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PRESSURE VESSEL SYSTEM

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MASTER

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ADVANCED TECHNOLOGY FOR MINIMUM WEIGHT PRESSURE VESSEL SYSTEM*

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ABSTRACT

Bosses were made of fiber/resin composite materials to evaluate their potential in lightweight pressure vessels. An approximate 25% weight savings over the standard aluminum boss was achieved without boss failures during burst tests. Polymer liners and metal liners are used in fiber composite pressure vessels for containment of gases. The internal support of these liners required during the filament winding process has previously been provided by dissolvable salt mandrels. An internal pressurization technique has been developed which allows overwinding the liner without other means of support and without collapse. An earlier study of polymer liners for fiber composite pressure vessels was unsuccessful in scaling up to full-scale vessels. Study was made of several additional concepts including styrene/Saran, styrene/flexible epoxy and ABS. Use of these materials still did not produce a successful large-scale polymer-lined vessel.

INTRODUCTION

Filament-wound fiber composite pressure vessels offer performance gains and significant weight savings over conventional metal pressure vessels. Much of the technology associated with Kevlar/epoxy composite vessels with metal liners and polymer liners has been developed under the sponsorship of NASA/Lewis Research Center. As part of the FY'76 Lawrence Livermore Laboratory effort for NASA/LeRC, three advanced technology problems were studied: (a) the replacement of metal bosses by lighter weight composite bosses; (b) the use of internal air pressure to replace salt mandrels as support for polymer and thin metal liners during filament winding; (c) additional polymer liner concepts for their suitability in large-scale vessels. This report discusses the results of these studies.

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COMPOSITE BOSSES

All fiber composite pressure vessels have used metal bosses. These have been integrally formed with or welded into the liner in metal-lined vessels, and have been discrete interference fitting in polymer-lined vessels (Fig. 1a,b). The bosses represent a sizable percentage of the total vessel system weight, especially the small-scale vessels. For a 10-cm-diameter Kevlar/epoxy polymer-lined vessel with a total weight of 162 grams, the weight of two aluminum fittings[1] is 19 grams each. Fittings made of composite materials were developed principally to effect a weight savings, but also to better match thermal expansion characteristics of the boss and the composite vessel.

Materials

Three materials were considered for this application: (a) a special order 3-D quartz/phenolic; (b) a commercial grade 2-D glass cloth/epoxy; and (c) a molded chopped glass/epoxy. Table 1 gives vendor-type information on these materials.

TABLE 1. Materials Information for Composite Bosses

	3-D quartz phenolic	2-D glass cloth/epoxy	Molded Chopped glass/epoxy
Supplier	AVCO Corp. Lowell, MA	Formica Corp. Cincinnati, OH	Unknown
Designation	None given	Grade FF-91 (Nema Grade G-10)	
Specific Gravity	1.75	1.80	∿1.7
Shear Strength* (punching)	69-76 MPa	∿41 MPa	∿14 MPa
Cost	$80/blank	<$1/blank	<$1/blank
Form	Rod	Thick plate	Partially formed

*LLL test of composite bosses, shear across flange thickness

Design

The bosses were machined from the composite blanks to the dimensions noted in Fig. 2. The Z-axis direction of the 3-D blank and the through thickness direction of the 2-D blank were oriented to the vessel polar axis. Three methods of producing threads were considered: (a) direct threading of the composite material; (b) a threaded aluminum insert; and (c) a stainless steel helicoil insert epoxied onto the threaded composite. The choice of thread wear and strength and positive sealing as design criteria resulted in the decision to use the helicoil insert.

The final manufactured weight of the composite fitting was 14 grams as compared to the aluminum weight of 19 grams, a 26% weight reduction. Figures 3a and b show the 3-D quartz/phenolic boss in a failed polymer-lined Kevlar/epoxy vessel. Four 10-cm-diameter Kevlar 49/epoxy vessels with a 1.5 mm polymer liner were manufactured with the 2-D glass cloth/epoxy bosses. Fifteen similar vessels with air mandrels and 3-D quartz/phenolic bosses were manufactured. The bosses were bonded with urethane adhesive 8089, 0.25 mm bondline thickness, and room temperature cured.

Performance

Vessels with the 3-D quartz/phenolic and 2-D glass cloth/epoxy bosses were tested without any failures in the bosses. A maximum pressure of 35.8 MPa was sustained by the quartz/phenolic system, and 19.3 MPa was the maximum pressure seen by the 2-D glass cloth/epoxy system. Failures were in the hoop windings of the vessels. The molded glass/epoxy bosses were of questionable quality and were eliminated from consideration on the basis of low shear strength (see Table 1).

Conclusions

A significant 26% weight savings over aluminum bosses was achieved with composite bosses. A commercially available, inexpensive material was used successfully in this application as well as a very expensive, $80/blank specialty material.

No permeation tests were conducted with composite bosses.

AIR MANDRELS

The use of a soluble salt mandrel for internal support of the polymer-lined and thin metal-lined vessels can produce problems of corrosion. It is possible to avoid this by using internal air pressure to provide the required mandrel support during filament winding. The necessary pressures and a pressurization/fiber tension sequence for polymer-lined vessels were developed in this study.

Procedure

Pressurization of the mandrel was provided by compressed air ducted through the spindle shaft. The 10-cm-diameter cylindrical vessel was sealed at the fittings with O-ring seals. Two types of polymer liners were used as air mandrels: ABS and styrene/epoxy with thickness of 0.75 mm and 0.50 mm, respectively. Two winding patterns were used with the ABS liners: a single pattern and a double pattern. The pressurization sequence of both ABS vessels is given in Table 2. Pressure was maintained through the curing of the matrix. A similar procedure was used with the styrene air mandrels.

TABLE 2. Air Pressurization Sequence for ABS Air Mandrels

Liner Material	Liner Thickness	Winding Pattern	Fiber Tension	Pressurization Schedule (MPa)	Composite Thickness
ABS	0.75 mm	2H	4.5 N	0.07	1.8 mm
		2L		0.165	
		2L		0.23	
		2H		0.30	
		2H		0.30	
ABS	0.75 mm	2H		0.07	3.6 mm
		2H		0.14	
		2L		0.21	
		2L		0.28	
		2L		0.35	
		2L		0.41	
		2H		0.41	
		2H		0.41	
		2H		0.41	
		2H		0.41	

Performance

All vessels were successfully wound using the internal pressurization procedure. There were no questions about the resulting liner integrity for the ABS air mandrels. The vessels wound on the styrene/epoxy all leaked during attempted burst testing. The leakage occurred due to cracks in the liner. One possible explanation was the occurrence of micro-buckling in the liner during fabrication. This explanation could not be proven or disproven.

Conclusions

The air mandrel concept appears to be a viable alternate to an internal soluble mandrel in composite pressure vessel fabrication. Corrosion problems associated with the salt are avoided.

IMPROVED POLYMER LINERS

Previous study of polymer-lined Kevlar/epoxy pressure vessels,[1,2] demonstrated high performance in static burst and cyclic fatigue tests. The systems which gave the high performance were the subscale 10-cm-diameter vessels. Attempts to scale up these vessels to 20-cm- and 38-cm-diameters were unsuccessful because of liner leakage. Problems associated with lack of the uniformity of the large polymer mandrels and with insufficient strain capability of some of the materials were the principal causes. Various repair techniques noted in Ref. 2 were attempted. However, the systems which resulted in successful burst results still gave poor cyclic fatigue performance. In this study, consideration was given to additional material systems in an effort to improve the performance of large-scale vessels.

New Concepts

Three material systems and four design concepts were studied: (a) a styrene mandrel with a 0.20 to 0.28 mm coat of Saran; (b) a styrene mandrel with a 0.075 to 0.13 mm coat of flexible epoxy; (c) a one-piece, 0.75 mm thick ABS mandrel/liner; and (d) a joined two-piece, 0.75 mm thick ABS mandrel/liner. All vessels were 10-cm-diameter vessels conforming to the previous study. The styrene/epoxy and two-piece ABS mandrels were also used as the experimental air mandrels of the previous section. Fiber Science was contracted to supply the ABS mandrels. They were not able to fabricate the one-piece mandrel, so this concept has not been evaluated.

Performance

The coated styrene mandrels gave poor performance. Leaks developed in four vessels at pressures less than 10.3 MPa. Liner cracks were evident in the tested vessels. The general quality of these mandrels was considered to be poor. The mandrels seemed to possess insufficient flexibility for the application. Four additional vessels burst during pressurization at pressures below 14 MPa. The failures were in the end or knuckle regions.

These failures may have originated near the edge of the boss flange or at non-symmetrical regions of the mandrels.

Seven vessels with two-piece ABS were manufactured. The first two used a single pattern and the last five used a double pattern. Both are noted in Table 2 of the preceding section. One of the first two vessels was burst at 15 MPa for a performance factor PV/W = 0.138 MJ/kg. Failure was in the hoop winding. The second vessel leaked. The cause was thought to be poor alignment between the two liner halves. The double pattern was decided upon in order to improve the vessel performance and to evaluate the liner at higher pressures. The best performing vessel burst in the hoop windings at 36.8 MPa for a PV/W of 0.23 MJ/kg. The total vessel weight was 148 grams, of which liner and bosses comprised 61 grams (30 grams for the liner). Figure 4 shows a burst ABS lined vessel.

Conclusions

Of these new liner systems considered, only the ABS liner produced a high performance vessel. These liners, however, are heavier than earlier polymer liner systems. No permeation or fatigue cycling tests were performed. No larger vessels were fabricated.

SUMMARY

Composite bosses are able to produce a 7 to 8% weight savings for small pressure vessels without degrading the vessel burst strength. A 3-D quartz/phenolic boss was successfully demonstrated in a vessel at 36.8 MPa pressure. A 2-D woven glass/epoxy boss also was successfully demonstrated. The 3-D material is very expensive while the 2-D material is a readily available, inexpensive, commercial grade. Stainless steel helicoil inserts were bonded in place to provide the necessary fitting thread strength.

An air mandrel technology was successfully demonstrated with polymer liners. An internal pressurization and fiber winding tension sequence was developed which did not collapse the liner/mandrel. This procedure eliminates the corrosion problems associated with soluble salt mandrels.

One new concept for a polymer liner was a limited success. A two-piece ABS liner with a double pattern overwind resulted in good vessel performance without leakage during pressurization. No fatigue cycling or permeation tests were conducted. Also, the vessel was the 10-cm-diameter size. The vendor was not able to successfully fabricate a one-piece ABS liner. Liners of pure Parylene C leak. Styrene mandrels were of poor quality and not flexible enough with resulting leakage during pressurization. At the present time there is still no proven polymer liner system with the required low permeability and high flexibility. Further, the thickness necessary to obtain liners which do not leak is three times as thick as successful titanium-lined vessels.[3] Hence, there are no significant weight savings. The lack of consistency of the polymer liners as leak-free systems also indicates that with present technology they are unreliable. Further, they are of limited use since they only prevent permeation of N_2 gas. Recent fatigue results with thin titanium liners indicates that sufficient fatigue life can be obtained.[3] Hence, the main driving force for the polymer liner has been removed.

ACKNOWLEDGEMENTS

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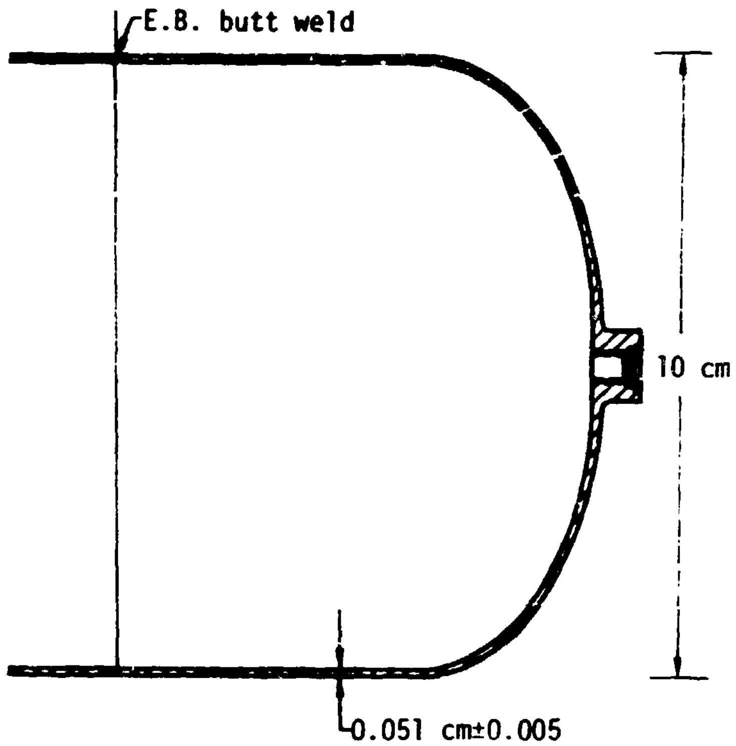
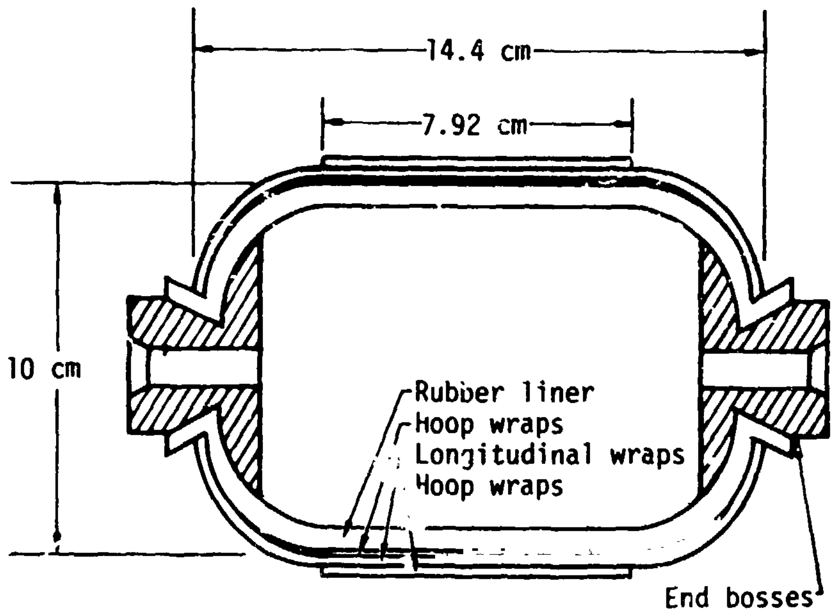
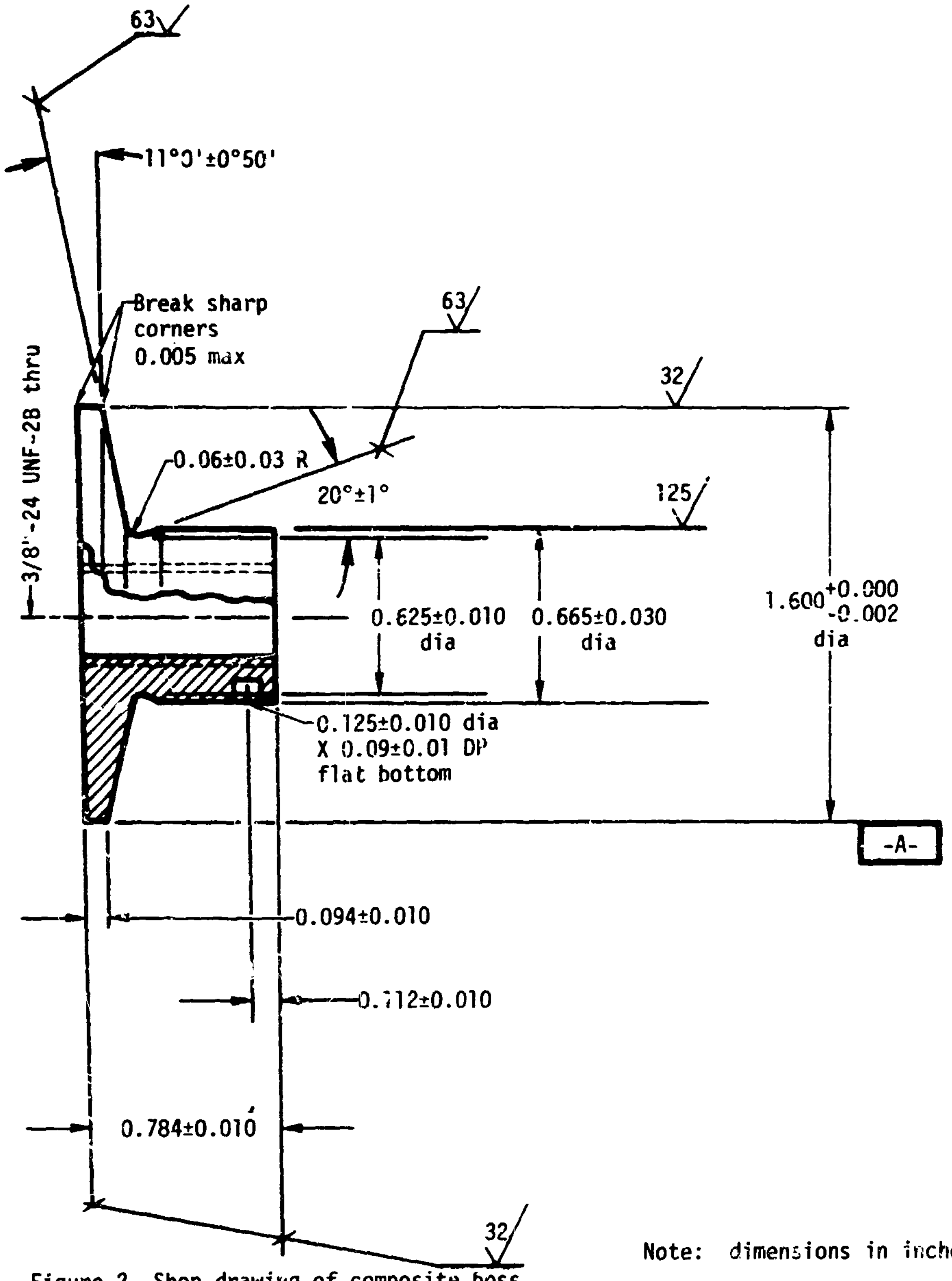


(a) Integral boss and metal liner



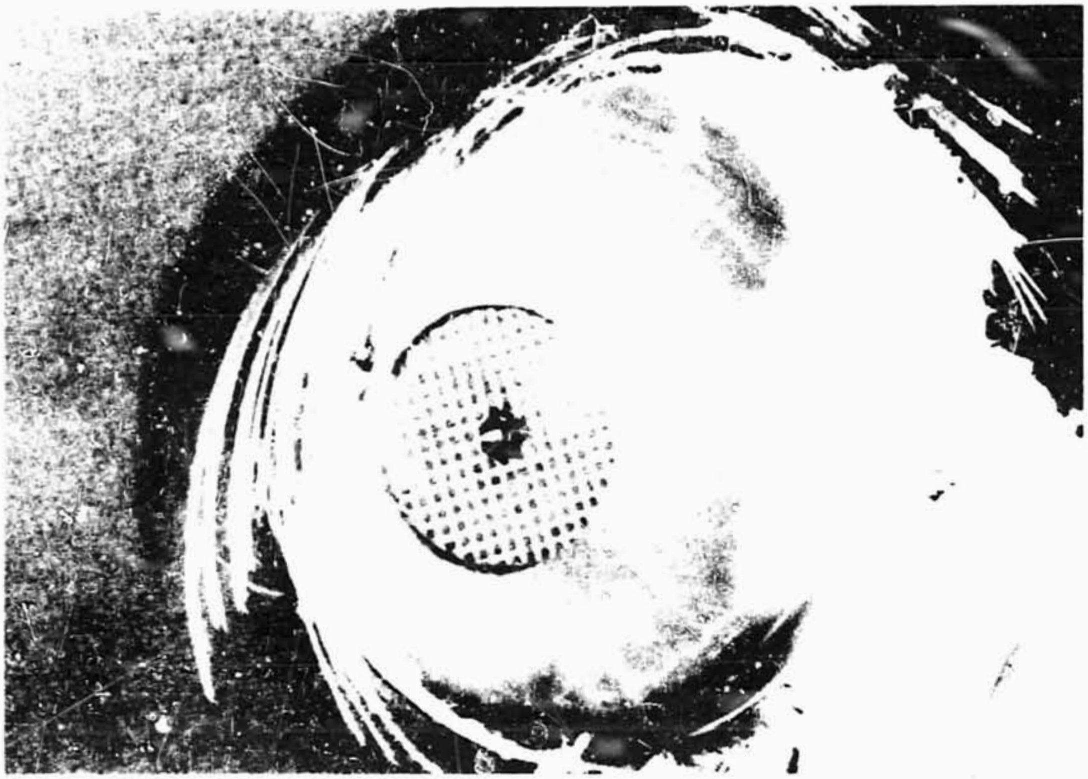
(b) Interferences fitted boss in polymer-lined vessel

Figure 1 Typical boss configurations in metal and polymer lined vessels

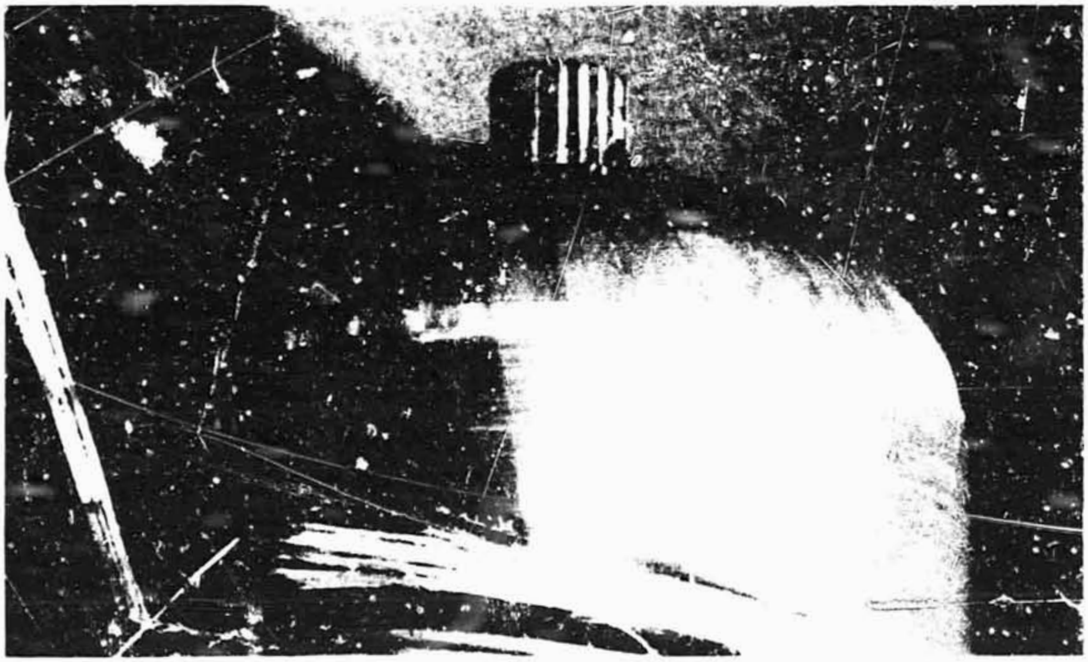


Note: dimensions in inches

Figure 2 Shop drawing of composite boss



(a) Interior side of boss



(b) Exterior view of boss

Figure 3. Three-dimensional quartz/phenolic boss in an ABS-lined pressure vessel.

Figure 4. ABS-lined pressure vessel; double winding pattern; hoop failure at 36.8 MPa.

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