Publication AT 4

# Practices for the Repair of Automotive Sheet Aluminum

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# 1.0 Introduction

One of the inevitable consequences of the use of automobiles is that from time to time accidents will cause damage to a vehicle's body. Knowing how to appraise and repair collision damage correctly is a major responsibility of the collision repair industry. Over the years, as new materials have been introduced to the car body, repair procedures have been developed and accepted by the collision repair industry. Examples include FRP body panels and high strength steels. Aluminum is taking its place as an accepted body panel and structural material and it is the purpose of this publication to highlight those practices that may be used for effective repair of aluminum by describing some of the features of aluminum that are important for repair. This guide will not teach repair. For an introduction to that we, The Aluminum Association, recommend the course "Aluminum Alloy Repair, Replacement, and Welding" offered by I-CAR. All repair personnel should also seek hands on training to develop proficiency.

Steel has been the dominant material for vehicle bodies and to this point most repair practices have focused on it. In many respects practices for aluminum repairs are similar to those for steel but there are important distinctions to be made. Often the similarities lead to a choice of practices and this publication will focus on those preferred by the aluminum industry. There is sometimes a temptation to "make do" with borrowed practices and while we recognize that sometimes this works, it is always better to use practices specific to aluminum.

Since large scale use of aluminum in vehicles is relatively new there is a tendency to assume that it is more difficult to use, both in manufacture and repair. Auto manufacturers are coming to realize that aluminum is practical and economical to manufacture and that the same will be true of repair. There is a certain amount of art to metal working and it requires experience to perfect that art. The aluminum industry has an informal motto that working aluminum is "different, not difficult" and it is hoped this publication will help show the accuracy of that statement.

The Aluminum Association acknowledges the pioneering work in developing repair techniques done by the auto manufacturers, the Inter-Industry Conference on Auto Repair (I-CAR)*, and many others from the auto insurance and repair equipment supply industries. In the preparation of this guide, much of the material has also been drawn from other related Aluminum Association publications.

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# 2.0 Characteristics of Aluminum

Aluminum has many characteristics that make it suitable for a variety of automotive applications. It is:

- **Strong** - the entire vehicle body can be aluminum
- **Durable** - good resistance to corrosion and fatigue
- **Conductive** - both thermal and electrical — for efficient engine and electrical components
- **Nonmagnetic** - useful in electronics
- **Nontoxic** - important in any material used in cars
- **Abundant** - adequate supply worldwide
- **Recyclable** - saves energy, benefits the environment
- **Workable** - uses well understood metalworking processes
- **Available** - aluminum's many product forms offer design flexibility

and above all, its **low density** and **high strength** means that aluminum parts weigh much less than traditional materials such as steel, copper, brass and automotive plastics.

It is the overall value of aluminum that makes it suitable for so many kinds of vehicle applications but it is the weight characteristic that stands out. In the 1970's a series of fuel crises made it clear that America could no longer be insensitive to the energy impact of the automobile. Fuel use is directly related to weight and over the years goals for fuel economy have been raised and the auto manufacturers have responded with many innovations to reduce fuel consumption while providing the other characteristics their customers want. Simply making a little car with an anemic engine no longer suffices and the increasing addition of safety features and other improvements have combined to make it necessary to find additional avenues to keep weight in line. Aluminum has come forward as a major solution to the weight problem. In all, a body-in-white structure of aluminum will have a primary weight savings of 45% to 50% over conventional steel construction. In the Ford Taurus/Sable-based aluminum intensive vehicles (AIV) this meant a total vehicle weight reduction of 11.6% without secondary weight savings.

Additional savings are found wherever aluminum is used and leads to still more savings, referred to as secondary savings, through the ability to downsize other components, such as the suspension and engine.

Aluminum is produced from bauxite ore which is recovered from open pit mines.The ore is processed through a multi-step process collectively called the Bayer process to produce alumina ($Al_2O_3$). This in turn is smelted into metallic aluminum in the Hall/Heroult process. In this process the alumina is placed in carbon lined reduction cells, known as pots. It is dissolved in sodium-aluminum fluoride, called cryolite, and an electric current in passed through the mixture.This current reduces the alumina into aluminum, with the release of carbon dioxide.The molten aluminum settles to the bottom of the pot and is drawn off to solidify into unalloyed ingot, also known as pig. The aluminum thus produced is known as primary aluminum. Roughly one-third of the North American aluminum supply is primary metal. Another third is imported metal and the final third is produced from recycled aluminum. In automobiles substantial use is made of recycled aluminum, especially in powertrain applications.

Aluminum is not, however, used in its pure form for vehicles. Rather it is alloyed with other elements suited to the product form it will be used in to produce a desired set of physical properties or characteristics as, for example, corrosion resistance. The three broad classes of aluminum products are ingot, wrought products, and castings. Ingot is cast from holding furnaces, in which alloying is carried out, and is the starting material for both cast and wrought products. Casting is employed to produce net shape products in which mechanical properties are determined by the alloying elements and thermal treatments after casting. Wrought products are defined by the fact that they are given some mechanical deformation in production. Wrought products are sheet, plate, foil, extrusions, tube, rod, bar and forgings. The collision repair technician will be dealing with sheet products for exterior panels, but vehicles with other aluminum applications will present the technician with a variety of product forms, especially extrusions and castings. The Aluminum Association's publication Aluminum for Automotive Body Sheet Panels AT3 gives a thorough discussion of the sheet alloys used. This publication will utilize some of that information because repairs depend upon alloys and their characteristics.

Wrought alloys are described by a four digit numerical designator (see Section 3). The first digit indicates a family of alloys having the same principal alloying element and the other three define the specific alloy. The families also fall into one of two groups:

- heat-treatable (HT) which gain their mechanical properties by thermal processes; and,
- non-heat-treatable (NHT) which gain their mechanical properties from cold working.

There are many variations to the processing of any given alloy and the subject is complex. For the repair technician, it is only necessary to know that these two groups will behave differently in some repair processes. Casting alloys employ a different numbering system using a three digit number.

Each alloy, cast or wrought, is supplied in various tempers, which dictate the level of mechanical properties of the material. The temper is identified by a suffix to the alloy number. For heat-treatable alloys the suffix begins with a "T", as in 6111-T4. For non-heat-treatable alloys the suffix begins with an "H", as in 3003-H14. In both groups the suffix "0" indicates the annealed or, as it is sometimes called, "soft" condition. For automotive applications, heat-treated sheet is normally supplied in the -T4 temper. The next section lists alloys that may be encountered and their typical automotive applications, with the more current alloys underlined. The collision repair technician should know the alloys being worked with because that can affect the repair, as for instance in the selection of weld wire, if welding is to be employed.

For the repair of body panels, dent resistance and amount of deflection under load are two of the principal criteria. Dent resistance is based on many factors, the shape of the part and its support being of primary importance. Given the same design, the factors affecting dent resistance are yield strength and thickness and in comparing steel and aluminum the greater thickness of the aluminum panel can more than compensate for its lower yield strength. If the yield strength of the aluminum and the steel are the same, the dent resistance will be equivalent for the same thickness. The deflection under load, or stiffness, of a panel is not influenced by the strength of the material but is controlled by the material's modulus of elasticity (Young's Modulus) and its thickness. Compared to steel, aluminum is at a disadvantage because its modulus of elasticity is one-third that of steel and therefore may seem to be less sturdy. However, the greater thickness of the aluminum quickly compensates for this because panel bending stiffness increases with the third power of thickness. In practice, however, it is usually beneficial to reduce the spacing of the supporting structure for an aluminum design in order to achieve the required resistance to deflection.

Later in this manual the use of heat in making repairs is discussed. The following table taken from The Aluminum Association publication AT3 shows the properties of selected sheet alloys as supplied and after heat and cold work. It should be noted that, when the materials are heated in the typical OEM paint bake cycle, the strength of the non-heat-treatable alloys (5xxx) are not affected but, when stretching (as in panel forming)

TABLE 2.0 TYPICAL PROPERTIES OF ALUMINUM BODY SHEET ALLOYS FOLLOWING A SIMULATED PAINT BAKE CYCLE [1]

| Alloy & Temper | Original Material | | | | | Paint Bake Only (No Prior Stretch) | | | | | 2% Stretch + Paint Bake | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ultimate Tensile Strength | | Tensile Yield Strength | | Elongation in 50mm or 2 in | Ultimate Tensile Strength | | Tensile Yield Strength | | Elongation in 50mm or 2 in | Ultimate Tensile Strength | | Tensile Yield Strength | | Elongation in 50mm or 2 in |
| | **MPa** | **(ksi)** | **MPa** | **(ksi)** | **%** | **MPa** | **(ksi)** | **MPa** | **(ksi)** | **%** | **MPa** | **(ksi)** | **MPa** | **(ksi)** | **%** |
| 2008-T4 | 250 | (36) | 125 | (18) | 28 | 255 | (37) | 145 | (21) | 26 | 260 | (38) | 165 | (24) | 23 |
| 2010-T4 | 240 | (35) | 130 | (19) | 25 | 235 | (34) | 130 | (19) | 26 | 250 | (36) | 170 | (25) | 22 |
| 2036-T4 | 340 | (49) | 195 | (28) | 24 | 315 | (46) | 180 | (26) | 28 | 330 | (48) | 195 | (28) | 25 |
| 5182-0 | 275 | (40) | 130 | (19) | 21 | 275 | (40) | 130 | (19) | 21 | 275 | (40) | 145 | (21) | 19 |
| 5454-0 | 250 | (36) | 115 | (17) | 22 | 250 | (36) | 115 | (17) | 22 | 240 | (35) | 130 | (19) | 21 |
| 5754-0 | 220 | (32) | 100 | (14) | 26 | 220 | (32) | 95 | (14) | 26 | 220 | (32) | 110 | (16) | 25 |
| 6009-T4 | 220 | (32) | 125 | (18) | 25 | 275 | (40) | 180 | (20) | 22 | 285 | (41) | 195 | (28) | 20 |
| 6111-T4 | 280 | (42) | 150 | (22) | 26 | 310 | (45) | 200 | (29) | 24 | 315 | (46) | 240 | (30) | 22 |
| 6022 | 257 | (37) | 148 | (22) | 26 | | (45) | | (25) | 26 | | (41) | | (31) | 24 |

(1) 30 min at 177°C (350°F).

is included, the strength goes up. The other alloys show mixed results with the 6xxx alloys gaining by both heating and stretching. Alloys from the 6xxx group are being more and more frequently specified for exterior panels because of this strengthening capability and because of their good overall corrosion resistance.

Corrosion resistance is one of the valuable characteristics of aluminum but aspects of it seem to be among the most “worried about” factors in deciding to use aluminum, not surprising in view of the harsh environmental conditions many vehicles can be expected to face. The subject is complex but there are certain principles the repair person should know about. Aluminum exposed to air instantly reacts with it to form a thin coherent oxide film. This oxide film or layer effectively seals off the aluminum from further contact with air, thereby providing aluminum’s high corrosion resistance.

This film will get thicker, at a declining rate, over a period of months (assuming no other surface coatings) and even though it should be removed before some procedures it will reform immediately. Because of that the collision repair technician need not fear that repair will impair the inherent corrosion resistance of the aluminum.

In the presence of other metals, aluminum may be subject to galvanic action, an electrolytic reaction where one metal is anodic to another and will preferentially corrode to protect the other in the presence of a severe environment. This reaction is somewhat dependent on the alloy type and some alloys have better corrosion resistance than others in equivalent exposure. In vehicles, aluminum is anodic to most metals except magnesium and zinc. This means of course that if aluminum is connected to the most common material, steel, without proper preventive steps, the aluminum may suffer corrosion by protecting the steel electrochemically. In manufacturing this potential for corrosion is eliminated by using coated fasteners, appropriate coatings and sealants, and by isolating the metals by using non-metallic insulation such as gaskets and washers between parts. The repair technician must insure that all such preventive steps are maintained after the repair. The manufacturers’ service manuals specify what should be used.

In practice, most aluminum panels are painted for appearance. If an improperly applied coating is damaged, a type of corrosion called filiform corrosion can occur between the coating and the surface of the aluminum. Correct finishing is therefore an important part of the repair process.

# 3.0 Applications of Aluminum

There are many alloys used in automotive manufacture. The following is a list of those that may be encountered by the repairer and where they may be found. Those underlined are generally in more widespread use in vehicles.The manufacturers' service manuals will give specifics for each model.

## Wrought Alloy Series

### 1xxx Series

With aluminum of 99 percent or higher purity, these compositions are characterized by excellent corrosion resistance, high thermal and electrical conductivity, low mechanical properties and excellent workability. Moderate increases in strength may be obtained by strain hardening.

1100 Trim, nameplates, appliqués
1200 Extruded condenser tubes and fins

### 2xxx Series

Copper is the principal alloying element in this group. When heat-treated, the mechanical properties are similar to, and sometimes exceed, those of mild steel. Artificial aging may be employed to increase strength.

These alloys in the form of sheet are often clad with a high-purity 6xxx or 7xxx series alloy. This provides physical and electrolytic protection to the core material, and greatly increases resistance to corrosion.

2008 Outer and inner body panels (also suitable for structural applications)
2010 Outer and inner body panels (also suitable for structural applications)
<u>2011</u> Screw machine parts
<u>2017</u> Mechanical fasteners
2024 Mechanical fasteners
2036 Outer and inner body panels, load floors, seat shells
<u>2117</u> Mechanical fasteners

### 3xxx Series

Manganese is the principal alloying element in this group. These alloys are not heat-treatable. They have a superior combination of corrosion resistance and formability.

3002 Trim, nameplates, appliqués
<u>3003</u> Braze-clad welded radiator tubes, heater cores, radiator, heater and evaporator fins, heater inlet and outlet tubes, oil coolers, and air conditioner liquid lines
3004 Interior panels and components
3005 Radiator, heater and evaporator fins
3102 Extruded condenser tubes

### 4xxx Series

Silicon is the major alloying element in this group. Silicon is used in wrought alloys to lower the melting range without causing brittleness. Aluminum-silicon alloys are used to make welding wire and as cladding alloys for brazing sheet, where a lower melting range than that of the base metal is required. One application in addition to joining and brazing filler applications is alloy 4032 which has good wear resistance, and thus it is well suited to the production of forged engine pistons.

4004 Cladding for brazing sheet
4032 Forged pistons
4043 Welding wire
4045 Cladding for brazing sheet
4104 Cladding for brazing sheet
4343 Cladding for brazing sheet

### 5xxx Series

Magnesium is one of the most effective and widely used alloying elements for aluminum, and is the principal element in the 5xxx series alloys. When it is used as the major alloying element or combined with manganese, the result is a moderate- to high-strength, non-heat-treatable alloy. Alloys in this series are readily weldable and have excellent resistance to corrosion, even in marine applications.

| | |
|---|---|
| 5005 | Trim, nameplates, appliqués |
| <u>5052</u> | Interior panels and components, truck bumpers and body panels |
| <u>5182</u> | Inner body panels, splash guards, heat shields, air cleaner trays and covers, structural and weldable parts, load floors (sheet) |
| 5252 | Trim |
| <u>5454</u> | Various components, wheels, engine accessory brackets and mounts, welded structures (i.e. dump bodies, tank trucks, trailer tanks) |
| 5457 | Trim |
| 5657 | Trim |
| <u>5754</u> | Inner body panels, splash guards, heat shields, air cleaner trays and covers, structural and weldable parts, load floors (sheet), body-in-white structures |

### 6xxx Series

Alloys in this group utilize magnesium and silicon in various proportions to form magnesium silicide, which makes them heat-treatable. A major alloy in this series is 6061, one of the most versatile general purpose heat-treatable structural alloys. The magnesium-silicon (or magnesium-silicide) alloys possess good formability and corrosion resistance with high strength.

| | |
|---|---|
| 6009 | Outer and inner body panels, load floors, bumper face bars, bumpers reinforcements, structural and weldable parts, seat shells |
| 6010 | Outer and inner body panels, seat shells and tracks |
| 6016 | Outer and inner body panels |
| <u>6022</u> | Outer and inner body panels |
| 6053 | Mechanical fasteners |
| 6061 | Body components (extruded), brackets (extruded and sheet), suspension parts (forgings), driveshafts (tubes), driveshaft yokes (impacts and forgings),spare tire carrier parts (extruded), bumper reinforcements, mechanical fasteners, brake cylinders (extruded), wheels (sheet), fuel delivery systems |
| 6063 | Body components (extruded) |
| 6082 | General structural, brake housings |
| <u>6111</u> | Body panels |
| 6262 | Brake housings, brake pistons, general screw machine parts (anodized) |
| 6463 | Luggage racks, air deflectors |

### 7xxx Series

Zinc is the principal alloying element in this group. When it is combined with smaller percentages of magnesium and, in some cases copper, it results in heat-treatable alloys of very high strength.

| | |
|---|---|
| 7003 | Seat tracks, bumper reinforcements |
| 7004 | Seat tracks, bumper reinforcements |
| 7021 | Bumper face bars, brackets (sheet), bumper face bars (bright), bumper face bars (bright anodized), bumper reinforcements |
| <u>7072</u> | Condenser and radiator fins |
| 7116 | Headrest bars |
| <u>7129</u> | Bumper face bars, bumper reinforcements, headrest bars (extruded), seat track |

## Casting Alloys

Aluminum alloy castings which for the most part, are aluminum-silicon alloys, can be produced by virtually all casting processes in a very large range of compositions possessing a wide variety of useful engineering properties. The choice of a specific casting alloy depends on the chosen casting process (which include: sand, permanent mold, die, lost foam, or squeeze), the product design, the required properties of the product and other relevant factors.

| Alloy | Typical Applications |
|---|---|
| 319.0 | Manifolds, cylinder heads, blocks, internal engine parts |
| 332.0 | Pistons |
| 356.0 | Cylinder heads, manifolds |
| A356.0 | Wheels |
| A380.0 | Blocks, transmission housings/parts, fuel metering devices |
| 383.0 | Brackets, housings, internal engine parts, steering gears |
| B390.0 | High-wear applications such as ring gears and internal transmission parts |

As for what vehicles these alloys are on, the following table gives some examples:

| Body-in-White | Alloy |
|---|---|
| Acura NSX | 5182 Body Structure, 6xxx rocker beam extrusions, 5052 inner door panels, 6xxx outer panels |
| Audi A8 | 6016 body panels, 6xxx extrusions |
| Jaguar XJ220 | 5754 and honeyconb panel body structure |
| GM EV1 | 5754 body structure/6xxx extrusions 356 castings |
| Plymouth Prowler | 6022 body panels, 6xxx extrusions |
| Panoz Roadster | 6xxx extrusions, Al-mg body panels |

TABLE 3.0 SAMPLE APPLICATIONS

| Components | Average Unit Weight (In Pounds) | Total Aluminum Usage in 1996 (In Millions of Pounds) | Percent Penetration |
|---|---|---|---|
| Condenser | 14.30 | 195 | 95% |
| Cylinder Heads | 24.0 | 288 | 84% |
| Engine Block | 45.0 | 179 | 25% |
| Evaporator | 4.2 | 57 | 95% |
| Heater Core | 2.5 | 34 | 95% |
| Engine Pistons | 1.5 | 101 | 100% |
| Transmission Pistons | 1.5 | 50 | 100% |
| Power Steering Rack | 4.0 | 58 | 100% |
| Transmission Case | 40.0 | 515 | 100% |
| Wheels | 72.0 | 502 | 35% |

| Hang-on Panels | Part/Alloy |
|---|---|
| Oldsmobile Aurora | Hood - 6111 outer/2010 inner |
| Buick Park Avenue | Hood - 6111 outer |
| Buick Riviera | |
| Ford Crown Victoria | Hood - 2036 Outer/2008 inner |
| Mercury Marquis | Decklid - 6111 outer and inner |
| Lincoln Mark XIII | Hood - 6111 inner and outer |
| Lincoln Town Car | Hood - 2036 outer and inner |
| Mazda RX7 | Hood - 5xxx |
| Mazda Miata | Hood - 5xxx |
| Land Rover Discovery | Exterior panels (ex-roof) 6016 inner and outer except rear doorwhich has steel inner |
| Mercedes Sport Roadster | Removable top - 6016 |
| Porsche 928 | Hood - 6016 outer Door - 6016 outer Front Fenders - 6016 |
| Ford F150 Pickup | Hood - 6111 |
| Mercury Sable | Decklid - 6111 inner and outer |
| Chevrolet Venture Van | Hood - 6111 inner and outer |

There are many more vehicles with significant amounts of aluminum under the hood.The Saturn for example has all aluminum engine and transmission castings, an interesting and significant sidelight of which is that these are made from recycled material. Indeed the preponderance of applications are for cast products made in large part with recycled metal.The Aluminum Association commissioned Ducker Research Company to compile the uses of aluminum in 1996 model year cars and light trucks. By application, total usage is shown in Figure 3.1 and by alloy in Figure 3.2.

FIGURE 3.1 SYSTEM ALUMINUM CONTENT IN POUNDS
OVERALL NORTH AMERICAN PRODUCTION VEHICLES.

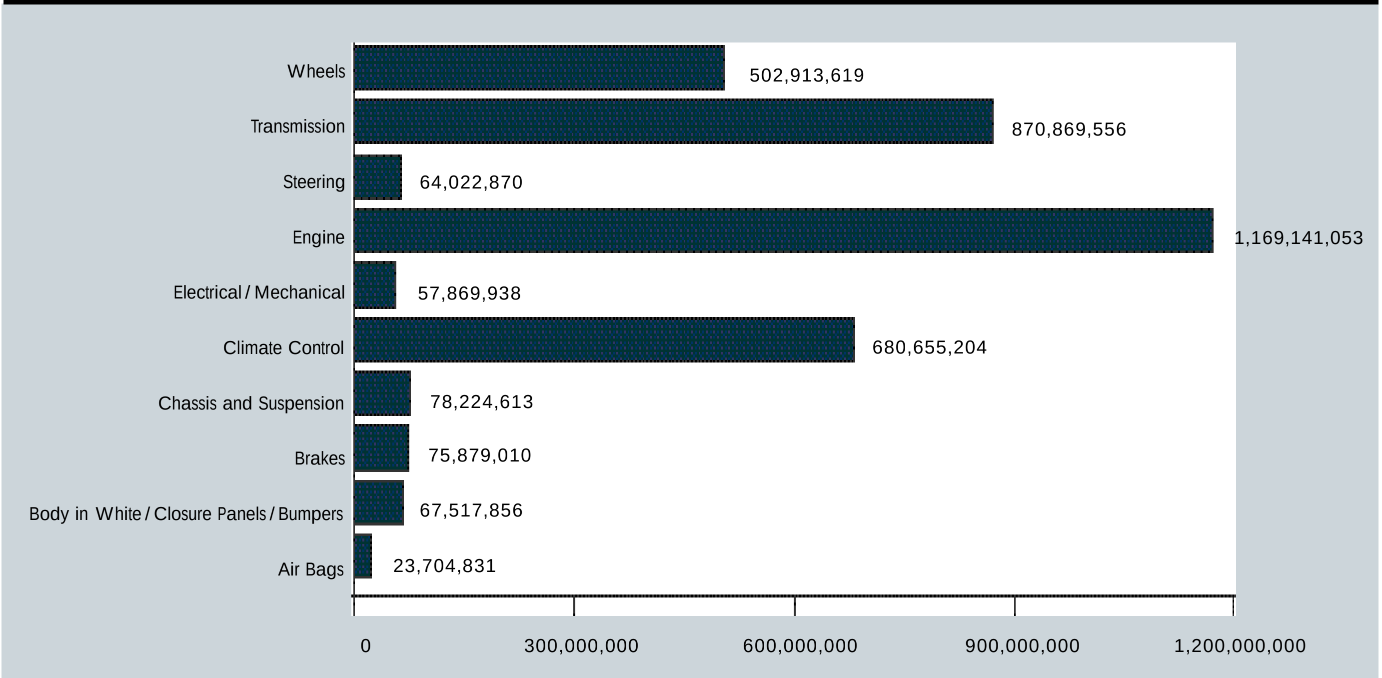
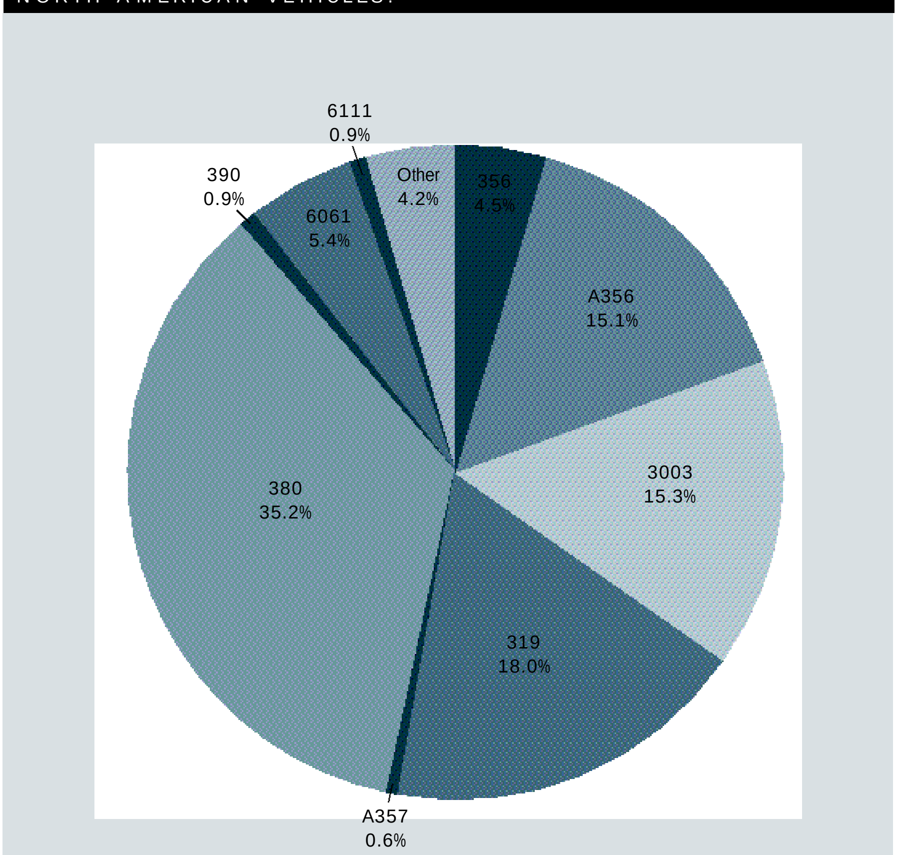



FIGURE 3.2 ALUMINUM CONTENT BY ALLOY ALL PRODUCTION
NORTH AMERICAN VEHICLES.



# 4.0 Metalworking

The processes used for working aluminum are similar to those used for conventional steel body panels. That said, there are differences that are important for the repair person to be aware of. This chapter will review general practices and highlight practices especially applicable to aluminum. Repair industry safety precautions must always be observed.

## Handling

Aluminum has a tendency to scratch or scuff more easily than steel and that is the first thing the collision repair technician needs to keep in mind. Replacement parts will be carefully packaged and they should be treated with care as they are unpacked and brought to the workplace. Aluminum should not be worked on a steel table or on the floor unless a sheet of plywood or the like is first put on the table or workplace.

Proper storage is also important. Aluminum gains its good corrosion resistance from the presence of a thin dense oxide layer, or film which is present from the time the aluminum is exposed to air. This layer is very thin but will thicken over time with continued exposure.The layer can trap dirt and moisture which in turn may affect repair processes such as welding. Sanding, grinding, etching, etc. are used to remove this layer, although for welding preparation wire brushing is recommended. Often the question arises as to how soon after removal can processes such as welding or painting begin. There are no hard and fast rules, but leaving cleaned aluminum overnight if it is well stored and is not subject to moisture, does not pose a problem.

When aluminum is stored with the sheets stacked closely together moisture condensing between the sheets can be trapped and over time cause excessive oxide buildup called water staining. Therefore, it is recommended that aluminum always be stored indoors in a climate controlled area where there are no rapid changes in temperature and humidity.

## Tools

Tools for working aluminum are basically the same as those used for working steel. Using the same set of tools, however, introduces the possibility of contaminating the aluminum with steel particles and where possible tools should be kept separate. In particular sanding discs, cutting tools, files and even shop towels should not be used interchangeably on steel and aluminum. Power tools should be cleaned off before using on aluminum. All this is done to avoid the possibility of contaminating the aluminum surface with steel particles which could cause problems with welding, finishing, and even corrosion. Metal tools such as hammers, dollies, and spoons should have smooth and polished faces and rounded edges so as not to gouge the aluminum. Wood, leather and plastic faced hammers are generally preferred. Do not use hammers with serrated faces. For wire brushing, use stainless steel brushes and again maintain the brushes strictly for aluminum.

## Cutting

Aluminum sheet is in most cases best cut using mechanical means and in fact cutting aluminum is more like working with wood than with steel. Reciprocating saws and band saws can be used effectively. Blade tooth shape and spacing differ from those used for steel and appropriate blades are available for aluminum. In general, the best results are achieved with high blade speeds. Use of the wrong blades and/or too slow speeds can cause the blade to snag in thin sheet found in auto body work.

An important difference between aluminum and steel is that oxy-fuel cutting is not effective on aluminum because the oxide film and the aluminum melt at different temperatures and because aluminum conducts heat rapidly away from the work area.The result is a ragged cut that will have to be further trimmed.

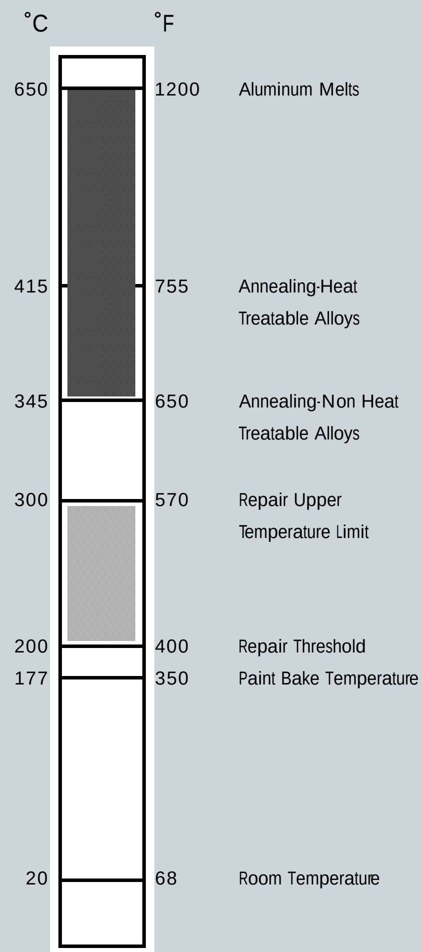
Plasma arc cutting is a suitable process for aluminum. It works by heating a gas with a tungsten arc and directing the hot plasma through an orifice at high velocity. For thin sheet, as found in vehicle construction, air is the gas and cutting speeds in the range of 200 in./min (85 mm/sec) are achieved. However the process leaves a heat affected zone (HAZ) at the cut edge which may have to be removed mechanically if the application demands.

### Grinding, Sanding, and Filing

For sanding aluminum, use orbital or dual-action sanders with open-coat sanding discs on soft or flexible backing pads. Do not use discs coarser than 80 grit. In general, use only light pressure for best results.

Files and stones are used to trim edges and on panels to highlight damaged areas. Filing should be done very carefully to avoid gouging the surface and in fact a dull file is preferred over a sharp one. Frequent cleaning of the file is necessary to avoid buildup of particles. As noted before do not use the same file on both aluminum and steel. A long sanding board, typically used for sanding filler, effectively highlights high spots without removing metal.

FIGURE 4.0 TEMPERATURE CHART FOR ALUMINUM REPAIR




### The Use of Heat

Hammers, dollies, picks, etc. are used to physically move metal so that dents and similar imperfections are removed and the original appearance of the panel is restored. To avoid metal thinning, the hammer off-dolly method is preferred.The heat-treatable aluminum alloys used for exterior panels are as strong as steel and can require considerable force to remove dents. In addition, the heat-treatable and non-heat-treatable alloys, are strengthened with a concurrent reduction in ductility by cold working. For these reasons, heat may be considered as a means of facilitating the repair because at elevated temperatures the metal softens and is easier to work and less likely to crack. Figure 4.0 gives the recommended temperature ranges for repair with other temperature milestones applicable to aluminum.

At the top of the temperature column is the reminder that aluminum melts at about 1200˚F (650˚C), a temperature less than half that of steel. There is another marked difference between aluminum and steel and that is as aluminum is heated all the way to its melting point it does not change color. If the repair person is inattentive, an unwanted hole may suddenly appear in the work. Offsetting this characteristic is the fact that aluminum conducts heat much more rapidly than does steel and in most cases it will take longer to heat an aluminum panel. Tests conducted by The Aluminum Association for I-CAR for inclusion in their classroom video shows by means of special imaging the difference in the rate of heat transfer. For example: the photos in Figure 4.1 show the difference in temperature distribution in comparable steel and aluminum panels. Due to the high conductivity of the aluminum a larger area is heated, as can be seen in Figure 4.1. With the same heat source the aluminum takes longer to reach the same temperature as the steel.

**4.1 TEMPERATURE DISTRIBUTION IN STEEL AND ALUMINUM PANELS**

First image
Steel Panel
Maximum temperature: 476˚F
Time to reach maximum temperature: 6 sec.

Second image.
Aluminum Panel
Maximum temperature: 293˚F
Time to reach maximum temperature: 6 sec.

Third image.
Aluminum Panel
Maximum temperature: 477.6˚ F
Time to reach maximum temperature: 23 sec.

The next two temperatures in Figure 4.0 are the annealing temperatures for heat-treatable and non-heat-treatable alloys. Aluminum is annealed by heating to this range and then cooling to room temperature. When annealed, aluminum is in its softest condition. Under these conditions it has its lowest mechanical strength properties and greatest ductility, which makes it very workable. It is rare, however, that it will be useful to anneal aluminum alloys in the repair process because in most cases it is desirable to retain as much as possible of the original properties of the alloy being used. It is that consideration that sets the range at which the work is done from 400˚F (200˚C) to 570˚F (300˚C). When the material is heated to within that range for the relatively short times used in repair, it will soften enough to make it more workable but tests show that when it has cooled to room temperature most or all of the original properties are retained. The lowest temperature in the graphic is 350˚F (177˚C) and is the typical temperature at which paint is cured. Some of the aluminum alloys in use for body panels (and some steels as well) gain in mechanical properties if held at this temperature.That feature is valuable where the as-supplied material can be readily formed to the required shape and then can gain strength during the paint bake cycle.

The non-heat-treatable alloys used in an automotive body are usually supplied in the -0 temper and it might therefore be thought that heating would not help in repair. However, cold work may occur in manufacturing or in the collision damage itself. A panel distorted by damage will have had some unknown amount of cold work and the metal working necessary to bring it back to shape will introduce more, possibly necessitating the use of heat to effect the repair. If the damage is severe, dye penetrate should be used to check for cracks.

Heat-shrinking can be used to cause a panel to return to shape through heating and working to manipulate the internal stresses in the metal. Because of aluminum's rapid heat transfer this method may not always be as effective as in steel but it is a viable and widely used technique. Heat can also be used without mechanical work to remove or reduce the size of dents.This process works well with aluminum because of its thermal expansion rate. The I-CAR aluminum course has a video showing the proper technique for removing a dent using heat.

Achieving the required temperature range in a material that doesn't show that it is being heated requires the use of temperature indicators. These may be electronic measuring devices using either contact or non-contact probes, or they may be heat sticks, thermal paints, or thermal labels which change color or melt at a specified temperature. Generally indicators for suitable temperatures are placed at varying distances from the heat source to permit monitoring the heat spread.

Heating is usually accomplished with an oxy-acetylene torch with a low temperature neutral flame. Propane torches or heat guns may be used to control heat, but especially with the latter, the time to heat to the desired temperature may be noticeably longer than with the oxy-acetylene torch because of the rapid heat transfer in the aluminum demonstrated in Figure 4.1.

Occasionally the repair technician will need to disassemble an adhesive bonded joint. Heat applied in the recommended repair temperature range, Figure 4.0, will help break the bond. For this reason, too, care should be taken to not overheat a bonded area that is adjacent to an area being repaired.

# 5.0 Joining Methods

Automobile manufacturers use a wide variety of joining methods in building a car and each may have some impact on repair. This section will review these and then highlight the ones that will be used in repair.

**Resistance spot welding -** This is used to make lap joints and is the principal joining method used in conventional steel construction and is also used for aluminum.The oxide film on aluminum is an insulator and to get acceptable consistency and extend tip life the surface is sometimes prepared with an etching cleaner. Higher currents are used for aluminum than for steel but on the other hand the heating time per spot is shorter. Resistance spot welding equipment found in collision repair shops is not suitable for welding aluminum.The OEM's spot welds will in many cases have to be removed to replace parts. They may be drilled out or removed with a spot weld cutter depending on the repair, and are often replaced with plug welds.

**Ultrasonic Welding -** Not widely used yet but growing, this technique is similar to resistance spot welding but uses high energy vibration to join the parts. Its advantage is that there is no heat affected weld nugget as in resistance welding and larger weld areas lead to better shear strength. This type of equipment is also not usually found in collision repair shops.

**Inert Gas Welding -** This is the most common welding method used for aluminum. The two types used are metal arc (called MIG or GMAW) in which aluminum filler wire is used as the electrode, and gas tungsten arc (called TIG or GTAW) in which a tungsten electrode is used and filler wire may or may not be used. Fluxes and coated rods are not used for aluminum. Inert gas welding can be used for butt welds, fillet welds, and also for lap welds by means of spot or plug welds. In the repair of light sheet, TIG has normally been employed but, with suitable equipment, MIG can be satisfactorily used and is the preferred equipment in the collision repair industry.

**Oxygas Welding -** An old standby, this welding method uses a torch, filler rod and flux to make the weld. It is difficult to do, tends to cause a large heat-affected zone, and requires careful flux removal to avoid corrosion. It is not used by the OEM's and is found only in specialty applications for repair.

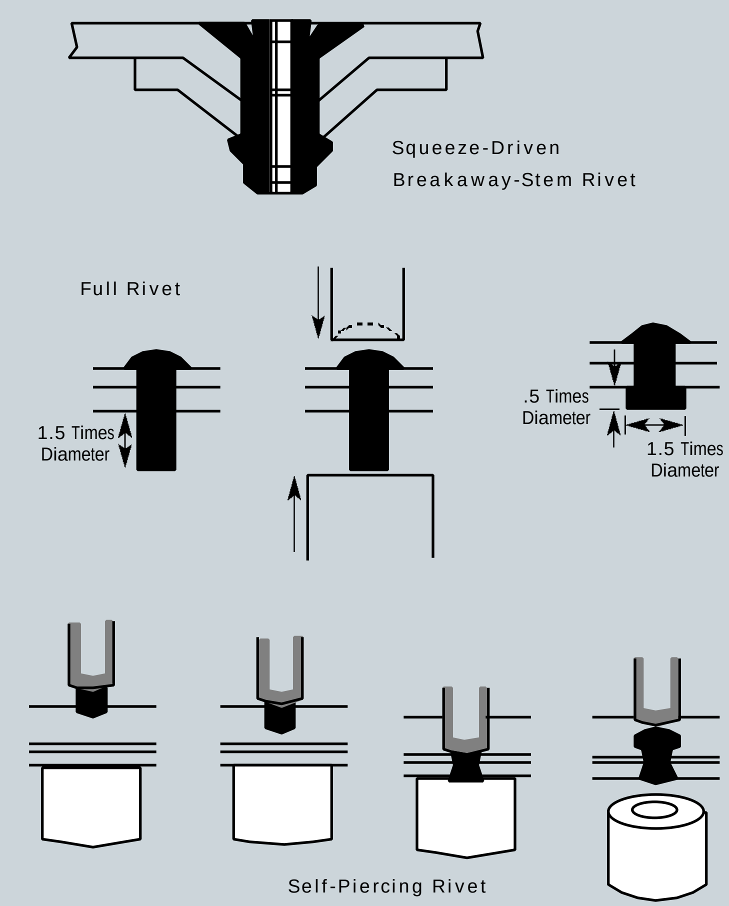
**Adhesive Bonding -** Chemical bonding is increasingly in use to join a variety of materials. There are a wide range of adhesives available and they are used in both OEM and repair scenarios. In repair heat is used to soften adhesive joints so they can be separated as needed.

**Weldbonding -** Weldbonding is a variant of adhesive bonding developed for automotive use wherein resistance spot welding is employed to assist accurate assembly, to hold the joint together during cure and to improve the joint's resistance to peeling. The spot welding is done through the uncured adhesive film which is squeezed out by the clamping pressure at the spot locations. For removal heat and spot weld cutters may be used.

**Hemming -** This assembly method is used for parts like doors, deck lids and hoods. Joints are made by folding an edge of one part over on itself clamping the mating piece in the fold. For aluminum rope hems are usually used.

**Riveting -** A joining method that does not require heat and can be used to join dissimilar materials. The presence of a protruding head or

FIGURE 5.0 RIVETING



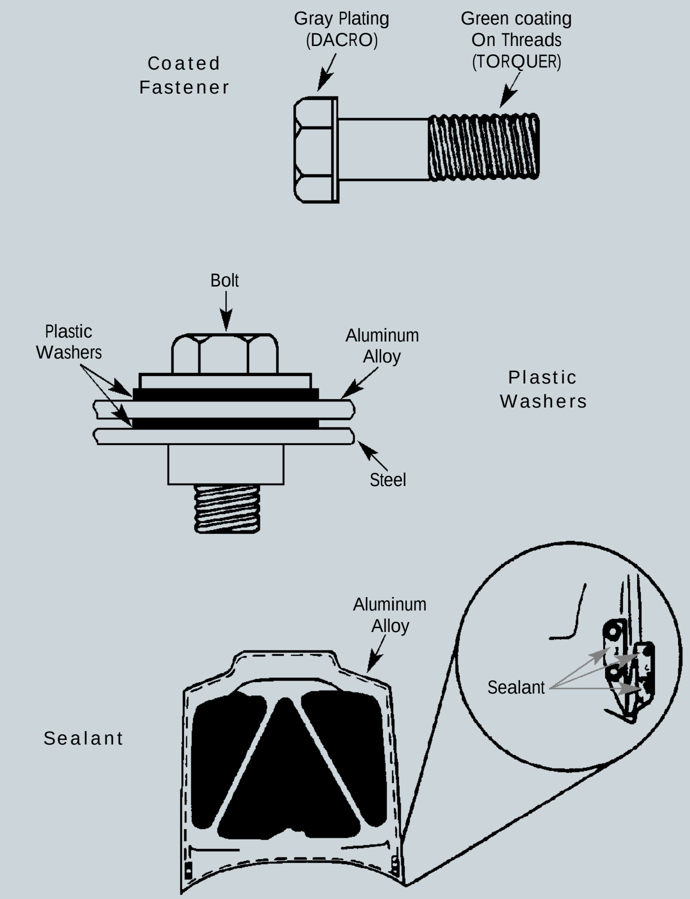

Courtesy of I-CAR

shank limits use to where cosmetic appearance is not a factor unless countersunk rivets are used but nonetheless riveting is used widely in repair. Removal of rivets requires grinding and/or drilling. Self-piercing rivets, also called punch rivets, do not require a hole but do require an anvil and therefore access to both sides of the joint.

**Screws and Bolts -** Also not requiring heat, these fasteners offer the advantage of being removable. They are frequently used in vehicle construction and in repair.

**Clinching -** Clinching is used to join thin materials and is a combination compression and punching operation resulting in joints similar to spot welding or riveting. The sheet itself is its own fastener and there is no hole in the sheet. In repair clinched joints are separated by drilling or using a spot weld cutter.

FIGURE 5.1 EXAMPLES OF GALVANIC CORROSION PREVENTION




Courtesy of I-CAR

## Repair Joining Methods:

### Mechanical Fastening

The repair shop can make use of mechanical fastening in many applications, including those where a spot weld was the original joint. Standard riveting operations are used for aluminum. Typically rivets are of several types. A conventional rivet will have a solid or tubular shank. It requires a hole and access to both sides of the joint so that it can be struck on one end against a backing anvil on the other. Squeeze-driven breakaway stem rivets, perhaps most common in repair and often called pop or blind rivets, require a hole and are used where only one side access is available.The collision repair technician must give attention to materials. Most common rivets are steel. Section 2 discussed corrosion and pointed out that unprotected aluminum and steel in contact will result in corrosion of the aluminum under automobile service conditions of moisture, salt and dirt.Therefore only stainless steel and aluminum fasteners are recommended and are available for most applications. Squeeze-driven breakaway-stem rivets may have an aluminum body and an aluminum stem but the most common ones will usually have a steel stem. In some kinds the stem pulls through but in most the stem stays in. This could represent a corrosion hazard if moisture can get in and aluminum or stainless stems are preferred. It is not possible to specify rivets for each application in this manual and the repair shop will have to rely on the auto manufacturer's recommendations for each repair.

Where screws and bolts are to be used, the same issues about corrosion arise. In vehicle construction, coated steel bolts are often used.These have coatings on the head and/or the threads that act as a barrier between the fastener and the aluminum. If the aluminum panel is to be attached to a steel panel, plastic washers should be added to separate the aluminum from the steel and the bolt. In addition sealant can be used in and around the joint to exclude moisture in service.

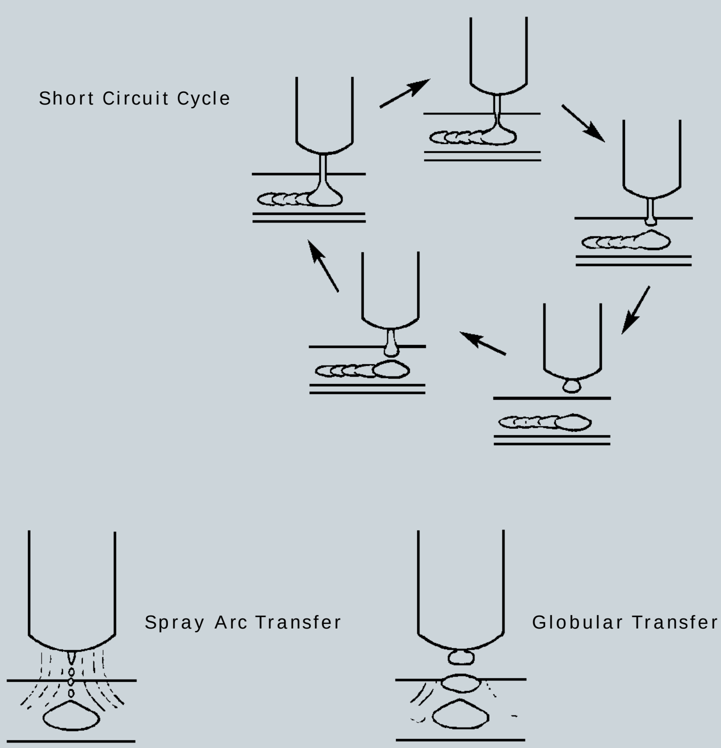
In the case of screws, stainless steel is the recommendation for most uses but the aluminum should not be directly joined to steel. Non-metallic inserts or keeps must be used so that neither the aluminum nor the screw are in direct contact with the steel. (See Figure 5.1)

### Welding

Joining of aluminum in repair is easily accomplished with the use of inert gas welding. MIG welding is preferred because the high frequency alternating current used in TIG welding can damage sensitive electronics if the technician fails to isolate the work properly. To make welds in thin sheet using MIG requires the proper technique and equipment to give best quality. TIG remains a viable way of repairing aluminum and full treatment of the TIG and MIG processes are given in The Aluminum Association publication Repair of Aluminum Automotive Sheet by Welding AT1.

In this manual the focus is on MIG and highlights some of the considerations for welding aluminum that differ from steel. MIG welding is accomplished by striking an arc between the work and a consumable filler wire in an inert gas shield. In the process, the work zone and the wire are melted and drops of the molten wire are transferred to the work. How this transfer takes place is important to the production of high quality welds in aluminum. There are four recognized mechanisms- globular, short circuit cycle, spray arc and pulsed spray arc. Globular transfer is not recommended because it is likely to cause weld defects. Short circuit transfer is used in steel and while aluminum can be welded using this technique, cold uneven welds with less penetration result. Spray arc transfer permits rapid welding and creates a larger, more fluid weld puddle, better penetration and produces good quality welds in all weld positions. (Figure 5.2)

FIGURE 5.2 TRANSFER METHODS




Courtesy of I-CAR

### Equipment

It is recommended that inverter pulsing be considered for thin sheet as the pulsed-spray arc transfer permits easier welding by minimizing the chance of burn through. Equipment that will do this costs more than the lower power machines needed for short circuit transfer. 220-240 volt power supplies work best. The 110-120 volt power supplies found in many shops are generally unacceptable for quality aluminum welding. This is a particular burden on the individual that must supply his own equipment, a situation often found nowadays. The welding industry recognizes the situation and types of equipment balancing low cost with adequate power for spray transfer on aluminum are being developed.

In addition to the DC power source, the repair technician needs an inert gas supply of 100% argon with the proper regulator, flow meter and the necessary hose and fittings; a welding gun and wire feeder, helmet with no less than #10 shade, protective clothing, and a stainless steel wire brush.

There are several different designs of wire feeder on the market. The major differences among them involve the location of the motor and drive rolls which feed the wire. One type, called a "push" feeder places the motor and feed rolls back at the feeder and pushes the wire through a conduit into and through the welding gun. This type of feeder will perform acceptably on larger diameter and/or higher strength aluminum wires (1/16 in. (1.5 mm) and larger and with 5356 instead of 4043) but probably will not reliably feed the smaller diameter wires.

Another type, called a "pull" feeder, places the motor and feed rolls in the welding gun and pulls the wire through a conduit into and through the gun. The pull feeder though has the same limitations as the push feeder with respect to aluminum filler alloys.

A third type, the "push-pull" feeder, uses two motors and two sets of drive rolls, one in the feeder and one in the gun, to obtain the most uniform feeding for the small diameter (3/64 (1.2 mm) and lower) welding wire used for sheet metal.

The last type, the "1-lb. spool gun", holds a 1-lb. spool of wire right on the welding gun. Since the wire is fed only a short distance a single motor and drive roll is adequate to feed any wire diameter of 1/16 in. or lower. The guns tend to be light duty and so should not be used for heavy section welding but are perfectly adequate for welding sheet gauges. These guns also tend to be the least expensive. The added bulk caused by having the wire spool hung on the gun can sometimes be a problem when welding under conditions of restricted access.

Whatever feeder is used, nylon or Teflon gun liners are recommended, since the coiled steel wire liner used when welding steel will shave the soft aluminum wire and clog the gun with fine shavings. For the same reason, any inlet and outlet guides used in the feeder gun should be plastic, not metallic. Drive rolls should be designed for soft wires. Never use knurled drive rolls. Drive rolls of the U- or V- groove, top and bottom, are preferred for aluminum.

Wire feeders should possess a "touch-start" or "slow run-in" arc initiation feature. This is necessary for use with the constant energy (constant current) type of power supply. This feature is also preferred with constant voltage power supplies to minimize arcing in the contact tube and/or frequent "burn-backs" to the contact tube. The "touch-start" feature, which delays electrode feeding until the electrode is touched to the base metal, provides: (1) better weld fusion at the starting location than can be obtained with a fast run-in feed, (2) rapid restriking of the arc for termination crater filling, and (3) increased productivity resulting from less "burn-backs" due to high current surges at starts.

An additional feature desired in the MIG welding gun is a long contact tube, 4-6 in (100-150 mm), to provide multiple points of current commutation between the electrode and the contact tube. A long contact tube in combination with the "touch-start" wire feed feature can provide many arc starts without a "burn-back".

## Filler Wire

Filler wire is selected from Table 5.3. Typical wire diameters are .030 in. (0.8 mm), .035 in. (0.9 mm), and 3/64 in. (1.12 mm). The filler wire itself must be free of grease, dirt, or foreign matter, otherwise unsound welds may result. Electrode wire is supplied on spools, with the spool

TABLE 5.3 FILLER WIRE SELECTION CHART

| For welding these alloy series to these alloy series [1] | 2xxx | 5xxx | 6xxx |
|---|---|---|---|
| 2xxx | 4043<br>4145 | Not recommended | 4145<br>4047<br>4043 |
| 5xxx | Not recommended | 5356<br>5183 | 5356<br>5183 |
| 6xxx | 4043<br>4047<br>4145 | 5356<br>5183 | 4043<br>5356[2] |

[1] The preferred filler alloy is shown first.

[2] 6009, 6010, 6013 and 6111 alloys have high copper content and should be welded to another 6xxx series with 5356 electrode wire

size depending on the type of gun and feeder. The collision repair technician should make certain that spools of filler wire are kept packaged and dry until ready to use. Unused wire should be returned to its original carton or put in a sealed plastic bag.

### Technique

The welding gun should be held at an angle of 5° to 20° perpendicular to the work, pointed in the direction of travel. After the arc is initiated, the gun is moved forward at the proper speed. The angle of the gun is dependent upon both speed of travel and the position of the joint. This angle should be adjusted to give the proper cleaning action, depth of penetration, and bead contour.

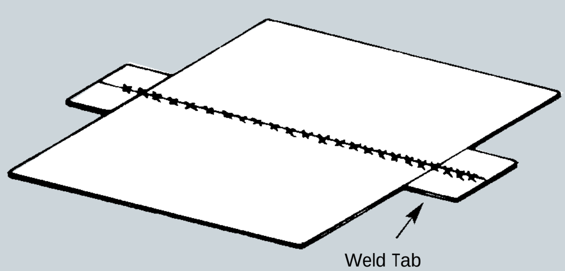
When welding unequal sections, direct the arc against the thicker piece to obtain equal fusion in the two edges. A slight weave may be helpful when welding thin gauge material to thicker gauge; the arc is always directed to the thicker member and the weld pool is washed up to the thinner member. Regardless of the technique used, it is important to watch the edge of the weld pool and the arc to see that the edge of the pool fuses into the adjacent metal.

Weld craters must be filled in when welding aluminum. Several methods can be employed to avoid or reduce the crater at the end of the weld pass. The first option is to increase the weld speed just before breaking the arc. This is best accomplished on the surface of a previous weld deposit or along the side of a bevel, rather than in an unfused root of a weld. A second option is to reverse direction and accelerate weld backwards to tail out the weld. A third option is to break and restrike the arc to build up the crater area before it solidifies. This is done best with a "touch-start" wire feed feature. A slow or fast run-in feature is too slow in reinitiating the arc to crater fill effectively before solidification and possible cracking of the weld crater.

Another, better, method is to use "run-off" tabs. It is recommended that "run-off" and "run-on" tabs be used whenever feasible. These can be small scraps of aluminum placed at each end of the weld joint on which the weld is started or stopped as shown in Figure 5.4.

Backings are very important to achieve weld quality in thin sheet with MIG welding. Close sheet fit-up over the backup bar will be difficult to achieve in areas of sheet tears; however, effort should be made to bring the sheet edges together. Grooved removable backing is commonly used. Openings in excess of .015 to .020 in. (0.4-0.6 mm) in thin sheet are difficult to bridge without

FIGURE 5.4 WELD TAB



## TABLE 5.5 TYPICAL PRACTICES FOR GAS METAL ARC (MIG) WELDING

| Material Thickness (in.) | Weld Position | Joint Design | DC Current (A) | Arc (V) | Electrode Diameter (in.) | Argon Gas Flow (cfh) | Number of Passes |
|---|---|---|---|---|---|---|---|
| 0.040 | All | Square Butt | 40-45 | 16-20 | 0.030 | 30 | 1 |
| | | Fillet and Lap | 50-60 | 16-20 | 0.030 | 30 | 1 |
| 1/16 | All | Square Butt | 60-80 | 16-20 | 0.030 | 30 | 1 |
| | | Fillet and Lap | 60-90 | 17-21 | 0.030 | 30 | 1 |
| 3/32 | Flat | Square Butt | 70-110 | 18-22 | 0.030 | 30 | 1 |
| | Horiz., Vert., and Overhead | Square Butt | 110-120 | 18-22 | 0.030-3/64 | 30 | 1 |
| | All | Fillet and Lap | 100-130 | 18-22 | 0.030 | 30 | 1 |
| 1/8 | Flat | Square Butt | 110-130 | 19-23 | 3/64 | 30 | 1 |
| | Horiz. and Vert. | Square Butt | 110-120 | 19-23 | 3/64 | 30 | 1 |
| | Overhead | Square Butt | 110-120 | 19-23 | 3/64 | 40 | 1 |
| | Flat | Fillet and Lap | 125-150 | 20-24 | 0.030-3/64 | 30 | 1 |
| | Horiz. and Vert. | Fillet and Lap | 110-130 | 19-23 | 0.030 | 30 | 1 |
| | Overhead | Fillet and Lap | 115-140 | 20-24 | 0.030-3/64 | 40 | 1 |
| 3/16 | Flat | Square Butt | 175-200 | 22-26 | 3/64 | 40 | 1 |
| | Horiz. and Vert. | Square Butt | 150-200 | 23-26 | 3/64 | 35 | 1 |
| | Overhead | 60' Single Vee | 150-175 | 23-27 | 3/64 | 60 | 1 |
| | Flat | Fillet and Lap | 180-210 | 22-26 | 3/64 | 30 | 1 |
| | Horiz. and Vert. | Fillet and Lap | 130-175 | 21-25 | 0.030-3/64 | 35 | 1 |
| | Overhead | Fillet and Lap | 130-190 | 22-26 | 0.030-3/64 | 45 | 1 |

## TABLE 5.6 TYPICAL PRACTICES FOR GAS METAL ARC (MIG) WELDING

| Material Thickness (mm) | Weld Position | Joint Design | DC Current (A) | Arc (V) | Electrode Diameter (mm) | Argon Gas Flow (L/min) | Number of Posses |
|---|---|---|---|---|---|---|---|
| 0.8 | All | Square Butt | 40-45 | 16-20 | 0.6 | 14 | 1 |
| | | Fillet and Lap | 50-60 | 16-20 | 0.6 | 14 | |
| 1.6 | All | Square Butt | 60-80 | 16-20 | 0.6 | 14 | 1 |
| | Fillet and Lop | 60-90 | 17-21 | 0.030 | 0.6 | 14 | |
| 2.4 | Flat | Square Butt | 70-110 | 18-22 | 0.6 | 14 | 1 |
| | Horiz., Vert., and Overhead | Square Butt | 110-120 | 18-22 | 0.6-1.2 | 14 | 1 |
| | All | Fillet an Lop | 100-130 | 18-22 | 0.6 | 14 | 1 |
| 3.2 | Flat | Square Butt | 110-130 | 19-23 | 1.2 | 14 | 1 |
| | Horiz. and Vert. | Square Butt | 110-120 | 19-23 | 1.2 | 14 | 1 |
| | Overhead | Square Butt | 110-120 | 19-23 | 1.2 | 19 | 1 |
| | Flat | Fillet and Lop | 125-150 | 20-24 | 0.6-1.2 | 14 | 1 |
| | Horiz. and Vert. | Fillet and Lap | 110-130 | 19-23 | 0.6 | 14 | 1 |
| | Overhead | Fillet and Lap | 115-140 | 20-24 | 0.6-1.2 | 19 | 1 |
| 4.8 | Flat | Square Butt | 175-200 | 22-26 | 1.2 | 19 | 1 |
| | Hertz. and Verl. | Square Butt | 150-200 | 23-26 | 1.2 | 16 | 1 |
| | Overhead | 60' Single Vee | 150-175 | 23-27 | 1.2 | 28 | 1 |
| | Flat | Fillet and Lop | 180-210 | 22-26 | 1.2 | 14 | 1 |
| | Horiz. and Vert. | Fillet and Lop | 130-175 | 21-25 | 0.6-1.2 | 16 | 1 |
| | Overhead | Fillet and Lop | 130-190 | 22-26 | 0.6-1.2 | 21 | 1 |

melting the sheet edges back. If excessive gap occurs, an integral aluminum backing strap can be used advantageously.

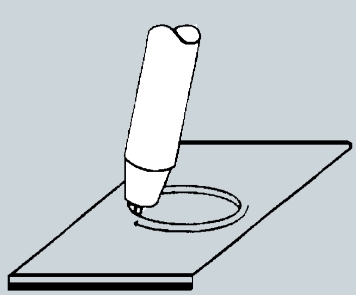
See Table 5.5 and 5.6 for welding procedures and practices for MIG welding aluminum sheet.

### Plug Welding

When welding two thickness' of sheet together in a lap configuration (as opposed to a butt weld), the plug weld is a good technique to use. In plug welding, shown in Figure 5.7, a hole is drilled or punched in the top sheet.The weld is then made in the hole and joins the top and bottom sheets together.

A few cautions are in order. The hole should be 3/8-1/2 in. (9-12mm) diameter. Larger diameter holes increase the risk of burning through the backing sheet and will create a larger pool leading to more shrinkage while smaller holes usually result in marginal quality welds, i.e., poor fusion.The temptation is to place the welding gun in the center of the hole, strike the arc, and let the weld spread out to melt the edges of the hole.

FIGURE 5.7 PLUG WELDING



Proper wire placement for plug welding

This practice is not recommended and often results in poor fusion between the top and bottom sheet. The recommended practice is to position the gun at a convenient spot on the circumference of the hole, strike the arc, delay briefly before beginning to move to allow the weld puddle to be established, and travel smoothly around the circumference of the hole, as shown in Figure 5.7. During welding the gun should be held roughly perpendicular to the hole but with a small leading angle.

Another technique sometimes used to weld two thickness' of sheet together in a lap joint is MIG spot welding. This technique is similar to plug welding except no hole is present in the top sheet. MIG spot welds, however, have been shown to exhibit a lack of consistency from weld to weld and the mechanical properties are not as good as a plug weld. Plug welds are therefore recommended for most applications.

For additional discussion of welding, refer to Aluminum Association publication AT1 and the I-CAR aluminum repair course materials. Welding of aluminum is different from welding steel and some of the key differences may be summarized as follows (DC constant energy power supply is assumed):

- Spray-arc transfer is used for aluminum and this necessitates more powerful welding equipment with pulsing power supplies.
- Pure argon is used for the shielding gas. $CO_2$ is never used.
- The welding gun is angled to the direction of travel and pushed. Pulling, or dragging, should not be employed.
- When welding vertically, aluminum is welded from the bottom up, just the opposite of steel.
- Push-pull feeders or spool guns are recommended for aluminum.
- Spiral steel liners are not used to feed aluminum wire, nor are knurled drive rolls.

### Adhesives

Adhesives are widely used to make lap and flanged joints in vehicle construction for a number of reasons. Bonded joints have better stiffness and fatigue strength than spot welded or mechanically fastened joints. They can be used to join different kinds of materials and different thickness' of materials. Adhesives also can act as electrical and thermal insulation and form a barrier to corrosion, although some organic adhesives are adversely affected if exposed to moisture leading to reduced strength over time. Adhesives are particularly well suited to joining aluminum because the inherent corrosion resistance of aluminum and the stability of a pretreated aluminum surface make bonded joints strong and durable even in adverse environments. Appearance is good because there are no protruding fastener heads or weld beads and nuggets. For automotive aluminum they can be used alone or in conjunction with spot welding or riveting. Weldbonding is a technique developed for automotive production where resistance spot welding is used to position and to support the joint during cure, and to improve the peel strength of the joint.

There are many kinds of adhesives used by the OEM's. Some are one-part and heat-cured, some are two-part using a room temperature, induction and/or an elevated temperature cure, some are anaerobic (curing in the absence of air) and some cure by exposure to ultraviolet light. They are based on various types of organic polymers such as vinyl, urethane, acrylate, epoxy, phenolic, or polyamide which are modified with fillers and additives to provide a very wide range of properties.

A different balance of product properties such as strength, toughness, flexibility, creep resistance, vibrations damping, impact strength and failure mode will be required for each application. Various processing properties may be even more important, for instance, tolerance to lubricants, pumpability, slump resistance, curing characteristics or expandability. OEM's may require the use of a production adhesive or specify particular repair products. In either case, the technician must follow the OEM's recommendations.

Increasingly, adhesives are being supplied in easy-to-use forms and packaging.

Adhesive resins can be applied quickly and without mess. Two-part paste adhesives are supplied in dual syringe cartridges which automatically dispense the correct ratio of resin and hardener. These dual cartridges can be used in a manual or pneumatic gun and are fitted with disposable mixer tubes. Mixer tubes are available in a wide range of sizes (diameter, length, and number of vanes). To obtain correct mixing it is important to use the recommended tube size. Always discard the first few inches of adhesive dispensed from a mixer tube to insure adequate mixing.

Adhesive resins are generally harmless to handle provided that normal precautions for handling chemicals are observed.The uncured materials must not be allowed to come in contact with foods or food utensils, and for many products it is advisable to prevent the uncured materials from coming in contact with skin, since people with particularly sensitive skins may be affected. The wearing of impervious rubber or plastic gloves will normally be recommended; likewise the use of eye protection and adequate ventilation in the working area is recommended. The skin should be washed at the end of each working period with soap and warm water. Do not use solvents which can carry chemicals into the skin. Disposable paper - not cloth - towels should be used to dry skin.

This publication repeatedly points out the necessity of proper surface preparation, whether for welding, refinishing, or, in this, section, adhesive bonding. The strength and durability of the joint depends on adequate preparation. Some OEM's may state that replacement panels need not have further preparation on the replacement part if it is supplied coated as they have confidence in the adhesion of the coating. In any case the old, or separated, part will have to be cleaned.The old adhesive can be removed by grinding or sanding to a clean aluminum finish. From there the choice of surface preparation is dictated by the recommended adhesive system and any pretreatment or primers will be designed so that full strength of the bond is obtained.The collision repair shop may have primers on hand for refinishing but these may or may not be suited to a given adhesive and should not be used without the adhesive manufacturers recommendation. Again, the OEM's will have specific recommendations for the surface cleaning and pretreatment for each adhesive they specify for repair use.

# 6.0 Refinishing

The key to the successful refinishing of aluminum is in the preparation of the surface. Whether the purpose of the coating is to smooth the work, to provide protection, or to give a desired appearance, that coating must stay in place and intact. Dirt, grease, and such contaminants must be completely removed. On a new clean aluminum surface, the oxide film is smooth and hard and needs to be treated to give a satisfactory "tooth" for many coatings. (Oddly enough, a weathered aluminum surface with substantial oxide buildup will, if clean, take a coating more readily but this is not the situation the technician will have.) Systems offered by the coating manufacturers recognize aluminum's surface characteristics in their recommendations.

When panels have been reworked it is often necessary to use body fillers to smooth minor imperfections before final painting. Most of these fillers are polyester based. Some are formulated to be applied directly to clean aluminum while others require a primer, usually epoxy. Procedures are described below.

The final step in the repair process is to restore the vehicle to its original appearance. All the major OEM paint suppliers, plus numerous other coatings manufacturers, offer aftermarket paint repair systems for use in collision repair shops. Care should be taken to make certain the products are recommended specifically for aluminum as opposed to general metal, i.e., steel or galvanized, refinishing. Most of the procedures for these repair systems are quite standard for all the suppliers. However, there are some distinct differences and care must be taken to follow the supplier's recommendations, particularly if warranty claims are to be upheld.

The first situation to consider from a refinishing point of view is when the work is sanded to bare metal. Clearly when this happens not only is the OEM metal pretreatment removed but there is also the possibility of contamination of the bare metal surface. What follows is a generic description of a paint repair procedure when sanding to bare metal is required.

## Procedure A

### Steps

1 Clean around area to be repaired.

2 Dry sand to bare metal using 180-220 grit paper.

3 Carefully clean to remove all residual debris on bare metal.

4 Water rinse.

5 Apply aluminum conditioning treatment.

6 Water rinse.

7 Air dry.

8 Apply epoxy primer.

9 Air dry.

10 Apply primer/surfacer.

11 Air dry.

12 Apply appropriate topcoats.

## Notes

**Step 1 -** The purpose of this first step is to remove dirt, grease, and waxes which otherwise could be ground into the metal surface during sanding. The coatings suppliers have a number of recommended products for this step. This cleaner is generally not the same as the cleaner described in Step 3.

**Step 2 -** The sanding should produce adequate surface roughness to allow good mechanical interlocking with the primer while being sufficiently smooth to achieve satisfactory paint appearance.

**Step 3 -** This is arguably the most critical step in the repair process. The coatings suppliers typically specify an acidic cleaner for this step but in some cases solvent wiping alone is used. In any case careful removal of all contaminants is essential to good paint adhesion.

**Step 5 -** This material is ordinarily a chromium based pretreatment product.

**Step 8 -** Some companies recommend an epoxy etch primer while others suggest a non-etch primer. An etch primer is often recommended by a supplier especially if Step 5 is omitted.

When it is not necessary to sand down to bare metal, i.e., in areas of light damage, then the following procedure can be used:

## Procedure B

### Steps

1 Clean around areas to be repaired.

2 Dry sand using fine grit (minimum 220-240) sandpaper.

3 Clean to remove all debris.

4 Apply filler/ surfacer.

5 Air dry.

6 Apply appropriate topcoats.

Earlier it was noted that it is often necessary to use body fillers to smooth repaired surfaces. Ideally they should be applied to sanded and pretreated aluminum as outlined in Steps 1-7 of Procedure A above. When approved by the supplier, it is also acceptable to apply filler to a cleaned metal surface without using the aluminum conditioning treatment. (Omit Steps 5 and 6 in Procedure A).

# 7.0 Glossary of Terms

**Absorption -** the ability of a particular alloy composition to use or absorb another alloy or scrap as part of the makeup of a new aluminum ingot.

**Aging -** a thermal treatment used to modify and/or stabilize mechanical properties.

**Alloy -** a metallurgical mixture of aluminum with selected other elements to give a desired set of performance characteristics.

**Alumina -** aluminum oxide, the refined raw material from which new primary aluminum is produced.

**Annealing -** using heat to remove the effects of heat-treatment or strain hardening.

**Bauxite -** the ore from which alumina is refined.

**Cast products -** parts produced by pouring molten aluminum alloys into a mold.

**Contaminant -** any material in scrap that is not wanted or needed in recycling.

**Delacquering -** the term used in the aluminum industry to describe coating removal in recycling.

**Filler alloy -** additional aluminum alloy in the form of rod or wire used in inert gas welding to augment the base metal melted to produce the weld.

**Heat-treatable alloy -** an alloy that gains its mechanical properties from being heated to elevated temperature and rapidly cooled, usually followed by other low temperature thermal treatment.

**Ingot -** stock for making products of aluminum products. Unalloyed ingot is often referred to as “pig”.

**Non-heat-treatable alloy -** an alloy that gains its properties by physical deformation, or strain hardening, obtained from mechanical working.

**Permanent joint -** used in this manual to describe a joint not normally separated by the auto dismantler during the recycling process.

**Primary aluminum -** new aluminum from ore produced by the Hall/Heroult process. Also called virgin aluminum.

**Secondary aluminum -** aluminum alloys produced by the remelting and reprocessing of scrap.

**Segregation -** achieving high quality scrap by keeping different material streams apart.

**Sorting -** achieving high quality scrap by mechanically or thermally separating mixed materials.

**Sustainable recyclability -** the ability of aluminum alloys to be recycled over and over.

**Thermal treatment -** the use of heat to achieve desired properties in aluminum alloys other than by heat-treating.

**Temper -** the final set of properties possessed by a given alloy after processing.

**Wrought products -** those products in which some physical deformation is used to give the final product form, including sheet and plate, extrusions, forgings, rod, bar and wire. Any product that is not cast.