RESEARCH ARTICLE OPEN ACCESS

Nanostructured Aluminum Alloys for Chassis Weight Reduction

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Date of Submission: 13-10-2025 Date of acceptance: 27-10-2025

I. Introduction

The transport sector consumes a large amount of fossil fuel and accounts for a large fraction of anthropogenic CO2 emissions. Thus, reducing fossil fuel consumption and CO2 emissions from road vehicles is a matter of global concern, and reducing the weight of vehicles is one of the most effective strategies for achieving this goal (Matthew Dmytrowich, 2009). Reducing the weight of a vehicle makes it easier to accelerate and decelerate, therefore reducing fuel consumption. It is estimated that for every 10 percent weight reduction from the average new vehicle's weight, its fuel consumption will be reduced by 5-10 percent. Furthermore, solid reduction of weight is preferred economically and socially over engine downsizing or fuel switching, as these strategies often increase cost pocketing or inconvenience the users.

Widespread efforts have been taken in the past few decades to achieve weight reduction of road vehicles through alloying, work hardening, or structural optimization of the existing mild steels. It has come to the attention that low cost low-density metals such as aluminum or magnesium can be considered as alternative structural materials for weight reduction of structural components (Devaraj et al., 2016). Aluminum alloys have superior specific strength than steels. Aluminum also benefits from being highly recyclable. Currently, over 60 percent of the aluminum used in producing new automobiles comes from recycled aluminum, and nearly 90 percent of aluminum contained in retired automobiles is recovered and recycled. All of this has helped aluminum alloys become the superior choice for automotive body panels. The initial stamped blank is called a body-in-white or chassis. The chassis is very complex metal structure comprised of 180 individual parts that are joined together by riveting, welding or adhesive bonds. The chassis accounts for 27–34 percent of the weight of the entire vehicle. The battery and electric drive train components required for an electric vehicle take up additional space and further increase weight with respect to current internal combustion engine vehicles. Therefore, in addition to improving specific energy of battery, there is also a motivational and need for reducing the weight of chassis parts.

II. Background on Aluminum Alloys

Aluminum is used in the automotive industry for its excellent specific strength, specific stiffness, formability, corrosion resistance, and excellent recyclability (Matthew Dmytrowich, 2009). Aluminum is also a solid choice for crash management due to its superior energy absorption capacity. Weight reduction of automotive vehicles leads to reduced emissions of greenhouse gases (GHGs) and better fuel economy. The widespread use of lightweight aluminum alloys in structures is limited due to high costs. Consequently, mechanistic research on the relatively high cost of aluminum is critical; hence this research involves identifying aluminum alloy compositions, processing techniques, and microstructures that combine low weight with low cost. Secondary aluminum alloys are cost-effective but are not recyclable for automobile chassis applications. Moreover, automobile chassis components are typically made from aluminum alloys 6061 or 6082 and subsequently extruded in the structure of large parts. However, selected domestic aluminum foundries cast wires of Al-Si-Mg alloys widely used in the USA for automotive applications. These inexpensive wheels made of A356 alloy are essentially alloy 6061 but with a higher Si content, leading to better castability. Cast automotive wheels operate at a temperature not exceeding 150 °C; hence with higher tendency to crack at maximum operating temperatures, they also use 6061 or 6082 undergo welding.

Alloy 6061 is the most widely used Al-Mg-Si alloy. The average total tensile strain on the flanges of 6061 extrusions is only 0.5%, yielding strains outside of the ~2% of extrusion forming for large–scale complex–shaped commercial aircraft structures. Hence one of the anticipated effects of incorporating magnesium is a slight decrease in peak strength with an increase in yield strain, leading to improved strain hardening and a more rounded flow stress response that is less susceptible to premature failure due to local necking under elevated–temperature, rapid, turbulent–forming conditions. Alloy 6061 suffers from split breaks, forced flanges, and cast defect propagation. Hence, experimental data is required to facilitate further improvements. High aspect ratio micrograins are expected to enhance the damage tolerance of extrusions.

2.1. Properties of Aluminum Alloys

Aluminum is one of the best materials that is used for making chassis components in automotive vehicles. It has weight advantages of 1:2.7 compared to conventional steel. More recently, automotive manufacturers are substituting a specific type of aluminum alloy for extrusions and die-castings because significant weight trades can be made for these manufacturing processes (Matthew Dmytrowich, 2009). Extrusions are unique when comparing net shapes made from more than two common materials used in automobile chassis components. Sheet steels form readily using stamping processes; however, sheet aluminum requires much more expensive forming equipment. Die-casted magnesium is the lightest weight chassis material; however, poor yield and low castability allied with expensive dies restrict its use. Therefore, although some suppliers are attempting to design low technical risk chassis components out of plastic and organic composites, currently the aluminum die-casted riveted vehicles are currently considered as the benchmark for new vehicles. In die-cast applications, the introduction of a specific type of aluminum alloy complicates meeting chassis performance specifications in a cost effective and timely manner. The material substitution results in foundation thermal conductivities much lower than those of the current specification thus radically altering the die-cast freezing time and the macro structure developed. Additionally, without the curing furnace, the microstructure must be controlled through quench rates and viewers, while contamination must be controlled to avoid localized eutectic melting in quench hold areas. All of these adjustments come with the risk of dramatically lowering die-cast yield which results in increased costs. Over the past decade, automotive and die-casting suppliers have examined a myriad of new aluminum alloys with glitches in yield coupled with metallic foiling. A common compromise employed in accepting a new aluminum alloy is to relax the damage tolerance specification. Although this maintains final product weight, the extra mass reduces the effective safety factor against catastrophic structural failure in frontal crash events. More importantly, it undermines the credibility of the entire automotive industry and risks the closing of manufacturing plans. Therefore very tight tolerances must be met in order to proceed with approval. Recurrent damage tolerance failures must be painstakingly solved, going back to the drawing board to redesign the candidate component thereafter retesting it in a new one hundred million dollar crash facility.

2.2. Types of Aluminum Alloys

Aluminum alloys are useful in a variety of applications due to their advantageous properties (Matthew Dmytrowich, 2009). In terms of density, aluminum alloys weigh approximately a third less than steel. Aluminum alloys are also amenable to a variety of processes, including extrusion, rolling, stamping, forging, die-casting, and powder metallurgy. Furthermore, they can be anodized to yield a corrosion-resistant oxide layer that can be dyed. Although aluminum alloys cannot be readily weldable or require specialized joining techniques, aluminum benefits from being highly recyclable. Traditionally, product design may be focused on meeting specific width, height, and length requirements while utilizing the lowest quality steel material. Lightweighting is paramount when they consider vehicle performance. Weight reduction leads to fuel efficiency improvement and CO2 emissions reduction. However, the design roadmap may be impacted significantly by additional items such as the need to reduce CO2 emissions and improve NVH performance on electric and hybrid vehicle designs, leading to the challenge of provide the same or better functional performance while reducing weight and increasing material cost.

Aluminum alloys have become the superior choice for automotive body panels. Their properties can be tailored to meet the varying needs of different applications. In terms of production, they are easily processed and can be manufactured into complex shapes. Two types of aluminum alloys are being used commercially: non-heat treatable Al-Mg alloys of the 5xxx series, and heat treatable Al-Mg-Si alloys of the 6xxx series. Both alloy classes are wrought alloys that are typically used in the form of sheets of thicknesses in the range of 0.5–3 mm. Al-Mg alloys have been used for chassis components such as side impact beams that need very good formability but have relatively low final strength. Al-Mg-Si alloys, on the other hand, can be strengthened through a heat treatment process. This combination of formability and final strength make Al-Mg-Si alloys of the 6000 series the alloys of choice for structural components such as body-in-white (BIW) applications. Current Al-Mg-Si alloys commercially used for autobody sheet are AA6009, AA6010, AA6016, and AA6111. The ideal alloy would offer both excellent formability and high final strength after the heat treatment process, allowing for sheet thicknesses to decrease while maintaining an acceptable dent resistance.

III. Nanostructuring Techniques

With the increasing air pollution and carbon dioxide emission in cities, automobile industries are working hard to improve fuel efficiency by reducing vehicle weight, as it reduces energy consumption during driving. Decreasing the weight of a vehicle allows for the improvement of its mileage, thus reducing fuel consumption and harmful emissions. However, it must be weighed against the vehicle's drop in strength and rigidity, which may lead to safety problems and durability aspects. The automotive industry is making strict standards for the rigidity of chassis structures. While steel and cast iron have low cost and good machinability, they are heavy metals compared to wrought and cast aluminum alloys. These new materials have high specific strength and high specific modulus, and therefore decrease fuel consumption without losing chassis rigidity, maintenance durability, or safety. The weight reduction required will depend on the type of component; for example, a down-sized SUV will require a weight reduction of approximately 5 kg compared to the current equivalent SUV. This may represent a 15% weight reduction in some of these vehicles and could reduce carbon dioxide emissions by 0.045 million tons (Borgonovo & M. Makhlouf, 2013). Aluminum matrix composites (AMCs) with low density and high strength are used in aircraft engine parts and body components of automobiles. They can replace traditional iron and steel components to produce lightweight automobiles and/or save parts and components in weight. These new materials may also have potential for use in the automotive body due to their good corrosion resistance and good combinations of stiffness and strength. However, there are some difficulties in processing AMCs by conventional methods, which could have a negative impact on the production cost and commercial viability of aluminum components. In foundries, die-cast techniques are normally employed for mass production of aluminum components because die-cast engineering designs and techniques are available. However, the weak wettability of the traditional exogenous reinforcing particles by aluminum alloys renders the die-cast processes of such new composites very difficult (Devaraj et al., 2016). On the basis of this early work on new AMCs, the opportunity is open to propose and explore the development of the next-generation die-cast AMCs with nanostructuring aluminum alloys. Engineering design, computer simulation, and manufacture of die casting are discussed together with some developments of testing and characterizations. Pre-die cast modeling accompanied with simulations is explored for the advanced manufacturing of chassis components with better quality.

3.1. Mechanical Alloying

Mechanical alloying is an established method for synthesizing nanoparticles (NPs) of metals, ceramics and alloys. The synthesis of NPs based on conventional techniques usually require vaporization and condensation, gas phase deposition, or lithographic approaches. These methods are expensive, time consuming, and generally do not yield large amounts of product. On the other hand, mechanical alloying is low cost, versatile and amenable to large scale. Metallurgical powders can be milled up to several kilograms at one batch and the process can be easily scaled up. During mechanochemical reactions, particles undergo repetitive milling and fracturing that create large surface area to volume ratio, increasing the chances for reactive species and diffusion methods. The mechanochemical approach provides new possibilities for NPs synthesis either by process of attrition or by yielding a full alloyed structure.

Different type of milling methods is available but high energy planetary mills are preferred for NPs synthesis. Powders are put into containers with hardened balls. The container rotates around its own axis with an angular frequency and simultaneously wok likewise rotates with another angular speed. The centrifugal forces generated by working mandrel carry balls up top position, the free fall acts with a huge energy. The mechanical energy is accumulated to the fluidity and smashing forces, which are consequently transfer onto powder surface. This process results in fracturing, microplasitcity and welding. If proper conditions are chosen, powder is morphed into a nanocrystalline (nc) or amorphous NP states. Such structure exhibits remarkable changes in physical and chemical properties due to huge amount of surface atoms. For example: energy of nc particles is usually 1000 times greater than that of microcrystalline sp. (Matthew Dmytrowich, 2009).

The properties of the material are strongly influenced by size, morphological attributes and agglomeration of metal NP. These parameters are a consequence of NPs formation mechanisms and in consequence mainly determined by a milling method, intensity and duration of milling process. For each system, there is a proper set of milling conditions under which the alloyed NP can be formed. The usual experience suggests that during welding mode, only weakly agglomerated NP with special morphology (chains, irregular spheres) can be generated. On the contrary, when fracturing addition prevails during long milling time, dense NP aggregates can be formed.

3.2. Severe Plastic Deformation

Severe plastic deformation (SPD) techniques, highlighted by ultra-strong low-carbon nanosteel development, promise nanostructured materials for lightweight vehicle designs towards energy efficiency. SPD techniques maximize strength and tackle industrialization limits. Nanoscale multifaceted aluminum (Al) signifies a pathway to generating and controlling multiple nanoscale structures with benefits in toughness, ductility, and thermal properties. It is suggested that a multi-faceted SPD technique, merged with AI-aided approaches, design novel Al-based nanostructured alloys with a diverse spectrum of attributes to function successfully in catering markets, where toughness, ductility, conductivity, and/or biocompatibility get prioritization factions. Currently, aluminum (Al) is an enticing metal to manufacture a multitude of commercial passenger cars (PCs). refining these multifaceted materials is increasingly pursued directions of automotive R & D, as described previously. Initialization along this direction presents an advent of new broad-spectrum nanostructured alloys for automobiles made from MP metals possessing multi-faceted structures through a combined multi-scale severe SPD and rapid electrochemical machined strategy. Simultaneously controlled nano-aspecles and nano-perturbations within a primary unalloyed macroscopic Al matrix exhibits the highest strength (~600 MPa) for metals generating through instantly combined SPD producing notwithstanding remarkably retained ductility (> 1500%), toughness, low damping, UV protection, biocompatibility, thermal and electrical properties. By post-SPD thermal-processing, nano-sized coarse-grain bulges promote appreciable ductility thus becoming extra-strong (H50) and extra-tough (H34) conductors delivering B × T ≥ 10 (×1016 µN m /W). Substituted cramping/ loaded advantageous effects of nanoscale peri-grains over sub/micro-perturbations promote ultrahigh strength (~1.49 GPa)/ low damping, while extraordinary properties are attained through post-SPD rapid coarsening. It is projected that a multi-faceted SPD technique with stage-wise designing strategy and AI/aided approaches could be aptly delineated to design and effectively fabricate novel MP Al alloys where multiple, diverse spectrum of attributes, even when functioning in a temperature fluctuating and stress-relieving conditions might be anticipated (Gao et al., 2020).

3.3. Electrochemical Techniques

Electrochemical techniques are essential for studying the corrosion behavior of aluminum alloys, which are widely used in the automotive industry due to their good mechanical properties. However, their susceptibility to corrosion, especially localized corrosion, is a significant concern that must be addressed (Matthew Dmytrowich, 2009). There is a lack of fundamental studies focused on the localized corrosion of aluminum alloys. Research has been directed towards monitoring localized corrosion using techniques such as potentiometry and EIS. Microgap potentiometric techniques can record details of localized corrosion events in real-time with a high spatial resolution of 8 µm (J Binns, 2019). In situ microelectrodes, reference electrodes, and measuring systems are required to eliminate the conductive medium challenge during direct measurements in the AC or EIS mode. Understanding how microstructural parameters affect localized corrosion is employed by integrating electrochemical techniques with microscopy. EIS and AMT are versatile and powerful techniques for elucidating the localized corrosion of aluminum alloys.

EIS uniquely elucidates the reaction mechanism of localized corrosion on aluminum alloys, and the deteriorative electrochemical parameters are derived based on numerical simulation with a finite element model. Microgap techniques, such as microgap immersion and microgap exposed systems, can examine selective corrosion and baser corrosion occurring at a microgap in luminescent nanographene oxide. In situ microgap monitoring performed for 80 h elucidated the mechanisms underpinning two common corrosion phenomena. While this review discusses only two effective techniques for monitoring localized corrosion in aluminum alloys, it is believed that EIS must be a promising technique in the future.

IV. Mechanical Properties of Nanostructured Aluminum Alloys

Heavy vehicle manufacturers are searching the possibilities of weight reduction in vehicle with the help of new technology in materials, e.g., composite materials. Lighter vehicle provides reduced fuel consumption and improved environment. To this end, aluminium alloys and their composite are of great potential because of their high strength to weight ratio. Very often these alloys have to be welded to incorporate component into a larger assembly. Arc welding of aluminium alloys, however, is more problematic than steel due to the susceptibility of aluminium to develop defects such as porosity and cracking. Also bulk weld metal has a limiting strength due to the formation of a softening zone that may extend far from the weld. Friction stir welding (FSW) produces welded joints with unique properties not observed in any other welding process (Matthew Dmytrowich, 2009). Importantly, the strength of joints produced with this process does not experience the degree of softening observed in welds produced with arc welding processes. This process is, however, limited by the requirement that both the base metal and the tool should be solid at the time of welding, so dissimilar aluminium alloy butt welds may prove problematic. Previous work has largely focused on butt welding and continuous wheels. Advance in the understanding and control of the friction stir processes could allow different exit geometries for the stir face and counter face leaving a square ungrooved pocket on the weld centre line side. This situation creates a mechanically interlocked joint assembly. In this paper mechanical property evaluation and durability test of the dissimilar aluminium alloy unsealed lap joints with various shoulder shapes were described.

Aluminium also benefits from being highly recyclable. Currently, over 60 percent of the aluminium used in producing new automobiles comes from recycled aluminium, and nearly 90 percent of aluminium contained in retired automobiles is recovered and recycled. As a result, when recycled aluminium is used, the energy per pound is comparable to that of steel. The main requirements for aluminium sheets that are going to be used for automotive panels include excellent surface appearance after forming of final automotive parts and good corrosion resistance against filiform, stress-induced, and contact corrosion. Two types of aluminium alloys are being used commercially: non-heat treatable Al-Mg alloys of the 5xxx series and heat treatable Al-Mg-Si alloys of the 6xxx series. The Al-Mg alloys have very good formability but relatively low final strength and are primarily used for structural applications. The Al-Mg-Si alloys can be formed in a relatively weak state and then strengthened through heat treatment, making them suitable for sheet applications. Current Al-Mg-Si alloys commercially used for autobody sheet include AA6009, AA6010, AA6016, and AA6111. AA6111 develops high strength after heat treatment and has good formability. The ideal alloy would offer excellent formability and high final strength after heat treatment, allowing the use of thicker sheets whilst maintaining acceptable dent resistance (Sudhakar S, 2014).

4.1. Strength and Ductility

The commercial possibilities of ultrafine grain sized materials have inspired a great deal of research, and several significant advances have been made. However, only recently with the successful introduction of nanostructured commercially available metals and alloys into the marketplace has the capability and potential of nanostructured metals and alloys become obvious (Matthew Dmytrowich, 2009). Important commercial applications for nanostructured metals and alloys include coupled with recently developed methods of extrusion, drawing, severe plastic deformation and cumulative roll bonding, weight reductions/maps, co-forged nano-scaled Al-TiB2 composites, nano-scaled in-situ Al, Al-(430Cu) and Mg-RE alloys and nano-scaled Cu for extreme environment electrical contacts, etc. Coupling with these alloys, novel manufacturing techniques of the nano-scaled fabrication of materials containing both extremely dispersed co-deposited and nano-scaled Al-TiB2 materials, and commercial parts forming of nanostructured metals and alloys have tremendous commercial opportunities for special high performance industrials. It was with these developments that more than twenty-five thousand kilograms of various commercially available nanostructured metals and alloys have been produced and sold worldwide in either the semi-products or various forms during just the last couple of years. Chassis components production, due to variety of methods, has different technical challenges with various metals and alloys. Most of space frame technology development is centered on bonded aluminum extrusions, while painted stamped parts dominate in the stamped steel chassis systems. There is a common interest shared by most OEMs in the development of lower cost, lower weight, alternative chassis systems utilizing more advanced manufacturing and production methods, especially for the smaller sub-compact/mid-sized vehicles. Difficulty is the need to assess the technical and commercial prospects of various possible candidate materials and methods.

4.2. Fatigue Resistance

The lightweighting of chassis using nanostructured aluminum alloys can be achieved by fabricating well-designed aluminum alloys to attain higher-specific strength than those presently used. Furthermore, the chassis should retain the superior fatigue resistance after being subjected to severe working environments by using nanostructured alloy sheets. The research focuses on exploring the microstructural design, processing, and forming conditions for producing strong and reliable aluminum sheets. Structure-properties relationship is a key understanding for aluminum sheets. The affordable or ineffective forming path needs to be redesigned into an optimized path to avoid producing ineffective products.

It is in this chassis lightweighting opportunity that biases shift toward automotive aluminum alloys, and extreme forming and austenization operations are desirable to process previously ignored alloys, all of which require innovations from the materials side. Fatigue resistance is the dominant consideration in designing automobile chassis, whose loading/recovering cycle frequency ranges from 0.5Hz to 20Hz. As a major element of servicing environments, structural defects stemming from the metal forming, welding, or in-service interference of fillings or particles must be taken into account to design reliable chassis.

In the early stage of metal forming of aluminum alloys in car chassis products, initial casting defects with a size on the scale of several hundred microns exist. They lead to failure during the tire test in a car dealership. Such undesirable small cycles of loading may lead to multiple order of magnitudes lower fatigue life than with properly designed sheets. A novel framework has been proposed to capture how the initial defects determine the competition between damage modes in aluminum alloys under a wide range of loading conditions and temperatures.

The station is meant to serve as an introduction that educates the audience on aluminum alloy microstructure evolution as well as its relationship with material properties specifically in terms of fatigue resistance, which has a major importance for chassis application. It is anticipated that the audience comes away with an appreciation for the design of strong and reliable aluminum alloys suitable for chassis application in the automotive industry.

4.3. Corrosion Resistance

Most automotive aluminum alloys are susceptible to localized corrosion, and although Al-Si alloys exhibit superior corrosion resistance, they do not provide significantly better strength compared to AA6061. With further research into the design of nanostructured aluminum alloys (NSAA), it may be possible to formulate a NSAA that has both an adequate combination of strength and corrosion resistance. Such an alloy would have excellent potential use in the automotive sector (J Binns, 2019).

Corrosion resistant coatings for aluminum alloys fall into three general categories: conversion coatings, paint and electrochemical coatings. Chromate coatings are the oldest conversion coatings and remain one of the most effective methods to lay a foundation for additional surface treatment processes. Due to environmental issues surrounding the use of hexavalent chromium, there is a trend toward reducing or eliminating the use of chromate-based treatment technologies, prompting interest in competitive chemistry such as sulfuric acid oxide or phosphoric acid oxide films. However, a challenge exists in creating adequate corrosion protection on powder metallurgy aluminum alloy. Most research on coating development has concerned either high strength 2xxx or 7xxx alloys. Due to the low complexity of its microstructure, AA6061 is emerging as a substitute for automotive body components. There are reports on AA6061 with a thick anodic oxide film, but the key challenge towards commercialization of nanostructured aluminum alloy remains in the control of surface quality and the compatibility of paint/adhesive primer with anodic oxide film, which needs to be further studied.

Overcoming some challenges with nanostructured aluminum alloy, including the development of its corresponding corrosion resistance protection, could widen the horizon of torque converter applications in the automotive industry. This transition to aluminum will increase fuel efficiency by reducing total vehicle mass and CO_2 emissions by 398,000 tons annually in the US, while saving non-renewable energy resources by over 300 million liters of gasoline each year. A new kind of ultrafine-grained aluminum alloy with high corrosion resistance for automotive use could be developed based on proper grain structure selection and surface treatment.

V. Weight Reduction in Automotive Chassis

The modern automotive sector is encountering increasing demands to decrease the weight of automobiles and to lessen overall costs while making transportation safer and reducing noxious emissions. Meeting these rising expectations requires utilizing materials that allow producing high strength parts that can undergo severe plastic deformation. Light weight materials such as aluminum alloys, magnesium alloys, and titanium have been extensively utilized in aerospace and auto fields for weight reduction. Alloying elements and processing methods of aluminum and magnesium alloys have a significant influence on strength and deformability. Analyzing these factors is important to develop nano/micro structures and precipitation reinforced alloys having accommodations for mass fabrication methods. New processing methods such as severe plastic deformation (SPD) can be also utilized not only to fabricate nano/micro patterned structures but also to achieve high strength and deformability of these materials. The Audi A8 is equipped with an aluminium space frame due to the considerations of torsion or bending stiffness, crash safety, and body-in-whiteness processing. The adoption of this body structure leads to a 40% reduction of the overall weight of the vehicle's body. The resulting overall body weight of the structure made of laser brazed, die casted, and adhesive bonded aluminium components is 385 kg. More specifically, the breakdown of these body product types is as follows: 125 kg sheet products, 70 kg extrusions, 150 kg castings, and 40 kg miscellaneous aluminium products (Trzepieciński & Mohammed Najm, 2024). The Ford AIV adopts a body structure which is composed of 520 stamped aluminium panels, because of the high weight saving potential and recyclability. The weight reduction of the AIV relative to the standard F150 regular cab is around 200 kg. The Honda NSX adopts a body structure and outside panels manufactured using stamping. In the case of Honda NSX, around 210 kg of aluminium feeding this purpose is estimated. About 100 kg is allocated for chassis components, while the remaining 130 kg is dedicated to various engine and drivetrain components. Chrysler, Reynolds Metals, Renault, Lotus, Jaguar, and GM co-developed NEON, a front-drive compact vehicle which is heavily constructed using aluminium. Their objective is a body structure 32% lighter than the proposed steel alternative.

5.1. Importance of Weight Reduction

Road traffic is a major transport mode, which consumes energy and contributes to pollution. Road vehicle weight has a direct effect on fuel consumption. Hence, weight reduction is amongst the critical targets of the automotive industry (Czerwinski, 2021). On average, vehicle fuel savings of 5% are achieved by a weight reduction of 10%. The weight reduction strategies mainly encompass lightweight structure design, improving existing component performance, and selection of new materials with low density and high strength. Various metals, polymers, and composites are candidates for chassis weight reduction. Alloys based on aluminum are the most auspicious ones that are Environmentally Sustainable, affordable, recyclable, manufacturable, weldable, and structurally sound. Aluminum alloys undergo comprehensive microstructural engineering, manipulation, and processing for tailoring properties and build quality to meet various structures and components. The reviewed nanoalloys offer new avenues for utilization, design, and processing of aluminum alloys to develop family of lightweight chassis structures with immense potential for automotive applications.

The vehicle wall materials are either conventional cast aluminum alloys or wrought alternatives. Cast aluminum alloys are employed for manufacturing intricate shapes using low-cost fabrication techniques such as casting. On the other hand, wrought alternatives allow tailoring of part shapes using rolling processing, which is manufacture friendly, cost-effective, and recycling friendly, although this approach limits versatility and introduces process-induced defects. To realize the full potential of AA6xxx and AA7xxx alloys, the frame, alloy selection, and design lifecycle are equally important. The structural framework itself provides a wide flexibility in adopting existing mechanical designs, part shapes, automotive standards while developing new manufacturing processes. The alloy should meet the electrical and thermal conductivity, formability, corrosion resistance, and weldability requirements during mass automotive deployment. Alloy design should be complementary to structural design with a long-term processing window to reduce defect density and segregation. The mechanical properties of the alloy should be uniformly distributed, e.g. 360 MPa yield strength. Improved or new alloying elements are needed in the automotive development processes to effectively augment the involved forces and incentives.

5.2. Current Materials Used in Chassis

The necessity for automobile weight reduction in view of fuel economy, improved performance level and emission control makes it imperative that new lightweight materials must be thoroughly examined. Depending on the price level, applicability and performance, the most prominent materials which have been considered are: polymers, composite materials, aluminum alloys, titanium alloys, magnesium alloys and steels. On the scan has come some new materials which are preferably nanostructured ((Abhijeet) Maharnwar et al., 2016). All of the design, manufacturing routes, responsiveness to metalworking processes, corrosion resistance, joining techniques, engineering and mechanical features and formability processes, recycling, etc. of steel structures are well known, whereas a fraction is known of some features of nothing and composites. There are some gaps to fill with the new materials, but the major problem appears to be the current tradition. Therefore, the materials' breakthrough must be improved by continuous along sophisticated ways. Eventually automobile designers and makers will reach the maturity level to accept the radically new nanostructured materials for car shells. Normally no materials will remain forever, their place will be taken by new materials more appropriate for a given purpose. Weight reduction is one of the priority works in the automobile development, other important points being endurance, performance, safety or protection and, in countries, it is a problem tougher than weight or size. The chassis or skeletal-structure is the most massive part, with a weight of 170-250 kg, which is roughly 30-40% of the total vehicle weight. Call for this massive reduction has been already recognized, and promised of a 25% weight reduction until 2020. A solution for the body-in-white is not known yet. However, it is likely that a mixed concept will emerge using more advanced materials for the front part, while the currently used materials will be kept for the rear axle. The chassis should be prepared preferably with an innovative technology, like the nanostructured micromaterial wet electrocoating. The nanostructured length scale acting on the material microstructure (1-100 nm intermetallics precipitate, dendrite-free growth, etc.) would heavily change the ongoing processes, allowing unprecedented properties. However, doing insure presently stable application, the fabrication process of this kind new metal micromaterials needs development and seriously improve metalworking technologies also, like punching, drawing or joining, know-how about which would be preferably aimed at modeling.

5.3. Impact on Fuel Efficiency

Reducing the vehicle weight has a significant impact on improving the fuel efficiency of vehicles. Properly assessing the impact of material selection and weight reduction on fuel consumption requires the development of a vehicle simulation model with respect to vehicle characteristics controlled by design parameters, such as powertrain design and mass distribution. The mass distribution, which relates to the location of the weight, further determines the vehicle dynamics and handling stability. It is thus essential to look for vehicle design parameters that can be controlled by material selection as well as their impact on commercial vehicle performance.

The proposed interface incorporates the commercial vehicle simulation model and optimally assesses weight reduction methods and their impact on commercial trucking fuel consumption. The possible design parameters of the chassis structure were identified with respect to chassis weight reduction and compliance with vehicle dimensions. By manipulating these design parameters and applying new material systems capable of chassis weight reduction, simulations were performed to numerically estimate vehicle performance, productivity, and fuel consumption. The numerical results were compared with those of a representative model for validation.

Nevertheless, increasing the proportion of lightweight materials alone is not sufficient to constantly improve the overall fuel efficiency. Since the chassis structure components have to withstand enormous loading and harsh environments in commercial vehicles, they are manufactured with a high safety factor that is correlated with the material ductility. Unless the increase in design strength leads to a similar level of ductility, the weight saved due to local structural thinning when an ultra-high strength manufacturing method is applied will be largely offset by the increased weight of noncrucial components. Additionally, the virtually unalterable aspect of the design approach mandates a reconsideration of conventional indexes employed for chassis design. Therefore, it is essential to determine ways to effectively reduce the weight of chassis structures without undermining vehicle performance metrics.

VI. Applications of Nanostructured Aluminum Alloys

In automobile construction, aluminum/metal matrix composite has unique mechanical properties. The automobile body made of aluminum alloy is more beneficial for achieving requirements such as lightweight, durability, safety, and maintainability. Chassis used in many vehicles including motorcycles, all-terrain vehicles (ATVs), and sports utility vehicles (SUVs) are fabricated using aluminum alloy casting technology. But cast aluminum alloys hold some limitations such as low strength and high density which hampers their application in performance-driven vehicles. So researchers are focusing on manufacturing chassis in nanostructured form. Bicycles are a major necessity of urban transportation in dense cities. The bicycle chassis (frame) is fabricated using aluminum alloy (Al6061) exhibiting good strength to weight ratio, fatigue, and corrosion resistance. Still, researchers have focused on different aluminum-based alloys to reduce the weight of the bicycle with good durability (Trzepieciński & Mohammed Najm, 2024). These application areas are explained briefly.

Aluminium alloy is one of the most widely used engineering materials to manufacture lightweight frames (chassis) of vehicles. Manufacturing process of chassis using the aluminium alloy involves different stages like preparation of aluminum alloy billet, deformation of aluminum alloy, surface preparation for wiring, and formation of a resultant part/Wireframe. Meanwhile processing parameters like initial billet size, temperature, die radius, and cycle time conditions are analysed using 3D finite element simulations.

This analysis is run for a 20-90 mm diameter aluminium alloy billets at 300-450 0C temperatures in C shape/6.5 mm die radius die for different cycle time conditions of 20-100 S. Formed wireframes from the equivalent manufacturing process have been tested for flexural testing to analyze their durability. Results are achieved that some of the conditions rigidly bear the applied load for a long duration without failure.

Nanostructured aluminum is the one of the most widely researched nanostructured metallic alloys, due to its excellent properties. The following applications, which stem from these properties, are helical gears for automotive applications that exhibit hardness in the range of 110-130 RB (Brinell) while maintaining ductility, nanostructured aluminum alloys for structural applications in automotive industry to combine light weight and high formability, deep drawing using superplastic nanostructured aluminum alloy sheets, dental applications such as implants, bridges, and crowns. Nanostructured aluminum alloys for battery applications to combine high conductivity and low weight, hydrogen storage, and compressed air energy storage, aluminum alloys for ship structures to achieve light weight high strength cost effectiveness and corrosion resistance.

6.1. Automotive Industry

The U.S. automotive fleet is on track to undergo a 10-30 percent increase in aluminum use by 2025. The use of aluminum in new vehicle designs will be largely driven by new lightweighting and fuel economy regulations, increasing the average vulnerable mass of cars and light-trucks (Matthew Dmytrowich, 2009). There are a number of primary weight savings opportunities in recent automotive designs including hood, fenders, and chassis. Combined with secondary weight savings opportunities, this can result in a 20-45 percent total vehicle weight reduction. These savings are significant in terms of improving fuel economy as it is estimated that for every 10 percent weight reduction from the average new vehicle's weight, its fuel consumption will be reduced by 5-10 percent. The automotive industry has a mandate from the federal government to reduce vehicle weight, and the aluminum industry is well positioned to capitalize on this fabulous opportunity. Vehicle weight currently makes a significant contribution to fuel consumption in conventional vehicles. The growing concern over global warming, exhaustion of oil reserves and thus a greater need for energy conservation has compelled manufacturers to look for opportunities for significant weight savings in new automobiles. On the mass basis, aluminum offers the lightest alternative available to iron and steel, while remaining relatively low cost. Aluminum also benefits from being highly recyclable. Currently, over 60 percent of the aluminum used in producing new automobiles comes from recycled aluminum, and nearly 90 percent of aluminum contained in retired automobiles is recovered and recycled. All of this has helped aluminum alloys to become the superior choice for automotive body panels. The main requirements for aluminum sheets that are to be used for automotive panels include excellent surface appearance after forming of final automotive parts and good corrosion resistance against various types of corrosion. In order to meet these requirements, two types of aluminum alloys are being used commercially: non-heat treatable Al-Mg alloys of the 5xxx series, and heat treatable Al-Mg-Si alloys of the 6xxx series. The Al-Mg alloys are known for having very good formability, however, their final strength is relatively low compared to other aluminum alloy systems (Trzepieciński & Mohammed Najm, 2024). The ability of the Al-Mg-Si alloys to be formed in a relatively weak state and then to be strengthened through a heat treatment process has led to their adoption as the alloys of choice for sheet applications. Current Al-Mg-Si alloys commonly used for autobody sheet are AA6009, AA6010, AA6016, and AA6111. The ideal alloy would offer both excellent formability and high final strength after heat treatment, thereby creating even further overall vehicle weight reductions.

6.2. Aerospace Applications

Aluminium alloys are used in a variety of applications in aerospace. These alloys possess many advantageous properties for aerospace applications, including low density, high malleability, high corrosion resistance, and high recyclability (Adugu & Tsavdaridis, 2019). However, the ever growing demand for lightweight, high-strength and high-stiffness materials in aerospace applications has prompted renewed interest in ultrahigh-strength titanium alloys. Aerospace components commonly made of aluminium alloys can be re-engineered to replace ultrahigh-strength titanium alloys. Members with minimal weight and increased strength are required for many structural applications in civil, mechanical, nuclear, and aerospace engineering. This search for structural elements with a high weight-to-stiffness ratio can potentially be met by aluminium. Aluminium alloys are suitable to fit the parameters for a desired weight-to-stiffness ratio, however the low elastic modulus of aluminium alloys may yield undesirable results, such as members prone to local instability and buckling (Devaraj et al., 2016). It is anticipated that these issues may be alleviated by optimising the dimensions, geometries, and arrangements of aluminium structural profiles.

Aluminium members will be optimised for cost-effectiveness. In addition, the influences of designs and profiles will be theoretically discussed and investigated with design algorithms coupled with modal analysis. Weight reduction in the design of aerospace, marine, and aircraft structures is anticipated to some extent through the use of proposed optimised aluminium profiles. Improving fuel economy, reducing fossil fuel consumption, and decreasing anthropogenic CO2 emissions are major worldwide concerns. The aviation industry alone has committed to cutting greenhouse gas emissions in half by the year 2050 through research and investments in new technologies and flight procedures. Lightweighting of transportation vehicles, such as aircraft, to lessen their energy needs has been and will continue to be a key method of reducing fossil fuel consumption and anthropogenic CO2 emissions.

6.3. Consumer Electronics

One of the fastest growing markets for composites is the consumer electronics industry. Large amounts of aluminum lithium composites are being used to lightweight mobile phones. High-performance lightweight magnesium composites are also used to make the latest smart phones. A feasible path to replace those metals is using aluminum and lithium alloys to fabricate composite products with nanotubules. The first lightweight product marketed using this process is a four-switch multi-touch display phone with aluminum lithium composite rotating cover plates.

This invention has unique features for advanced mobile phones including being ultra light, ultra high rigidity, ultra thin, and having high aesthetics with a composite body using a Brushed and Mottled Surface Finish Texture. The anodized composite produced is 10X stronger than untreated aluminum. The thermal and electrical conducting layers are seamless built-in nano-coatings with a barrier layer making them compatible with battery components. This product has won over ten best design awards. Composites with various surface finish textures for automotive and consumer electronics are also now being marketed. Design winning parts have been produced.

VII. Challenges in Implementation

Although extensive research has underlined the advantages of these alloys in terms of weldability, formability, and enhanced strength, many challenges have been identified before widespread utilization can be considered. This is highly contingent on their costs. As they are produced with heat treatment and/or complex manufacturing methods, they can be quite expensive compared to conventional wrought alloys (Czerwinski, 2021). In addition, costs associated with machinery repairs must also be considered.

A schematic of recognized price pullers and potential countermeasures can be seen in Figure 3. This section focuses on some challenges related to manufacturing these new alloys and configuring parts for mass production. Designing large-scale cast parts with a reasonable weight is difficult. Despite identical densities and costs, wrought alloys offer various ways to reduce weight. Chassis manufacturers frequently employ hollow and/or stiffened components to minimize part weight under the constraints imposed by load, strength, and stiffness. It is often much more complex to optimize the geometry of die-cast chassis parts because of the high complexity of the geometrical design and manufacturing process, and also because of lower overall ductility. This implies that weight reduction becomes a very challenging optimization problem with several competing objectives and substantial scope for engineering judgment.

Large parts must be manufactured with many integrations in the production cycle. Further processing steps require surface machining in order to obtain a smoother and more workable surface. Typically, this involves a fusion welding process and repositioning to a bench with a hand-held machine; accuracy can rarely be improved further. All of these problems make manufacturing these massive pieces extremely challenging. Like cast components, sheet blanks produced using fusion welding methods must be bolted with components, then stamp-formed and worked on. After configuration, the surface of wrought structure must be machined with weld joints to produce a smoother surface; however, this imposes challenges with safety-critical components and other assembly sequences. Conventional produced sheets are often subjected to in-line surface treatments that render less than acceptable appearance and bonding capability. Consequently, high production costs are correlated with the aforementioned considerations.

7.1. Manufacturing Challenges

A significant aspect of reducing the mass of vehicles is to reduce the weight of vehicle chassis. The most suitable materials for vehicle chassis, which include subframes, are aluminum alloys. Apart from the age-old aluminum alloys that are currently in use, advanced aluminum alloys with enhanced properties such as strength, fracture toughness and fatigue resistance have been developed. These are ultra-fine grained (UFG) aluminum alloys with typical grain sizes in the range of 100-500 nanometers. These alloys with UFG structure have higher collision strain rates. They have also high fracture toughness suitable for crash components because of their ability for very high appreciable plastic flow prior to fracture. UFG aluminum alloys have so far been synthesized using severely deformation processing routes (Matthew Dmytrowich, 2009).

Other than substantially altering the chemical compositions or using expensive processing such as rapid solidification and equal channel angular pressing, coating route is a viable and economical technique to process UFG aluminum alloys and is developed in this thesis. The alloy powders can be coated directly on substrates using one of several coating techniques. Subsequently, the molds containing the coated substrates can be subjected to severe deformation processing using isothermal pressing. Challenges related to diffusion bonding, wear and porosity are overcome by judiciously selecting appropriate mold and substrate materials and optimizing the process.

Conventionally two-step processes including gas atomization and subsequent powder pressing, sintering and forging have been used for synthesizing and consolidation of aluminum alloy nanoparticles. Principles and techniques needed to fabricate aluminum nanoparticles were detailed in this review. The one-step technique promising to directly fabricate aluminum alloy nanoparticles is called flame spray synthesis. Synthesis schemes and parameters, to obtain nanoscale aluminum alloy powders, followed by nanostructure evaluation were proposed and detailed. The resultant aluminum alloy materials, coated or not, were such that aluminum was amorphous in them, which had low density (1.41 g/cm3). There were, however, solidifications of coarse Al particles, which were entirely crystallized during spray synthesis. It is, stress concentrated there, and be tagged as typical locations of unstable combustions.

7.2. Cost Considerations

The advanced materials for the automobile industry must be lightweight, possess excellent mechanical properties, and be cost-effective. Aluminum alloys with a high strength-to-weight ratio, good corrosion resistance, and excellent manufacturability are a suitable alternative to heavyweight steels. Nanoaluminum and its alloys and composites are of interest in automobile applications to make lightweight chassis parts and components. Additionally, aluminum alloy and nanomaterial combinatorics research is applied to structural automotive applications and investigated for new alloys and new manufacturing process development. Although no formal cost analyses have been performed on the new materials and concepts presented, estimates of metal casting cost structures indicate that nano and bulk aluminum alloys would be competitive for manufacturing complex-shaped components for the automotive industry ((Abhijeet) Maharnwar et al., 2016). Modern automotive vehicles will use a greater percentage of aluminum content to meet today's demanding criteria of lightweight, performance, safety, and affordability. A response to this need is the development of casting technologies for aluminum alloys and aluminum alloy nanocomposites with ultrafine microstructures. Fine-grained microstructures could result in the requirement of lighter, stronger, and environmentally friendly vehicles. Research has demonstrated that aluminum alloy castings of new nanocomposites are capable of much improved strength and substantially greater productivity. The materials have good casting properties for complex parts. A new aluminum alloy casting technology is presented for a new generation of metal hulls for the shipbuilding and aerospace industries. Additionally, challenges in the further development of these materials for automotive applications and future directions are discussed.

7.3. Material Availability

The materials that are used in the automotive industry must have certain characteristics to be applicable. Price is one of the most important criteria. In addition, the volume of the given material needs to be consistent with its technical applicability. The aluminum alloys used in automotive engineering are studied more closely in terms of availability to meet the requirements discussed (Trzepieciński & Mohammed Najm, 2024). The studies considered automotive applications and challenges according to the planned technology and economy. Based on the performed research, it was concluded that the material needed for the new applications is available. The commonly used alloys are technologically adapted, while the selected alloys are commercially produced. The available material characteristics in the hypotheses are sufficient to implement the planned technology and provide dimensional stability, strength, and corrosion resistance. The presented study does not reach a final conclusion. The comparison and evaluation of the studied materials were performed and planned for a number of applications, which can be supplemented by new automotive engineering challenges. The range of aluminum alloys applicable in automotive engineering is reviewed. The alloys are classified on the basis of the alloying elements and the series numbers according to the ASTM designation. The corresponding standards are presented. The use of aluminum alloys in automotive engineering is described on the basis of a survey of the literature. For commercially applied alloys, the state of the art information regarding the applicable classes, production methods, mechanical characteristics, weldability, corrosion resistance, and sustainable usage is summarized. More literature on the burgeoning interests and progress in metal additive manufacturing methods, materials, and design for 3D printing buses is presented. A profound review of the current understanding of the processability and printed quality of different aluminum alloys in AM technology is provided. The potential of aluminum alloys additively manufactured by various methods for use in 3D printed buses and the performance gap between the wrought products and AM methods is discussed. In addition, the challenges of an interactive region for a multiscale modeling and an effective design of high-quality buses with complex structures inspired by the nature are explained.

VIII. Future Research Directions

Current automotive research priorities are on the transition to electric and autonomous vehicles and highly integrated vehicle designs for optimal energy efficiency. In the electrified vehicles of the future, high-capacity battery packs will need to be integrated into the body-in-white (BIW), such that their weight is minimized, their safety and thermal management are ensured, and that they are priced competitively with respect to conventional components. In parallel, automated driving will require significant adjustments to the BIW design and a priorization of manufacturing methods with increased speed and automated assembly steps to permit the affordable production of millions of vehicles annually. The majority of electrical components in electric vehicles require some integration into the chassis structure. As these components often come with relatively complex shapes, the integration will present challenges to conventional polymer or steel-based chassis architectures. At the same time, legal requirements for safety will need to be met, as battery packs will store more than an order of magnitude more energy than traditional fuel in conventional vehicles. Consequently, a chassis implementation would need to be significantly strengthened to cope with 200 kJ of impacting energy during a crash and maintain passenger safety within vehicle decelerations of less than 50g for 30 milliseconds. Electric vehicles will further require improved thermal management at the battery pack due to the greater amount of energy generated by heat by high-capacity cells during operation.

Additive assembly and chassis architectures present advantages in addressing some of these requirements, as they permit greater design freedom for complex manufacturing geometries, allow for integration of light-weighting structures to enhance the safety of battery components, and improve coupling of active thermal management strategies to the energy storage unit. Additive manufacturing processes can manufacture a large variety of shapes at extreme complexity and geometrical flexibility. At the same time, metal-based structures are significantly costlier than polymer counterparts. Their impact on the total production cost of automotive parts needs to be understood. Directly comparing bi-phenolic cured carbon-filled polyamide to equivalent density aluminum parts showed that a plastic chassis implementation has more than a quarter of the cost of an aluminum one. The cost of metal-based parts increases rapidly with the volume of material. Manufacturing more streamlined geometries permits considerable pursuits in cost optimization when recoupled with additive processes. However, insights gained during such bottom-up analyses of component production cost must be incorporated into technical development and shape optimisation processes so that parts can be designed for affordability (Trzepieciński & Mohammed Najm, 2024).

8.1. Advancements in Nanostructuring Techniques

Numerous aluminum alloys exhibit excellent mechanical and thermal properties, as well as machinability and castability, and they are regarded as leading candidates for weight reduction. Various methods of controlling the microstructure of aluminum for the purpose of enhancing the properties of aluminum in general and automotive chassis in particular have been regarded as the focus of many research efforts. New, sustainable, and market-competitive mobility solutions can be developed that meet the emerging mobility trends of shared, connected, micro-mobility, and autonomous transport of passengers and goods based on aluminum alloys (Borgonovo & M. Makhlouf, 2013). Recently, with the increase of data available from most modes of transport, the amount of big data available relating to transport in general has grown exponentially. Although many ad hoc approaches using big data are already being explored, an innovative modeling framework is proposed that allows the generation of new sustainable means of transport and logistics services using big data.

Several aluminum alloys exhibit excellent mechanical and thermal properties, as well as good machinability and castability. These materials are regarded as leading candidates for lightweighting applications. The weight of vehicles, vessels, and/or aircraft strongly affect their efficiency. In this respect, good candidates for the weight reduction of such components are, for instance, aluminum chassis for cars and vessels or titanium chassis for aircraft (Devaraj et al., 2016). It may be mentioned that a reduction of 10% of the weight has been estimated to lead to 5–7% improvement of fuel efficiency in each case.

8.2. Long-term Performance Studies

Weight reduction of the automotive chassis is an ultimate goal of composites in the past decades. New approaches to achieve weight reduction with aluminum alloys with nanostructure is expected to be cost effective, eco-friendly and of high manufacturing throughput compared to other high strength lightweight materials. Existing aluminum alloys with conventional structure were obtained from local suppliers in the as-received form, which were car quality and extrusion quality alloys. In this study new aluminum alloy combinations containing Mg, Si and Cu were prepared in the composition range 0.5-2.9wt% of solute elements. An AA6064 product can be of less weight or more stiffness than a held AA6063 in chassis assembly. New aluminum alloys were made… Alloys with up to 2.9wt% Mg, Si or Cu were microalloyed with up to 0.18wt% Zr, Ti or V, respectively. Central specimens need… Solute solute combinations were created thru thermal processing of alloys with large concentration difference. Alloys with… They were fully solution heat treated except alloys wrought by forging. Thermomechanical treatment consisting of manufacturing, working, aging conditions were modified. After the T5 temper and subsequent natural aging time, the strength of cast quality AA6063 increased while strength decrease was observed in car quality AA6061. Strength varies were small after the T6 temper. Prior to rapid strain aging, flow stress obtained at steady state increased with the period of natural aging regardless of aluminum alloys. In general, large effect of aging state on the aging behavior of solid solution alloys with an initial low modulus of elasticity could be observed. Peak aging was large in AA6061 at the T6 temper and long period of natural aging. For the strain rates of $3.2x10^{-4}s^{-1}$ and above, the age hardening was greater and peak aging was higher with the increase in solute concentration. An increase in true strain retardation in new alloy containing less addition of solute after sufficient aging period were observed. An increase in amount of new strength precipitates with solute concentration was responsible for show greater age hardening peak. AA6063 and AA6061 containing tungsten obtained in T6 temper were a waste of the aluminum alloys yet utilized in chassis assembly… The effect of solute concentration on the compatibility and safety temperature in a De Boer diagram containing higher order phase diagrams should be evaluated (Matthew Dmytrowich, 2009).

8.3. Sustainability Considerations

There are numerous sustainability considerations to take into account when making the transition to nanostructured aluminum alloys for chassis applications. Applications in vehicles, in particular electric vehicles, will have a stringent life cycle assessment for both energy consumption and CO2 emissions due to government regulations limiting their environmental impact. While nanostructuring aluminum alloys for automotive applications brings assurance for weight savings, significant questions remain as to how it impacts the sustainability metrics of the chassis components.

The Life Cycle Assessment (LCA) of 20 million vehicle sales in North America over a 15-year period provides early insight into sustainability considerations surrounding nanostructured aluminum for chassis applications. As an extreme case study, it is assumed that a material with performance metrics similar to the fictitious low density and high specific strength Ultra-Fine Grained (UFG) aluminum is introduced 1-5 years into the LCA. If this full fleet were comprised of a UFG aluminum chassis, it would admittedly receive an A on weight reduction. The primary impact would be from building the vehicle (1st cycle), with minimal impact during operation due to the same mileage and battery capacity (2nd cycle). Unavoidably however, this score would dwindle after 15 years as vehicles go off the road. Importantly, material subtractions still result in a passing grade due to greater battery use and oil reduction. Two key metrics should be considered in future design guidelines for nanostructured aluminum light-weighting chassis applications. The first is revenue generated per unit mass of light-weighting material, which for aluminum is USD 41.4 kg-1 versus USD 112.7 kg-1 for Mg. The second consideration is the minimum mass of light-weighting material needed to be removed to affect grades, which is 107.5 kg for UFG aluminum versus 12.4 kg for Mg.

An LCA of two types of Lightweighting Technologies, namely Substituting magnesium for steel and Aluminum, shows the projected Light-weighting Technologies for 2020-2040 (Kulkarni et al., 2018). It also digs into the potential use of impact-adjusted weight productivity metrics for optimizing Life Cycle Energy Consumption estimates prior to the design stage of weight transition. An example based on Quebec's power grid is presented.

IX. Case Studies

The absolute density of aluminum alloys is 2.7 g/cm2, approximately a third of that of steel. An aluminum component can offer significant weight savings compared to steel provided that the same design constraints, such as joint and fastening techniques, processing temperatures, and safety factors are maintained. Weight reduction can lead to tangible benefits in reduced energy and raw materials use across a product's entire life span, from extraction to reuse or recycling. To be considered for widespread commercial adoption, a new material must be low-cost and mass-producible. An ideal structural alloy for automotive chassis applications must be weldable and maintain properties during processing and service. A cost-effective alloy would be one where all the processes involved in its manufacturing were already established. Industrial temporally stable superplasticity in Al-Mg (5083) sheet alloys was demonstrated . Superplasticity is an increase in ductility in the temperature range below the melting point, which generally occurs in bulk materials. The joint between the aluminum sheet and the press hardened steel part was made by the servo-shifted laser welding. Because of the high power density, the temperature at the weld seam is high enough for super plasticity, even at the speed of 120 mm/s. This helps to avoid brittle fracture at the weld joint during crash tests. Nano-structured materials (grain size < 100 nm) have been known for their unique properties since 1984. This research involves the application of nanostructured materials in lightweight aluminum alloys for the automotive and automotive industries. A weight reduction of about 40% compared to steel could significantly reduce energy and raw material consumption, especially in vehicle construction. Al alloy components have favorable properties such as corrosion resistance, machinability, and formability at the macroscopic and nanostructured level. Nano-sized grain sizes in aluminum alloys offer unique processing routes, e.g., severe plastic deformation, to produce materials with fracture energies increased by a factor of up to 40, increased material strengths, and significantly increased corrosion resistance . One aim of this work is to understand the influence of synthesis and processing conditions on the stability of nanostructured films during post-deposition heat treatment and mechanical processing.

9.1. Successful Implementations

Weight reduction has been identified worldwide as one of the most effective means for decreasing the fuel consumption and CO2 emission of automobiles, trucks and commercial vehicles. This study outlines an economic approach to weight reduction through the implementation of a novel nanostructured Al alloy made from nanostructured bulk metallic Al alloy chips and powder, which can be widely used in the chassis of existing vehicles. Detailed modeling shows that this new alloy can achieve ~45% weight reduction in existing commercial vehicles and the suggested automobile weight reduction of ~23%. Thus, by effectively implementing the novel materials, lightweighting of automobiles and commercial vehicles can be achieved with a high cost saving for manufacturers when using the existing chassis.

With increasing demand and stricter regulations for lowering the fuel consumption and CO2 emission from automobiles and commercial vehicles, lightweighting of vehicles has been actively pursued. By weight reduction of transportation vehicles, substantial decrease in the consumption of fossil fuels and anthropogenic CO2 emission can be realized. Therefore, pressing efforts have been focused on lightweighting of structural materials for automotive applications, weight reduction of which has a high sensitivity for fuel consumption and thus CO2 emission. Generally, as two principal low-density metallic structural materials, aluminum alloys provide a potential weight reduction of ~40% compared to steels and are currently the most used materials for automotive lightweighting. To further reduce the density of the Al alloy and hence the weight of the vehicle structure, aluminum alloys with nanoscale structures can be designed and fabricated.

There are currently many novel nanostructured Al alloys with superior strength and other mechanical properties that can potentially achieve additional weight reduction for demanding structural applications. If implemented, it has been modeled that such alloys made from commercially available nanostructured Al alloys should be able to achieve weight reduction in existing vehicles by 23%. However, economic implementation of the nanostructured Al alloy in automotive applications must overcome the cost challenge for alloy fabrication. As a viable approach, the low-cost nanostructured bulk metallic Al alloy chips generated during fabrication of existing Al alloy automotive components can be reconstituted into a low-cost nanostructured Al alloy strip applicable in chassis applications.

Modeling of weight reduction potential with the new approach reveals a potentially large weight reduction of existing commercial vehicles by 45%. Implementation of this alloy for new weight reduction designs of the automobile chassis is also modeled, showing that the new alloy has a large weight reduction potential on the chassis of unibody vehicles and certain weight reduction on the chassis of body-on-frame vehicles.

9.2. Comparative Studies with Traditional Alloys

Lightweight components are fundamental to achieve the aforementioned objectives. Different macro and microstructural strategies have been explored to decrease the density of automotive components. Lattice structures comprising AL-foam and aluminum lattice alloys are compared with conventional Al alloys and Mg alloys scaffolds based on their design, processability, manufacturability, cost, weight reduction, and mechanical properties ((Abhijeet) Maharnwar et al., 2016). Among the macro-microspatial strategies, polymer composites are found susceptible to environmental conditions and whose costly recycling is a major drawback while honeycomb structures are modular and easy to manufacture with a fixed geometry. Hierarchical cellular design optimizes properties but tedious manufacturability remains a challenge. Nano-scale strategies impede the diffusion of dislocations or phase transformations but majorly increase component costs and require further research for in-situ manufacturing. Comparatively, disparate structural alloys available, including dual phase titanium, magnesium, and aluminum alloys, nanostructured titanium and CuAl alloys, and high entropy alloys, overcome the shortcomings of macro and microstructural strategies. Nanostructured aluminum alloys alloying with Sc and Zr and undergoing cold-rolled and further annealing offer new perspectives for future mass-production automotive chassis components with extraordinarily high strength and ductility improved to tens of percent by incorporation of precipitates ranging from nano- to several-micrometers in size. Remarkably, strength and ductility can also be greatly improved by alloying with Zr alone. Additionally, the cost of utilizing nanostructured aluminum alloys with nano-precipitates for automotive chassis and other components is calculable and comparably cheaper than commonly used traditional aluminum and magnesium alloys based on current global market prices for raw materials and running costs for available mass-production techniques for both solid and solution-annealed NAA components, making interesting prospects for applications in automotive and allied industries.

X. Conclusion

The automobile industry has a strong, enduring focus on weight reduction. One of the greatest impacts on a vehicle's weight comes from the vehicle chassis. This is a desirable target for advanced materials to replace heavier existing materials. Current automotive materials like steel tend to be heavy and less efficient for fuel economy, and automobile manufacturers are researching and applying replacement materials like aluminum alloys and carbon fiber composites. Aluminum alloy use is proliferating in automobile designs, most notably in body structure and closures, and more recently in crash components and chassis structures. It is one of the few candidate materials for Advanced High Strength Steels replacement due to being aggressive for the light-weight competition. It does tend to have passive energy absorption but absorbs energy differently than steels, so there are valid reasons to wish to restrict aluminum use to more benign energy absorbing applications.

Current cast aluminum chassis layouts are readily optimized using topology optimization to maximize weight reduction. However, cast aluminum is limited in part design, and some geometries are difficult or expensive to cast. Thin-walled stamp die designs would be an attractive alternative to homogenized casting ones if stamping could be turned into a net-shape process suitable for mass production. Aerodynamic optimization is used to improve drag and thus improve fuel economy of the vehicle in motion. This design and problem is solved through simulation, but it could benefit from faster optimisation and thus more iterations, which are currently limited by higher simulation run times.

Comprehensive aluminium chassis layout is put forward, targeting weight reduction for an electric autonomous vehicle compared to all-aluminium chassis structures, where a mixed chassis layout of 7075 steel and aluminium alloys is used while annulling weight reduction through optimisation and mass constraints. Low cycle fatigue exists due to load scenario considering vehicle robustness and hardening strategies, with a proposed 7075 alloy strut ferrule using model uncertainty being structurally robust despite an initial double sheared design inflating stress. Overall, due to greater strength, cost, recyclability and, as a result, carbon footprint, alloy 7075 is proposed over 6060 and 6082 alloys. The changing component shapes and load scenarios along morphable design are also reviewed, where generative/adversarial/transfer learning and contemporary reinforcement learning architectures, especially multi agent architectures, could benefit the next stage of design.

ISSN: 2248-9622, Vol. 15, Issue 10, October 2025, pp 63-78

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