Aluminum Panels
And Structures
Damage Analysis
(DAM05e)
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Module 1 - Aluminum Properties And Identification
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Learning Objectives
Learning objectives for this module include:

- identifying the physical properties of aluminum.
- describing aluminum alloys.
- identifying aluminum vehicle part design.

Reasons For Aluminum Usage
Aluminum is being used for automobile construction for several reasons. First and foremost, aluminum is lightweight. Lighter weight helps with key items such as fuel economy, lower emissions, and improved vehicle performance without sacrificing vehicle size or strength.

Aluminum is also highly corrosion resistant. Aluminum forms a sacrificial oxide coating that bonds to and protects the aluminum from corroding. It is a self-healing coating. If this oxide is removed, it will begin to reform almost immediately. Aluminum is easy to initially form into multiple shapes; it is also recyclable, and abundant. About 8% of the Earth’s crust contains aluminum.

In Europe, certain recycling requirements are being implemented by the European Commission in efforts to reduce landfill waste from end-of-life vehicles. The European Commission has set target recycling standards to be met by European vehicle makers. European manufactured vehicles must be at a minimum 85% recyclable by the year 2015.

Work Hardening
Aluminum has certain characteristics to consider when performing damage analysis. One of these is work hardening. When aluminum is stamped or bent into a specific shape, it gains strength. The internal molecules tend to lock into that shape and resist any further stamping or bending.

If the aluminum is stamped or bent again, it again gains strength. Along with gaining strength, it becomes increasingly brittle from the repeated internal compression of the molecules that are resisting these reshaping attempts. If the stamping or bending is continued over the same area, the aluminum will eventually crack due to the excessive work hardening. Generally, the thicker the aluminum is, the faster the work hardening will take place.
**Galvanic Corrosion**
Galvanic corrosion can occur when dissimilar metals come in contact with the presence of an electrolyte. An example of dissimilar metals is aluminum and steel and an example of an electrolyte is water mixed with road salt.

When galvanic corrosion occurs, the more active metal corrodes faster. For example, when galvanic corrosion occurs between steel and aluminum, aluminum will corrode faster. Galvanic corrosion can appear as a white ash-like residue or black pitting on the aluminum.

**Aluminum Alloys**
Pure aluminum is very soft and ductile. Aluminum alloys are pure aluminum mixed with other elements. The adding of other elements can affect the strength, formability, weldability, and corrosion resistance.

Aluminum alloys are designated into series. The series are given four-digit designations. The first digit indicates the main alloying element. The most common aluminum alloys used for automotive applications are 5000 and 6000 series. Any numbers following the first digit are part of the scientific formula that identifies the percentage of alloying agent used when making a specific alloy.

**Heat-Treatable And Non-Heat-Treatable**
Aluminum alloys are also classified as heat-treatable or non-heat-treatable. This means that during the aluminum alloy manufacturing process, aluminum alloys have the ability to gain strength from being exposed to elevated temperatures or from being stamped or bent.

Aluminum alloys 2000, 6000, and 7000 series are heat-treatable. Aluminum alloys 1000, 3000, 4000, 5000 series are non-heat-treatable. Both heat-treated and non-heat-treated alloys can be heated during the repair process.

**Temper Designations**
Temper designations are given to identify how aluminum is strengthened during the manufacturing process. These designations are the letter “H” and the letter “T.” The letter “H” stands for strain hardened. This is used for non-heat-treated alloys that gain strength from being stamped or bent. The letter “T” stands for thermally hardened. This is used for heat-treated alloys that gain strength from being exposed to elevated temperatures.

Numbers that indicate the process that was used for tempering can follow designation letters. For example, aluminum alloy 6061-T4 is solution heat-treated and then naturally aged. T4 is obtained by heating the aluminum up to 900°F, quenching, and then aging at room temperature for 16 to 24 hours.
The number can indicate that the part is stronger, but this is not always the case. For example, aluminum alloy 5056-H18 has a higher strength and hardness rating than 5056-H38.

Temper designations are also applied to replacement service parts.

**Bake Hardening**

Some vehicle makers further increase the temper and strength of aluminum vehicle parts with bake hardening. This requires elevated temperatures for a specific amount of time. For example, Audi bake-harden an assembled A8 body shell for 30 minutes at 400°F to increase the aluminum alloy 6016 temper to T6. Service parts also receive this bake-harding process from the vehicle maker. Some vehicle makers bake-harden aluminum during the paint bake process.

**Aluminum Vehicle Parts**

Vehicle parts that are made from aluminum may be stampings, extrusions, or castings.

**Stampings**

Pressing or stamping aluminum sheeting in a die forms stampings. They are used for exterior body and structural parts. Stampings can be visually identified by their raised, ribbed, or dimpled areas. These areas are generally for strengthening purposes.

Signs of gathering from the material bunching together or signs of thinning due to stretching during manufacturing can be a visual indicator of a stamping. Also, a visible mating flange used for an attachment point can indicate the part is a stamping.

Stampings are typically more repairable than castings or extrusions. This does not mean, however, that they can always be repaired.

**Extrusion**

Forcing a heated aluminum billet through a die forms extrusions. The die may use a mandrel to form a hollow extrusion. Extrusions are generally used for structural applications such as lower rails and inner rocker panels. Extrusions are sometimes used for inner door intrusion beams.

Some visual indicators of an extrusion may include that the part is seamless. Some designs may have a flanged area for attaching other panels or they may be a C-channel shape. Extrusions may be straight or have varying curved areas.

Extrusions can also have single or complex cross sections.
Extrusions may be made using a process called hydroforming. This process uses high-pressure liquid to further shape an extrusion during the manufacturing process.

Extrusions have limited repairability.

**Castings**
Pouring molten aluminum into a mold and allowing it to cool forms an aluminum casting. Castings are typically used for structural applications such as suspension or drivetrain mounting locations. Inner door reinforcements may also be cast.

Castings can have varied shapes and wall thickness or textured surfaces caused by being poured in sand molds. Castings may have machined surfaces and tapped holes which is common on cast suspension mounting areas.

Castings use a three-digit series designation. 300 series aluminum castings, which are alloyed with magnesium and silicon, are commonly used for automotive applications.

Castings are not repairable.

**Aluminum Identification Methods**
Identifying aluminum parts is an important step during damage analysis. Aluminum parts can be identified several different ways. Identification can be done using a magnet. A magnet will not be attracted to an aluminum panel. This is an easy and quick identification method.

Referring to the vehicle maker service information may also help with identification. Some vehicle makers list panel material type and alloy series used on certain vehicle models. Most vehicle makers’ service information is available over the internet. Links to many vehicle makers’ service information websites are available at [www.i-car.com](http://www.i-car.com).

The Aluminum Association website, [www.autoaluminum.org](http://www.autoaluminum.org) also has listings of vehicles that have used, and may currently be using, aluminum for exterior body panels and structures.

**Identifying Aluminum By Attachment Methods**
Part attachment methods can help to identify aluminum parts. Bolts that use isolators, such as corrosion-resistant coatings or nylon washers, may be used for attaching aluminum parts. Isolating strips that are made from rubberized sealant or have a bi-metallic design are sometimes used between aluminum exterior body panels and steel inner structures.
Clinches are also common to aluminum panels. A clinch is formed by compressing the material that a part is made from between two dies to form an interlocking connection. Aluminum exterior panels typically use clinches to connect outer skins to inner reinforcements.

Another attachment method used on aluminum is a rope hem flange. A rope hem flange will appear gradually rolled instead of sharply crimped. This is done to prevent cracking of the outer panel. Aluminum exterior panels typically use rope hem flanges to attach outer panels to inner reinforcements.

**Self-Piercing Rivets (SPR) Identification**

Self-piercing rivets, or SPRs, are commonly used on aluminum vehicles. Self-piercing rivets may also be called Henrob rivets. These are tubular rivets that pierce through the parts being joined and expand into the backing piece without breaking through the surface. No hole is needed for installation.

SPRs are made from hardened steel that is coated to help prevent galvanic corrosion. SPRs are typically removed by pressing them out. Special dies are used with pneumatic or electric riveters to press out self-piercing rivets. The next preferred removal method is pulling. Stainless steel studs can be welded onto the head of an SPR and then extracted with a pneumatic or electric rivet gun. Drilling out SPRs can be done. This may require several drill bits or repeated drill bit sharpening due to the rivet hardness. Grinding has the greatest chance of introducing galvanic corrosion and is typically a last resort for SPR removal.

**Module Summary**

Topics discussed in this module included:

- the physical properties of aluminum.
- what aluminum alloys are.
- identifying aluminum vehicle part design.
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Module 2 - Aluminum Exterior Panel Damage Analysis
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Learning Objectives
Learning objectives for this module include:

- describing characteristics of aluminum exterior panels.
- describing damage analysis considerations.
- discussing repair and replace practices used for aluminum exterior panels.

Panel Usage
Aluminum exterior panels are used on many different vehicles. The vehicle may have an inner structure made of steel or aluminum. Magnesium and composite material, such as carbon fiber, are also currently being used.

Panel Thickness
Aluminum exterior panels typically are similar in thickness to a steel exterior panel and weigh less when compared to a mild steel equivalent.

Exterior Panel Design
Aluminum exterior panels are typically six thousand-series heat-treatable aluminum alloys that are bake-hardened to T6 temper during the manufacturing process. Aluminum exterior panels tend to be stampings, which offer the most repair options.

Dent Resistance
Aluminum exterior panels generally have a high degree of dent resistance. This is achieved from the initial stamping process. The aluminum sheet is pressed or stamped into the desired shape, which work hardens T4 aluminum. After stamping, a part is typically bake-hardened, which tightens the internal grain structure of the 6000 series aluminum. The bake-hardening process strengthens the part to T6 and increases dent resistance.

Memory
Aluminum exterior panels have poor memory. Collision damage could have a tendency to “set” in the panel. This is common on large dents and sharp creases, where the elastic limits of the aluminum have been exceeded. Along with the molecular grain structure possibly not remembering its original shape, the panel takes its new damaged shape and becomes stronger from work hardening.

Exterior Panel Damage
Damage on aluminum exterior panels can include dents, creases, and buckles. Kinks, tears, and cracks are also common damage that can happen to exterior aluminum panels.

Extent Of Damage
Damage on aluminum exterior panels can include damage that has transferred to areas around the initial point of impact. This damage can include high spots and subtle waves.
in the panel from the radiating damage. Damage may include inner reinforcements that are joined to the exterior panel. An example of this would be a door intrusion beam that is bent from an impact to the outer door panel.

**Size And Type Of Damage**
The size and style of the damage on an aluminum exterior panel can influence repair or replace decisions. For example, damage, such as dings and dents, are typically the easiest to repair depending on the location. Medium to heavy damage may have caused the aluminum to exceed its elastic limits. Creases and large buckles will typically cause this. Heavy damage may require replacement. Kinks typically cause aluminum exterior body panels to become over-work hardened and crack.

**Paintless Dent Repair (PDR)**
Paintless dent repair, commonly referred to as PDR, may be an option to consider for repairing aluminum exterior panels. PDR should be reserved for smaller dings and dents. PDR should not be considered if the paint finish is damaged from the impact. PDR equipment should be dedicated for aluminum use or use protective covers to prevent scratching and possibly introducing galvanic corrosion.

**Location Of Damage**
The location of the damage on an aluminum exterior panel can influence repair or replace decisions. For example, panel edges or bodylines are typically the strongest areas on the panel. They have been extensively work hardened during the manufacturing process. Extensive damage to these areas, especially panel edges, can affect the integrity of the panel. Cracking will typically take place in these areas from the collision or during repair attempts. Therefore damage to these areas may warrant panel replacement.

**Accessing Backside Of Damage**
Damage on aluminum exterior panels is typically removed by working from the backside of the panel. When working on the backside of a panel interior trim removal may be required. Caution must be used to prevent breaking retainer clips when they are removed. Some retainer clips may be one-time use.

Some inner reinforcements may interfere with access. Cutting windows or drilling holes in reinforcements to gain access can compromise the structural integrity of the part. Therefore, cutting windows and drilling holes to gain access is not recommended. Aluminum stud welding equipment and glue-on dent pulling systems are options that may be used for dent removal without accessing the backside of the panel.

When using aluminum stud welding equipment, caution should be used to prevent burning panel adhesives or foams that may be located in the are where stud welding is being done.
Panel Attachment
Aluminum exterior panel attachment methods may be a factor in repair versus replace decisions. It may be more practical to replace a part than repair it based on how it is fastened, or vice versa. For example, in cases where a rivet-bonded exterior body panel can be properly repaired, the factory rivets, adhesives, coatings, and overall appearance of the joint can be preserved. Conversely, if the panel is bolted, it may be more practical to replace it rather than attempt repairs. How a panel is attached, such as rivet-bonded, can indicate that special equipment is required for panel replacement.

Cracks And Tears
Cracks and tears can be caused from stress, collision damage, or repair attempts. Areas adjacent to cracks and tears are excessively work hardened and prone to further cracking. Repairing cracks in areas subjected to stress are likely to fail. Some vehicle makers recommend that the panel be replaced if cracks form from collision damage or repair attempts. Repairing cracks in aluminum exterior body panels when there is no recommendation is a subjective business decision.

A dye penetrant may be used to inspect a panel for cracks. Using dye penetrant requires cleaning the area to be tested, applying a spray dye, allowing the dye to sit for 5 - 10 minutes, wiping off the dye, and applying a spray developer. Dye that has seeped into any cracks will be drawn out with the developer. Paint coatings should be removed before dye penetrant testing to avoid false readings from cracked paint.

Repairing Cracks In Exterior Panels
The vehicle maker may recommend repairing minor cracks on aluminum exterior body panels with GMA (MIG) or GTA (TIG) welding. The panel should be removed from the vehicle if GTA (TIG) welding is used. GTA (TIG) welding on aluminum uses a high frequency signal to maintain the welding arc. High frequency can harm control modules in the vicinity during welding.

Removing Cosmetic Damage Considerations
Removing cosmetic damage from aluminum exterior panels typically requires controlled effort. Multiple pushing or pulling attempts may be required to return the panel to its original contour because of aluminum’s lack of memory. Direct striking of the panel should be avoided to reduce the chance of stretching the aluminum. Stretched aluminum panels will require shrinking. Stretched panels that cannot be shrunk typically require replacement.

Generally, most of the damage should be removed and original panel contours restored. Some vehicle makers limit the types of body filler used and thickness allowed.

Using Heat
Using heat is a common practice for repairing aluminum exterior panels. This allows the internal molecules to relax and may make repair attempts more successful. Caution must
be used to avoid heating areas with adhesive since it may weaken the adhesive bond and release toxic fumes. Cold straightening should be done if working around adhesives.

**Aluminum Properties Related To Heating**

Aluminum has certain properties that must be considered when it is heated. Aluminum has high thermal conductivity and rapid heat transfer. Heat travels very rapidly through aluminum. It will spread rather than stay concentrated in a small area. Panel thickness affects the heat transfer. For example, a thick panel will have more heat transfer than a thin panel.

Aluminum has no color change when heated. It will appear to change state just before it melts. There is no other indication that the surface temperature is rising. Aluminum has a melting temperature of 1,200°F. Aluminum oxide melts at 3,725°F.

**Repair Temperatures**

Aluminum has a certain repair temperature range. When heat is used, the temperature of the aluminum should be between 400 - 570°F.

**Heat Monitoring**

Heat monitoring of aluminum can be done several different ways. One is using heat detection crayons. These crayons leave a residue on the panel that melts at a specific temperature.

Another is using heat monitoring strips. These are adhesive strips that stick to the panel. They change color as they are heated.

Heat detection paint may also be used. These paints melt when they reach specific temperature.

Lastly, non-contact thermometers can be used for heat monitoring. Noncontact thermometers work by reading the surface temperature with infrared light.

**Consumable Items**

Consumable items that may be required when repairing aluminum exterior panels can include undercoats. Some vehicle makers recommend a self-etching or epoxy primer be applied to any bare aluminum before applying body filler or primer-surfacer. Some may have recommended products that are only available from the vehicle maker. Epoxy primer has to be applied and allowed to cure before body filler application. If the primer is sanded throughout, it should be reapplied before any body filler or primer is applied.

Specific body fillers may also be required. Some vehicle makers have recommended aluminum filler to use for repair.
Consumable items may also include welding rods for GTA (TIG) welding and electrode wire for GMA (MIG) welding if cracks are being repaired. Weld-on pins and glue-on cups for aluminum dent pullers are considered consumable items. Also heat monitoring equipment such as crayons, strips, and paints are one-time use items.

**Exterior Bolted Panels**
Aluminum exterior body panels that may be attached with bolts include hoods, fenders, doors, deck lids, and quarter panels. Bolted-on exterior panels may require that the bolt be replaced once the panel is removed. Most vehicle makers use steel bolts with a Dacromate coating. This is typically a gray or green coating on the threads or washers which helps reduce the chance for galvanic corrosion. When fasteners are removed, they must have the coatings inspected for signs of wear. Bolts with worn or damaged coatings must be replaced. Damaged coatings cannot be repaired.

Exterior bolted panels may have isolators, such as nylon washers or rubberized sealant strips. These must also be inspected for damage such as cracks or tears and replaced if necessary.

Generally, coated fasteners are only available from the vehicle maker. The vehicle warranty could be voided if a corrosion issue ever arose from the use of a nonapproved coated fastener.

**Riveted Exterior Panels**
Aluminum exterior panels that are attached with rivets include roofs, outer A-, B-, and C-pillars, outer rocker panels, and quarter panels. Riveted exterior panels typically use SPRs from the factory. They may use self-piercing, solid, blind, or a combination of rivets when a panel is replaced.

Vehicle-specific replacement rivets are generally recommended. This can help to ensure that rivets used for collision repair are the proper design, length, diameter, alloy, grip range, and strength rating. These rivets may be available from the vehicle maker.

Riveted exterior panels may require special equipment to remove and install SPRs. Extracting SPRs using weld-on stainless steel studs requires one stud per rivet. Pressing out SPRs uses different styles of electric or pneumatic riveters with removal dies. Caution must be taken to avoid damaging removal dies during rivet removal. SPRs may be removed by drilling if recommended by the vehicle maker. SPRs are made from hardened steel and may dull drill bits frequently.

**Adhesives**
Aluminum exterior panels that are attached with adhesive may also use bolts, rivets, or a rope hem flange. Adhesives are typically not used as a stand-alone fastening method for
aluminum exterior panels. Generally, the vehicle maker will recommend an adhesive for panel replacement.

The vehicle maker may also recommend pre-treatments for the adhesive. Pre-treatments come in two, two-step styles, a flame treatment followed with a primer application or a silicate stone followed with a primer application. The first step involves passing a pyrosil treated flame or abrading a silicate stone on the bare aluminum surface. Both leave deposits of silicate on the aluminum. The second step is brushing a chemical primer on the aluminum that reacts with the silicate deposits. This seals the aluminum surface to prevent oxide from forming and improves adhesion properties. Audi, Jaguar, and Mercedes-Benz are some examples of vehicle makers that use adhesives and pre-treatments for some aluminum exterior panel replacement operations.

**Welded Exterior Body Panels**

Aluminum exterior panels such as roofs, outer A-, B-, and C-pillars, outer rocker panels, and quarter panels may be attached by the vehicle maker with GMA (MIG) welding, squeeze-type resistance spot welding, or laser welding. Laser welding uses a laser to join thinner outer panels to thicker inner structural parts. The laser beam penetrates through the top piece into the bottom piece, joining the two together.

**Replacing Welded Exterior Body Panels**

Aluminum exterior panels that are attached by the vehicle maker may be replaced using a different attachment method. For example, squeeze-type resistance spot welds are typically replaced with GMA (MIG) plug welds.

Laser welds are typically replaced with GMA (MIG) slot welds or with blind-rivet bonding. A slot weld is made by cutting a slot in the aluminum panel and then welding on one side of the slot to the inner reinforcement. Slots may not be made on replacement parts by the vehicle maker and have to be created by the repair technician.

**Replacing Welded Exterior Body Panels (cont’d)**

GMA (MIG) welding, used to attach aluminum exterior panels, can be duplicated by a collision repair facility for panel replacement. Some vehicle makers may have recommended welding equipment. This equipment may have pre-programmed weld parameters that are vehicle specific based on welding wire, alloys being joined, shielding gas, panel thickness, and transfer method.

**Parts With Clinches**

Clinches are not currently duplicated during collision repair. Clinches that are broken or separated may require complete panel replacement. Clinches may be replaced with rivets if recommended by the vehicle maker. For example, clinches on the lower mating flange of the quarter panel may be replaced with blind-rivet bonding. Clinches on the
upper mating flange of the outer door panel on some vehicles are replaced with blind-rivet bonding.

**Aluminum Exterior Replacement Parts**

Aluminum exterior panel replacement service parts are typically bake hardened separately from the assembled vehicle body shells. Inner molecules may gather differently when the panel is bake hardened detached from the vehicle. Replacement parts may seem bowed or shorter than needed. Panel gaps and bodylines may not align properly.

Also, some vehicle makers may have replacement service parts manufactured by outside vendors as vehicle model years change. Manufacturing from outside vendors also may result in slight variations in exterior body panel fit.

**Panel Reshaping**

Panel reshaping may be required to achieve proper fit on some aluminum exterior replacement parts. This may require multiple test fittings. Welding panel edges to build up base material for filing and finishing may also be necessary. This should not be done to compensate for improper structural alignment causing exterior panel fit problems. Also, adjacent, undamaged panel edges may need reshaping due to factory modifications during vehicle assembly.

Some operations are more common on early production models of certain vehicles and low production exotics that are extensively hand built. Vehicle bodies are assembled in certain sequences using fit methods such as panel edge filing in attempts to streamline production. Original production sequence may have to be duplicated or undone to achieve panel alignment.

**Panel Replacement**

Aluminum doors may not have outer replacement service panels available. Only a complete door assembly may be available.

Doors that have outer replacement service panels available typically require different installation procedures and products than an outer panel made of mild steel. Aluminum doors may use extrusions and / or castings for inner shell construction. These are crucial to structural integrity of the door assembly and will require replacement if damaged.

**Rope Hem Flange**

A rope hem flange is used on some exterior body panels with adhesive to fasten the outer panel to the inner reinforcements. A rope hem flange requires a different technique when used on aluminum. A more gradual controlled rolling or forming of the flange is required to prevent cracking on the panel edge. A rope hem flange for aluminum has a larger radius than a hem flange used for steel panels. This is done during the manufacturing
process and also during the repair process for some aluminum exterior panel replacement operations.

**Aluminum Pillars And Rocker Panels**
Aluminum side panels may be available as individual outer A-pillar, outer B-pillar, outer rocker panel, or quarter panel sections. Side panels use different attachment methods depending on the vehicle maker and may have sectioning procedures available to allow for partial part replacement.

**Aluminum Panel Preparation**
Aluminum exterior panel replacement typically requires panel test fitting and adjacent part fit-up before final installation. Adhesive pre-treatment may be needed before bonding operations, as well as burr removal from plug weld or rivet holes to help ensure mating flange flushness. Lastly, making an insert to be used for panel sectioning may have to be done since pre-made inserts may not be available from the vehicle maker.

Aluminum exterior panel replacement may require numerous preparation steps. These may include flange straightening. Mating flanges must be flush. This is crucial for increasing weld performance and having adequate bond-line thickness when using adhesives. Aluminum flanges require careful straightening to avoid thinning or fracturing.

Another step is flange cleaning. Depending on vehicle maker repair procedures and attachment methods, E-coat may require removal from the replacement service parts. E-coat and existing factory adhesive may also require removal from the vehicle mating flanges. Oxide that forms on bare aluminum mating flanges also should be removed.

Countersinking or dimpling for blind or solid countersunk rivet installation may be needed. This is done to both mating flanges for correct rivet compression. Countersinking and dimpling are done for some exterior panel replacement procedures on the Audi A8.

**Aluminum Panel Finishing Operations**
Common finishing operations that are done following aluminum panel replacement may include adhesive clean up and flange straightening for rivet-bonded panels. Adhesive squeeze-out must be removed so weather stripping fit is not affected. Flange straightening may be needed if rivet compressions slightly deform the mating flanges. Depending on rivet location, flange reshaping may be needed. Both of these are done to help ensure a proper weatherstripping seal and correct interior trim fit.

Weld finishing is also common. Aluminum welds require lighter pressure, slower speeds, and finer grit discs for weld finishing. This is so stress fracturing from heat build up does
not occur. Also, dye penetrant testing of welds to inspect for cracks or pinholes is quite common when working with aluminum exterior panels.

**Consumable Items**
Consumable items that are commonly required when replacing aluminum exterior panels include coated bolts, rivets and adhesives and flange pre-treatments. Weld cutting and finishing tools are also considered consumables since cutting and finishing welds on aluminum may more frequently clog grinding or sanding discs.

Consumable items that are commonly required when replacing aluminum exterior panels include aluminum welding wire and self-piercing rivet removal equipment such as weld-on stainless steel pins and drill bits. In addition, noise, vibration, and harshness foam, and anti-corrosion compounds are also considered consumables.

**Activity: Panel Repair / Replace Decisions #1**
In this activity you will be shown images of vehicle panel damage. At the end of this activity you will need to make a repair or replace decision based on the damage shown.

**Activity: Panel Repair / Replace Decisions #2**
In this activity you will be shown images of vehicle panel damage. At the end of this activity you will need to make a repair or replace decision based on the damage shown.

**Module Summary**
Topics discussed in this module included:

- the characteristics of aluminum exterior panels.
- damage analysis considerations for aluminum exterior panels.
- repair and replace practices used for aluminum exterior panels.
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Learning Objectives
Learning objectives for this module include:

- identifying aluminum structural design and construction.
- discussing damage analysis considerations.
- identifying repair / replace practices for aluminum structural panels.

Monocoque / Unibody
Aluminum monocoque, or unibody structural designs may use stamped panels extensively for construction while limiting the use of extrusions and castings. There may be no castings used depending on the vehicle.

Aluminum monocoque or unibody structures may use rivet bonded or squeeze-type resistance spot welded mating flanges. This depends on the vehicle maker. GMA (MIG) welding may also be used. Depending on the vehicle maker, it may be very limited in use.

Space Frame
Aluminum space frame designs have extensive use of castings and extrusions used for the main structural parts. Stamped panels are also used. Space frames may use rivets with or without adhesives and may use several different styles of welding. Depending on the vehicle, there may be GMA (MIG) welds, laser welds, (GMA) MIG laser hybrid welds, or squeeze-type resistance spot welds.

Full Frame
Aluminum full frame structural designs may use extrusions for the main construction parts with limited castings and stampings. GMA (MIG) welds, rivets, and laser welds are typically used for joining.

Aluminum And Steel Structures
Aluminum and steel structural designs use a combination of both materials for vehicle construction. Designs vary based on the vehicle maker. There are several examples of design variations that combine steel and aluminum. For example, aluminum radiator core supports are used with a steel front structure on vehicle makers pickups. Aluminum inner rocker panels used with steel outer rocker panels is another example. An aluminum unibody construction is used from the cowl forward and attached to a steel unibody construction from the A-pillars rearward on some BMW 5 and 6 Series model years.

Characteristics
Vehicles with an aluminum structure typically share some common characteristics. 5000 or 6000 series aluminum alloy is used for part construction. Some parts can be up to 5
mm thick. Aluminum structural parts have very high rigidity and resistance to twisting and bending. This characteristic is why part replacement is very common for damaged aluminum structural parts.

**Point Of Impact**
A visual inspection at the point of impact is where inspection should begin. Direct damage on an aluminum structure can appear as kinks, bends, buckles, gouges, tears, and cracks. Generally, structural parts with visual direct damage will require replacement. Correctly identifying the structural part design will help with damage analysis. Determine the path that the collision energy traveled through the vehicle to help look for indirect damage.

**Indirect Damage**
Indirect damage to an aluminum structure is caused from collision energy traveling through the vehicle. Indirect damage may be greater depending on the collision force. Vehicle construction may also have an affect on the amount of indirect damage. Certain designs may allow more indirect damage than others. Indirect damage is not always visible during a preliminary inspection.

**Indicators Of Indirect Damage**
Indirect damage indicators include exterior panel misalignment, which can cause improper panel gaps and improper exterior panel operation. Hoods, deck lids, or doors that snap open or hang up on striker plates can indicate structural damage.

A buckling or a rippled look in exterior body panels as well as variations of interior trim fit from side to side can indicate radiated structural damage. Also, cracked welds or seam sealers on structural and exterior body panels and rivet or flange separation on structural or exterior body panels can indicate structural damage that has traveled past the direct point of impact.

**Vehicle Disassembly**
Some vehicle disassembly is generally required for a complete and thorough visual inspection. It may also be necessary to access measuring points or fixture locations.

Vehicle disassembly can be extensive. Suspensions, engines, and interior trim, such as instrument panels, carpets, and headliners, are commonly removed items when inspecting for damage.

**Measuring**
Measuring is vital for structural damage analysis since it identifies how far the damage traveled through the vehicle. Small increments of structural misalignment cannot be seen without measuring. Even the slightest amounts of structural misalignment can affect exterior panel operation and fit, along with key safety features such as airbag deployment.
timing. Measuring may require the vehicle to be mounted on frame straightening equipment.

Measuring can be done using vehicle maker data. Some vehicle makers supply point-to-point measurements in their vehicle repair manuals. Vehicle makers may also have measuring specifications available through frame straightening equipment makers.

Measuring may require a fixture system depending on the vehicle maker's recommendations. Measuring may also warrant that the vehicle be taken to a vehicle-specific structural repair facility. Fixtures for measuring specific vehicles are only supplied to structural repair facilities directly from the vehicle maker.

**Dye Penetrant**

Dye penetrant can be used to inspect for cracks in areas that are suspected of having indirect damage. Damaged topcoats should be removed to reduce the likelihood of a false reading from cracked coatings.

Plastic sheeting should be used to reduce the chance of dye staining undamaged parts.

**Cracked Aluminum Structural Parts**

Cracked aluminum structural parts found during damage analysis should be replaced. Repair is not recommended. Parts that are cracked have already exceeded their limits of work hardening.

**Cracked Welds On Structural Parts**

Cracked welds found on aluminum structural parts during damage analysis may be repairable if allowed by the vehicle maker. Adjacent structural parts must be undamaged and in correct structural alignment for this to be an option.

There may be a length limitation and specific repair procedure from the vehicle maker for repairing cracked welds on aluminum structural parts.

**Structural Straightening Considerations**

When making structural straightening decisions on aluminum, items to consider include vehicle maker recommendations, structural part design, and kink versus bend.

**Vehicle Maker Recommendations**

Vehicle maker recommendations must always be the first consideration. Structural straightening may be recommended, may be limited to very slight damage, or may not be recommended at all. Vehicle makers that recommend no structural straightening of aluminum include BMW and Ferrari. Part replacement is the only recommended repair
for structural parts. Vehicle makers that do allow straightening may have structural repair equipment requirements for specific vehicles.

**Structural Castings**
Structural castings that are visibly damaged cannot be straightened or repaired. This includes cracked, bent, gouged, or dented castings. Castings are prone to internal and external cracking and must be replaced.

**Structural Extrusions**
Structural extrusions can vary in length, shape, wall thickness, and cross-section design. This can affect how extrusions react from collision damage. For example, a single-celled extrusion may be more flexible than a multicelled extrusion.

Structural extrusions must be returned to the original shape and state to be considered structurally sound. Extrusions that measure to specification, but are visibly deformed from collision forces, should be replaced. This is critical for future vehicle collision performance.

**Structural Stampings**
Damaged structural stampings may have the most opportunity for repair. Repair decisions can be affected by having access to both sides of the panel. This can aid in removing minor structural damage and help return the stamping to the original shape and state.

Also, the attachment method can play a role in straightening decisions. Rivet-bonded stampings that have panel separation from collision damage will require some, if not all, affected parts to be replaced so new adhesive and rivets can be installed. The same may be needed for squeeze-type resistance spot welded stampings that have been separated by collision damage.

**Kink Versus Bend**
Considering the work hardening characteristics of structural aluminum, the kink versus bend rule does not always apply when considering weather to straighten an aluminum structure.

**Kinked Structural Parts**
Kinked aluminum structural parts have been bent sharply over a tight radius. Excessive work hardening has taken place in the areas that are kinked. Typically, kinked areas will have already cracked or will crack when straightening attempts are made. Kinked aluminum structural parts must be replaced.

**Bent Structural Parts**
Bent aluminum structural parts may require replacement or may be straightened depending on the vehicle maker recommendation, structural part design, and severity of
the damage. If straightening is going to be performed, the damaged part or parts must be returned to the original shape and state.

**Anchoring**
Anchoring typically requires vehicle-specific equipment. Styles of clamps include pinchweld clamps that are designed for rivet-bonded flanges, rotating cams that fit into specific holes in the structure and lock down to hold the vehicle, and bolts that attach the vehicle directly to fixtures.

Anchors should be dedicated for aluminum, or cleaned, to prevent introducing galvanic corrosion.

**Straightening**
Structural straightening will generally require extra anchoring. Counter anchoring is done to help apply the straightening force where it is most needed and to hold the vehicle without damaging the anchoring locations. Generally more force is needed. Aluminum structures tend to be very rigid and resist straightening. Multiple pulling towers or extra pushing with portable hydraulic rams is needed to compensate for aluminum’s lack of memory. Controlled heat may also be needed to help temporarily relax the internal molecular structure of the aluminum.

**Structural Shape And State**
Aluminum internal grain structure must be returned to its original shape and state and be relaxed internally to prevent future spring-back. Spring-back refers to the aluminum trying to return to the damaged shape and state. Stress-relieving using heat or vibration helps relax the internal molecules.

**Heating Considerations**
Some considerations for heating an aluminum structure include the size of the area that will need to be heated. The larger the area to heat, the faster the heat will transfer. Therefore, it may be difficult to reach the suggested heat range for straightening.

Also, there may be adhesive in the area. Caution should be used if heating these areas. Temperatures required for straightening may weaken the adhesive bond and affect structural integrity. Heat monitoring must be done to help prevent overheating the aluminum and adhesive. Also, vehicle maker recommendations must be considered. Some vehicle makers, such as BMW, Ferrari, and Audi recommend no heating of the aluminum structure.

**Removal Of Indirect Damage**
Removal of indirect damage on aluminum structures is the key reason for structural straightening. This includes realignment of exterior body panels where fit or operations
were affected from collision energy. Structural straightening also returns misaligned adjacent structural parts with no visual damage to vehicle maker specifications. Generally, structural parts with direct damage will require replacement.

Straightening is generally done before part replacement. This allows damaged parts to be used for pulling attachment points. Partial removal of damaged parts may be needed for access and to decrease straightening resistance and focus pulling forces.

**Restoring Dimensions**
Restoring vehicle dimensions must be done to the underbody and upperbody, if needed. Repeated pulling attempts are typically required. This is needed to overcome the spring-back that is common to aluminum structures. Progress is generally made in small increments at a time.

**Procedures Following Straightening**
Some procedures that typically are done after structural straightening can include inspecting clamping locations for damage and using dye penetrant to test areas that were counter anchored, pushed against, or stress relieved. If cracks are found in structural parts after straightening, these parts must be replaced. Refinishing clamping locations may be needed to restore corrosion protection and appearance.

**Bolted Crush Boxes**
Bolted aluminum crush boxes are used by many vehicle makers and can be found on the front and rear lower rails of some vehicles.

Bolted crush boxes are designed to absorb collision energy in a low-speed frontal impact. They are sacrificed to protect the lower rails. Bolted crush boxes are not repaired if damaged. Bolts used for fastening bolted crush boxes may require replacement.

**Part Availability**
Structural aluminum parts may be available as separate pieces or as complete assemblies. Assemblies such as lower rails may come with suspension mounting areas attached. This may be the only way some vehicle makers service some suspension mounting areas.

Structural parts, such as cowls may only be available with a complete front-end assembly. Some vehicle makers do not make cowls available as separate service parts. Also, floors may not be available as replacement service parts.

**Replacement At Factory Seams**
Replacing structural parts at factory seams is the only accepted repair by some vehicle makers such as Honda and Acura. This involves removing the entire part by cutting or grinding away all welds or removing all rivets.
Replacing structural parts at factory seams typically requires extensive disassembly of the vehicle. This varies on the part that is being replaced. There may not be a published procedure even though the service part is available.

**Sectioning**
Sectioning structural aluminum parts does not require the complete part to be removed. Sectioning may reduce the amount of vehicle disassembly required. This also keeps more fasteners, adhesives, and mating flanges intact. Structural sectioning will generally have recommended cut locations from vehicle makers.

Sectioning structural parts that do not have vehicle maker recommendations is a subjective business decision.

**Sectioning Applications From Vehicle Makers**
Some parts where sectioning is allowed by the vehicle maker can include the upper fender rails, front and rear lower rails, and inner rocker panels.

**Part Replacement Considerations**
When replacing structural parts and sectioning, multiple fit-ups are typically needed. Service parts may have mounting locations added by different tooling methods than what is used during assembly at the vehicle makers. Therefore, slight variations in part construction could result. Structural part fit is crucial to all other parts fitting correctly. Measurements and adjacent part fit-up is required before final installation of structural parts. Inserts may need to be constructed for sectioning also. Some inserts are available from the vehicle maker.

Structural part replacement may require undamaged adjacent parts be removed and replaced to gain access. A consideration to keep in mind is that some sectioning applications may be less practical. Full part replacement may be a better repair option. For example, sectioning a structural part may require making an insert, more welding than replacing the same part at the factory seam, and the same amount of vehicle disassembly.

**Structural Part Attachment**
Structural parts are commonly attached with GMA (MIG) welding. Rivets also are used for attaching structural parts. Adhesive may or may not be used with the rivets. Combinations of GMA (MIG) welding and rivets are also used.

Aluminum structural part attachment generally requires vehicle maker recommended equipment and products. Some vehicle makers such as BMW do not want welding duplicated on the 5 and 6 Series aluminum front structure.
Structural Part Preparation
Aluminum structural part replacement may require numerous preparation steps. These may include flange straightening, making sure mating flanges are flush. This is crucial for increasing weld performance and having adequate bond-line thickness when using adhesives. Aluminum flanges require careful straightening to avoid thinning or fracturing.

Another step is flange cleaning. Depending on vehicle maker repair procedures and attachment methods, E-coat may require removal from the replacement service parts. E-coat and existing factory adhesive may also require removal from the vehicle mating flanges. Oxide that forms on bare aluminum mating flanges also should be removed.

Adjacent part fit-up before final installation is common.

Countersinking or dimpling for blind or solid countersunk rivet installation may be needed. This is done to both mating flanges for correct rivet compression.

Adhesive pre-treatment may be needed before bonding operations, as well as burr removal from plug weld or rivet holes to help ensure mating flange flushness.

Finishing Operation
Common finishing operations that are done following aluminum structural part replacement may include adhesive clean up and flange straightening for rivet-bonded panels. Adhesive squeeze-out must be removed so overall appearance is not affected. Flange straightening may be needed if rivet compressions slightly deform the mating flanges.

Weld finishing is also common. Aluminum welds require lighter pressure, slower speeds, and finer grit discs for weld finishing. This is so stress fracturing from heat build-up does not occur. Also, dye penetrant testing of welds is used to inspect for cracks or pinholes and is quite common when working with aluminum structural parts.

Activity: Structural Repair / Replace Decisions #1
In this activity you will be shown images of vehicle structural damage. At the end of this activity you will need to make a repair or replace decision based on the damage shown.

Stationary Glass
Stationary glass is considered a structural part of the vehicle and may require removal for some repairs. Stationary glass may have many built-in electronics such as antennas and
defroster grids. Glass may need to be temporarily installed following removal to achieve proper spacing of adjacent parts, for replacement of one-time use encapsulated moldings, or to achieve correct electronic device operation.

**Stationary Glass Adhesive Considerations**
Adhesive that is used to install stationary glass on aluminum vehicles may be required to be non-conductive. Some glass adhesives contain carbon, which can be reactive with aluminum, causing galvanic corrosion. Specific adhesive generally will be recommended by the vehicle maker and may only be available from the vehicle maker. Specific adhesive guns may be needed for application.

**Mechanical Considerations**
Mechanical considerations for aluminum vehicles may include vehicle maker scan tools that are typically required for pre-repair and post-repair operations. Pre-repair operations can include disabling of vehicle functions such as air suspensions or telecommunication systems. These must be deactivated by a scan tool prior to main battery disconnection. Post-repair operations can include computer module reprogramming or re-enabling vehicle functions.

Another consideration is vehicle transportation to mechanical repair facilities. Vehicles with removed engines and / or disabled computer modules may need towing services. Some vehicle makers have recommended the use of flat bed towing equipment with wheel strapping for transporting their aluminum vehicles. This reduces the chance of damage during transport.

**Module Summary**
Topics discussed in this module included:

- aluminum structural design and construction.
- structural damage analysis considerations.
- repair / replace practices for aluminum structural panels.
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Module 4 - Aluminum Collision Repair Facilities
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Learning Objectives
Learning objectives for this module include:

- discussing the equipment that is needed by an aluminum repair facility.
- discussing aluminum vehicle repair networks.
- identifying aluminum repair training courses.

Aluminum Repair Facilities
Aluminum repair facilities that specialize in aluminum repair are outfitted with specific repair equipment. This includes dedicated repair areas, aluminum welding equipment, riveting equipment, and straightening equipment. Aluminum repair facilities also require highly trained technicians.

Dedicated Repair Area
Dedicated repair areas are common to aluminum vehicle repair facilities. Typically it is a separate room or a curtained-off area having dust extraction specially designed for aluminum dust collection. These are typically explosion proof in case the aluminum dust combusts.

Dedicated repair areas also may have hand tools dedicated to working on aluminum vehicles. These can include body repair tools and some mechanical tools. Dedicated repair areas are used to protect vehicles from cross contamination and reduce the likelihood of galvanic corrosion. Some vehicle makers will have requirements on this as well.

Welding Equipment
GMA (MIG) welding equipment used on aluminum vehicles requires higher current output to compensate for heat dissipation. Dedicated liners and drive rollers must also be used to prevent cross contamination. GMA (MIG) welding equipment may have pre-programmed welding parameters for specific vehicle applications or the vehicle maker may have specific recommendations.

Riveting Equipment
Riveting equipment for aluminum vehicles is generally a vehicle-specific application. This equipment is used for removing and installing self-piercing rivets and installing solid rivets and blind rivets.

Straightening Equipment
Straightening equipment for aluminum vehicles may be recommended by the vehicle maker. This can include vehicle-specific fixtures for measuring and rebuilding, vehicle-specific anchoring, and aluminum dedicated clamping equipment.
Aluminum Repair Networks
Some vehicle makers have aluminum repair networks in place. These networks:

- consist of collision repair centers for specific aluminum vehicles.
- have direct involvement between the vehicle maker and the collision repair facility.
- have equipment and product requirements.
- have vehicle-specific collision repair training.

Network Operations
Some aluminum repair networks have different repair facility categories. They are generally divided into non-structural and structural repair. Non-structural repair facilities perform cosmetic repair and bolted panel replacement. Structural repair facilities perform all repairs. Vehicle makers may supply vehicle transportation to structural repair facilities. Vehicle warranties may be voided if structural repairs are done at non-structural certified repair facilities. Some vehicle makers recommend aluminum-structured vehicles be repaired by properly trained technicians using specific products and equipment.

Current Aluminum Networks
Current vehicle-specific aluminum repair networks in North America are established for Audi, BMW, Jaguar / Land Rover, Mercedes-Benz, Ferrari, and Lamborghini. In addition, Tesla and Aston Martin have been recently added.

For information on joining an aluminum repair network, contact the appropriate vehicle maker.

Vehicle-Specific Training
Vehicle-specific aluminum training is required to become involved with an aluminum repair network. Training may involve a GMA (MIG) aluminum welding qualification or certification. Also, vehicle-specific aluminum training typically covers vehicle construction including design and joining methods and covers vehicle maker recommended repair procedures and equipment use.

Vehicle-Specific Training Available
Vehicle-specific aluminum training is available from Audi, Jaguar / Land Rover, BMW, and Ferrari. In addition, Tesla, Aston Martin, Mercedes-Benz, Lamborghini, Chevrolet, and Ford have aluminum training available.

I-CAR offers vehicle-specific aluminum training, specifically:
- Collision Repair Overview For The 2006 Chevrolet Corvette Z06 (GEN01)
- 2015 Ford F-150 Structural Repair Training Course (FOR06)

**I-CAR Aluminum Repair Training**
I-CAR offers the following aluminum repair training courses:

- Aluminum Panel Repair (APR01)
- Aluminum-Intensive Vehicle Repairs (ALI01)

**I-CAR Aluminum GMA (MIG) Welding Training**
I-CAR offers the Welding Training & Certification: Aluminum GMA (MIG) Welding (WCS03) aluminum welding training course.

**Module Summary**
Topics discussed in this module included:

- equipment used by an aluminum repair facility.
- aluminum vehicle repair networks.
- aluminum repair training courses.
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