aluminum

TANK REPAIR

REYNOLDS METALS COMPANY

ALUMINUM TANK REPAIR

Foreword: This book describes the basic operations associated with the repair of both mobile and stationary aluminum tanks. Since considerable welding is required in any tank repair operation, all the pertinent aspects of welding aluminum are thoroughly covered in this presentation.

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ALUMINUM TANK REPAIR

Aluminum has long been recognized as an excellent metal for chemical containers and processing equipment. More recently, however, it has become widely accepted for use in shipping and storage tanks, drums, transport tankers, pressure vessels, and applicator tanks. Its use in many of these applications is dictated by the need for a combination of physical properties found in no other metal. The applications extend throughout many basic industries including chemical, petroleum, food, brewing, paint, textile, paper, and many others. Probably the largest users of aluminum tanks are the manufacturers, transporters, distributors, and consumers of petroleum hydrocarbons, nitrogen-solution fertilizers, hydrogen peroxide, acetic and nitric acids, and missile propellants.

Aluminum has several points in its favor for the construction of industrial tanks, both stationary and mobile. These advantages stem from its light weight, corrosion resistance, nontoxicity, high heat reflectivity, good thermal and electrical conductivity, non-sparking properties, and ease of fabrication.

All types of tank designs are permissible with aluminum. Stationary tanks can be mounted either horizontally or vertically. The head design, whether flanged, dished, or hemispherical, is determined by end-use requirements. Frameless aluminum trailer tanks have become quite popular in the transportation industry.

A large number of aluminum alloys have now been sanctioned by the American Society of Mechanical Engineers' Boiler and Pressure Vessel Code (see Page 13), The American Petroleum Institute (Page 79), and Interstate Commerce Commission regulations (Page 79). Those best suited are 5052, 5083, 5086, 5154, 5454, 5456. These alloys are serviceable throughout the temperature range from $-320°F$ to $150°F$ or higher. See Table 1, Page 13, for details of ASME Code limitations.

Since the use of aluminum tanks has become so widespread, situations have occurred whereby the tank has become damaged through misuse, abuse, severe service conditions, or accident. It is quite conceivable that these inadvertent forces could deform, dent, puncture, tear, or rupture the aluminum skin. As a result of such damage, the tank must be repaired before it can be returned to service. In these cases, questions often arise concerning the procedures to be followed when repairing an aluminum tank.

The purpose of this book is to fill the need for explicit information on the repair of aluminum tanks. With the help of the data presented herein, it is hoped that more metal shops will be in a position to repair tanks fabricated of aluminum. Although the inherent characteristics of aluminum may slightly change usual repair procedures, no difficulties will be encountered. Considering the myriad number of aluminum trailer tanks on the highway today, it is particularly important for more tank and body shops to become familiar with repairing aluminum trailer tanks. Road mishaps frequently require a nearby point of repair.

Keep in mind that one of the distinct advantages of aluminum is its ease of fabrication. This feature naturally carries over into the repair field, and greatly simplifies the repair of aluminum tanks. Since aluminum is more easily formed than most any other metal, it is relatively simple to fabricate patch-sections of the required contour, employing standard plate forming rolls and head manufacturing equipment. Recent advances in welding technique now permit aluminum joints to be fusion welded easily and quickly. Aluminum tanks are repaired in basically the same way as steel tanks, with the few differences favoring aluminum. Most steel-tank shops can repair aluminum tanks with existing facilities, but may require additional welding equipment.

This book covers the proper sequence of repair operations commencing with the arrival of the damaged tank at the repair station. Of course, the extent of damage and the nature of the tank's contents determine the need for each specific operation. The four basic steps involved are as follows:

(1) Tank cleaning
(2) Removal of damaged sections
(3) Mechanically forming repair sections
(4) Welding new sections in place and repairing damaged welds

In the event of damage to a tank containing flammable liquids or corrosive chemicals, public safety may demand the disposal of the hazardous material together with preliminary tank cleaning at the site of the accident.

The welding of aluminum tanks will be covered in detail. Recommended welding processes will be explained thoroughly so that the required welding procedure can be fully understood. Weldor qualification tests are also included to aid in the training of personnel for this type of welding.

This book lists only the recommended methods for repairing aluminum tanks. If you are not experienced in this particular field, read it carefully before attempting any repairs.

TANK CLEANING

Before attempting to repair any tank, whether steel or aluminum, it is of vital importance that the internal surfaces be cleaned properly. There are two reasons for the need of strict adherence to this cleaning procedure in addition to being a welding requisite.

First, personnel safety demands that all sources of flammable vapor be removed from the tank to avoid an explosion with possible fatalities and property damage. Also, workmen should never be exposed to the hazard of corrosive liquids or noxious gases which might be present in some tanks. Proper cleaning includes purging to eliminate these dangerous situations. *Never, no matter what the circumstances may be, attempt to weld an uncleaned tank.*

The second reason for cleaning is to remove any residue that would become carbonized by the heat of welding. If such material is not removed before heat is applied, it may form a hard deposit that defies cleaning by ordinary methods. Proper cleaning of the tank before repair will avoid this problem.

Aluminum tanks may be cleansed by the use of steam, hot water or chemical solutions, in the same manner as steel tanks are cleaned. The choice of a cleaning method is primarily governed by the nature of the deposit to be removed. Organic solvents and inhibited acids and bases have been used effectively for the removal of specific deposits. Water jets will adequately remove many loose and soft sidewall scales.

Most hazardous are tanks which have contained a flammable petroleum product. In this case, a very exacting cleaning operation must be followed to make sure that all flammable vapor is removed before it can be ignited by the repair procedure. The non-sparking characteristic of aluminum is important here since it means that the aluminum tank walls can be struck with a tool without producing sparks to ignite the vapor. However, this property does not eliminate the need for cleaning. But it does allow a wider margin of safety when removing tank covers in preparation for cleaning.

Causes of Explosions: Flammable fuel in vapor form, air, and ignition temperature are the three things required. If a mixture of flammable vapor and air is partially confined at the time of exposure to a source of ignition, an explosion or flash fire will usually result. But no combustion can occur without all three factors. If any one is removed, no combustion or subsequent explosion is possible. The purpose of tank cleaning procedures is to remove the flammable vapor since air and sources of ignition cannot possibly be excluded during tank repairs.

Certain mixtures of petroleum vapor and air can be iqnited. Gasoline vapor will ignite in air if the vapor forms between 1 and 6 percent of the mixture by volume. Other flammable vapors have different limits. Combustible gas indicators are available to detect the presence of flammable vapor, and are designed to indicate the percentage of the lower flammable limit of vapors present in the tank atmosphere.

A tank may contain a "rich" mixture immediately after the flammable liquid has been removed. This means that too much flammable vapor is present in proportion to the available air for the mixture to burn. However, a mixture "too rich" for ignition in a closed tank may quickly reach the flammable range after the tank has been opened and the mixture diluted with more air. For this reason, no tank containing vapor above its upper limit of flammability can be considered safe.

Flammable mixtures may be ignited by open flames, welding arcs, discharges of static electricity, and by sparks from electric lamps, electric tools, defective electrical extension cords, and electrical equipment which is not explosion-proof. Since there are so many possible ways to ignite a flammable mixture, it is vital that all combustible vapor be removed before beginning tank repairs.

Vapors which emanate from the shell manhole may travel a considerable distance from the tank at ground level. This is particularly true of gasoline since its vapor is heavier than air. Any source of ignition may ignite such vapors, and the resultant fire can easily flash back toward the tank.

Even after a tank has been freed of vapor, flammable mixtures may again be formed by the admission of flammable vapor from some other source such as an unblanked line, or the evolution of vapor from sludge, sediment, or sidewall scale. Allowances must be made for these sources of contamination if a safe atmosphere is to be maintained in the tank.

The ignition temperature of any flammable liquid or gas is an important factor in determining the degree of hazard involved in handling that material. In general, liquids and gases with low ignition temperatures are far more hazardous than those which ignite at higher temperatures.

For example, gasoline which has an ignition temperature of approximately 495°F is relatively more hazardous than benzine whose ignition temperature is about 1000°F. Such a comparison indicates that gasoline in the proper vapor-air ratio for combustion will ignite far easier than a similar mixture of benzene.

The significance of ignition temperature can best be understood by explaining its role in an explosion. Using gasoline as the flammable liquid involved, if a source of ignition at a temperature of 495°F or above is brought into contact with a gasoline vapor-air mixture inside a tank within the range of flammability, the mixture will be ignited instantaneously and an explosion will result. The source of ignition might be an acetylene torch, or the heat generated by mechanical work on the tank. Since flame propagation is highly erratic, it is even possible for a molecular-sized particle with a surface temperature above 495°F to ignite the mixture. This fact explains how slight discharges of static electricity or small metal sparks are capable of causing severe explosions.

With the aforementioned facts in mind, it is easy to understand the need for meticulously cleaning all flammable liquid tanks before starting repair operations. Keep in mind that any slight degree of heat generated by either hot or cold work is capable of causing a catastrophic explosion when flammable vapor is present.

On the following pages, a specific procedure is given for cleaning or safeguarding leaded gasoline (gasoline containing tetraethyl lead) tanks. This procedure was included because the cleaning of such tanks demands great care to render the tank safe for subsequent repair work. The recommendations listed herein are in accordance with the standards of the National Fire Protection Association and the American Petroleum Institute.

The same procedure will also hold true for tanks containing other flammable materials. However, in many cases, a less stringent procedure will be adequate, particularly where workmen are not required to enter the tank.

CLEANING OR SAFEGUARDING TANKS THAT PREVIOUSLY CONTAINED LEADED GASOLINE

The procedure described herein is recommended for the safe removal of flammable vapors, liquids, gases, or solids from leaded gasoline tanks that may be stationary or mobile, or to safeguard these vessels by other means. This procedure is required to permit hot work (welding or cutting) or other work which may create a potential fire or explosion hazard. The objective here is threefold: (1) To remove flammable vapor-air mixtures which might be ignited, (2) To remove liquid or solid residues which might release further flammable vapor when heated by the welding or cutting processes, and (3) To protect personnel from the toxic effects of a leaded gasoline atmosphere.

Definitions: For the purpose of this procedure, the following definitions shall apply.

Bonding shall mean the electrical interconnection (bare metallic bond wire or metal-to-metal contact) between two conductors. Such bonding is used to ground tanks and hoses electrically so that static electricity can be dissipated.

Flammable gas shall mean any substance that exists in the gaseous state at normal atmospheric temperature and pressure and which is capable of being ignited and rapidly oxidized when mixed with proper proportions of air or oxygen.

"Gas-free" means that the concentration of flammable vapors in a tank as measured by a combustible gas indicator is not more than 14 percent of the lower flammable limit.

Inert gas shall mean any gas which is nonflammable, chemically inactive and noncontaminating for the use intended. Nitrogen and carbon dioxide are the commonly used inert gases.

Inerting shall mean the use of an inert gas to render the atmosphere of a tank substantially oxygen-free or to reduce the oxygen content to a level at which combustion cannot take place.

Leaded gasoline refers to any fuel that contains tetraethyl lead as an additive. Tetraethyl lead is a powerful poison that can cause intoxication by both inhalation and skin absorption.

Purging is the process of displacing the flammable vapors from a tank.

Before any cleaning operation is started, the tank must be completely drained. When working with trailer tanks, care should be taken to ensure that all compartments, depressions, pockets, lines, and valve manifolds are free of liquid entrapment.

General Procedures for Safeguarding Leaded Gasoline Tanks

1. **Supervision:** Work on tanks that have held leaded gasoline shall be done under the supervision of persons who understand the fire and explosion potential, assisted by workmen sufficiently skilled to carry out safely the operations required.

2. **Location:** All gas-freeing work by any of the methods outlined here should be conducted out-of-doors, remote from known sources of ignition, and the tank should be stationed where the vapors will not blow indoors.

3. **Open Outlets:** In the case of mobile trailer tanks, open all drawoff faucets, disconnect inter-compartment lines, and remove all strainers and check valves.

4. **Plug Inlets:** When stationary tanks are involved, disconnect, plug, or blank all piping and service lines.

5. **Testing:** After carefully removing tank access cover at top of tank, test the tank atmosphere for the presence of flammable vapor through the use of a combustible gas indicator. Tests should be made at various points within the tank. It is essential that the operator using the indicator be well instructed in the use of the instrument and that he performs the checks recommended by the manufacturer to ensure that the instrument is in good operating condition. An instruction manual accompanies each indicator. Readings obtained from the combustible gas indicator can be particularly misleading when the tank atmosphere is too rich in fuel vapor and contains less than 5 percent of oxygen by volume. In this case, the indicator needle will momentarily give a full scale deflection and then fall back to zero. When this situation prevails, consult the instruction book as an air dilution valve may be required by the instrument to give an accurate reading.

6. **Purging:** If the combustible gas indicator shows no more than a trace of vapor, the tank can be considered "gass free" and safe for hot work. But if the indicator registers in excess of 14 percent of the lower flammable limit, the tank atmosphere must be rendered safe by purging out the flammable vapor.

7. **Worker Protection:** Even though a leaded gasoline tank tests "gas free," workmen must never enter the tank without respiratory equipment and protective clothing. See Step No. 20.

Methods for Gas-Freeing Tanks:

8. **Displacement of Flammable Vapor with Water:** The tank is filled completely with water and allowed to drain. Repeat this operation several times. A constant overflow of water can be maintained if practical. This method works well with relatively small tanks and is also applicable to mobile trailer tanks. In some cases, this procedure permits hot work to be performed on the tank while it is full of water.

9. **Displacement of Flammable Vapor with Inert Gas:** By first purging the vapor from the tank with an inert gas, such as nitrogen or carbon dioxide, and then ventilating with air, the hazards incident to passing through the flammable range are eliminated. This method works particularly well on small tanks.

10. **Inerting of Vapor Space:** If properly used, inerting is a means of safeguarding a small tank by reducing the oxygen content to the point where combustion cannot take place. In this method, nitrogen or carbon dioxide is used to displace the air from the tank. Individuals in direct charge of this procedure must be thoroughly familiar with the limitations and characteristics of the inert

gas being used. For example, if liquid carbon dioxide is employed, the gas must be released at such a rate as to avoid the formation of solid carbon dioxide particles which may generate static electricity. The oxygen content must be maintained at substantially zero during the entire period that hot work is in progress. Attempting such work without proper knowledge or equipment can be hazardous because of the false sense of security given.

11. **Ventilating:** There are several means available for ventilating tanks. Air movers, blowers, or compressed air can be utilized. However, no matter what method is used, the progress of ventilation should be checked frequently by tests with the combustible gas indicator.

12. **Mechanical Ventilation with Air Movers:** A steam or air-operated venturi-type air mover is mounted at a suitable opening so that fresh air is drawn through the tank. Metal-to-metal contact should be maintained between the air mover and tank shell. If the size of the openings will not accommodate an air mover, the tank may be purged by means of compressed air introduced through a metallic pipe bonded to the tank. This latter method is better suited to small tanks as a much smaller volume of purge air is produced.

13. **Mechanical Ventilation with Blower:** A fan-type blower is employed. The air discharge duct should be introduced at the top of the tank and extended down to a level relatively close to the bottom. Since gasoline vapors are heavier than air, it is essential that the air source be positioned close to the bottom of the tank so that the air can displace the more-dense flammable vapors. Continuous use of a blower throughout the repair operation will obviate vapor accumulation.

Inspection

14. **Visual Inspection:** After tests with gas indicator show the tank to be "gas free", the tank should be visually inspected to determine if any petroleum residues are present. It is recommended that this inspection be made by personnel positioned outside of the tank. The use of flashlights or electrical extension lamps with the aid of a mirror will facilitate such an inspection procedure. *All flashlights and internal inspection lamps used in tank cleaning operations must be approved for Class I, Division I, Group D hazardous locations.* However, if a man must enter the tank for this inspection, he should wear respiratory equipment and protective clothing. See Step 20.

15. **Mopping:** If residual solids are found within the "gas free" tank, further cleaning is required to remove these substances since the application of heat may cause them to evolve flammable vapor.

In many cases, a mopping operation at this stage of cleaning may prove expeditious for removing some portion of this residue. Mopping is permissible provided a long-handled mop is used which allows the worker to stand outside the tank. In addition, the employee doing the mopping should don suitable protective clothing so that his skin cannot contact the residue which may contain tetraethyl lead. *Under no circumstances, should a man enter the tank to perform the mopping operation.*

Removal of Residual Liquids or Solids

In certain cases, it may be impossible to remove all potentially hazardous residues, that is residues of the type that will produce flammable vapors when heated. Such residues may be trapped behind heavy scale or rust, and may not be easily detected. Whenever examination after purging shows that this hazardous condition exists in the tank, hot work should not proceed without additional precautions being taken. Use one of the preceding methods to ensure that an inert atmosphere is maintained within the tank while work is in progress.

16. **Steaming** is effective primarily for the removal of heavy petroleum residues. Steam may be introduced into the tank through a pipe inserted through an opening and bonded to the tank, or by connecting a steam hose directly to a valve on the tank. Low-pressure steam should be supplied at a rate sufficient to exceed the rate of condensation so that the entire tank is heated to approximately 170°F. The required time for steam injection will vary from 4 to 24 hours, depending upon the size of the tank. The tank must be steamed long enough to vaporize the residues from all portions of the walls and heads.

The principal objection to steaming lies in the fact that, when steam enters a tank, it may accumulate static electricity. To compensate for this source of danger, both the tank and steam hose should be grounded. Other objections are the difficulty of obtaining steam in sufficient quantity and the time required to accomplish gas-freeing. Furthermore, the heat of steam is destructive to painted surfaces on the tank as well as to composition valve seats.

17. **Chemical Cleaning.** When the residual substances are not readily soluble in water or cannot be removed by steaming, the tank may be treated with a hot chemical solution, or with a non-flammable proprietary material.

Probably the most efficient techniques for cleaning and degreasing tanks require the use of proprietary commercial cleaners. These materials are compounded to remove stubborn residues of scale, dirt, and petroleum deposits without endangering the aluminum tanks.

These chemical cleaning procedures usually require a source of steam to maintain the solution at its proper working temperature and frequent tank flushing and draining. Goggles, gloves and other necessary protective clothing are also needed to protect workmen from skin or eye injuries. When using a proprietary cleaning solution, the manufacturer's instructions should be followed.

Many conventional household detergents at a concentration of 4 ounces per gallon have also been found satisfactory for tank cleaning in some cases. However, compared to proprietary commercial cleaners, these are more expensive and less effective.

18. **Removal of Sludge and Sediment:** Depending upon the construction of the tank and the number of openings, sludge may be removed by various methods, or by a combination of methods. Possibly the simplest means is to sweep or wash the sludge into piles, shovel it into buckets, and remove it from the tank. If the tank has a bottom opening, it is convenient to wash the sludge through this opening by means of a hose and catch it in a suitable container positioned under the tank. Here again, it is recommended that these operations be performed by personnel stationed outside the tank. If it is necessary for a workman to enter the tank for a sweeping operation, he must be equipped with the safety protective equipment as outlined in Step 20.

19. **Sludge Disposal:** Sludge and sediment from tanks which have contained leaded gasoline are hazardous to handle, even after they have been taken out of the tank. These sludges should be kept wet, and they should be buried promptly in a place where they will not be uncovered later.

20. **Safety Requirements for Personnel Entering Leaded Gasoline Tanks:** Any person who enters a "gas free" leaded gasoline tank should wear a hose mask of the blower type through which air is supplied under positive pressure. In addition, he should wear clean clothing from the skin outward and be equipped with first quality impermeable gloves and boots. (Acid-proof rubber is an acceptable material.) The workman should continue to wear this equipment until all material which may give rise to lead vapors has been removed.

Keep in mind that any cleaning procedure which requires personnel to enter a tank is potentially hazardous. Although the tank may be "gas free", it is quite possible for an oxygen deficiency to exist in the tank. This situation frequently is encountered after the tank has been purged or inerted with inert gas. If workmen must enter a tank treated with inert gas, it is strongly recommended that the tank atmosphere be tested for oxygen content with an approved oxygen indicator meter.

21. **Rechecking:** After the tank has been cleaned thoroughly, check it once more with the combustible gas indicator before moving it into the repair shop. Then, at various intervals during the repair cycle, check it again to make certain that the tank atmosphere remains safe, and that the heat of welding has not evolved some additional flammable vapor.

Removal of Damaged Sections

Concerning the removal of damaged sections from an aluminum tank, it is impossible to present a detailed procedure since the method and extent of removal depends upon the degree of tank damage. In trailer tanks, for example, damage can occur to the shell as well as compartment walls and internal baffles.

Survey the Damage: The first step in any repair procedure is to survey the damage and take note of what can be repaired and what must be replaced. Previous experience will prove helpful here as many costly manhours can be involved in the repair of a section that is cheaper to replace.

Examine the tank thoroughly so that all points of damage may be ascertained at one time. Otherwise the entire repair scheme may be disrupted by the corrective measures required for defects discovered later. After listing all the areas and types of damage, determine as accurately as possible the sequence of the necessary steps to complete the repair work. When establishing the sequence of repair, consider what must be disassembled for access to points that require welding. Also, what sections must be removed in order to perform special forming operations such as bending, flanging, dishing and straightening. If the structural components of a tank, such as the frame or supporting members, incur damage, a complete disassembly of the tank probably will be required to effect this type of repair.

If any doubt exists about the damaged tank relative to the design features or technicalities of fabrication, the repair facility should contact the tank manufacturer for these details.

Determine the Alloys of Construction: During the initial stages of planning the repair procedure, it is essential to know what alloys are involved in the repair operations. Therefore, the aluminum alloys used in the fabrication of the tank must be positively identified. By knowing exactly what alloy is to be worked, the recommended procedures for forming and welding this particular alloy can be followed to expedite the entire repair job. If replacement sections are needed, the new section must be fabricated of the same alloy as the damaged section, or from another alloy that can fulfill the strength and corrosion resistant requirements of the original section. Then too, the recommended welding processes

Table 1. ALUMINUM ALLOYS APPROVED FOR USE BY ASME CODE[1]

Sheet and Plate	Bars, Rod and Shapes	Pipe and Tube
1060	2024	1060
1100	5083(3)	3003
3003	5154(2)	Alclad 3003
Alclad 3003	5454	5154(2)
3004	5456(3)	5454
Alclad 3004	6061	5456(3)
5050		6061
5052	**Bolting Materials**	6063
5083(3)	2014	
5086(3)	2024	**Forgings**
5154(2)	6061	2014
5454		3003
5456(3)	**Casting**	6053
6061	43(4)	6061
Alclad 6061		

(1) Maximum operating temperature is 400° F. unless otherwise noted.
(2) 300° F. max. operating temp.
(3) 150° F. max. operating temp.
(4) Sand castings only.
Note: Also see Tables 27, 28 on Page 79.

for aluminum tank repair demand filler metal that is compatible with the composition of the base metal.

On some aluminum tanks, the alloys of construction will be listed on the name plate attached to the tank. If this data is not available on the tank itself, the owner of the tank should be consulted as to the alloys he stipulated on the original purchase specifications. When these two approaches prove futile, it will be necessary to contact the company that fabricated the tank in order to identify the alloys of construction.

Since in most cases it will take the greater part of a day to clean and prepare the tank for repair, the repair facility will have ample time to telephone or telegraph the tank manufacturer regarding the alloys of construction identified through the corresponding tank serial number.

Saw Away the Damaged Sections: In most cases with aluminum tanks, the damaged sections can be cut away with an electric rotary hand saw. This practice can considerably shorten the time requirement for this phase of the repair procedure.

When tears in a tank are encountered, an electric saber saw will effectively cut out the damaged area to accommodate a patch section. In this case, a square hole with round corners should be cut so that the replacement section can be flush fitted into the aperture and readily welded.

Stationary power saws, such as arbor and band saws, usually available in most shops, will also cut aluminum sections easily. They are particularly useful for sizing the square edges of a patch or replacement section. The table below lists some manufacturers of this cutting equipment.

Cutting Equipment Recommended for Tank Repairs

Type of Saw	Sold By
Electric Saber Saw Electric Rotary Hand Saw Electric Table Saw Electric Arbor Saw	Black & Decker Mfg. Co. 600 East Pennsylvania Ave. Towson 4, Maryland
DoAll Band Saw	The DoAll Company 256 North Laurel Avenue Des Plaines, Illinois

Sawing Aluminum: For cutting aluminum, circular saws fabricated of high-speed steel will be adequate for tank repair operations. A rake angle of 10-20° with a bottom tooth clearance of 6-9°, and a side tooth clearance of 1-2° will be satisfactory. A tooth design that works well with aluminum is the "triple chip grind". Alternate teeth have 40-60° chamfered corners and only the chamfered teeth cut deep; the other teeth merely clean out the corners left by the chamfers.

Band saws of spring temper steel with 4-11 teeth per inch and amply radiused gullets are recommended for aluminum. When cutting heavy sections, the restricted chip space requires about 4 teeth per inch to avoid clogging and excessive temperature rise. Use an alternate-set type of blade with an alternate side rake of about 15° and a top rake of approximately 10°.

High speeds and fine to moderate feeds are recommended for both circular and band saws when cutting aluminum. Peripheral speeds may range from 2000-7000 sfpm for high-speed-steel circular saws. The limiting factor is usually the maximum safe operating speed of the machine and blade. Do not exceed manufacturer's recommendations.

Band saws of spring temper steel may operate at linear speeds ranging from 2,500 fpm for heavy cuts, and up to 5,500 fpm for moderate cuts.

Feeds for circular or band saws will range from 2 inches to 2 feet per minute, depending upon alloy, temper, thickness of section, and speed.

Mechanically Forming Repair Sections

This phase of the repair procedure for aluminum tanks, in most instances, will parallel the repair of similarly damaged steel tanks. However, keep in mind that aluminum has a greater tendency to buckle than steel because of its lower modulus of elasticity. Therefore, severely damaged heads, shells, or baffles should be reshaped more gradually than a similarly damaged steel section.

In general, the work hardening rate of aluminum alloys is moderate to rapid, depending upon the alloy and temper used. The effect of rapid work hardening is particularly noticeable in the non-heat-treatable, high magnesium alloys of the 5000 series. Alloys 5083 and 5456 exhibit this tendency as they work harden very quickly. Consequently, it is recommended that alloys 5083 and 5456 be worked hot at a temperature not exceeding 450°F. If the aforementioned alloys cannot be worked hot, it is strongly recommended that they be stress relieved at 450°F for several hours after cold forming, or completely annealed according to standard practice. The time and temperature for annealing these particular alloys is a 2-hour soak at 675°F.

Supporting structures such as rails, channels, or I-beams in alloys 6061-T6, 6062-T6, or 6063-T6 should be worked cold if at all possible. Since these are heat-treatable alloys, the application of excessive heat can easily impair the strengthening effects of the previous heat treatment. However, if it becomes necessary to form these sections hot, the forming should be done at a temperature not exceeding 400°F and for a period of time not exceeding 15 minutes. When the temperature and time stated above are exceeded, mechanical properties will be reduced.

Other heat-treated alloys such as 2014 and 2024 should not be worked hot at a temperature exceeding 375°F and for a period of time not exceeding 15 minutes. For alloys 7075 and 7178, these limits are 300°F and 15 minutes, respectively.

Shell: Slightly damaged shells can be reworked using conventional hand forming tools. If the shells are severely damaged, it may be necessary to replace sections, or disassemble the damaged portions and reroll them to the desired curvature.

Heads: Moderate damage may be corrected by using hand tools. If the head has sustained relatively heavy damage without incurring any fractures or sharp creases, it is usually possible to reshape the damaged head by "bumping".

Severely damaged heads should be replaced. If the necessary equipment is available, the forming of a replacement head can be done locally. When shops in the immediate vicinity do not have

Table 2. MINIMUM RECOMMENDED RADII FOR 90-DEGREE COLD BENDING OF NON-HEAT-TREATABLE ALUMINUM SHEET (1)

Alloy	Temper	Bend Radii in 32nds of an Inch — Thickness of Sheet — Inch									
		.016	.025	.032	.040	.050	.063	.090	.125	.190	.249
1100 (2)	-O	0	0	0	0	0	0	0	0	0	0
	-H12	0	0	0	0	0	0	0	0	3	6
	-H14	0	0	0	0	0	0	0	0	3	6
	-H16	0	0	0	0	1	2	3	4	..	..
	-H18	1	1	2	2	3	4	6	8	..	..
3003	-O	0	0	0	0	0	0	0	0	0	0
5005	-H12 or -H32	0	0	0	0	0	0	0	0	3	6
5357 (3)	-H14 or -H34	0	0	0	0	0	0	1	2	4	8
5457	-H16 or -H36	0	0	1	2	2	3	5	6	..	..
5657	-H18 or -H38	1	2	3	4	5	6	9	12	..	..
3004 &	-O	0	0	0	0	0	0	0	0	2	4
ALC. 3004	-H32	0	0	0	1	1	2	3	4	8	16
5154	-H34	1	1	1	2	2	3	5	6	12	24
5254	-H36	1	2	3	4	5	6	9	12	..	..
5454	-H38	2	3	4	5	7	8	12	16	..	..
5050 (4)	-O	0	0	0	0	0	0	0	0	0	0
	-H32	0	0	0	0	0	0	1	2	4	8
	-H34	0	0	0	1	1	2	3	4	8	12
	-H36	1	1	2	2	3	4	6	8	..	..
	-H38	1	2	3	4	5	6	9	12	..	..
5052	-O	0	0	0	0	0	0	0	0	0	0
5652	-H32	0	0	0	0	0	0	2	3	6	12
	-H34	0	0	0	1	1	2	3	4	8	16
	-H36	1	2	2	2	3	4	6	8	..	..
	-H38	1	2	3	4	5	6	9	12	..	..
5083 (5)	-O	..	..	..	..	3	4	6	8	12	16
	-H32	..	..	..	..	6	7	10	14	20	28
	-H34	..	..	..	..	8	10	14	20	28	36
	-H113	..	..	..	..	..	..	..	14	20	28
5086	-O	0	0	0	0	0	0	2	3	6	12
5155	-H32	1	1	1	2	2	3	5	6	12	24
	-H34	1	2	3	4	5	6	9	12	24	32
	-H36	3	4	5	6	7	9	12	18	..	..
5456 (5)	-O	..	..	..	..	..	..	..	8	12	16
	-H24	..	..	..	..	8	10	14	20	32	40
	-H321	..	..	..	..	..	..	..	..	24	32

(1) Based upon Press Brake forming in air-bend die having a minimum width of 8 $\times$ t.
(2) Use these data for No. 1 reflector sheet.
(3) Use these data for No. 1, No. 2, No. 11 and No. 12 brazing sheet, No. 2 reflector sheet and RF10, RF15, RF20 finishing sheet.
(4) Use these data for porcelain enameling sheet.
(5) These materials may require annealing or stress-relieving after cold forming. If formed at a metal temperature of 425-450° F. a 50 percent smaller bend radii may be used.