

APPLICATION OF ALUMINUM BRONZE IN THE AUTOMOTIVE INDUSTRY

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Annotation: This paper explores the application of aluminum bronze alloys in the automotive industry, highlighting their mechanical strength, corrosion resistance, and wear performance. It discusses current uses, advantages, limitations, and future trends in adopting these materials for enhanced vehicle durability and efficiency.

Keywords: Aluminum bronze, automotive industry, corrosion resistance, mechanical strength, wear resistance, vehicle components, copper alloys.

Introduction

Automobile manufacturing relies on a variety of materials to balance performance, weight, and cost. Steel remains the dominant material (about 54% of vehicle weight) due to its strength and recyclability. Lightweight metals like aluminum have grown substantially – for example, aluminum content per vehicle rose from ~84 pounds in 1975 to ~466 pounds by 2020– reflecting efforts to improve fuel efficiency. Alongside steel and aluminum, specialty alloys (such as copper-based bronzes) serve niche roles. Copper-alloy components (including aluminum bronze) are widely used in automotive friction and bearing systems for their tribological and corrosion-resistant properties. This article reviews current knowledge of aluminum

bronze in automotive contexts, covering its material properties, automotive applications, benefits and drawbacks, and future developments.

Literature Review

Recent research on aluminum bronze has focused on microstructure, wear behavior, and novel applications. For instance, Patel and Patel (2019) reviewed a high-strength nickel-aluminum bronze (C95500) containing ~10–11% Al, 4–5% Ni, and 4–5% Fe; they noted its common use in heavy-duty sleeve bearings, bushings, shafts, and valve components for seawater service, highlighting its excellent wear resistance and low friction. In the context of automotive wear surfaces, Shaburov *et al.* (2020) demonstrated that laser-clad aluminum bronze coatings on steel can form a strong bronze–iron diffusion layer with hardness 1.5–2× that of the substrate. These coatings are of interest for engine and transmission parts because “copper-alloy details in friction pairs...are widely used in automotive...due to their tribological properties”. More application-specific, Yuvaraja *et al.* (2020) investigated an aluminum-bronze alloy for a car wheel rim: a 90% aluminum alloy with 10% Cu–Sn bronze gave adequate strength and showed no corrosion after 240 h of salt-spray testing. In summary, the literature includes studies on alloy composition and processing (e.g. heat treatments, additive fabrication) as well as targeted prototyping (e.g. wheel rims), all pointing to aluminum bronze’s potential in high-stress automotive parts.

Properties of Aluminum Bronze

Aluminum bronze alloys (copper with ~5–12% Al, plus Ni, Fe, etc.) offer a unique property set valuable to automotive use. Key attributes include:

- **High Mechanical Strength:** Nickel–aluminum bronze (e.g. UNS C63200, ~9% Al, 5% Ni, 4% Fe) can reach tensile strengths of ~640–725 MPa and yield strengths ~330–380 MPa (cold-worked). Rockwell hardness is high (~92–97 B for C63200). In practical alloys (e.g. C95500), tensile strength and hardness are comparable to low-alloy steels, often exceeding those of stainless

steels. (Note: increasing Al or Ni content typically raises strength but can reduce ductility, eventually causing brittle behavior.)

- **Good Corrosion Resistance:** Aluminum bronzes form a tough, adherent Al_2O_3 surface film, markedly improving resistance to oxidizing and marine environments. They resist seawater and many industrial chemicals much better than common bronzes or steels. Nickel additions further enhance resistance to erosion and stress-corrosion cracking.

- **Wear and Tribological Behavior:** These alloys exhibit excellent wear resistance and low friction in sliding contacts. They often serve as bearings or bushings (sometimes oil-free with embedded graphite) where anti-galling and seizure resistance is needed.

- **Physical Properties:** Density is about $7.6\text{--}7.8 \text{ g/cm}^3$ (roughly the same as steel, much denser than aluminum). Thermal conductivity is moderate ($\sim 36 \text{ W/m}\cdot\text{K}$) and thermal expansion relatively high (compared to steel). Nickel-aluminum bronzes are non-magnetic and non-sparking, which is advantageous for safety in flammable or explosive atmospheres.

Overall, aluminum bronzes combine **high strength and hardness with good corrosion and wear resistance**, while remaining non-ferrous. These properties make them suitable for demanding automotive components, though their higher density and hardness must be managed in design.

Applications in the Automotive Industry

Aluminum bronze alloys are applied in specific automotive parts that benefit from their unique properties:

- **Bushings and Bearings:** Many suspension and steering components use bronze bushings (e.g. control-arm pivots, sway-bar links) for their load capacity and corrosion resistance. Oil-impregnated (self-lubricating) aluminum-bronze bearings are used in heavy vehicle driveline joints and

pivots. In high-load transmissions, bronze bushings or bearings can replace plain steel bearings for improved wear performance.

- **Gears and Pumps:** Some gear pumps (for oil or fuel) use aluminum-bronze rotors or gears to reduce seizure risk. Smaller drivetrain gears in legacy vehicles or specialty equipment have been made from aluminum bronze when strength and fatigue resistance are critical.

- **Valve and Engine Components:** High-performance engines often use nickel-aluminum bronze for valve seat inserts and guides, especially when mating with titanium valves or under lean-burn conditions. Bronze alloys withstand valve impact and gas corrosion better than some steels. Oil pump gears, fuel injection pump shafts, and timing gear washers are other potential engine uses, exploiting bronze's wear resistance.

- **Fasteners and Fixtures:** In limited cases, automotive fasteners (e.g. bushings, jack components, tool lugs) are made of aluminum bronze to combine strength with corrosion resistance, especially in undercarriage or outdoor environment.

- **Electrical Connectors and Heat Sinks:** Because of good conductivity and corrosion resistance, copper-aluminum alloys can serve as electrical connectors or heat-conductive parts, though pure copper alloys (e.g. CuCrZr) are more common. In hybrid/electric vehicles, aluminum bronze could find use in high-current connectors where mechanical strength is also needed.

While data on each specific use is limited, the broader literature confirms these patterns: heavy-duty sleeve bearings, bushings, shafts, and valve components are typical applications for alloys like C95500, and automotive suppliers market *oil-free bronze bushings* for suspension and hydraulic parts. In all cases, aluminum bronze is chosen where **load-bearing wear resistance** and **corrosion resistance** are more important than lightweight or low cost.

Advantages and Limitations:

- **Advantages:**

- *High Strength and Wear Resistance:* As noted, aluminum bronzes achieve steel-level strength and excellent wear properties. This allows for thinner sections and durable surfaces in bearings and bushings.
- *Corrosion Resistance:* The protective alumina film grants resistance to saltwater and most automotive fluids, outperforming steels and many brasses. This is especially valuable for brake-system and suspension components exposed to road salts.
- *Low Friction and Anti-seize:* These alloys have low adhesion to mating metal (anti-galling), reducing seizure risk under boundary lubrication. They can operate in lightly lubricated or even “dry” conditions with acceptable wear.
- *Non-sparking, Non-magnetic:* Being copper alloys, aluminum bronzes will not spark upon impact, a safety feature in fuel-system or battery contexts.
- *Stability and Damping:* Their high mass provides vibration damping, and they retain strength at elevated temperatures (up to ~300–400°C), suitable for under-hood use.

- **Limitations:**

- *Higher Cost:* Aluminum bronze is significantly more expensive than steel or common aluminum alloys. The alloying elements (copper, nickel, aluminum) and specialized casting/forging processes drive cost up, confining use to critical components.
- *Machining Challenges:* The very properties that make these alloys strong (high tensile strength and hardness) also make them difficult to machine. They work-harden quickly, abrade tools, and their

high copper content tends to stick to cutting tools. These factors lead to shorter tool life and longer cycle times.

- *Brittleness (at High Alloy Content):* Highly alloyed grades can exhibit low ductility. For example, increasing Al/Ni content raises hardness but can cause the microstructure to fracture with little elongation. Designers must balance strength with toughness to avoid brittle failure.
- *Weight:* With density $\sim 7.7 \text{ g/cm}^3$, aluminum bronze is heavier than aluminum (2.7 g/cm^3) and only slightly lighter than steel. Thus, it does not contribute to lightweighting efforts and is used where performance outweighs weight penalty.
- *Weldability and Casting:* Some aluminum bronzes are prone to hot cracking and require careful heat treatment. Casting intricate shapes can be challenging due to shrinkage and oxidation. (In practice, many components are wrought or machined from billet to ensure quality.)

Overall, the **benefits** of aluminum bronze (strength, wear and corrosion resistance) make it ideal for specific automotive parts, but its **drawbacks** (cost, machining difficulty, weight) limit its use to specialized applications.

Future Prospects

Research and innovation are expanding the possibilities for aluminum bronze in automotive engineering. Key trends include:

- **Advanced Manufacturing:** Additive manufacturing (AM) and surface-cladding techniques are enabling new aluminum-bronze applications. For example, *laser cladding* can build hard aluminum-bronze layers on steel parts for improved wear performance in engines or transmissions. Suppliers of metal powders note that nickel-aluminum bronze is compatible with powder-bed and

wire-arc 3D printing, allowing complex, customized automotive parts (e.g. optimized bushings or heat exchangers) to be produced. Such AM processes may reduce material waste and enable lightweight lattice or composite structures of aluminum bronze.

• **Alloy Development:** Ongoing materials research is refining aluminum-bronze compositions for specific needs. For instance, adding manganese or silicon can improve castability, while controlled heat treatments (or thermomechanical processing) can optimize strength vs. toughness. Recent studies on Al–Ni ratios and heat treatment protocols aim to tailor the hardness and ductility balance. Research into aluminized steel/bronze hybrid components (e.g. WAAM-joined bronze–steel parts) also shows promise for combining properties.

• **Self-lubricating and Composite Bearings:** Aluminium-bronze composites with solid lubricants (e.g. graphite) or ceramic reinforcements are being explored for automotive bearings that require long life with minimal maintenance. Such developments could see aluminum bronze used in new “bushless” pivot joints or electric motor bearings where reliability is critical.

• **Electrification:** As vehicles electrify, some new requirements emerge. Aluminum bronze’s good conductivity and corrosion resistance could make it a candidate for high-current battery or inverter connectors, or as liners in fuel cell flow components. Its non-sparking nature may also be useful in hydrogen fuel systems. Meanwhile, the push for noise and vibration reduction may leverage aluminum bronze’s higher damping (vs. steel) in certain structural parts.

In summary, while aluminum bronze is already established in a few automotive roles, future trends in manufacturing technology and vehicle design could expand its use. Additive manufacturing and advanced alloys may allow aluminum bronze to

enter applications (especially in EVs or extreme environments) that were previously impractical.

Conclusion

Aluminum bronze alloys combine high strength, wear resistance, and corrosion resistance in a copper-based material system. These attributes make them well-suited for specialized automotive components such as heavy-duty bearings, bushings, and valve hardware. In practice, however, their higher cost, greater weight relative to aluminum, and machining challenges restrict their use to critical areas where steel or plastics would fail. Ongoing research – including alloy optimization, composite formulations, and additive manufacturing – is poised to mitigate some drawbacks and open new niches for aluminum bronze in future vehicles. Ultimately, aluminum bronze will continue to complement (but not replace) conventional automotive materials, serving where its unique properties yield clear benefits.

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