ALUMINUM FOR NITROGEN FERTILIZER EQUIPMENT

Twenty years of experience has resulted in recommendations for use of aluminum in varied applications within plants

Paul B. Mara
The Aluminum Assn.
New York, N. Y.

Aluminum has been used for more than 20 years to construct equipment for the storage and handling of nitrogen fertilizer solutions. As a result, literally thousands of aluminum storage tanks, tank cars, and tank trailers are now in service. The performance of these vessels and the results of industry research and development programs form the basis of recommendations made in the following pages by the Aluminum Machinery and Equipment Committee of The Aluminum Association for the design, construction, and operation of aluminum equipment for safe, long-lasting, and efficient handling of nitrogen fertilizer solutions.

Nitrogen Fertilizer Solutions

Nitrogen fertilizer solutions listed in Table 1 are typical of those to which the recommendations contained herein apply. All nitrogen fertilizer solutions are classified as "straight material" because they contain only the single plant nutrient, nitrogen, in the form of ammonia, ammonium nitrate, or urea. This classification is subdivided into (1) non-pressure liquids, (2) low-pressure liquids, and (3) high-pressure liquids, depending upon the amount of free or volatile ammonia they contain. Not shown is the basic material for nitrogen fertilizer solutions, 83% ammonium nitrate. To prevent salting-out, this solution is stored at approximately 180 F.

Storage And Distribution Equipment

A flow sheet for nitrogen solution transportation and storage from the manufacturing plant to the farmer's field is shown in Figure 1. In-plant storage tanks range in capacity from one million to five million gallons. They may be 100 ft. in diameter and more than 30 ft. high. Railroad tank cars that carry about 8,000 gal. of solution are frequently used for deliveries to depot storage tanks that hold about one million gallons. Vertical 12,000 gal. tanks and horizontal 22,500 gal. tanks service tank trailers for local distribution to nurse tanks of about 1,000 gal. capacity and to smaller application tanks.

Table 1. Typical Nitrogen Fertilizer Solution Analysis

Type	Composition				
	Total N.	Ammonia	Ammonium Nitrate	Urea	Water
Ammoniated Ammonium Nitrate	37%	17%	67%		16%
	41%	19%	73%		8%
	49%	34%	60%		6%
Ammoniated Urea	45%	37%		33%	30%
	45%	31%		43%	26%
Ammonia-Ammonium Nitrate-Urea	43%	20%	68%	6%	6%
	45%	25%	56%	10%	9%
	49%	33%	45%	13%	9%
Ammonium Nitrate-Urea			40%	31%	29%
			45%	35%	20%

Note: Some nitrogen solution fertilizers may contain sodium nitrate instead of urea or ammonium nitrate or may partially replace these nitrogen compounds.

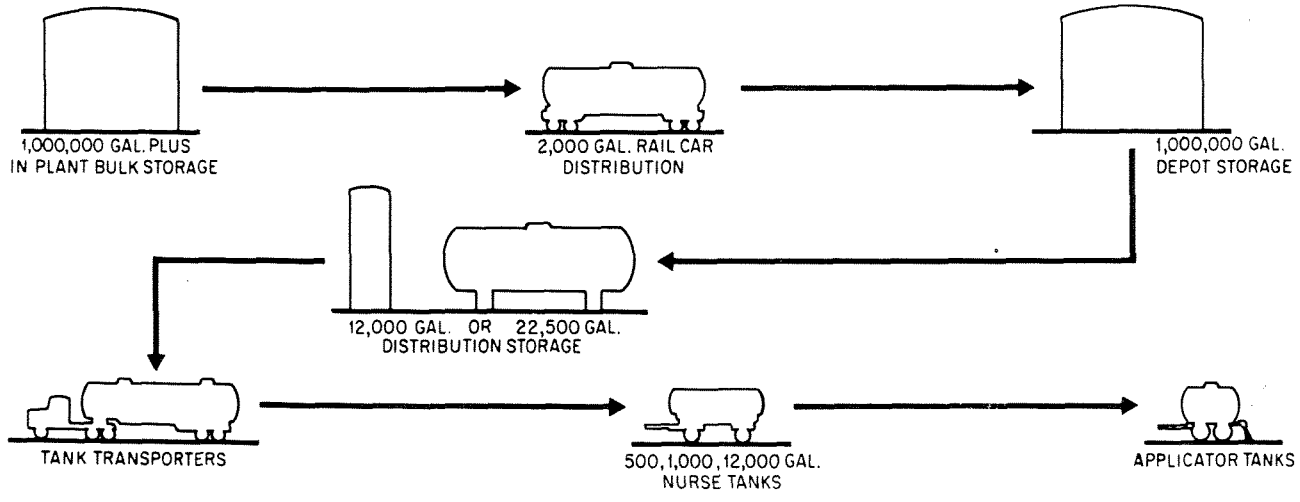

Figure 1. Flowsheet showing movement of nitrogen solution fertilizer from plant to farm.

Pressure vessels are required for some nitrogen solutions containing high concentrations of ammonia so that the ammonia is kept in solution. These vessels operate at pressures of 5 to 40 lb./sq.in. and must be designed to resist these pressures in addition to hydrostatic pressures and dynamic forces.

Advantages Of Aluminum

No single material is perfect for all applications in fertilizer service. However, aluminum alloys offer many advantages for nitrogen solution vessels and no storage or distribution system for these solutions should be designed without considering aluminum.

- The high strength-to-weight ratio of aluminum alloys is important in the design of railroad tank cars, tank trailers, nurse tanks, and application tanks.
- No toxic compounds of aluminum are formed which might harm plant life.
- Aluminum alloys reduce maintenance costs since tank surfaces do not need protective coatings on either the inside or the outside.
- Elimination of protective coatings reduces explosion hazards because contaminants such as organic matter leached from the coatings and heavy metal ions are reported to make nitrogen solutions sensitive to detonation.
- Aluminum alloys suitable for service with nitrogen solution fertilizers are available in a wide range of product forms including plate, structural shapes, pipe, forgings, and castings.
- Aluminum's attractive economy is enhanced by its ease of fabrication and corrosion resistance.

Corrosion Resistance

Aluminum is highly resistant to corrosion by anhydrous ammonia as well as to most aqueous solutions and aqua ammonia containing 30% ammonia. In the narrow range of 1-5% ammonia, appreciable corrosion can occur initially, but the usual formation of a protective film on the metal can reduce further corrosion. This initial corrosion can be eliminated by the addition of ammonium nitrate or other nitrates to the solution. Aluminum has also demonstrated a high order of corrosion resistance to the solid forms of fertilizer nitrogen. Many solutions containing ammonia, ammonium nitrate, and urea are handled in aluminum tanks. Ammonium nitrate solutions containing excess ammonia are not corrosive to aluminum. Solutions containing both urea and ammonium nitrate are even more compatible than solutions containing either urea or ammonium nitrate alone.

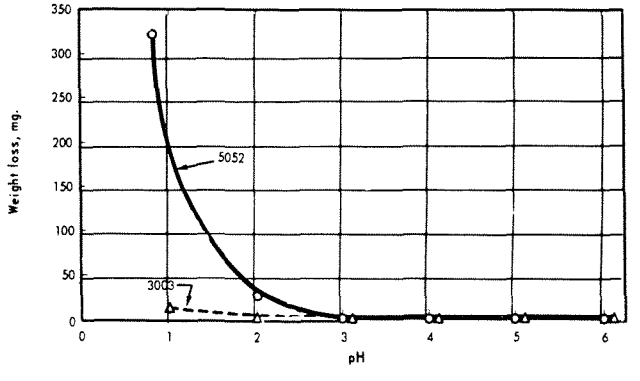

Figure 2. Effect of pH on resistance of two aluminum alloys to corrosion; weight loss after 17 days of sheet specimens, ½ in. x 3 in. x 0.064 in. in 83% ammonium nitrate solutions at 190 F.

Some corrosion problems were encountered when aluminum was first used for tanks storing hot 83% ammonium nitrate. The corrosion was generally confined to localized areas. Research revealed that acidic conditions contributed to this type of attack. Data reproduced in Figure 2 demonstrate the effect of pH on the resistance of two aluminum alloys to corrosion by 83% ammonium nitrate at 190 F. It is also shown that alloy 3003 is much more tolerant to hot acidic 83% ammonium nitrate than is alloy 5052.

Therefore, it is necessary to avoid acidic conditions in aluminum equipment handling hot 83% ammonium nitrate. It is recommended that the pH should be maintained at a value between 6 and 7. (See Operations and Maintenance Section.) Since it is difficult to measure and control pH in piping systems, alloy 3003 is recommended for these applications.

Proper design, operation, and maintenance can eliminate other cause of corrosion of aluminum equipment such as,

1. The presence of mud or silt on the tank bottom.
2. Contacts with heavy metals, their ions, or their compounds.
3. Stray electrical currents in the ground, or galvanic or chemical action which might affect the underside of the tank bottom.

Design and Construction Of Aluminum Tanks

Material Selection

Aluminum alloys recommended for tank and equipment components for various nitrogen solutions are shown in Table 2. The product forms in which they are available are covered in the ASTM Specifications listed in Table 3. The chemical compositions of these alloys are given in Table 4 and their typical mechanical properties appear in Table 5. The two 6000-series alloys are heat-treatable. The others are strain-hardenable. These alloys are all weldable and their recommended filler metals are shown in Table 6.

Attention is called to the limits of temperature and pH shown in Table 2 in connection with the alloy recommendations. The emphasis on the operating limits of temperature and pH for aluminum tanks is based in great measure on the influence they can have on the corrosion performance of aluminum. This primarily concerns the 5000-series alloys and, more specifically, those surfaces where the original structure has been altered by heat during fabrication, as for example, heat of welding, grinding, or heating to facilitate forming. Corrosion of surfaces so altered may occur under acidic and excessively hot operating conditions.

Because alloy 3003 is more resistant to corrosion under the conditions just described, it is often specified for tank bottoms where strength requirements are minimal. Alloy 3003 welded with 1100 filler metal is also preferred for piping because practical difficulties exist in measuring and controlling pH in piping systems.

Aluminum alloy recommendations for cast fittings are included in Table 2. In general, the use of castings is usually limited to non-pressurized external appurtenances.

Design Specifications

Several codes and standards apply to the design and construction of aluminum equipment for ammonium nitrate service. A listing of regulations will be found in Table 7. Among these are:

ICC Specifications for railroad tank cars and over-the-road cargo tanks, ASME Boiler and Pressure Vessel Code.

American Standards Association Specification B96.1 - WELDED ALUMINUM-ALLOY FIELD-ERECTED STORAGE TANKS.

Allowable design stresses for welded construction are based on the minimum properties of the alloys in the annealed condition, except for the heat-treatable alloys 6061 and 6063, which are only

partially annealed by the heat of welding. Allowable stresses for these alloys are based on the strength of groove welds. Weld joints for both tank plates and attachment of fittings should be designed to be crevice-free so that entrapment of fertilizer solutions does not occur.

Table 2. Aluminum alloys for nitrogen solution tanks.

Environment tank component	Alloy				
	3003 3004	5052 5454	5083 5456	6061 6063	B214 356
1. Ammonium Nitrate 83%, pH 6.0-7.0 *, 180 degrees F. max.					
Sidewalls, roofs, ends	X(1)	X	—	—	—
Floor	X(1)	X	—	—	—
Structurals, forgings, pipe (2)	X	—	—	X	—
Castings	—	—	—	—	X
2. Nitrogen Solutions pH 4.5-9.0, 150 degrees F. max.					
Sidewalls, roofs, ends	X	X	—	—	—
Floor	X	X	—	—	—
Structurals, forgings, pipe (2)	X	—	—	X	—
Castings	—	—	—	—	X
3. Nitrogen Solutions pH 6.0-9.0, 100 degrees F. max.					
Sidewalls, roogs, ends	X	X	X	—	—
Floor	X	X	X	—	—
Structural, forgings, pipe (2)	X	—	—	X	—
Castings	—	—	—	—	X

(1) Alloy 3003 is more tolerant to out of parameter operations in 83% ammonium nitrate service.

(2) For piping systems, pipe, fittings and flanges of alloy 3003 are preferred.

* To be measured at room temperature using a solution consisting of equal parts of distilled water and 83% ammonium nitrate. (Room temperature reading will be 1.0 to 1.5 units higher than pH of solution in tank at temperature.)

Components And Accessories

Accessory equipment used with aluminum tanks should preferably be aluminum or plastic of a suitable composition; 18-8 type stainless steel is compatible, except under acid conditions, but copper and copper alloys should be avoided. This will eliminate possible corrosion of the aluminum due to heavy metal contact or pickup. If galvanic effects between stainless steel accessories and aluminum are otherwise expected, electrical isolation, with plastic insulators will eliminate the possibility if short-circuiting is avoided. Gaskets should be of a solid, non-wicking type compatible with aluminum.

Mercury or mercury compounds (from broken thermometers or blown manometers) can find their way into nitrogen solution tanks. These compounds can cause severe localized corrosion of aluminum and should be avoided for this reason as well as because of the toxic effect of mercury on plant and animal life.

External heat exchangers are recommended with sparge piping for maintaining temperature in ammonium nitrate storage vessels, since it is believed that stratification and stagnant areas are less likely to occur due to the resulting circulation. Thermal insulation is also of value in maintaining uniform temperature and avoiding local salting-out.

Fabrication And Erection

Fabrication and erection should be carried out in accordance with the applicable specifications noted above. Where necessary, aluminum alloy plates may be heated to facilitate forming, provided the temperature and the holding time at temperature are controlled.

Corrosive fluxes must not be used in the welding of aluminum tanks. Therefore, processes such as the inert gas tungsten arc (TIG) or inert gas metal arc (MIG) are employed. Weld filler metals should be specified in accordance with Table 6. Welding procedures, welders, and welding operators are required by the aforementioned specifications to be qualified in accordance with Section IX of the ASME Boiler and Pressure Vessel Code.

Inspection of butt welds is usually by radiographic examination, although the sectioning method is also used and recommended where incomplete penetration is permitted.

Foundations And Supports

Flat-bottomed, vertical wall aluminum alloy storage tanks may be supported on concrete slabs sand or gravel fill, or fill with a concrete ring wall as recommended in ASA B96.1. If a concrete

Table 3. ASTM specifications for aluminum alloy products.

Product	Astm Specification
Sand Castings	B26
Die Castings	B85
Permanent Mold Castings	B108
Sheet and Plate	B209
Drawn Seamless Tubes	B210
Bars, Rods and Wire	B211
Extruded Bars, Rods, Shapes and Tubes	B221
Drawn Seamless Tubes for Condensers and Heat Exchangers	B234
Seamless Pipe	B241
Forgings	B247
Welding Rods	B285
Drawn Seamless Coiled Tubes for Special Purpose Applications	B307
Standard Structural Shapes	B308
Round Welded Tubes	B313
Welding Fittings	B361
Seamless Condenser and Heat-Exchanger Tubes with Integral Fins	B404
Extruded Structural Pipe and Tube	B429

Table 4. Chemical composition limits.*

Alloy Designation	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Nickel	Zinc	Titanium	Others Each	Others Total	Aluminum Min.
1100	1.0 Si+Fe		0.20	0.05	—	—	—	0.10	—	0.05	0.15	99.0
3003	0.6	0.7	0.20	1.0-1.5	—	—	—	0.10	—	0.05	0.15	Remainder
3004	0.30	0.7	0.25	1.0-1.5	0.8-1.8	—	—	0.25	—	0.05	0.15	Remainder
5052	0.45 Si+Fe		0.10	0.10	2.2-2.8	0.15-0.35	—	0.10	—	0.05	0.15	Remainder
5083	0.40	0.40	0.10	0.30-1.0	4.0-4.9	0.05-0.25	—	0.25	0.15	0.05	0.15	Remainder
5154	0.45 Si+Fe		0.10	0.10	3.1-3.9	0.15-0.35	—	0.20	0.20	0.05	0.15	Remainder
5183	0.40	0.40	0.10	0.50-1.0	4.3-5.2	0.05-0.25	—	0.25	0.15	0.05	0.15	Remainder
5356	0.50 Si+Fe		0.10	0.05-0.20	4.5-5.5	0.05-0.20	—	0.10	0.06-0.20	0.05	0.15	Remainder
5454	0.40 Si+Fe		0.10	0.50-1.0	2.4-3.0	0.05-0.20	—	0.25	0.20	0.05	0.15	Remainder
5456	0.40 Si+Fe		0.10	0.50-1.0	4.7-5.5	0.05-0.20	—	0.25	0.20	0.05	0.15	Remainder
5554	0.40 Si+Fe		0.10	0.50-1.0	2.4-3.0	0.05-0.20	—	0.25	0.05-0.20	0.05	0.15	Remainder
5556	0.40 Si+Fe		0.10	0.50-1.0	4.7-5.5	0.05-0.20	—	0.25	0.05-0.20	0.05	0.15	Remainder
6061	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.35	—	0.25	0.15	0.05	0.15	Remainder
6063	0.20-0.6	0.35	0.10	0.10	0.45-0.9	0.10	—	0.10	0.10	0.05	0.15	Remainder
B214	1.4-2.2	0.6	0.35	0.8	3.5-4.5	0.25	—	0.35	0.25	0.05	0.15	Remainder
356	6.5-7.5	0.6	0.25	0.35	0.20-0.40	—	—	0.35	0.25	0.05	0.15	Remainder

*Composition in percent maximum unless shown as a range.

slab is used, a suitable cushion for the tank bottom should be provided, such as a layer of clean sand. Of prime importance is the establishment of a grade which will provide for the drainage of ground water and runoff from the tank roof away from the tank foundation. In addition, fill materials used to build up the grade should be non-corrosive to aluminum. Cinders, slag, chlorides, chemical wastes and similar materials should not be used.

To minimize the possibility of corrosion of the underside of the tank bottom, a layer of asphalt or tar, or a film of poly-vinyl chloride at least .020 in. thick, may be applied on the sand about 6 in. below the tank bottom. Sand or gravel fill is placed on this barrier to form the finished grade. Where a concrete ring wall is used, or where a horizontal tank is mounted on concrete saddles, a non-absorptive membrane should be placed between the concrete and the aluminum to prevent chemical or concentration cell corrosion of the aluminum.

Where aluminum tanks are mounted on steel supports, the faying surfaces should be protected against galvanic corrosion. This can be accomplished by painting the faying surfaces with zinc chromate primer. If only one surface is painted, it should be the steel. One or more finish coats of aluminum pigmented paint may be applied to the steel. A joint compound, membrane, or solid non-wicking gasket capable of insulating the metals from each other and excluding moisture from the joint can also be used.

Operation And Maintenance

Performance will be best if conditions of temperature and pH listed in Table 2 are closely observed.

In 83% ammonium nitrate service the likelihood of the development of local acidic conditions will be minimized by maintaining the lowest storage temperature possible without salting-out and by providing circulation. As the temperature increases, more ammonia tends to be driven off, leaving an excess of nitric acid which must be neutralized with additional ammonia to keep the pH at the recommended level of 6 to 7.

The pH of 83% ammonium nitrate stored at elevated temperatures can be more easily measured at room temperature. Use a solution consisting of equal parts of distilled water and 83% ammonium nitrate. At room temperature the pH of this solution will be 1 to 1.5 units higher than the pH of the solution at the elevated temperature in the tank. This difference must be taken into account when adding ammonia to raise the tank pH to the limiting value of 6.

It was previously mentioned that contamination of aluminum surfaces with materials such as mercury and copper should be avoided. Therefore, aluminum tanks should not be used indiscriminately for storage of insecticides and herbicides since many of these agricultural chemicals contain mercury, copper, lead, and arsenic compounds.

Accumulations of silt and mud in nitrogen solution tanks have been known to reach several feet in depth as the result of two to six years of use without cleaning. These deposits reduce the storage capacity of the tank and contribute to corrosion of aluminum tank bottoms. Annual inspection and cleaning, when necessary, of aluminum tanks in nitrogen solution service is recommended.

Maintaining operation conditions as listed in Table 2 will also provide improved safety. When conditions permit evaporation of water and ammonia from ammonium nitrate solutions of high concentration, the solid nitrate that salts out can be a safety hazard. Safe operating practices also require that solution spills and leakage be cleaned up promptly to prevent accumulations of solid ammonium nitrate that can be a fire hazard. These good housekeeping practices will also reduce the possibility of tank corrosion, no matter what metal of construction is used.

Table 5. Mechanical properties (1).

ALLOY AND TEMPER	TENSION				HARDNESS	SHEAR	FATIGUE	MODULUS
	STRENGTH ksi		ELONGATION Percent in 2 in.		BRINELL NUMBER	ULTIMATE SHEARING STRENGTH	ENDURANCE (2) LIMIT	MODULUS of ELASTICITY
	ULTIMATE	YIELD	1/16 inch Thick Specimen	½ inch Diameter Specimen	500 kg load 10 mm ball	ksi	ksi	ksi x 10^3
3003-O	16	6	30	40	28	11	7	10.0
3003-H12	19	18	10	20	35	12	8	10.0
3003-H14	22	21	8	16	40	14	9	10.0
3003-H16	26	25	5	14	47	15	10	10.0
3003-H18	29	27	4	10	55	16	10	10.0
3004-O	26	10	20	25	45	16	14	10.0
3004-H32	31	25	10	17	52	17	15	10.0
3004-H34	35	29	9	12	63	18	15	10.0
3004-H36	38	33	5	9	70	20	16	10.0
3004-H38	41	36	5	6	77	21	16	10.0
5052-O	28	13	25	30	47	18	16	10.2
5052-H32	33	28	12	18	60	20	17	10.2
5052-H34	38	31	10	14	68	21	18	10.2
5052-H36	40	35	8	10	73	23	19	10.2
5052-H38	42	37	7	8	77	24	20	10.2
5083-O	42	21	—	22	—	25	—	10.3
5083-H321	46	33	—	16	—	—	23	10.3
5454-O	36	17	22	—	62	23	—	10.2
5454-H32	40	30	10	—	73	24	—	10.2
5454-H34	44	35	10	—	81	26	—	10.2
5454-H112	36	18	18	—	62	23	—	10.2
5454-H311	38	26	14	—	70	23	—	10.2
5456-O	45	23	—	24	—	—	—	10.3
5456-H112	45	24	—	22	—	—	—	10.3
5456-H311	47	33	—	18	—	—	—	10.3
5456-H321	51	37	—	16	90	30	—	10.3
6062-O	18	8	25	30	30	12	9	10.0
6061-T4,-T451	35	21	22	25	65	24	14	10.0
6061-T6,-T651	45	40	12	17	95	30	14	10.0
6063-O	13	7	—	—	25	10	8	10.0
6063-T1	22	13	20	—	42	14	9	10.0
6063-T4	25	13	22	—	—	—	—	10.0
6063-T5	27	21	12	—	60	17	10	10.0
6063-T6	35	31	12	—	73	22	10	10.0
6063-T83	37	35	9	—	82	22	—	10.0
6063-T831	30	27	10	—	70	18	—	10.0
6063-T832	42	39	12	—	95	27	—	10.0
(3) B214-F	20	13	—	2	50	17	8.5	—
356-T51	25	20	—	3.5	60	20	8	10.5
356-T6	33	24	—	2	70	26	8.5	10.5
356-T7	34	30	—	3.5	75	24	9	10.5
356-T71	28	21	—	5	60	30	8.5	10.5
(4) 356-T6	38	27	—	5	80	30	13	10.5
356-T7	32	24	—	6	70	25	11	10.5

(1) These typical properties are average for various forms, sizes and methods of manufacture, and may not exactly describe any one particular product.

(2) Based on 500,000,000 cycles of completely reversed stress using the R. R. Moore type of machine and specimen.

(3) Sand Castings

(4) Permanent Mold Castings

Cathodic Protection

Where optimum operating conditions are not maintained or where tank construction is not as recommended for corrosion resistance, cathodic protection may be employed to arrest attack of the aluminum which may be started and to prevent initiation of new attack. External cathodic protection can also be effective in preventing galvanic or stray-current corrosion of the underside of tank bottoms. Such systems are practical and economical to install and maintain.

Literature Cited

1. Cook, E. H., R. L. Horst, Jr., and W. W. Binger, CORROSION, 17, p. 97 (January, 1961).

Table 6. Recommended filler alloys for aluminum alloy weldments.

Alloy to Alloy	3003	3004	5052	5454	5083	5456	6061	6063
3003	1100							
3004	1100	5554						
5052	5554 5154*	5554 5154*	5554 5154*					
5454	5554 5154*	5554 5154*	5554 5154*	5554 5154*				
5083	5356* 5183*	5356* 5183*	5356* 5183*	5356* 5183*	5356* 5183*			
5456	5556*	5556*	5556*	5556*	5556*	5556*		
6061	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	
6063	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*	5554 5154*

*Limited to 150 degrees F. max.

Table 7. Codes and standards.

Storage Tanks, Field Erected	Description
American Standards Association B 96.1 Welded Aluminum-Alloy Field-Erected Storage Tanks	Design, fabrication, erection, inspection and testing of welded aluminum alloy, field erected, above-ground, vertical, cylindrical, atmospheric storage tanks.
Pressure Vessels, Unfired	
ASME Boiler and Pressure Vessel Code Section VIII Unfired Pressure Vessels Section IX Welding Qualifications	Minimum construction requirements for the design, fabrication, welding, inspection and certification of unfired pressure vessels not exceeding 3000 psi.
Railroad Tank Cars	
Interstate Commerce Commission	
79.10 General Design Specification	Tank cars
79.100 General Design Specification	Pressure tank car tanks
78.294 Specification ICC-105A100AL-W	Lagged fusion welded aluminum railroad tank cars
78.300 Specification ICC-105A300AL-W	Lagged fusion welded aluminum railroad tank cars
78.302 Specification ICC-109A100AL-W	Fusion welded aluminum railroad tank cars
78.308 Specification ICC-105A200AL-W	Lagged fusion welded aluminum railroad tank cars
78.313 Specification ICC-109A200AL-W	Fusion welded aluminum railroad tank cars
78.314 Specification ICC-109A300AL-W	Fusion welded aluminum railroad tank cars
78.291 Specification ICC-103AL-W	Fusion welded aluminum railroad tank cars
78.292 Specification ICC-103A-AL-W	Fusion welded aluminum railroad tank cars
78.310 Specification ICC-111A60AL-W	Fusion welded aluminum railroad tank cars
79.200 General Design Specification	Non-pressure tank cars tanks
Cargo Tanks for Motor Vehicle Transportation	
Interstate Commerce Commission	
78.323 Specification MC 302	Welded aluminum cargo tanks for motor vehicle transportation
78.325 Specification MC 304	Cargo tanks for motor vehicle transportation
78.326 Specification MC 305	Cargo tanks for motor vehicle transportation
78.330 Specification MC 310	Cargo tanks for motor vehicle transportation
78.331 Specification MC 311	Cargo tanks for motor vehicle transportation