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**MTRL 466 – Adhesive Bonding in Al Alloy Automobile Panels**

# Types of Al alloys in Automobiles (with Comparisons to Steel)

* **Selection criteria for Al alloys in automotive applications** *[1, V. Aluminum Alloys for Commercial Vehicles, pg. 44]*:
  + Availability of semi-finished products
  + Mechanical properties
  + Physical properties
  + Suitability for fabrication
  + Weldability
  + Corrosion resistance
* **Why is steel currently the preferred material in automotive design?**

First, there are several important aspects to consider why an automotive design would benefit by using an Al alloy in place of steel.

The design process for a piece of machinery like an automobile is indeed complex. Steel is still the most commonly used material in the automotive industry. However, certain automobile applications make use of certain aluminum alloy’s mechanical and physical property variability, in terms of their yield strength, stiffness, ease of fabrication, etc. They main benefit to using an aluminum substitute is that, in comparison to steel, it typically provides a lightweight solution [1, pg. 34]. Below are some major structural differences in Al alloys to steel [1, pg. 59].

**Elasticity:** The modulus of elasticity of aluminum is 1/3 of that of steel. This means that an aluminum beam with the same cross-section and the same loads as a steel beam will have a deflection 3 time that of the steel beam.

**Weight:** The density of aluminum is 1/3 of that of steel. This means that a steel beam will weigh 3 times more than an aluminum beam with the same cross-section.

**Thermal elongation:** The coefficient of thermal elongation of aluminum is twice that of steel. This means that an aluminum member will get twice the thermal elongation as a similar steel member with the same temperature difference. Since the elastic modulus of aluminum is 1/3 of steel, the stresses in an aluminum member with fixation are 2/3 of that in a similar steel member.

**Strength:** Most of the structural aluminum alloys have relatively high “strength-to-E modulus” ratio, roughly twice the “strength to E modulus” ratio of standard steel. This effect is especially clear when the aluminum alloy is strain-hardened or heat-treated. However, when compared with high strength steels, structural aluminum alloys have about the same “strength-to-E modulus” ratio.

The major concerns regarding the use of Al alloys are the higher prices associated with using Al alloys as well as overcoming some of the difficulties in manufacturing on large-scale production [2, pg. 365].

The types of components for which aluminum has been used successfully have typically been complex castings (engine blocks/heads, road wheels, steering wheels, steering column housings, etc.) where steel really is not suitable for reasons of geometry, thermal properties, etc.

However, steel and aluminum do compete for body structure and chassis applications. Steel has a wide range of available properties including excellent formability and high strength, but it is also quite dense. Also, high strength usually comes at the expense of good formability.

Chapter IV of *Aluminum Alloys for Commercial Vehicles* goes on to express service limits formulaically and numerically; this section provides some useful detailed information.

* **More detailed general requirements** *[2, Alloys for Car Bodies, pg. 367, 368]*:
  + Small grain sizes, usually less than 50μm
  + 0.2% yield stress in the quenched and naturally aged state no higher than 150 MPa
  + 0.2% yield stress elevated up to 300 MPa in artificial aging
  + Good formability, high corrosion resistance
  + Absence of Luders line to provide mirror surface after painting
    - No local yielding variation
  + Uniform thickness, high-quality surface
  + In most cases aluminum alloys are used in the body of a car in the form of parts die cast from sheets from 0.8 to 1.3 mm thick, which should possess good formability in combination with sufficient strength characteristics
  + The formability of the sheets depends on the chemical composition, properties, and structure of the alloy, the size and shape of the grains, the inhomogeneity of the grains, the morphology and sizes of intermetallic particles, the degree of isotropy of the mechanical properties, and the capacity of the metal for strain hardening and aging

→These requirements have been accessed and formulated by leading foreign car producers and were generalized to give approximate values/ranges for each point.

* **Multiple manufacturing processes** [3]:
  + Rolled aluminum (sheet is the focus)
    - Heat exchanger, heat shields, fin stock, BIW, **outer panels, c**hassis, structural parts, wheels, **inner panels**
  + Extrusion
    - Various extruded tubing, bumper beams, crash boxes, sub-frames, space frames, wind shield frames, dash board carrier, cant rails, seats and seat rails
  + Casting
    - Engine blocks, cylinder heads, cylinder blocks, transmission cases, steering wheels, suspension knuckles, turbocharger impellers

## What is their composition?

* **Most commonly used rolled (sheet) Al alloys in automobiles** *[3, Products → Rolled products → Alloys]*:
  + 5xxx series, Al-Mg --- Generally used in rolled product applications
    - 5005, **5052**, 5454, **5754**, 5182, 5083
    - Medium strength, corrosion resistance
  + 6xxx series, Al-Mg-Si --- Used in rolled product applications, extruded products and casted products
    - 6061, 6181, **6111**, 6022
    - Good formability, high strength
  + Select 1xxx and 3xxx alloys --- Used in rolled products and casted products
    - 1050A, 3003
    - Heat transfer, thermal stability
      * Important in automobile components vulnerable to heating
        + Engine block, cylinder head

## How are they strengthened?

*[4, Wrought Aluminum Alloys]*

* **5xxx series:**
  + The presence of magnesium as main alloying element leads to solute hardening of the alloy, and efficient strain hardening, resulting in medium strength
    - Strain hardening (work hardening) is achieved by plastically deforming the material
      * Energy is being added to the material
      * Dislocations move and are also produced during this process
        + Dislocations hinder lattice movement; deformation becomes more difficult; higher stresses are necessary
  + Generally stronger than the medium strength 3xxx series alloys, while having also very good formability
    - Typical yield strengths of 5xxx alloys range between 40.0 and 435 MPa
    - Typical yield strengths of 3xxx alloys range between 31.0 and 285 MPa
    - Typical yield strengths of 6xxx alloys range between 40.0 and 455 MPa
* **6xxx series:**
  + Can be strengthened by heat treatment (**precipitation/age hardening**), through the presence of their main alloying elements silicon and magnesium
    - Second phase particles cause lattice distortions, impede movement of dislocations
    - For up to 12% **silicon**, precipitation hardening of the alloys is possible when silicon is combined with magnesium
      * More than 13% Si reduces machinability
    - Magnesium and silicon form Mg2Si precipitates
      * The following study shows the importance of introducing Si to the 6xxx series Al alloy in aiding to the strengthening characteristics of precipitation hardening

*Precipitation hardening in Al–Mg–Si alloys with and without excess Si* <http://www.sciencedirect.com/science/article/pii/S0921509301012473>

* + - Furthermore, Si improves the corrosion resistance compared to other alloys except for those of the 1xxx series
  + These alloys are generally less strong than the 2xxx and 7xxx series, but have good formability and are weldable

## Where are they used?

* 4 key application areas for Al alloy products *[3, Products → Rolled products → Alloys]*:
  + Power train
  + Chassis
  + **Car body**
    - Body-in-white (BIW), doors, hoods, wings (fenders), bumpers, seats
  + Interior
* 5xxx series:
  + Chassis, structural parts, wheels, **inner panels**
    - Bending and torsion stiffness
* 6xxx series:
  + BIW, **Outer panels**
    - Static bending, torsion, stiffness
    - Dynamic dent resistance
    - High surface quality
* 1xxx series:
  + Heat shields, fin stock
* 3xxx series:
  + Heat exchanger

## References

[1] Aluminum in Commercial Vehicles <http://www.eaa.net/upl/4/en/doc/Aluminium%20in%20Commercial%20Vehicles.pdf>

[2] Aluminum Alloys: Promising Materials in the Automotive Industry <http://www.springerlink.com/content/l605843182pv7774/fulltext.pdf>

[3] The Aluminum Automotive Manual <http://www.eaa.net/aam/>

[4] AluMatter: Wrought Aluminum Alloys <http://aluminium.matter.org.uk/content/html/ENG/default.asp?catid=214&pageid=2144417044>