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ALUMINIUM: THE METAL OF CHOICE

ALUMINIJ: KOVINA IZBIRE

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This article summarizes the importance of aluminium as the metal of choice for many applications. Aluminium is a lightweight, durable metal. It is silvery in appearance when freshly cut, is a good conductor of heat and electricity, and is easily shaped by moulding and extruding. Aluminium has two main advantages when compared with other metals. Firstly, it has a low density, about one-third that of iron and copper. Secondly, although it reacts rapidly with the oxygen in air, it forms a thin, tough and impervious oxide layer that resists further oxidation. This removes the need for surface-protection coatings such as those required with other metals, in particular with iron.
All the indications are that the growth in the use of aluminium will likely accelerate. It is expected that in the near future the use of aluminium with specifically improved properties will grow in many applications, meeting the increased economic and ecological demands.
Considering the entire life-cycle of an automobile, from the extraction of materials to the final disposal, including recycling and reuse applications, aluminium proves to be a potential alternative to steels in future automotive applications.

Keywords: corrosion resistance, aluminium alloys, aluminium applications, aluminium in vehicles, CO_2 emission, aluminium recycling

Članek povzema pomembnost aluminija kot izbrane kovine z mnogimi možnostmi uporabe. Aluminij je lahka, zdržljiva kovina. Je srebrne barve, ko je sveže odrezan, je dober prevodnik toplote in elektrike in se lahko oblikuje z ulivanjem v kokile in z ekstruzijo. Aluminij ima v primerjavi z drugimi kovinami dve glavni prednosti. Prva je majhna gostota, okrog ene tretjine gostote železa ali bakra. Druga: čeprav hitro reagira s kisikom iz zraka, tvori tanko, trdo in neprepustno oksidno plast, ki preprečuje nadaljnjo oksidacijo. Zato ni potrebe po površinski zaščiti, kot jo zahtevajo druge kovine, še posebno železo.
Kaže, da se bo rast porabe aluminija še nadaljevala. V bližnji prihodnosti se pričakuje, da bo zaradi povečanja ekonomskih in ekoloških zahtev uporaba aluminija s posebnimi, izboljšanimi lastnostmi rastla na mnogih področjih uporabe.
Z upoštevanjem celotnega trajnostnega cikla avtomobila, od pridobivanja materiala do odlaganja, vključno z recikliranjem in možnostjo nadaljnje uporabe, aluminij dokazuje, da je mogoča alternativa jeklom v prihodnji proizvodnji avtomobilov.

Ključne besede: odpornost proti koroziji, aluminijeve zlitine, uporaba aluminija, aluminij v vozilih, emisija CO_2, recikliranje aluminija

1 INTRODUCTION

Aluminium is a light, conductive, corrosion-resistant metal with a strong affinity for oxygen. This combination of properties has made it a widely used material, with applications in the aerospace, architectural construction and marine industries, as well as many domestic uses.

Aluminium is the second most widely used metal in the world today. It is used extensively in aircraft, in building construction, and in consumer durables such as fridges, cooking utensils and air conditioners, as well as in food-processing equipment and cans.

Aluminium is not found in its metallic form in nature. It occurs as bauxite, a mixture of aluminium oxides, iron oxides and clay. Manufacturing aluminium metal from bauxite is a complex process.

Aluminium is one of the most important metals used by modern societies. Aluminium´s combination of physical properties results in its use in a wide variety of products, many of which are indispensable in modern life. Because of its light weight and electrical conductivity, aluminium wire is used for the long-distance transmission of electricity. Aluminium's strength, light weight, and workability have led to increased use in transportation systems, including light vehicles, railcars, and aircraft in efforts to reduce fuel consumption. Aluminium's excellent thermal properties and resistance to corrosion have led to its use in air conditioning, refrigeration, and heat-exchange systems. Finally, its malleability has allowed it to be rolled and formed into very thin sheets used in a variety of packaging.

In 1903, the Wright brothers made aviation history when they achieved the world's first flight powered by a lightweight engine made with aluminium components. Today, aluminium is fundamental to the aviation industry. It was in the 1920s that aluminium shipping applications started to expand due to new alloys becoming available for marine applications. In the 1980s, aluminium emerged as the metal of choice for reducing running costs and improving the acceleration of metros, tramways, intercity and high-speed trains. The average volume of aluminium used in passenger cars was significantly increased in 2000.

The examples given for its success prove the major breakthroughs in automotive applications for aluminium that have been achieved during recent years by developing innovative light-weight and cost-efficient solutions.

Vehicle manufacturers must constantly improve their performance at minimum costs. The choice of a material will therefore depend on its price, its mechanical properties and its impact on vehicle production costs. Due to its low weight, good formability and corrosion resistance, aluminium is the material of choice for many automotive applications, such as the chassis, auto body and many structural components.[1–4]

2 ALUMINIUM PRODUCTION

The major raw materials required for aluminium production are alumina, carbon, power, aluminium fluoride and cryolite. The aluminium industry consumes nearly 90 % of the bauxite mined; the remainder is used in abrasives, cement, ceramics, chemicals, metallurgical flux, refractory products, and miscellaneous products. Virtually all the alumina commercially produced from bauxite is obtained using a process patented by Karl Josef Bayer (Austria) in 1888.

Primary aluminium is produced by the electrolysis of alumina dissolved in molten fluoride salt. The process was independently invented in 1886 by Charles Martin Hall (United States) and Paul Louis Toussaint Héroult (France) and underwent continual improvement over the years. The electrolysis of alumina to produce aluminium involves the use of aluminium fluoride, carbon anodes, and large amounts of electricity.[5–7]

Taking the purity grades of aluminium into account, the aluminium content is usually the main consideration and other elements are considered only as impurities. The common purity grades of aluminium are listed in **Table 1**.[8,9]

3 CORROSION RESISTANCE

Aluminium's well-known corrosion resistance is an obvious advantage in road transport. It contributes to a long service life, especially in vehicles that work in conditions that can cause serious corrosion problems. Usually, no painting or other surface protection is required and it is easy to clean. Maintenance is therefore kept to a minimum.

Corrosion is an electrochemical interaction between a metal and its environment which results in changes to the properties of the metal and which may often lead to impairment of the function of the metal, the environment, or the technical system of which these form a part. Corrosion can occur locally (pitting), or it can extend across a wide area to produce a general deterioration.

A clean aluminium surface is very reactive and will react spontaneously with air or water to form aluminium oxide. This oxide builds a natural protective layer on each aluminium surface with a thickness of around 1–10 nm. The oxide layer is chemically very stable, has a good adhesion to the metal surface, repairs itself and protects the aluminium from further corrosion. The oxide layer can be destroyed in strong acidic or alkaline environments or where aggressive ions are present. Aggressive ions can destroy the layer locally and lead to local corrosion attack (pitting). A typical case for this reaction is the contact between aluminium and chloride ions, which are present in seawater or road salts. Some alloying elements might increase the corrosion resistance of the oxide layer, while others can weaken it. Vehicle manufacturers or fleet operators should contact the aluminium supplier in any case of critical working conditions, like elevated temperatures or aggressive loads.

Some general rules need to be applied to prevent corrosion, in most cases to prevent any kind of water trap or areas where condensation can occur.

Although aluminium can be used without any surface protection and keeps its natural beauty throughout its life, it is most likely to use different surface treatment methods to optimise its attractiveness and optical appearance and to protect it from severe atmospheric conditions.[10]

4 ALUMINIUM ALLOYS

In aluminium alloys other elements are deliberately added to improve the properties in some way. Many alloys have been developed, the aim being to improve the strength while retaining the desirable properties of aluminium, most notably its lightness and corrosion resistance. In general though, while the addition of an alloying element increases the strength, it reduces the resistance to corrosion, making a compromise of the properties necessary. A possible exception to this is magnesium alloys, which have improved corrosion resistance in marine environments. Aluminium-copper alloys have very poor resistance to corrosion, and sheets are often produced in sandwich form with thin layers of pure corrosion-resistant aluminium on the outside. A summary of typical alloys is given in **Table 2**.[6,7,9]

Table 1: Purity grades of aluminium
Tabela 1: Stopnje čistote aluminija

Aluminium content in mass fractions, w/%	Major impurities in mass fractions, w/%		Some typical uses
	Silicon	Iron	
99.95 (high purity)	<0.006	<0.006	Extrusion joinery, electrical conductor, anodic trim, foil
99.80	<0.15	<0.15	Plumbing, reflectors, jewellery
99.50	<0.25	<0.40	Chemical plant, tanks, tubes
99.50	w(Si + Fe) < 1.0 %		Pots, pans, sheet-metal work

Table 2: Aluminium alloys
Tabela 2: Zlitine aluminija

Major alloy element	Content in mass fractions, *w*/%	Product	Some typical uses
Copper	Up to 4.5	Sheet Extrusions Castings	High-strength aircraft parts
Manganese	1.25	Sheet	Sheet-metal work, pots, pans, etc.
Silicon	Up to 13	Castings	Motor parts, castings of all types
Magnesium and Silicon	0.7 Mg 0.4 Si	Sheet Extrusions	Architectural extrusions
Magnesium	Up to 5	Sheet	Marine uses, boats, fish boxes, beer-can lids, etc.
Zinc, Magnesium and Copper	5.8 Zn 2.5 Mg 1.4 Cu	Sheet Extrusions	High-strength aircraft

Aluminium alloys used in the manufacture of commercial vehicles and their accessories are easy to process. They lend themselves to a variety of shaping and joining techniques. Correctly used, aluminium alloys have been developed to offer optimum corrosion resistance in all environments. Just one example: the widespread use of unpainted aluminium in marine applications.

Aluminium alloys tailored by suitable variations in chemical composition and processing best fit many requirements, like the non-heat-treatable Al-Mg alloys used in chassis optimized for superb resistance against inter-crystalline corrosion and concurrent high strength or the heat-treatable Al-Mg-Si alloys for extrusions and auto-body sheet modified for improved age-hardening response during the automotive paint bake cycle.

Moreover, Al-Mg-Mn alloys show an optimum combination of formability and strength achieved by the mechanism of solid solution and deformation hardening due to their specific high-strain hardening. Further improvements in the properties required for specific applications (e.g., surface appearance, corrosion resistance, thermal stability) have been achieved by small additions of other alloy elements and/or modified processing routes, e.g., stretcher strain free (SSF) sheet, avoiding Lüders-lines. Non-heat-treatable Al-Mg-Mn alloys are often applied for automobile parts in larger quantities as hot- and cold-rolled sheet and hydroformed tubes, due to their good formability, which can always be regained during complex forming operations by inter-annealing, where quenching is needed for age hardening. In chassis parts or wheel applications the benefit is twofold, since the weight reduction in the unsprung mass of moving parts additionally enhances driving comfort and reduces noise levels.[11–19]

5 ALUMINIUM APPLICATIONS: ALUMINIUM IN VEHICLES

Aluminium in its pure form is a very soft metal and hence not suited for structural applications. Thanks to the addition of alloying elements such as copper, manganese, magnesium, zinc, etc., and thanks to adequate production processes, the physical and mechanical properties can be varied over a great range, making it possible to have suitable alloys for literally all applications.

There are challenges with aluminium. Perhaps the biggest challenge is the history of the auto industry. The many years of experience based on steel technology represents a significant barrier for aluminium, especially in the areas of manufacturing, i.e., forming and joining, which are critical to the automotive industry.

In the eighteenth century, aluminium was very expensive, in spite of the fact that aluminium is a very abundant metal in the earth's crust. Since that time the cost of aluminium has been on a continuous and steep decline in price based on technological advancements. This trend will certainly continue since there are a great number of initiatives, which will continue this decline in prices.

Aluminium can be used for the car body structure and there can be a weight advantage of at least 30 % without any loss of performance. In some cases where very high strengths are demanded, 7xxx series alloys can be used to maintain this significant weight advantage. For a large volume, aluminium solutions are the most cost effective. Castings will be applied for areas where a strong part integration is feasible. Extrusions can easily be applied as straight profiles, but also forming of an extruded profile is a competitive process for high volumes, e.g., as bumper beams. Aluminium is the ideal light-weight material as it allows a weight saving of up to 50 % over competing materials in most applications without compromising safety.

Due to the positive experiences and from former successful applications its volume fraction used in cars of all classes and all sizes will grow significantly. Applying full knowledge about the physical processes involved and the microstructure/properties correlation a tuning of properties is possible in order to produce optimum and stable products required for the high demands in automobile applications.

The automotive industry has more than doubled the average amount of aluminium used in passenger cars during recent years and will do even more so in the coming years. The automotive industry, in close co-operation with the aluminium industry, has developed and introduced numerous innovative light-weight solutions based on established and improved aluminium alloys and optimized aluminium-oriented car design. Synergic effects together with a multi-material exploitation can guarantee an optimum design solution. One of the main advances of aluminium is its availability in a large variety of semi-finished forms, such as shape castings, extrusions and sheet, all suitable for mass production and innovative solutions. Compact and highly integrated parts meet the strong demands for high performance, quality and cost-efficient manufacturability. Challenges involved here are mainly joining and surface treatment issues for which many suitable solutions have been developed. Aluminium semis are applied as castings, extrusions and sheet increases, e.g., in engine blocks and power-train parts, space frames, sheet structures or as closures and hang-on parts and other structural components.

Material-specific processing routes and individual solutions have been developed in close cooperation with partners and suppliers. With a sound knowledge about the specific material properties and effects excellent light-weight solutions for automotive applications have been successfully applied by the automobile industries. Intensive and continuous collaboration of material suppliers and application engineers provided optimum solutions for sometimes contradicting aspects of the specific requirements, e.g., for the specific material selection and optimum combinations of strength and formability. Safety has become a crucial issue for vehicle manufacturers. Aluminium has the advantage of being much stronger than steel on a weight basis, so that with proper design a lighter aluminium vehicle can be expected to protect vehicle passengers as well (or better) than a heavier steel vehicle.

The manufacturing flexibility of aluminium also represents a real advantage for the metal in auto applications. Thus, aluminium is easier to extrude and cast than steel. Other processes, such as semi-solid forming and forging, are finding niches in the automotive business as well. Aluminium sheet applications are increasing at a rapid rate in structural, exterior panels and closure panels.

The auto industry is highly competitive and increasingly global. Automakers are being challenged not only to meet the expectations of shareholders and customers, but also to answer the growing environmental concerns of society. Aluminium is the third most highly used material in vehicles and is rapidly gaining on its rival materials (iron and steel). Aluminium contributes to the reduction of CO_2 emissions from road transport. In recent years the potential problem of global warming has provided additional pressure on automakers worldwide to improve fuel economy. Carbon dioxide is considered to be the biggest anthropogenic contribution to global warming. It results primarily from the combustion of fossil fuels, hence the pressure on autos to burn less fuel. However, when one considers material substitutions, such as aluminium for steel, it is necessary to take account of the entire process of obtaining, processing, using and recycling the material.[20,21]

The automotive industry is known worldwide as being technically advanced and innovative. Based on economic and political pressure to reduce fuel consumption and CO_2 emissions the efforts for light weight in automobile design and constructions have increased significantly and specific solutions based on the intensive use of aluminium as modified or new alloys have been developed in recent decades.

Reducing manufacturing costs and tailpipe emissions by using light-weight materials which can be easily recycled or reused are among the major issues in today's automobile industry. The growing emphasis on total cost and environmental impact has forced the life-cycle cost issue to be the driving factor. Weight savings in the overall car mass is considered to be a major research focus. Aluminium is proven to be among the potential materials capable of achieving weight reduction without sacrificing either vehicle safety or performance. Despite significant technological advantages in aluminium alloys, the use of aluminium alloys to replace traditional materials such as steels has been slow due to the lack of a comprehensive economic analysis of the entire life-cycle of automotive products. In considering the total life-cycle of an automobile covering four stages (pre-manufacturing, manufacturing, use, and post-use), it is apparent that during the operational (use) stage of a vehicle, aluminium is proven to be a reliable alternative for traditional materials currently used in automotive body structures, largely due to its cost-effectiveness and superior performance due to light weight. With gas price variations, the initial cost advantage of using steel in body components gained in pre-manufacturing and manufacturing stages can be overcome during the operational (use) stage of the vehicle, since the lighter alternative provides significant savings in terms of fuel consumption and consequently the generation of air-borne gas emissions. Also, the superior recyclability and reusability of aluminium in the post-use stage outweighs that of traditional materials, despite the higher costs involved in producing primary aluminium.

Knowing that the greatest opportunity for weight savings comes from the body structure and exterior closure panels, and that additional weight reduction can be achieved by downsizing the other components such as engine components, it can be considered as achieving a weight reduction by replacing the conventional material used in the vehicle's construction (i.e., steel) with a lighter mass equivalent material (i.e., aluminium), maintaining the same vehicle design and using the same manufacturing processes for the body components.[22–28]

6 ALUMINIUM RECYCLING

Aluminium is easily and economically recycled. Aluminium does not degrade during the recycling process, which means it can be recycled over and over again. Recycling aluminium reduces the need for raw materials and reduces the use of valuable energy resources. Moreover, recycling reduces the amount of waste in landfill.

Aluminium is a valuable material to recycle due to the large amount of energy and resources used in the initial manufacture. It can be infinitely recycled. Recycled aluminium is made into aircraft, automobiles, bicycles, boats, computers, cookware, gutters, sidings, wires, cans, etc.

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