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Development of a Family of Commercial Marine Composite Ball Valves

ABSTRACT The Navy spends millions of dollars each year maintaining valves of various types due to erosion, corrosion, and other service-related problems. In addition, the current wide variety of valve types used throughout the Navy results in over 60,000 allowance parts lists (APL's) (and nearly 8,000 vendors) in the supply system which are cumbersome and costly to maintain. Composite technology offers the potential for significant cost savings in maintenance due to corrosion/erosion resistance. The application of composite technology along with new valve designs which minimize and standardize valve component parts has the potential to significantly reduce valve life-cycle costs.

The Navy is developing a family of non-metallic composite ball valves, NPS 0.5-12, for shipboard applications. A NAVSEA standard drawing will be issued for procurement purposes. The benefits of this valve design are reduced life cycle cost through significantly reduced maintenance and supply support; reduced weight; compatibility with all piping, and potential reduction in costs associated with valve APL's, due to increased standardization. Selected sizes have been prototyped for laboratory and shipboard tests and evaluations (T&E).

This paper describes the research, development, test, and evaluation (RDT&E) and planned implementation of this family of valves, including Fleet backfit.

INTRODUCTION

Each year the Navy spends millions of dollars maintaining valves of various types for surface ships. Part of the cost of maintaining these valves is associated with the cost of maintaining the Allowance Parts Lists (APLs) for the valves. The total Fleet APL population for valves totals over 60,000, with nearly 8,000 vendors. Numerous types of valves, such as gate, ball, globe, plug, and butterfly, are used for the simple function of securing fluid flow, that is, as shutoff valves. Each of these valve types has thousands of APLs associated with it. Many of the systems in which these valves are installed have low to moderate pressures and temperatures, i.e. below 250 psig and 150°F. The Navy could realize significant cost savings associated with valve APLs and supply system logistics, if it could begin to standardize on a valve design for simple shut-off functions to replace the numerous valves currently used for that function.

Part of valve maintenance cost is associated with shipboard, Intermediate Maintenance Activity (IMA), and depot level repairs of valves. Valves require repair for numerous reasons. Recent studies by NSWC-CD Code 61 indicate many bronze valve repairs are done due to deterioration of metallic trim components, such as discs and seats, primarily by corrosion/erosion in sea water systems, or deterioration of non-metallic seats, packing, gaskets, and O-rings due to wear. Corrosion/erosion of bronze valve bodies is a less frequent reason for valve repair, but can and does occur. Gate, globe, and butterfly valve discs are subject to corrosion/erosion in seawater systems. In addition, bronze ball and plug valves have been notorious maintenance headaches in applications such as Collection, Holding, and Transfer (CHT) systems, which are a particularly aggressive corrosion environment. In many cases, indications are that corrosion and pitting of valve balls, plugs, and bodies serve to exacerbate scaling formation, resulting in rapid deterioration and "freezing" and associated unacceptably high stem torque loads for these valves. Figure 1 shows the typical scoring and scaling found on the ball of one of these valves, which had seized in service aboard the USS *John F. Kennedy* (CV 67).

Recently, a study was conducted by Sigma Tech on Navy valve repair costs. This study covered the period 1991 through 1996 and looked at logistics data and maintenance costs associated with various types of valves. Some of the results are summarized in Table 1. They show that the Navy has spent nearly 163 million dollars over the last 5 years in maintenance associated with four valve types.

Composite Valve Design Evolution

In the 1980's the Navy evaluated a commercially available composite ball valve to address some of the valve corrosion problems in the Fleet. The most viable existing commercial valve design for Navy applications was determined to be one that consisted of a compression-molded, chopped-glass, fiber-reinforced, vinylester body; a graphite-reinforced vinylester ball; TFE seats and stem seals;

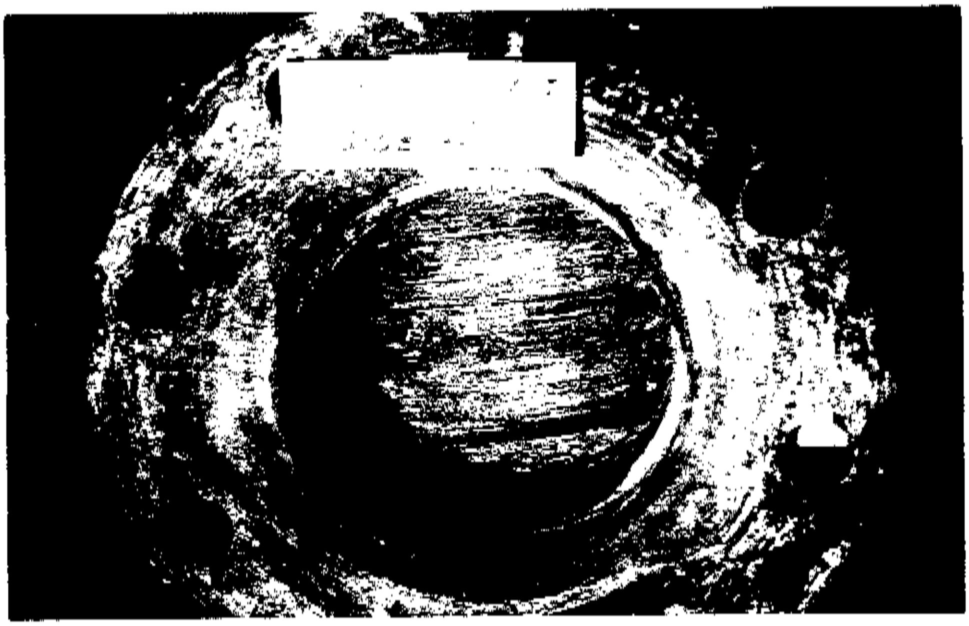

FIGURE 1. Bronze ball valve per MIL-V-24509 showing scoring and scaling of the ball

and a Hastelloy^{R} stem. The results of Navy laboratory evaluations of the NPS 3 and 6 versions of this valve showed the valve to be fairly rugged, but nevertheless, revealed some concerns about the performance limits of the valve in shock, fire, and under certain extremes of mechanical loading. The mechanical tests consisted of tension, compression, torsion, and bending, which subjected valve specimens to the design allowable stresses for 70-30 copper-nickel (Cu-Ni) piping; the strongest seawater piping used in the Navy at that time. The tests revealed that the valve body cracked under torsion, the valve flanges were susceptible to cracking if bolts were overtorqued during installation, the valve body can crack under water-hammer conditions (although water hammer is an undesirable condition for any piping system and can damage metal piping components as well), and the valve body also cracked and leaked during some full-scale fire tests in which the valve was pressurized and suspended several feet above a hexane pool fire. It was also quickly realized that in order for this valve to meet Navy shock requirements (MIL-STD-901-simulated bulkhead mounting) would required the fabrication of a steel bonnet to take the demanding "worst case" shock loads that Navy shipboard components may be exposed to one day.

TABLE 1

Valve Logistics Data & Maintenance Costs

Type of Valve	Fleet Quantity	Number of APLs	Maintenance Cost ($)
Gate	342,645	2,752	31,342,487
Globe	2,475412	5,339	90,430,410
Ball	261,344	3,664	12,431,969
Butterfly	294,990	1,902	22,717,879
Plug	28,909	510	3,074,042
Total:	3,404,300	14,167	162,996,787

Note: This information was derived from Maintenance Material Management (3-M) data files using the ORS program.

Nonetheless, the valve was given approval for operational testing in some non-vital shipboard systems. Subsequent ship installations in CHT systems, as well as pierside and dry-dock service in the Charleston Naval Shipyard during the 1980's and early 1990's, have shown this valve to perform well under normal conditions and require little, if any, maintenance relative to the conventional bronze valves that it replaced. However, achievement of maximum benefits from this technology required a broader application of the valve into more as well as vital shipboard systems, such as firemain and seawater cooling. This would clearly require a more durable version.

Meanwhile, as part of the new LPD 17 ship design, NAVSEA was considering the use of titanium piping for firemain and seawater systems to address piping erosion/corrosion issues. Composite valves were being considered to complement the titanium piping as an affordable alternative to titanium valves and, unlike bronze, are completely galvanically compatible. Since titanium pipe is capable of imparting loads to connected components in excess of that of the 70-30 Cu-Ni pipe loads, to which the original commercial valve was tested, a valve design which could support this factor, as well, was needed.

Considering the operational successes but dynamic loading concerns mentioned above, a modified commercial valve design was derived by the Naval Surface Warfare Center-Carderock Division (NSWC-CD) in Annapolis, MD. The design would retain many of the internal valve characteristics (e.g. seat and ball interface) of the installed commercial valves but "short-circuit" most of the mechanical loads around the valve via a tie-rodded arrangement, as well as employ a more durable filament-wound housing. The valve would employ commercial (ANSI Class 150) flange bolt patterns, to permit use with commercially available titanium pipe flanges in lieu of more expensive, unique flanges to Navy patterns. This ANSI approach would also allow for valve use in commercial piping applications, where stronger and more fire-resistant composite valves than are currently commercially available might be needed. For this latter reason, this design might be considered "dual use" in nature.

A commercial composite valve manufacturer was tasked to prepare the detailed valve drawings based on this conceptual design. Sizes NPS 1, 3, 6, and 12 were chosen for prototyping and laboratory evaluation. Testing of the NPS 1 and 3 sizes was successfully completed earlier this year and a production level drawing was developed for sizes NPS 0.5 through 4 based on these tests. NAVSEA approval is pending. NAVSEA is expected to extend the drawing and approval to eventually cover valve sizes NPS 0.5 through 12.

The commercial marine composite valve offers a number of advantages relative to current metal valves:

- Does not corrode in seawater
- Is extremely lightweight—typically only 20-30% of the weight of a metal valve
- Can handle dirty service (sewage) with minimal clogging
- Compatible with all pipe flange materials—no galvanic corrosion
- Has quick manual and automatic operation (quarter-turn versus multi-turn operation of gate and globe valves)
- Has quarter-turn operation—lends itself easily to automatic valve operation, resulting in simpler actuator options and greater compatibility with future "Smart Ship" designs
- Has reduced tendency to seize or increase stem operating torque
- Easy to maintain—no grinding/lapping of metal seats. Planned Maintenance System (PMS) reduction since corrosion and seizing reduced.
- Cost less than gate and globe valves. Comparable to existing ball valves.
- Valve design requires modification of only one part—the ball—to convert the valve into a flow control valve, thus allowing for greater standardization and reduction of valves and valve parts.
- The valve is shorter than many current MIL-V-24509 ball valves and most globe valves. This permits backfit into existing piping systems without pipe modification. Adapter plates for MIL-V-24509 mods will be part of the composite valve drawing package, and can be provided attached to the valve by the manufacturer for direct backfit.

Documentation Approach

Since an industry search of candidate composite valves for Navy applications revealed no commercial valves which could meet the shock, flexure and fire requirements necessary for the valve to satisfactorily perform in the Navy environment, and in view of the need for quick implementation of this "fix" into the fleet, it was determined that the modified commercial design should be institutionalized in the form of a NAVSEA standard drawing. A performance specification or commercial standard was not considered feasible since this valve was going to be significantly different than any composite valve that any manufacturer was already tooled up to produce or had experience with. Also, in view of a shrinking Navy market for piping components, among other things, it was felt that development expenditures by industry in general would not be seen by them to be a good business decision, and Navy sponsoring of a consortium of manufacturers would be untenable.

Therefore, as mentioned above, it was determined that funding of one prospective vendor to develop prototypes—with the agreement that all design details would be public information—would permit and promote eventual competitive procurements and, at the same time, allow more Navy (single point) control of the developmental process; the latter aspect serving to simplify and hasten the test development and document (drawing) approval process (extensive corrosion/seizing problems in the fleet, as well as impending LPD 17 ship specification completion, warranted an expeditious solution and immediately referable documentation).

As alluded to, the impact of the NAVSEA standard drawing approach on competition, compared to a commercial standard, was anticipated to be favorable, or at least neutral. It was determined, based on the expected simplistic final valve design and limited early surveys of the industry, that the valve's production would be possible by a broad spectrum of manufacturers, even some not primarily in the valve manufacturing industry. This determination has been confirmed by favorable reviews of draft versions of the valve design forwarded to a limited number of interested potential manufacturers. Some of these manufacturers are primarily pipe and pipe fitting vendors and/or have never worked with composites.

The use of this approach is also considered to be a main contributor to the fact that the first issue of the "Commercial Marine Composite Ball Valve" NAVSEA standard drawing is being considered by the NAVSEA Standards Improvement Board (SIB) for approval at this writing—approximately just two years after concept approval. Although the first issue ("Rev _") only includes sizes up to NPS 4, lessons learned during development and testing of these sizes are expected to allow issuance of "Rev A" (adding NPS 6-12) in early 1998. The confidence gained in the NPS 1/2-4 prototype valve design, and the concurrent nature of the design, testing and drawing development evolution, also encouraged and facilitated inclusion of a drawing number (803-7057878) for these valves into the LPD-17 ship specification—well prior to finalization of many of the valve design details. This inclusion was imperative if the advantages of such a valve were to be realized in this next class of Navy ships, not scheduled for start of construction until an expected two years after ship specification finalization. (The drawing number above is just applicable to the LPD-17 ship contract. A different number will be issued after SIB approval. The SIB approved drawing number will be considered the NAVSEA standard drawing number for future reference purposes for fleetwide applications, other than for the LPD-17. Expected approval is October, 1997 and copies of the drawing may be requested by calling [207] 438-2445).

Other benefits of pursuing a NAVSEA standard drawing format were also realized. For instance, during the prototype development process the prototype manufacturing company needed to produce it's own production level drawings. These drawings were easily convertible into the NAVSEA standard drawing format, which was done concurrent with most of the testing phase. The result is a "Level III" format for easy production by potential manufacturer's, most of whom are probably unfamiliar with some or most of the materials and/or features. Also, as previously alluded to, prospective manufacturers, as well as Navy activities, could more easily review progress being made on the design, while development was proceeding. This allowed comments to be considered and revisions to be made before some prototype production and expensive testing was finalized. In addition, the Government policy of converting detailed procurement specifications into performance specifications, at the time of this project, did not yet embrace drawings and, so, special scrutinization of a drawing, and the associated possible extra time inherent in the review and approval process, was avoided.

Despite this latter benefit, however, drawing "Notes" have been worded in the spirit of performance requirements so that the least amount of specifics are included. For instance, a wide range of material grades within the specified ASTM composite material standards have been approved for use. Also, a void sealing technique is mentioned in the drawing as a possible means of ensuring successful first article hydrostatic pressure testing but is not required, allowing other means better suited to a particular manufacturer to be used if leakage is evident during the first article pressure testing.

Essentially, an attempt was made to specify how the end product should perform vice how the manufacturing process should be conducted. Any particulars in the drawing requirements, such as some material, dimensions, etc. were justified on the basis of necessary functionality, fluid compatibility, standardization, interchangeability, dynamic loading and environmental (such as fire) requirements, to result in the most cost-effective product from the knowledge at the time. Specification of some dimensions and materials, based on Navy testing, also helps reduce testing requirements by prospective manufacturers to qualify an unknown product

System Applications

A review of MIL-STD-777 was conducted with particular note of the maximum pressures and temperatures of various shipboard systems. A total of 70 systems were reviewed. Our preliminary analysis indicates that the systems indicated in Table 2 are potential systems for composite ball valves, based on maximum system pressure and temperature, and fluid compatibility.

Types of Existing Valves which can be replaced by Composite Ball Valves are in Table 3. The table lists valve types, their materials of construction and the various systems where the composite ball valves may be substituted, based on performance capabilities. Globe valves are included because there are throttling balls available.

Valve Description

The 3-inch prototype composite ball valve is shown in Figure 2. The valve housing is made from E-Glass filament wound epoxy to ASTM D 2996, wound at an angle of plus or minus 54°. The ball is compression molded and made of graphite-reinforced vinylester. The valve has two identical chopped glass-reinforced, compression molded, vinylester inserts which, when inserted into the ends of the filament wound valve housing, form a part of the face-seal for the mating flanges. There is an O-ring seal between

TABLE 2

Potential Composite Valve Systems

SYSTEM	System category as listed in MIL-STD-777	PRESSURE, psi. Max	TEMP. deg F Max	REMARKS
Seawater	D-1, D-3	250	150	
Fresh Water	C-1, C-2	200	250	
Fuel Oil	E-3, E-4	200	125	*
Lubricating Oil	F-1	150	250	*
Hydraulic Oil	G-2, G-7	200	150	*
JP-5	I-1	200	100	*
Gasoline and Cleaning Fluid	H-1, H-2	150	150	*
Cooling (electronics)	L-1	150	150	
Seawater - Washdown	M-1	200	100	
Sprinkling System (dry)	N-1	175	125	*
Sprinkling System (wet)	N-2	175	125	*
Waste Water	R-1	50	150	
Chemical Drains	R-2	30	150	
Drains and Vents	R-3	50	150	
Sewage Collection	R-4	50	150	
Aqueous Filming Foam	S-1	250	125	*
Stripping	U-1	150	125	*

* Design modification(s) are being evaluated to adopt this valve for fire hazardous applications.

TABLE 3

Candidates for Composite Valve Replacement

Valve Type	Valve Spec/Dwg	Material for Body	Material for Disk, Ball, Plug, etc.	Material for Seat	Used in Systems listed in MIL-STD-777
Globe	MIL-V-22052D	Cast or Forged Carbon or Alloy Steel			E-4, F-1, G-7, J-9
	MIL-V-24109A	Alum-Bronze			R-1, R-4
	803-1385541G	Bronze	NI-CU	NI-CU	C-1, C-2, I-1, R-1
	803-1385623G	Bronze	TFE	NI-CU	C-1, C-2, D-1, D-2, D-3, E-3, G-7, I-1, N-1, N-2, S-1
	803-4384536F	Bronze	NI-CU	NI-CU	C-1, C-2, D-1, D-2, D-3, E-3, G-7, I-1, J-4, R-3, L-1, M-1, N-1, N-2, R-1, S-1
Gate	MIL-V-1189	Bronze			C-1, C-2, D-1, D-2, D-3, E-3, G-7, I-1
	803-138-5714	Bronze	NI-CU	NI-CU	C-1, C-2, D-1, D-3, G-7, I-1, J-4, J-8, K-3, L-1, R-1, S-1
	803-2177917D	Bronze	NI-CU	Bronze	M-1, N-1, N-2, R-1, R-2, S-1
	MIL-V-24509	Bronze or Ni-Cu			R-3, R-4
	803-5001003A	Cu-Ni, Bronze, CRES, Steel	TI, CRES	TFE	C-1, C-2, D-1, D-2, D-3, E-3, F-1, G-7, I-1, J-4, L-1, M-1, R-1, R-2, S-1
	803-5001004A	Bronze, Cu-Ni Alloy	TI, CRES	TFE	C-1, C-2, D-1, D-3, I-1, J-4, M-1, R-1, R-2, S-1
Ball	MIL-V-24509	Bronze or Ni-Cu			R-3, R-4
	803-5001003A	Cu-Ni, Bronze, CRES, Steel	TI, CRES	TFE	C-1, C-2, D-1, D-2, D-3, E-3, F-1, G-7, I-1, J-4, L-1, M-1, R-1, R-2, S-1
	803-5001004A	Bronze, CuNi Alloy	TI, CRES	TFE	C-1, C-2, D-1, D-3, I-1, J-4, M-1, R-1, R-2, S-1
Butterfly	MIL-V-24624	CRES, Ni-Al-Br			C-1, C-2, D-1, D-3, E-3, E-4, F-1, G-7, I-1, L-1, M-1, N-1, N-2, S-1

each of the ball seats and the inserts. There is also an O-ring around each of the inserts, to serve as a seal between the insert and the filament wound valve housing. The O-rings are Viton^R. The ball seats and stem seals are glass-reinforced TFE. The stem is 316 stainless steel (production valves will be upgraded to Hastelloy C^R for improved corrosion resistance in passive seawater) and the stem gland is Hastelloy C^R. The gland bolts are 304 stainless steel. The body is through-bored for ⅝″ grade 400/405 Monel^R tie rods to an ANSI B16.5, 150 lb. commercial flange bolt pattern. Production valves will be permitted to use housing material grade variances to the prototype which are within required strength limits. Valve sizes 2-inch and below are full-ported, i.e. the ball bore is the same as the pipe ID. Valve sizes 3-inch and above are reduced-port valves. However, a full-ported valve can be made by using the valve housing of the next larger valve along with special full-bore inserts. For instance, a full-bore 6-inch valve can be made from an 8-inch valve housing. The full-bore inserts will be part of the drawing package.

Summary of Tests

Each of the following mechanical tests were conducted on NPS 1, 3 and 6 valve prototypes:

1) Hydrostatic Pressure.
2) Pure tension, compression, bending, and torsion.
3) Shock per MIL-S-901D
4) Vibration per MIL-STD-167
5) Low-cycle fatigue
6) Valve Cyclic Actuation
7) Strength of machined penetrations for stem packing gland bolts
8) Breakaway stem torque measurements

HYDROSTATIC PRESSURE

Each of the valve specimens tested below was hydrostatically pressurized to 375 psig (1.5 times the maximum rated design pressure of 250 psig) while fully open and with the ball closed. No exterior leakage, leakage through the valve when closed, nor damage, was detectable. The valves were tested with the ends free to axially expand, and were not restricted or sandwiched between spools or plates. This was considered a more severe test than with the valve ends restricted since restrictive testing tends to promote sealing.

PURE TENSION, COMPRESSION, BENDING, AND TORSION

Piping components, including valves, can undergo significant stresses in the shipboard operational environment for various reasons, including hogging and sagging or prestressing due to improper pipe alignment and support during installation. As a minimum, a valve should be capable of withstanding the maximum design allowable stresses

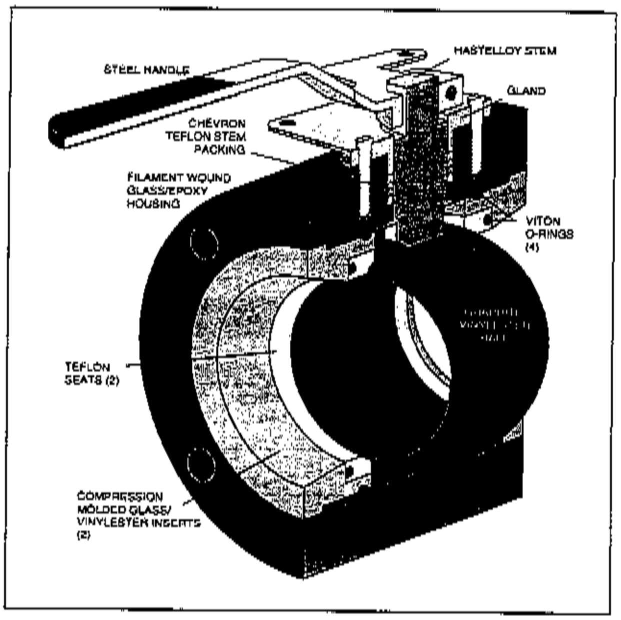

FIGURE 2. 3-inch composite commercial ball valve

permitted for a piping system, that is, the maximum static stresses the piping is allowed to see in a normal operating environment plus a factor of safety. Ideally, a valve should be capable of withstanding any load that the piping is capable of imparting to the valve. This load is referred to as the pipe limit load, and varies with pipe size, schedule, and type. The loads selected for evaluation were based on the limit loads of Schedule 10, Grade 2 titanium (Ti) pipe, which is the anticipated piping material for new LPD 17 seawater piping systems and possible fleetwide applications in the future. These loads, of course, are larger than the corresponding limit loads for both 90-10 and 70-30 Class 200 Cu-Ni pipe, and are summarized in Table 4. One each of the NPS 1, 3 and 6 valves were stressed in pure torsion, bending, tension, and compression, primarily to test the strength of the filament-wound valve housing/tie rod design.

Tensile loads were applied in the axial direction of the valves, as were compression loads; bending loads were applied in a plane perpendicular to the tensile load; torsional loads were applied with the moment of torque around the axis of the valve. The test rig for the bending load tests is shown in Figure 3. In all cases the tie-rodded valves were installed between steel spool pieces as shown in Figure 3, and pressurized hydraulic cylinders were used to create the required loads, except for the torsion test. In the torsion test the valve was installed between two flange faces, one of which was fixed, and the other rotated. The valves underwent fully reversed torque loading during the torsion test.

Each of the valves was in the open position and hydrostatically pressurized to at least 200 psig during these loading tests (the NPS 1 and 6 valves were pressurized to 250 psig while the NPS 3 valve was pressurized to 200 psig), except for during the compression test. During the compression tests the valves were tested with 0 psig internal pressure to prevent internal pressure effects from offsetting the axial compressive loads. The valves passed all of the load tests outlined above with no visible damage to the valve, internally or externally, or any sign of permanent leakage.

TABLE 4

Pipe Limit Loads

Pipe Size,NPS and Material	Tension & Compression (lbs)	Bending (ft-lbs)	Torsion (ft-lbs)	Shear (lbs)
1 Cu-Ni (90-10)	4343	146	112	1737
3 Cu-Ni (90-10)	17352	1594	1226	6941
6 Cu-Ni (90-10)	40478	7095	5458	16191
1 Cu-Ni (70-30)	5212	175	135	2085
3 Cu-Ni (70-30)	20822	1913	1471	8329
6 Cu-Ni (70-30)	49819	8732	6717	19928
1 Ti Sch 10, Gr 2	14454	472	363	5782
3 Ti Sch 10, Gr 2	44598	4083	3140	17839
6 Ti Sch 10, Gr 2	95639	16813	12933	38256

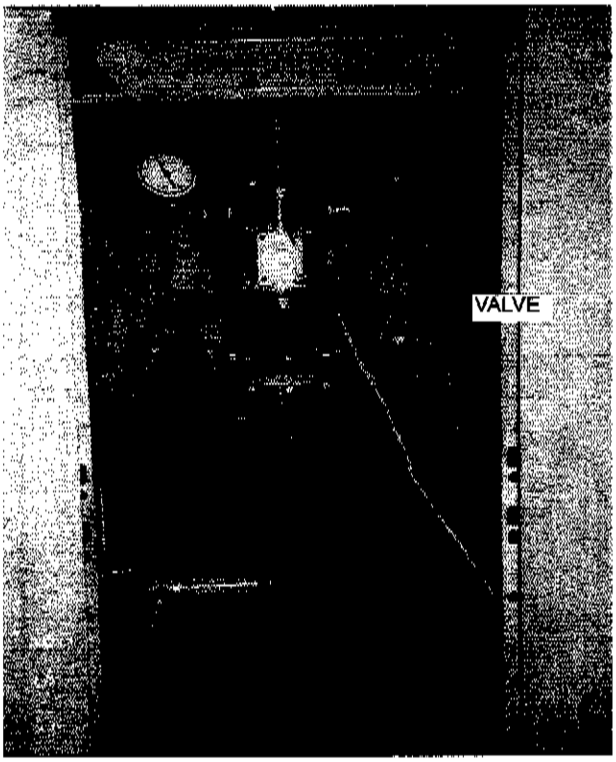

FIGURE 3. Test rig for bending load tests

SHOCK

One each of NPS 1, 3 and 6 valves, additional to those load tested above, underwent a series of shock tests per MIL-S-901D. The shock configuration for the 3-inch prototype is shown in Figure 4. The setup simulated a bulkhead mounting scenario in which the valve is subjected to a static bending load.

The valve was mounted on a steel strongback. The 3-inch valve was the first of the prototypes to go through laboratory evaluation and, at the time, NAVSEA was still considering use of Schedule-5, Grade-2 unalloyed Ti pipe for all seawater systems. A three-inch Schedule-5, grade-2 titanium pipe spool, approximately three feet in length, was bolted to the other end of the valve, with a 170 lb dummy load bolted to the far end of the Ti spool. The 170 lb weight, along with an internal pressure of 200 psig, resulted in a longitudinal stress at the pipe flange weld roughly equal to the allowable stress in the ship specifications for pressure and weight stress. The Dynamic Design Analysis Method (DDAM) as it applies to surface ships was used to calculate the shock stress. DDAM was used because it is the Navy's specified analytical procedure for qualifying non-testable equipment to shock requirements. Elastic-plastic shock design values appropri-

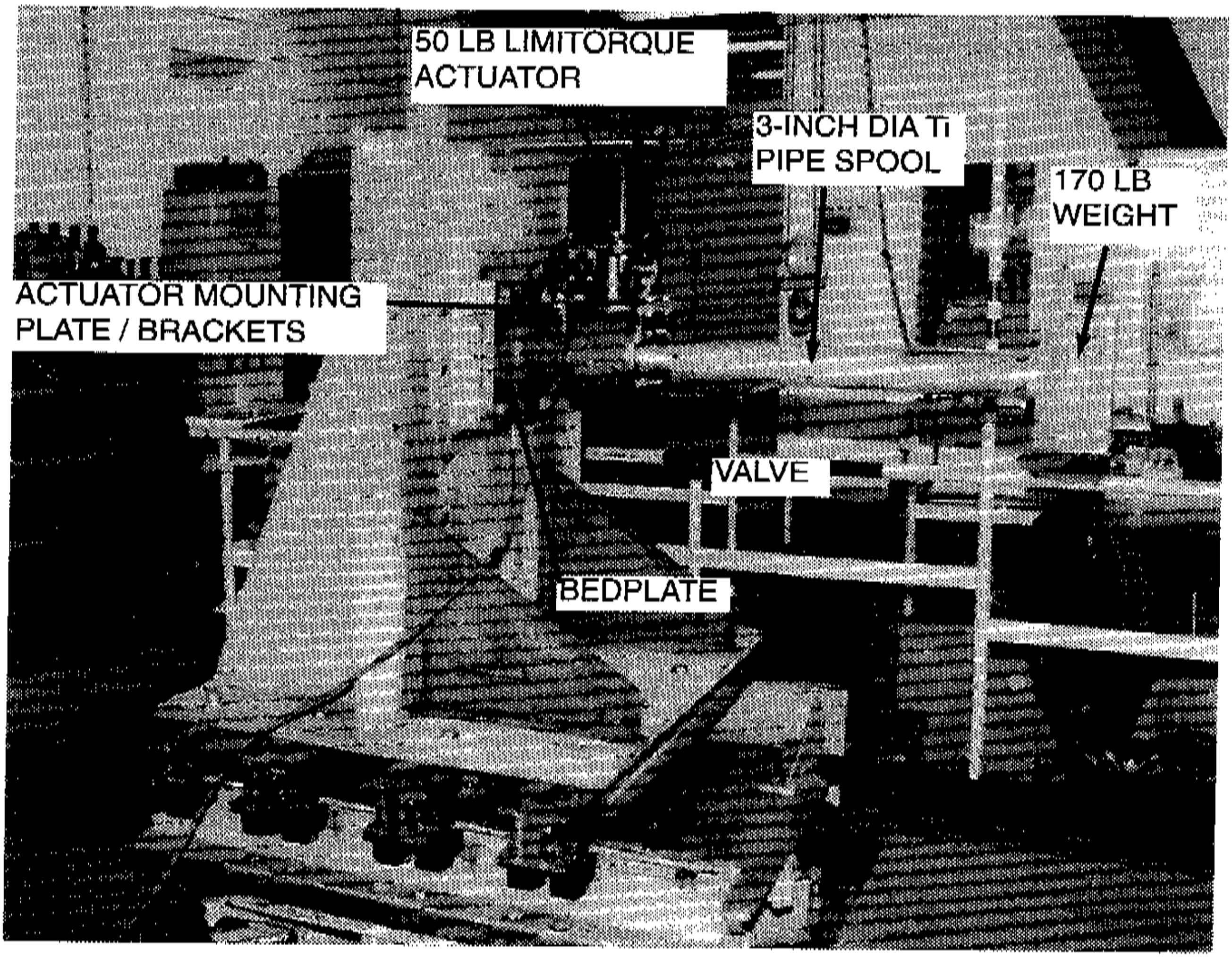

FIGURE 4. Shock test assembly

ate for hull-mounted equipment were used. The calculated shock stress was the maximum allowable for Schedule 5, Grade-2 titanium.

A Limitorque^R LY-1001 actuator weighing 50 lbs was mounted to the valve stem, but the load was short-circuited around the valve by means of a ⅜-inch steel bracket which was tied into each end of the top two tie rods on the valve. The actuator was not connected for cycling or operation during the test.

The valve was pressurized to 200 psig. It was hit a total of 12 times. Six blows were with the actuator mounted in the vertical direction (three blows with the valve open and three with the valve closed) and six with the actuator mounted in the horizontal direction (again, three with the valve open and three closed), i.e. rotated 90° from the original position.

The 3-inch composite prototype valve passed the shock test. At the end of the series of shock blows, there was no visible damage to the valve. It was capable of holding 200 psig with no leakage. The Limitorque actuator also remained structurally intact. The only observable damage was a small screw which came loose inside the housing.

Similar shock tests were done on the NPS 1 and 6 valves, with weight and bending loads corresponding to the maximum calculated shock stress allowable for NPS 1 and 6 Schedule 10, Grade 2 Ti pipe. Full-faced Garlock gaskets were used for these tests because experience with 3-inch valve testing, including fire, had shown this to be the gasket material of choice Actuator loads were simulated with steel weights. There was some minor chipping of one of the 6-inch valve inserts during shock. As a result, the 6-inch valve has undergone a minor re-design to strengthen the insert, reduce the insert loading under shock, and provide an additional factor of safety.

VIBRATION

The same composite valves which had been shocked were then vibrated per MIL-STD-167. The NPS 3 valve is shown in Figure 5. The valves were open and fully pressurized to at least 200 psig during vibration. The valve assemblies were vibrated with the Limitorque actuator or steel dummy actuators mounted vertically on the valve, which was bolted to a strongback. The valves passed the vibration test with no visible damage or leakage.

LOW-CYCLE FATIGUE

Each of the composite valves underwent a low-cycle bending fatigue test. During these tests the valves underwent fully reversed bending while pressurized to at least 200 psig. The valves were mounted so that the stem assemblies were in the plane of the bending load. The test rig for the 3-inch valve is shown in Figure 6. The design allowable stress for Schedule 10, Grade 2 Ti pipe was determined for 7,000 bending cycles, for each of the three pipe sizes. The stress was then doubled, representing a safety factor of 2, based on stress, and each of the valves was cycled for at least 7,000 cycles. There was no observable leakage or damage to the valves during this test, except for the NPS 6 valve, which experienced some minor chipping at the shoulder of one of the compression-molded inserts. The NPS 6 test had been performed with non-full faced Garlock gaskets at the flange joints. The test was re-run with full-faced Garlock gaskets and the valve passed with no damage. In addition, the NPS 3 valve underwent a cyclic fatigue test at a bending stress which represents the design allowable stress for Schedule 5, Grade 2 Ti pipe for 7,000 bending cycles. The valve was cycled for 140,000 cycles, for a safety factor of 20 on cycles. There was no leakage or damage during this test. Each of the composite valves has undergone a low-cycle bending fatigue test.

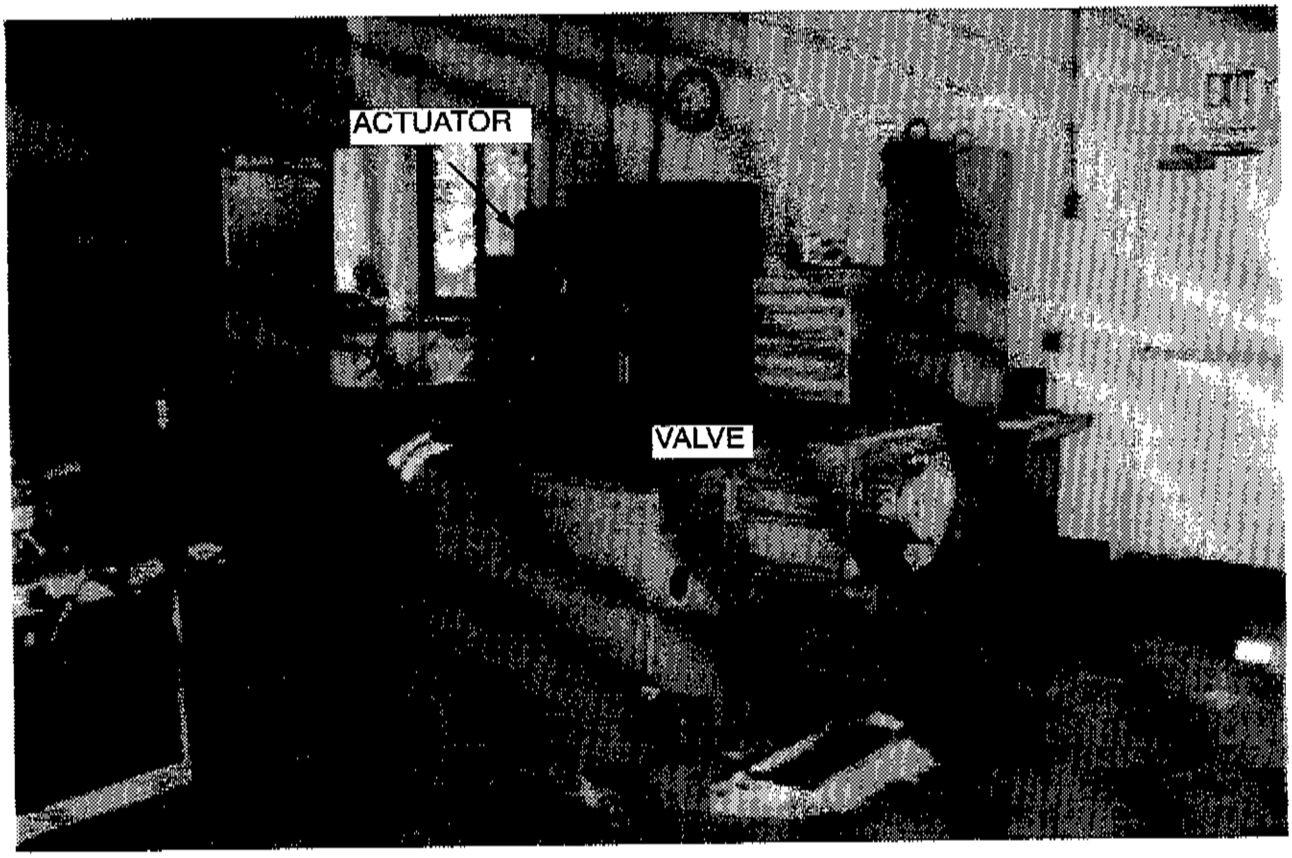

FIGURE 5. Vibration test assembly

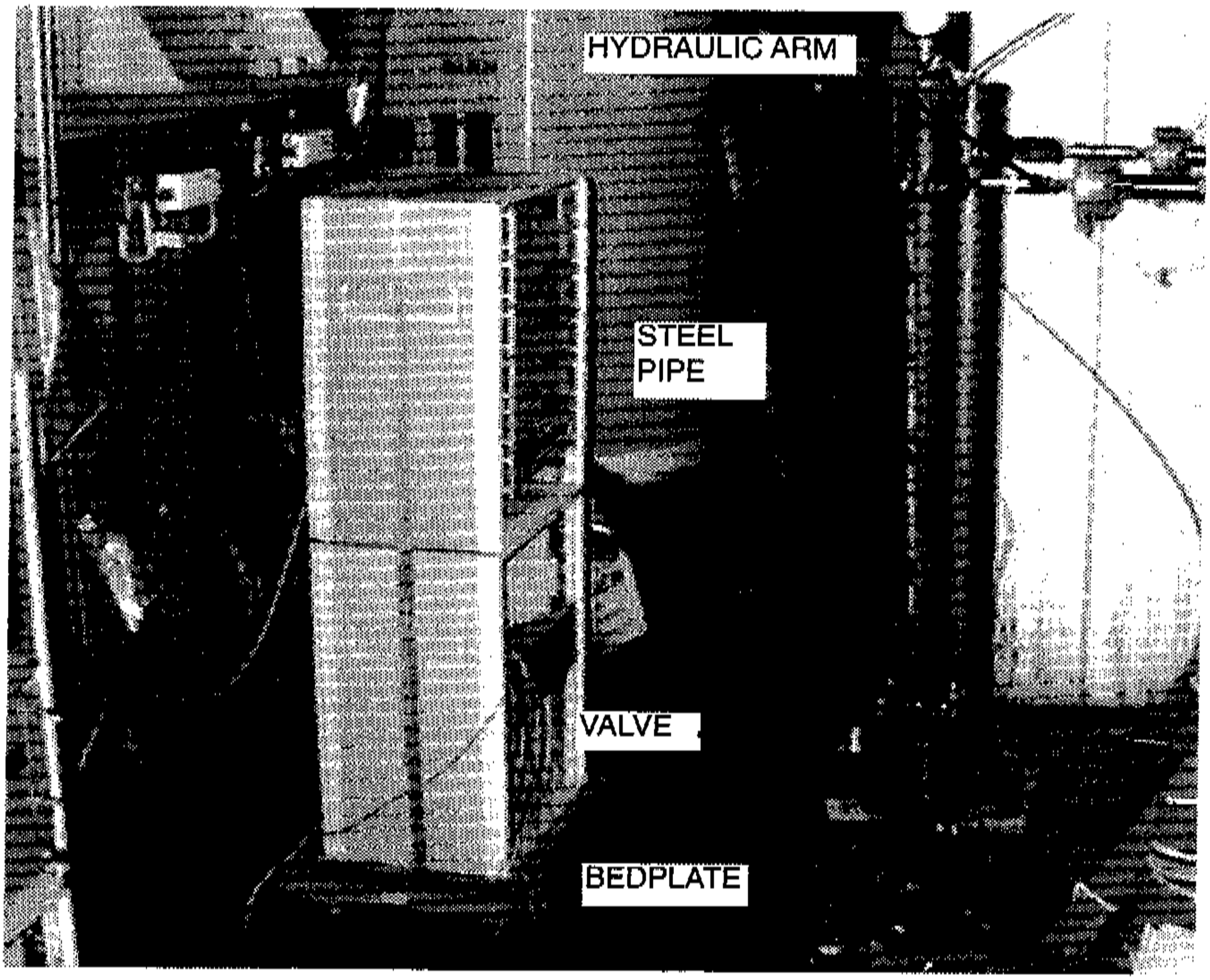

FIGURE 6. Low-cycle fatigue test assembly

VALVE CYCLE ACTUATION

Each of the valves was pressurized to at least 200 psig and cycled open and closed a total of 2,000 times in accordance with MIL-V-24509 requirements. The valves successfully passed these actuation tests with no damage or leaks.

VALVE HOUSING STRENGTH FOR STEM GLAND BOLTS

Concerns over the strength of the drilled and tapped composite gland packing bolt holes required testing to confirm the design to be robust enough for field applications. Thread pullout and torque pullout tests were conducted on a stock piece of filament wound epoxy pipe identical to that used to fabricate the valve body. The stock material was drilled and tapped ⅜-16 UNC × 1″ deep in several locations. Both the thread pullout and torsion tests were conducted with the bolts threaded into the composite a distance of ¾″, the same as the composite valve design. For the pullout strength tests, the composite section was installed in an MTS machine and the bolts were pulled out of the composite section under tension. Seven pullout tests were done. The failure loads ranged from 6,530 to 8,500 lbs. and the average was 7,367 lbs. The failure loads during five torque tests ranged from 45 ft-lbs to 58 ft-lbs, with an average of 52 ft-lbs. During torque testing, two of the steel bolts sheared off at the heads prior to failure of the composite threads. It should be noted that the gland bolts are not subject to stresses other than that required to squeeze the TFE stem seat. In addition, the valve manufacturer has indicated that 30 ft-lbs is usually the maximum torque the bolts see in commercial usage. Based on these results, it was determined that the use of metal inserts for the stem gland bolts would not be necessary.

VALVE BREAKAWAY TORQUE TESTS

A series of stem breakaway torque tests was done to determine how many ft-lbs of torque are required to turn the valve under various conditions. Being a tie-rod design, the valve stem torque is somewhat a function of the tie-rod torque or other axial compressive piping loads, which results in greater squeeze on the ball. The tests were conducted on the NPS 3 composite ball valve which had previously been used for cyclic fatigue tests. Monel[R] tie rods were used. First, breakaway torque was measured when the valve was unpressurized, with 0 psig across the ball with several tie-rod torque levels and with several types of face gaskets. Next, breakaway torque was measured with various differential pressures across the ball up to and including 300 psig at a constant tie-rod torque of 75 ft-lbs and using only a full-faced rubber gasket. The results are summarized in Table 1. All gaskets were ⅛" thick. Non full-faced gaskets had dimensions of 5½" O.D. and about 3 to 3⅛" I.D. The non full-faced gaskets were cut so as to ensure surface sealing on the filament wound valve housing, and not just the compression molded inserts. Therefore, the gasket O.D. was equal to the bolt circle diameter minus the bolt hole diameter and came up to the edge of the bolt hole. The Garlock[R] series 3000 gasket, non full-faced, was effective in sealing the valve end-faces with a minimum of resultant stem breakaway torque. Because of these results, along with the excellent fire performance results of the Garlock gaskets described below, the Garlock series 3000 gasket, or equal, is recommended as the gasket of choice for use with the commercial marine composite ball valve. Later evaluations with the NPS 6 prototype valve, including stem breakaway torque, low-cycle fatigue, and shock testing indicated that a full-face Garlock or Garlock-type gasket was preferable to the non-full faced gaskets, because the loading is more widely distributed on the valve end face, resulting in more load sharing by the stronger filament wound valve housing. Full-faced Garlock or rigid Garlock-type gaskets, therefore, are recommended for use with all valves in the commercial marine composite valve family.

Fire Evaluations

Fire testing involves both small scale and large scale evaluations. Small scale testing for smoke generation, toxic products of combustion, and flame spread, using ASTM standards E 662 (for smoke and gas tests), E 162 (for flame spread), and ASTM E 1354, (ignitability and heat release, among other things) have been performed on the glass-reinforced thermosetting epoxy and vinylester composite materials used in the composite ball valve. The housing, which is the primary structure directly exposed to the flame, is made of the same filament wound epoxy material used in Glass-Reinforced Plastic (GRP) piping, currently specified in MIL-P-24608. The small scale fire tests results for this material have been previously reported. As with the GRP piping, an intumescent epoxy paint coating will be specified for the composite valve in order to reduce smoke and flame spread.

Laboratory evaluations of the commercial marine composite ball valve included full-scale fire testing. Discussions with the NAVSEA Damage Control and Fire Protection Group (Code 03G) personnel resulted in the selection of American Petroleum Institute (API) Standard 607 (Fire Test for Soft-Seated Quarter Turn Valves) of May 1993 as the standard which would be used to evaluate the fire performance of the NPS 3 commercial marine composite prototype valve. In order to establish a baseline for comparison, the same standard would be used to evaluate various types of existing Navy metallic valves. By looking at the performances of the existing Navy valves in the same test, and comparing them to the composite valve performance, a more accurate assessment of the impact of the composite valve on overall system performance can be made.

The following NPS 3 Navy valves were procured for fire evaluation, either directly from the vendor, or from the Navy stock system:

1) A Navy Standard Ball Valve per Dwg 803-5001004
2) A Sewage/Seawater Ball Valve per MIL-V-24509
3) A Gate Valve per MIL-V-1189, Type 1, Class 2
4) A Butterfly Valve per MIL-V-24624 (Type 3—non fire-hardened)
5) A Butterfly Valve per MIL-V-24624 (Type 4—fire-hardened)

API 607 establishes a well defined test procedure, which calls for a one-half hour fire test at temperatures from 1400-1800°F. The valve is closed and pressurized on one side with stagnant water. The test pressure depends on the valve classification. For the types of valves and rated service pressures in this evaluation, the API standard specifies a test pressure of 30 psig. The standard establishes pass/fail criteria for average leak rate both through the valve and externally from the valve (i.e. leakage from the valve body) during the fire and cool down periods. The cool down period is the time at which the fire is extinguished to the time at which both the valve body and bonnet stem are below 212°F. For the valves in this evaluation, the passing leak rates were a maximum of 25 ml/NPS/min or 75 ml/min average external leak rate and a 100 ml/NPS/min or 300 ml/min leak rate through the valve. After cycling the valve open and closed against the test pressure, a post fire leakage is measured over a 5 minute period, both external to the valve body and through the valve. For the valves in this evaluation, the allowable post-operational test leak rates were 20 ml/NPS/min or 300 ml maximum through-valve leakage, and 25 ml/NPS/min or 375 ml maximum external body leakage. The API standard does not consider flange leakage to be part of the valve body leakage, and thus to run an API 607 test the valve flanges must be "fire hardened" so as not to contribute to measured leakage during the test.

An API 607 test loop was constructed at the NSWC-CD Annapolis NIKE site facility. A schematic of the test loop is shown in Figure 7. A more detailed view of the typical valve installation is shown in Figure 8.

Each test valve was typically mounted with the stem/handle assembly sideways, at 90° to the pipeline. Thermocouples were mounted 1-inch below the valve body and 1-inch below the stem seat. In addition, thermocouples were mounted to the valve body (at the center of the body under the valve) and on the stem bonnet (under the bonnet). All of the thermocouple locations were determined in accordance with API 607 requirements. In addition to the API thermocouples, a thermocouple was mounted inside the center of the upstream pipe spool, so as to measure the upstream water temperature. This thermocouple extended about 6 inches into the upstream pipe spool from the bronze capped end of the spool. Although API 607 did not call for such a thermocouple, previous fire test experience had shown that such a temperature measurement was a good indicator of when leakage, especially significant leakage, begins to occur, since a flowing water condition is established and the water temperature drops.

As mentioned, API 607 does not count the flange-joint leakage from flanged valves. Discussions with API representatives indicated that the use of spiral-wound gaskets (a combination of spiral wound graphite with 304 stainless steel) proved effective when used in combination with ASTM A453 Grade B660 steel alloy bolts, in "fire hardening" the flange joints and preventing leakage during the API test. The spiral-wound gaskets are non full-faced gaskets, i.e. the O.D. of the gasket is less than the diameter of the flange bolt circle. The initial test plan called for testing each valve with both conventional Navy cloth-rein-

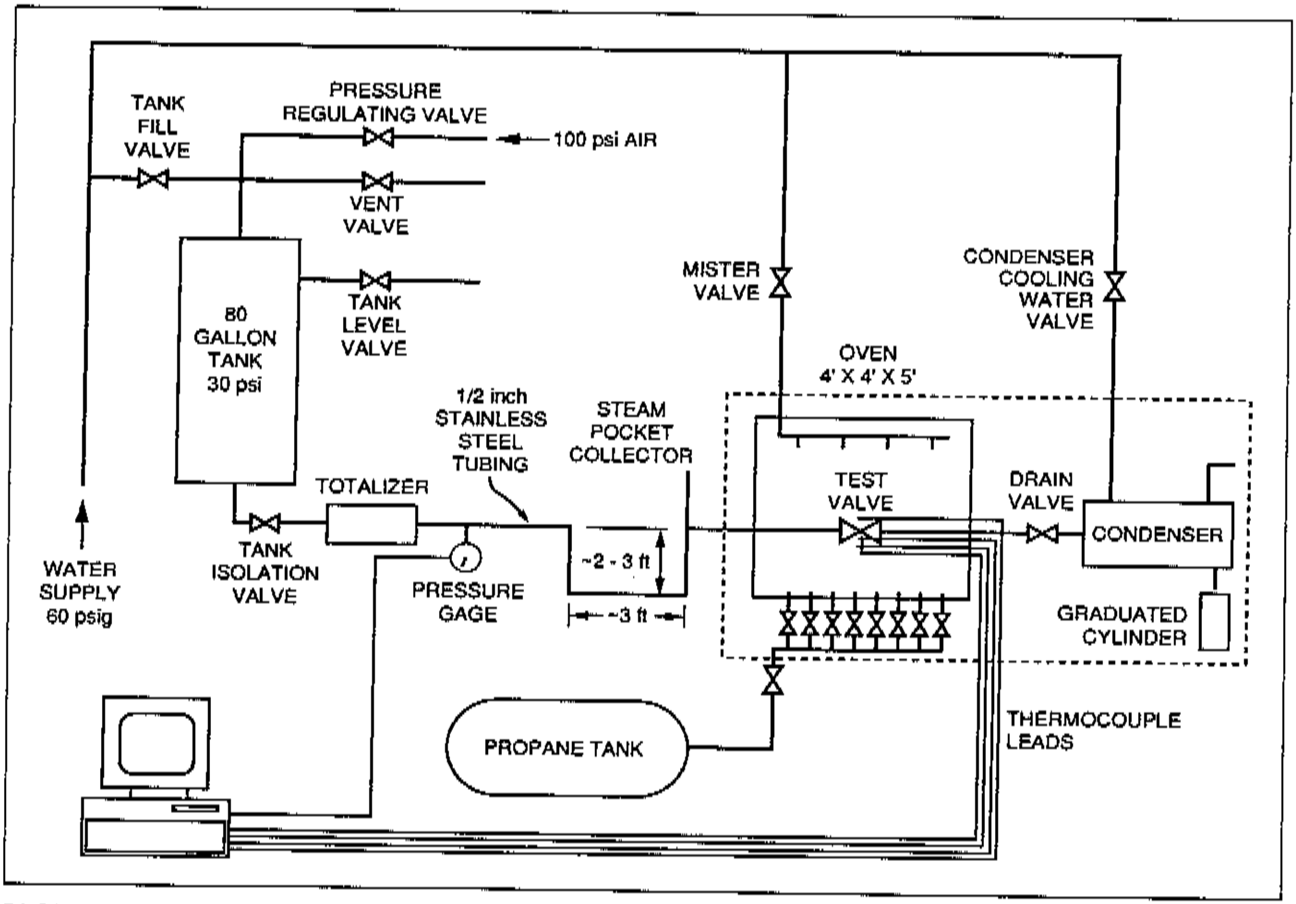

FIGURE 7. API 607 fire test loop

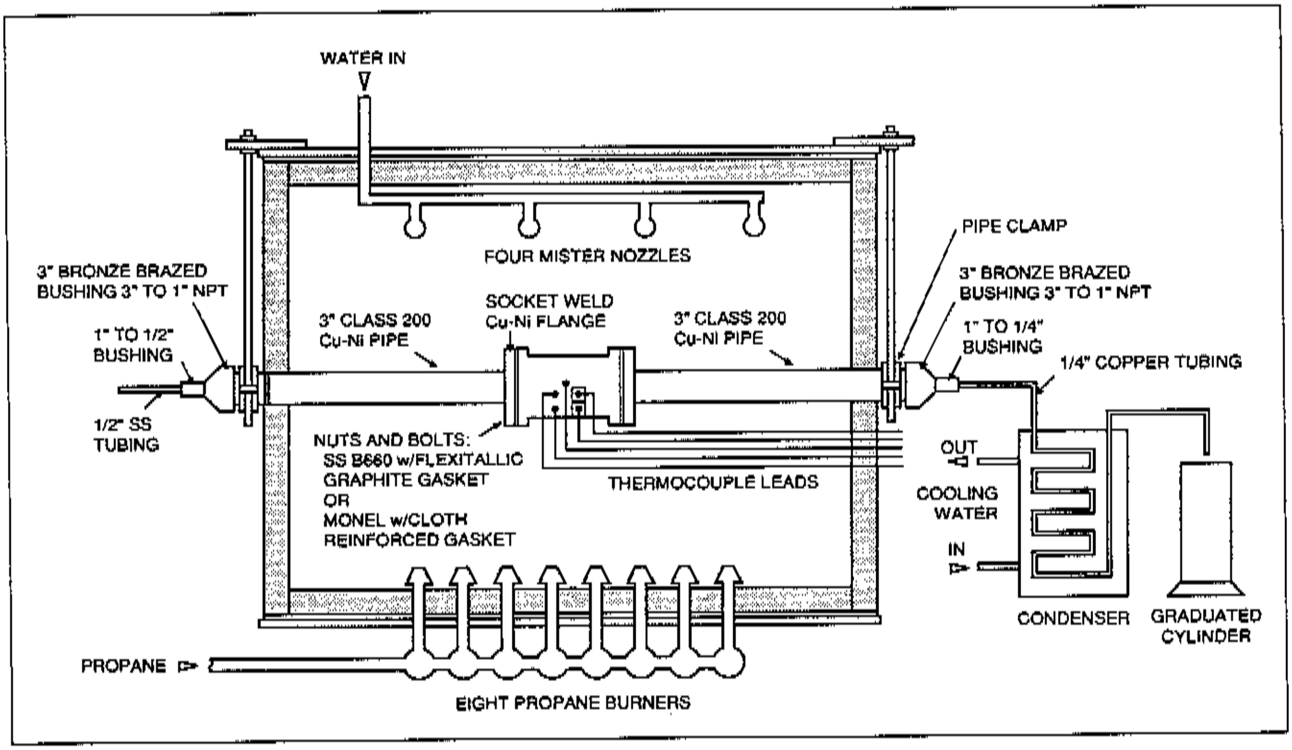

FIGURE 8. **API 607 oven and valve mounting detail**

forced rubber gaskets per HH-P-151 and Monel^{R} bolts as well as the spiral-wound gasket/B660 bolt combination. However, after the first test, in which a non fire-hardened Navy butterfly valve was used with the conventional bolts and gasket, the decision was made to run all subsequent tests with the fire-hardened flange joint arrangement using the spiral-wound/B660 bolt combination, torqued to 140-150 ft-lbs. The leakage using the conventional gasket/bolts occurred so soon into the test and at such a rate as to invalidate the test. The leak was so great that the water spray from the upstream flange leak helped cool the valve and it was impossible to reach or maintain the API temperature requirements. When the subsequent tests were run with fire-hardened flange connections, reasonable test temperatures were achieved, and the relative strengths and weaknesses of the valves became more apparent.

Tables 6 and 7 summarize the results of the valve fire tests. Table 6 summarizes the overall leakage from the valves, including through-valve and external body. It also shows the initial leak time for each valve. Times are referenced from the time at which the average flame temperature reached 1400°F, which was considered to be the start of the test. Table 7 separates the external leakage from the through-valve leakage for both the fire/cool down period and the post operational test, and compares the results with the API 607 pass requirements. For almost all of the fire tests, the duration of the fire/cool down period was between 32 and 39 minutes. This means that, in order to pass the external leak requirement for the fire/cool down period (75 ml/min), the valves would have to leak externally less than a total of between 2.40 and 2.92 liters (0.63 to 0.77 gal), depending on the particular test

TABLE 5

Summary of 3-inch Valve Stem Breakaway Torque Tests

TEST 1

TIE-ROD TORQUE (FT-LBS)	STEM BREAKAWAY TORQUE (FT-LBS) FULL-FACED RUBBER (1/8")	NON FULL-FACED CLOTH/RUBBER (1/8")	NON FULL-FACED GARLOCK (1/8")
50	33	42	33
75	42	75	42
100	67	117	42

TEST 2

DIFFERENTIAL PRESSURE (PSIG)	STEM BREAKAWAY TORQUE (FT-LBS)
0	50
50	50
100	50
150	58
200	58
250	50
300	67

TABLE 6

Results of API 607 Fire Tests

Description of Test Assembly	Time to Initial Leak (Min)	Cause of Leak	Avg. Leak Rate (GPM)*	Post Fire Leak Rate (GPM)*	Total Leakage (Gal)*
Butterfly, Mil-V-24624 (NFH), HH-P-151 gaskets, Monel® bolts, 35 ft-lbs torque	5	Flange Gasket	3.40	N/A	103
Gate, MIL-V-1189, Spiral-wound gaskets, A453 B660 bolts, 140 ft-lbs torque	19	Bonnet Gasket	2.90	0.25	89
Ball, MIL-V-24509 Swg/Seawater, Spiral-wound gaskets, A453 B660 Bolts, 140 ft-	19	TFE Seal	2.70	7.20	81

cool down period. A review of Table 7 shows that only the MIL-V-24624 fire-hardened butterfly came anywhere near meeting this requirement. Similarly, for through-valve leakage during fire/cool down the total leakage that the valves would have to pass (300 ml/min) would be less than 9.6 to 11.7 liters (2.54 to 3.09 gal). Table 7 shows that all of the valves except one, the non fire-hardened butterfly per MIL-V-24624, met this requirement, although they did not all meet the post operational through-valve leak requirement of 300 ml.

The only valve which passed all of the API 607 requirements was the fire-hardened butterfly valve, MIL-V-24624. All of the other valves failed either the external leak requirements, the through-valve leak requirements, or both.

A post-fire inspection of the commercial marine composite valve showed that the TFE seats were in relatively good condition, and the downstream seat had not been destroyed as in the case of some of the metal valves. This is believed to be due to the insulative properties of the filament wound composite housing relative to the thermally conductive bronze housings used in the metal valves. The compression molded inserts were found to be cracked, but it was not known if this cracking occurred during the removal of the inserts from the filament wound housing or during the fire. The post-fire valve was disassembled and is shown in Figure 9.

TABLE 7

Summary of Leakage Rates for Valves in API 607 Fire

Valve	Total External Leak (liters)		Total Through-Valve Leak (liters)	
	Fire & Cooldown	Post Op Test	Fire & Cooldown	Post Op Test
Butterfly, Mil-V-24624 (NFH), HH-P-151 gaskets, monel bolts, 35 ft-lbs torque	420.13	N/A	N/A	N/A
Gate, MIL-V-1189, Flexitallic gaskets, A453 B660 bolts, 140 ft-lbs torque	370.93	4.75	0	0
Ball, MIL-V-24509 Swg/Seawater, Flexitallic gaskets, A453 B660 Bolts, 140 ft-lbs torque	374.71	134.37	2.36	1.87
Ball, Navy Standard Drawing 803-5001004, A453 B660 bolts, 150 ft-lbs torque	46.11	4.00	0.96	5.56
Butterfly, MIL-V-24624 (FH), Flexitallic gaskets, A453 B660 bolts, 140 ft-lbs torque	0.46	0	0.14	0
Butterfly, MIL-V-24624 (NFH), Flexitallic gaskets, A453 B660 bolts, 140 ft-lbs torque	73.81	2.10	21.20	5.50
Ball, Composite Marine, Garlock gaskets, A453 B660 bolts, 110 ft-lbs torque	149.51	56.78	0.10	0
Ball, Composite Marine, Garlock gaskets, A453 B660 bolts, 110 ft-lbs torque	221.42	113.55	1.32	0
Ball, Composite Marine, Simsite Inserts, Garlock gaskets, A453 B660 bolts, 110 ft-lbs torque	40.95	41.64	1.63	0.87
API Requirements	~3.00	0.375	~12	0.30

A second fire test was done using the commercial marine composite ball valve. Again, significant leakage did not occur until 28 minutes into the fire test, and most of it appeared to be coming from the upstream flange joint. The valve was again successfully cycled after the fire. A post-fire inspection revealed that there was some cracking of the compression molded inserts, which is believed to have occurred during the fire/cool-down period.

A third fire test was done on the commercial marine composite ball valve. In this test the valve inserts were replaced with inserts machined from Simsite® 375, a glass reinforced epoxy material which is not compression molded, but laid up in two-dimensionally reinforced plies. A leak of some sort was detected at about 17 minutes into the fire, although the post fire leak rate measured somewhat less than the conventional (compression molded) inserts. The leak at 17 minutes is somewhat questionable, since the time/temperature data show a temperature recovery (increase) after the initial drop. Nevertheless, it was decided to mark the 17 minute point as an initial leak time for this test. The valve again successfully passed the post fire cycle (open/close) test. A post-fire inspection of the Simsite® inserts revealed that they had delaminated. Overall, however, there appeared to be no significant benefit to the Simsite® material over the conventional compression molded inserts used in the first two valves.

In summary, the valve fire tests showed that the commercial composite ball valve compared favorably to the other metallic Navy valves, in terms of time to leakage, and total leakage, both exterior to the valve body and through the valve. While it did not pass the challenging performance requirements of API 607, in two of the three tests, it came close (within 2 to 5 minutes) of meeting the requirements. None of the other metallic Navy valves except one, the MIL-V-24624 fire-hardened butterfly valve, strictly passed the API 607 requirements or approximated the test results of the commercial marine composite ball valve, for that matter. Most of the failures were due to damage to the TFE seats or body gaskets in these valves.

Based on these fire test results (as well as the successful mechanical performance detailed above), the commercial marine composite ball valve has been given approval for use in seawater and freshwater (other than potable water) systems as an option for LPD-17. Future approval for hydrocarbon-based systems, such as JP-5, fuel oil, or lube oil, will most probably depend on results of fire tests employing pressurization with a hydrocarbon-based fluid, such as the Oil Companies Mutual Association

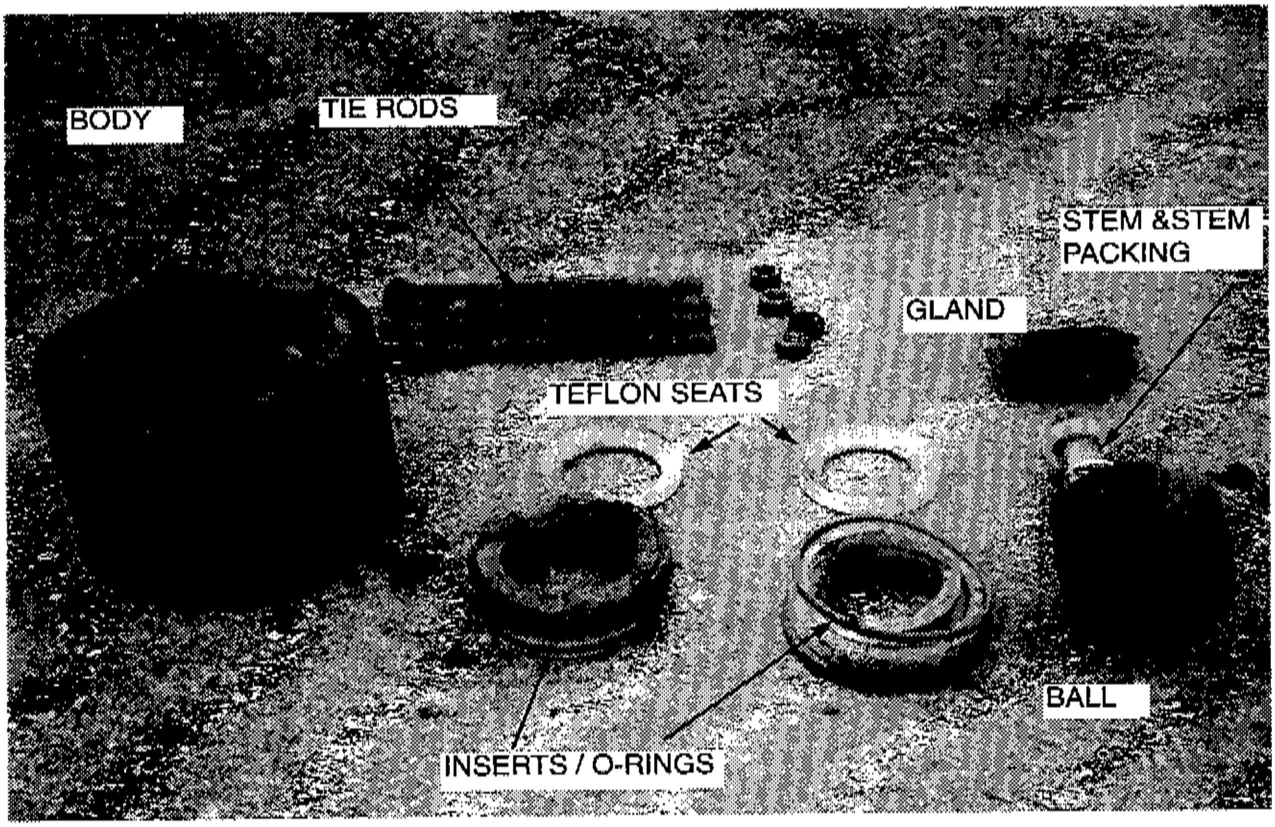

FIGURE 9. Commercial marine composite ball valve after API 607 burn

(OCMA) fire test standard or the British Petroleum Standard.

Summary and Conclusions

The Navy has developed a lightweight, nonmetallic, filament-wound, composite ball valve which addresses severe corrosion and erosion problems in seawater and CHT sewage systems in the fleet. Currently, bronze is specified for such services. The valve has undergone strenuous laboratory and field testing which includes compression, bending, torsion, pressure, operational torque, cyclic, shock and vibration testing. The composite ball valve is rated to 250 psi pressure and 150 degree F temperature. To establish dual usage in both the navy and the commercial industry, the valve was designed as a flanged valve drilled to ANSI 150 flanges.

The valve is currently available in sizes ½ inch through 4 inch, although plans are underway to include sizes up to 12 inch. The valve is shorter than MIL-V-24509 ball valves. Since the current bronze valves on naval ships have non-commercial, navy flanges per MIL-F-20042, the navy standard drawing will also include flange adapters and full-bore inserts so that the valve can be retrofitted into a MIL-V-24509 configuration. Also, since the ball valve body is composite, it will adapt to any piping material such as steel, CRES, bronze, cu-ni, or titanium without encountering galvanic corrosion.

The valve is made to a Navy Standard Drawing, and as such, this approach would reduce the life cycle cost through standardization, reduced maintenance and supply support. The composite ball valve is comparable in cost to the existing bronze ball valves and extremely simple to maintain. Only the soft parts such as the valve seat, seat O-rings, and stem packing are expected to need periodic replacement.

Although the composite valve is designed primarily for on-off service, it may be used for some throttling service as well. Currently, the valve is targeted to replace ball valves in seawater and CHT sewage systems. Also, since it needs only a quarter-turn rotation, even for throttling, it is extremely well suited to automation in view of the fact that the navy is gearing toward increased automation. As such, this valve has the potential to replace many existing multiple turn gate and globe valves which are cumbersome to automate.

Presently, NAVSEA approval for the composite valve applies to seawater and some other water systems. Plans are underway, however, to seek the approval of the National Sanitation Foundation (NSF) and, thus, the Bureau of Medicine (BUMED) certification so that the valve can be used in potable water systems as well. In addition, plans also include evaluation for the use of composite ball valves in flammable, and other services (fuel oil, lube oil, etc.) where the valve must meet stringent fire-testing criteria. In laboratory testing, the composite ball valve has come very close to passing fire-tests per the API 607 standard, currently required by NAVSEA for approval of new valve designs in fire hazardous applications (applications which can cause, support or fight fires in critical spaces). Additional fire testing and/or design modifications are planned to fire harden this valve for fire hazardous service.

As the Navy and industry strive to reduce life cycle costs, composite ball valves are expected to become an integral part of this effort. Present repair costs associated with existing bronze valves are high. Successful testing of composite valves aboard ship and in the laboratory, as well as similar shipyard experiences with commercial models, have established a confidence level that this will, indeed, be the case. ✣

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Prior to this, Mr. Reid was the life cycle manager for spiral wound gaskets and all Navy pipe fittings. He developed the Navy's requirements for ASTM F1387, Standard Specification For Performance of Mechanically Attached Fittings *(MAF) for which he received the 1993 Defense Standardization Program Outstanding Performance Award.*

Mr. Reid's previous experience includes: Two years at U.S. Coast Guard Headquarters supervising Marine Cranes and Passenger Submersibles, four years with Military Sealift Command (MSC) Headquarters supervising operations for T-AOs, T-AFSs, and T-AGs, several years as a Port Engineer in Jacksonville, Florida with the Army Corps of Engineers, and several years each with the Maritime Administration (MARAD), Bechtel Power Corporation, and John J. McMullen Associates in New York City.