-Pressure Laminating Polyester Resin, covered the polyesters and MIL-R-9300B, Low-Pressure Laminating Epoxy Resin, covered the epoxies; however, no military specification was identified for the vinyl esters. At this point it was decided to eliminate the vinyl-ester resins even though they exhibit good mechanical strength and chemical resistance properties, respectively. Therefore, the properties of the polyester and epoxy-resin systems were compared to select the composite matrix material. The criteria examined in the study included chemical resistance, mechanical strength, and cost.

Table 1<sup>7</sup> lists chemical resistance data for typical epoxy and unsaturated polyester resins, respectively. Table 1 is composed of two different sections. The upper section lists general chemical resistance data for the polymers in typical corrosive environments, while the lower section lists resistance data for these resins in specific chemicals. As indicated in Table 1, the unsaturated polyesters are generally more susceptible to chemical attack by nonoxidizing acids, aqueous alkalis, polar solvents, nonpolar solvents, and water at the elevated temperature (65°C) than are epoxy resins. Also, epoxy resins exhibit superior chemical resistance compared with polyesters in dilute solutions of sulfuric acid (1-50%) at the higher temperature (65°C).

A comparison of the mechanical properties was performed based on data contained in MIL-R-7575C, Low-Pressure Laminating Polyester Resin, and MIL-R-9300B, Low-Pressure Laminating Epoxy Resin. These specifications revealed that the epoxies have higher flexural strength at room temperature compared with polyesters. Therefore, the epoxies were selected over the polyesters for this application because of their better chemical resistance properties and higher mechanical strength characteristics despite a slightly higher material cost.

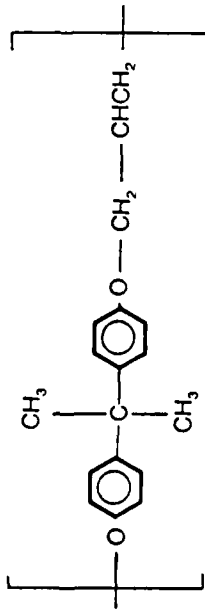
The specific epoxy resin system was selected based on fabrication considerations and also to meet the requirements specified in MIL-R-9300B, Low-Pressure Laminating Epoxy Resin. The specific resin system selected was Epon 828 with catalyst U (commercially available from Shell Chemical Company), which is a diglycidyl ether of bisphenol A (DGEBA) epoxy resin with a diethylenetriamine (DTA) adduct curing agent. The chemical structures of DGEBA, DTA, and a typical aliphatic amine adduct are shown in Figure 5.

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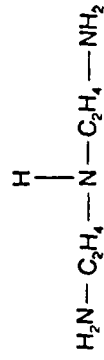
Table 1. Chemical Resistance Data for Typical Epoxy and Unsaturated Polyester Resins.

CHEMICAL	EPOXY		POLYESTERS (UNSATURATED)	
	25°C (77°F)	65°C (149°F)	25°C (77°F)	65°C (149°F)
Nonoxidizing acids (20% H <sub>2</sub> SO <sub>4</sub> )	S	S	Q	Q
Oxidizing acids (10% HNO <sub>3</sub> )	U	U	U	U
Aqueous salt solution	S	S	S	S
Aqueous alkalies	S	S	U	U
Polar solvents	S	S	Q	U
Nonpolar solvents	S	Q	U	U
Water	S	S	S	Q
Benzene	Q	Q	U	U
Castor oil	S	Q	S	Q
Detergents (general)	S	S	Q	Q
Diesel fuel	S	Q	S	Q
Ethanol (1-95%)	S	Q	Q	U
Ethylene glycol	S	S	S	S
Freons	S	Q	S	Q
Gasoline	S	Q	S	Q
Heptane	S	Q	S	Q
Hexane	S	Q	Q	U
Isopropyl alcohol	S	U	Q	U
Kerosene	S	Q	S	Q
Mineral oil	S	S	S	Q
Naphtha	S	Q	S	Q
Octane	S	Q	S	Q
Soap	S	S	S	Q
Sulfuric acid (100%)	U	U	U	U
Sulfuric acid (70%)	S	Q	Q	U
Sulfuric acid (1-50%)	S	S	S	Q
Toluene	Q	Q	U	U
Xylene	Q	Q	U	U

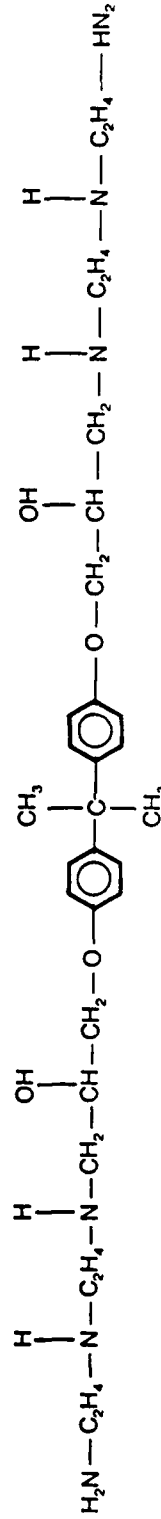
Legend: S = Satisfactory; Q = Questionable; U = Unsatisfactory.



Diglycidyl ether of bisphenol A (DGEBA) epoxy



Diethylenetriamine (DTA)



Typical amine adduct (DTA + DGEBA)

Figure 5. Chemical Structures of an Epoxy Resin and Curing Agents.

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The Marine Corps also requested that the composite box have a green color through the resin, if possible, even though the box is to be coated with a green paint. The reason for this is to minimize the damage to the camouflage scheme if the paint is chipped or removed in a localized area. To accommodate this request, the final matrix resin comprised three parts of green dye mixed with 100 parts of epoxy resin (Epon 828), and 25.75 parts of the curing agent (Catalyst U) on a weight basis. The green dye is commercially available from Ferro, Inc. as pigment GV 36610 (olive drab/epoxy).

Glass fiber was selected over more exotic reinforcements (e.g., graphite fiber, and aramid fiber) due to its high flexural strength properties, good wet-out characteristics with low-pressure laminating resin systems, and low cost.<sup>8,9</sup> The glass fiber reinforcement (E-glass) was selected to meet the requirements specified in MIL-C-9084C, Finished Glass Cloth for Resin Laminates. The particular fiberglass selected was a Class 2, Type VIII B (181-75DE) finished cloth, which is commercially available from Owens-Corning Fiberglas Corporation and is designated as ECDE 751/0.

### DESIGN OF COMPOSITE BATTERY BOX

After the material system and fabrication process were selected, design of the battery box was initiated. In addition to the 113-kg (250-lb) static load requirement mentioned above, there was also a requirement that the composite box must interface with the existing composite battery box lid. Therefore, the starting point for the design of the composite battery box was to analyze the design of the existing steel one. The Marine Corps provided an actual steel battery box (part number 124374D, FSCM 45152, NSN 2510-01-208-6581) for dimensional measurements since the drawings were unattainable from the original manufacturer. The dimensions of the existing steel box are approximately 30.5 cm high by 76.2 cm wide by 48.3 cm deep and 0.279 cm thick (12" by 30" by 19" by 0.11") as shown in Figure 6. During this design phase it became apparent that a few changes were necessary to tailor the design of the battery box to be compatible with the material and process selected.

The first change deals with the locations of the circular holes designated as A1 and B1 in Figure 6 (on the back of the box). Typically, the vacuum bag molding process requires larger radius corners than those common to welded joints. Therefore, since these hole locations were not critical, they were moved 1 inch inward to permit a larger radius corner more compatible with the selected molding process.

The second change involves increasing the thickness of the composite box to 0.356 cm (0.14 inches) in order to provide the strength necessary to meet the 113-kg (250-lb) load requirement, while also maintaining an interface that mates with the existing lid.

These design changes did not impact the form, fit or function of the composite battery box or its installation on the Marine Corps MK-48 ground vehicle.

### COMPOSITE FABRICATION PROCESS

The composite plaques and battery boxes were manufactured by Composite Horizons, Inc. (Covina, CA) using the fiberglass/epoxy material previously identified. The composite battery boxes were molded using a female composite tool fabricated from fiberglass/epoxy. The mold design concept permitted the top stiffening flanges of the battery box to be incorporated into a



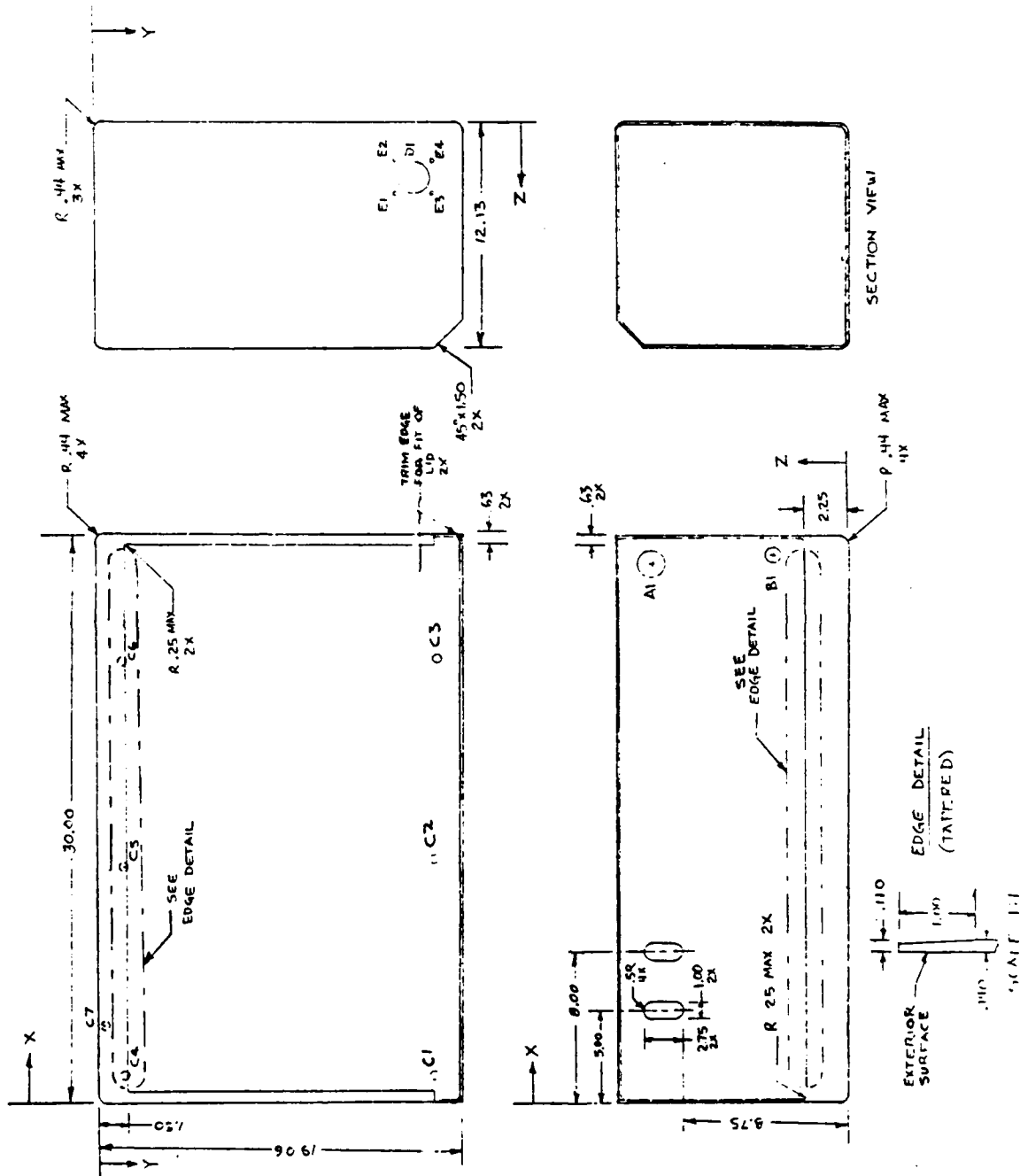


Figure 6. Detailed Drawing of Composite Battery Box.

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monocoque design. The battery box design required that the tool be a two-part, split-type construction to allow for demolding of the part.

The fabrication process began by assembling the mold halves followed by the application of mold release to the polished surfaces. The layers of fiberglass cloth were then wet-out with the pigmented resin and hand layed-up until the desired 0.356-cm (0.140-inch) thickness was achieved. With the lay-up complete, the entire mold and lay-up were placed in a vacuum bag under 0.088 MPa of pressure (12.8 psi or 26 inches of mercury) and allowed to cure at room temperature for 8 hours. Note that a peel ply and bleeder cloth were utilized to control the resin flow during the cure. After the cure cycle, the part was demolded and the outside parting line (created between the two mold halves) was sanded flush. The flanges were then machined to the proper dimensions and all of the hole features were installed using the appropriate drill fixture.

### EXPERIMENTAL PROCEDURE

All of the test specimens used for this work were machined from plaques consisting of 12 plies of fiberglass. The average plaque thickness was about 0.305 cm (0.120 inch).

#### DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT DETERMINATIONS

The density was measured in accordance with ASTM D792-66 (reapproved 1975), Method A1 using 2.54-cm by 2.54-cm (1" by 1") samples and deionized water as the immersion fluid. The fiber volume fraction was measured by igniting the 2.54-cm by 2.54-cm (1" by 1") specimens in accordance with ASTM D2584-68 (reapproved 1979). Void content of the composite was determined in accordance with ASTM D2734-70 (reapproved 1980). At least three replicates were tested for each of these measurements.

#### CHEMICAL RESISTANCE TESTING

Chemical resistance tests were performed at room temperature in accordance with ASTM D543-67 (reapproved 1978) using 2.54-cm wide by 7.62-cm long (1" by 3") test specimens. The samples were weighed before and after a 7-day chemical immersion, and weight change values were calculated. Additionally, after the 7-day immersion, the samples were conditioned for 7 days at room temperature and 50% relative humidity. Sample weights were taken again and compared with the initial weights to determine if there were any soluble constituents in the samples. The chemicals used for this test were a 30% sulfuric acid solution and distilled water.

#### MECHANICAL TESTING

Tensile testing of the selected composite material was performed in accordance with ASTM D3039-76 on a 10-Kip Instron test machine. A total of eight replicates were tested in the 0° direction at the room temperature/dry condition using 1.27-cm wide by 21.6-cm long (0.5" by 8.5") specimens. The failure stress was measured in the axis of loading. Fiberglass/epoxy end-tabs were adhesively bonded to the specimens to gradually move the load into the gage area. Additionally, a 90° fiber orientation on the bonded tab surface was used to match the 0°/90° orientation on the outer ply of the specimen to minimize adhesive bondline stresses. Furthermore, the end-tabs were also tapered to minimize the bondline stresses.

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Flexure testing was performed in accordance with ASTM D790-81 at the room temperature/dry condition in the 0° direction using 2.54-cm by 7.62-cm (1" by 3") samples. A total of 11 replicates were tested. These tests were conducted using the four-point loading method at 1/3 points and a support span-to-thickness ratio of 16 to 1.

### RESULTS AND DISCUSSION

#### DENSITY, FIBER VOLUME FRACTION, AND VOID CONTENT

The density of the composite material was determined to be 1.849 g/cc. To measure the fiber volume fraction, samples were weighed before and after ignition. The weight loss during ignition was 26.5%. Normally, this value is taken as the resin content and the remainder as the fiber content. However, the green dye added to the resin must be accounted for in this material.

It was learned from the manufacturer (Ferro, Inc.)<sup>10</sup> that the green dye contained five different components. The weight percentage of each component and their respective densities are listed in Table 2.<sup>10</sup> As indicated in Table 2, the dye consists of 50% epoxy and 50% metal oxides by weight. It is assumed that the 50% epoxy did burn and that the metal oxides did not burn or change in density during the ignition test. Therefore, the 26.5% that burned off is the weight percent matrix, and the remaining 73.5% by weight includes both the fiberglass and the four metal oxides.

Table 2. Weight Percent and Density Data for Green Dye.

COMPONENT	WEIGHT PERCENT	DENSITY (g/cc)
DGEBA Epoxy	50.0	1.16
Chromium Oxide	20.0	5.10
Iron Oxide	3.5	4.95
Magnesium Ferrite	11.5	4.40
Iron Oxide	15.0	4.05

To calculate the percent of fiberglass, it is necessary to recall the matrix formulation: 100 parts of DGEBA, 25.75 parts of curing agent, and three parts of green dye on a weight basis. Since the green dye is composed of 50% DGEBA, this equates to 1.5 parts of DGEBA. Therefore, the weight percentage of DGEBA in the dye may be computed as follows:  $(26.5\%)(1.5/(1.5 + 100 + 25.75)) = 0.3\%$ . Note that this is also equivalent to the weight percentage of metal oxides. Furthermore, the weight percentage of fiberglass is calculated as  $100\% - 26.5\% - 0.3\% = 73.2\%$ .

The theoretical density of the composite was calculated using the rule of mixtures. The density of the fiberglass used was 2.57 g/cc, according to the manufacturer (Owens-Corning Fiberglass Corp.).<sup>11</sup> The value used for the matrix density was 1.21.<sup>12</sup> The pigment densities used are listed in Table 2. Using this method, the theoretical density is calculated to be 1.983 g/cc. The volume percent of voids is computed as 6.8% using the following equation.

$$V_v = (100\%)(D_t - D_m)/(D_t) \quad (1)$$

where:

$V_v$  = volume percent voids

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Dt = theoretical density, and  
Dm = measured density

### CHEMICAL RESISTANCE PROPERTIES

The chemical resistance of the fiberglass/epoxy composite is a critical consideration that must be addressed if a material substitution is to occur. The composite must not dissolve or degrade upon exposure to common solvents or cleaning agents. In addition, exposure to battery acid (sulfuric acid) must not significantly change the performance or dimensions. After a 7-day immersion in 30% sulfuric acid, the samples gained an average of 0.8%. Upon conditioning at room temperature and 50% relative humidity, the weight gain decreased to 0.56%. The same test for distilled water produced weight gains of 0.29% and 0.031% respectively. These changes are not significant enough to affect performance. There is no loss of material, which indicates very little, if any, degradation is occurring. Upon drying in dynamic vacuum, the sulfuric acid samples returned approximately to their original weights. Total immersion in acid, although not likely in service, does not appear to degrade the performance of the battery box.

### MECHANICAL PROPERTIES

The tensile strength of the composite material was determined to be  $338 \pm 13$  MPa ( $49.0 \pm 1.9$  ksi). It was noted on most of the test specimens that the end-tabs had partially peeled from the composite material near the tip of the tapered region during testing. This may have introduced a small amount of error to the tensile strength values, but its effect is probably not significant. The tensile strength requirement specified in MIL-R-9300B is 331 MPa (48 ksi). Therefore, the measured tensile strength is slightly above this value despite the high volume fraction of voids (6.8%) present in the composite. This was no surprise since tensile strength is a fiber dominated property.

The flexure strength of the fiberglass/epoxy composite was determined to be  $399 \pm 15.8$  MPa ( $57.9 \pm 2.3$  ksi). It is noted that 6 of the specimens failed in compression while the remaining 5 failed in tension. This indicates that the compressive strength of the composite is approximately the same as its tensile strength. The above statement is supported by the compressive and tensile strength requirements of 345 MPa (50 ksi) and 331 MPa (48 ksi), respectively, specified in MIL-R-9300B. However, it is also noted that the measured flexural strength of 399 MPa (57.9 ksi) is considerably lower than the 517 MPa (75 ksi) requirement specified in MIL-R-9300B. This was probably due to the high-volume fraction of voids (6.8%) present in the composite.

### COMPOSITE BATTERY BOX EVALUATION

All composite battery boxes were inspected to assure both compliance with the dimensions shown in Figure 6 and overall quality workmanship. Each composite box was mated with the existing composite lid to assure that they interfaced properly. Additionally, a 113-kg (250-lb) load was applied to the center of the lid on the box/lid assembly as a performance test. Furthermore, the surface of each side of every box was A-scanned in two directions at 10.2-cm (4-inch) grid intervals to ensure that there were no areas with excessive amounts of internal porosity.

As a final quality check, each of the composite boxes were weighed. The average weight of a composite battery box was about 6.6 kg (14.6 lbs). The steel box provided by the Marine Corps weighed about 19.8 kg (43.7 lbs). Therefore, by replacing the steel box with the composite one, a 13.2-kg (29.1lb) weight savings may be achieved. Note that the composite box weighs about

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one-third that of the existing steel one. A photograph of both the existing steel battery box and the newly developed composite one is contained in Figure 7.

### **CONCLUSIONS**

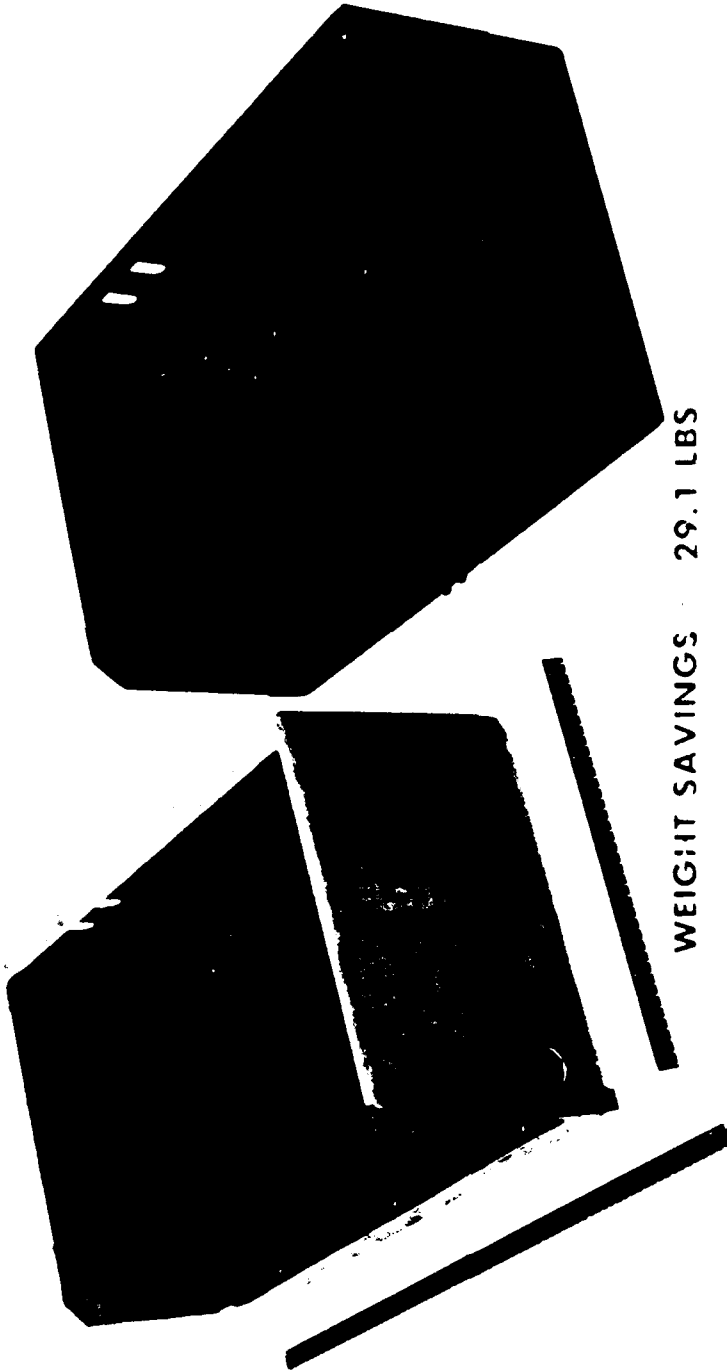
The void content was calculated to be 6.8%, which is acceptable based on the processing method employed (vacuum bag molding). There was no appreciable chemical degradation, and the mechanical properties met the requirements needed for the battery box. By replacing the steel battery box with the composite a weight savings of 13.2 kg (29.1 lbs) was achieved with the added advantage of significantly improved environmental durability.

### **RECOMMENDATIONS FOR FUTURE WORK**

The major thrust of future work for the Marine Corps should be concentrated on replacing other metallic components on the MK-48 or any other ground vehicle with composites. In general, components requiring improved corrosion resistance, lighter weight, or enhanced solvent resistance should be targeted first since they will have the biggest payoffs. In the present battery box application there are also a few internal parts which may be converted from metal to composite. Specifically, the brackets, the hold down frame, and fastening assembly (shown in Figure 3) may be fabricated using composites. Hence, the acid resistance of the entire battery box assembly would be enhanced.

FIBERGLASS/EPOXY  
COMPOSITE BOX  
14.6 LBS

EXISTING  
STEEL BOX  
43.7 LBS



WEIGHT SAVINGS 29.1 LBS

WEIGHT OF COMPOSITE BOX 1

WEIGHT OF METAL BOX 3

Figure 7. Photograph of Newly Developed Composite and Existing Steel Battery Boxes.

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