DOI 10.52209/2706-977X_2024_4_78 **IRSTI 55.09.33** **UDC 669.715**

Comparison of Different Types of Engineering Alloys Suitable for Automotive Industry

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Abstract: The automotive industry relies on a diverse array of engineering alloys to meet the rigorous demands of vehicle design and performance. This paper provides a comprehensive comparison of different types of engineering alloys suitable for the automotive industry. The alloys under consideration encompass a broad spectrum, including traditional materials such as steel and aluminum, as well as advanced options like titanium, magnesium, and composite materials. The comparison delves into key attributes such as strength, weight, corrosion resistance, and heat resistance, highlighting the advantages and applications of each alloy type. Additionally, the paper explores emerging trends and innovations in alloy development, emphasizing their implications for enhancing vehicle safety, fuel efficiency, and overall performance. By synthesizing information on the various engineering alloys, this study aims to offer valuable insights for engineers, researchers, and industry professionals involved in the design and manufacturing of automotive components.

Keywords: engineering alloys, automotive industry& materials, emerging trends, alloy development, vehicle safety

Introduction

The automotive industry, at the forefront of technological advancements, continually seeks innovative materials to address the evolving challenges of modern vehicle design. A critical aspect of this pursuit is the selection of engineering alloys, which play a pivotal role in shaping the performance, durability, and efficiency of automotive components. This paper undertakes a comprehensive exploration and comparison of various engineering alloys tailored for the automotive industry.

As the automotive landscape undergoes transformative shifts towards sustainability, safety, and enhanced performance, the demand for materials with specific properties becomes increasingly nuanced. The selection of an appropriate alloy involves a delicate balance of factors such as mechanical strength, weight considerations, corrosion resistance, and thermal stability. From the stalwart steel alloys to the lightweight and corrosion-resistant aluminum, the automotive engineer is presented with a diverse palette of materials to navigate.

This comparative study not only dissects the fundamental attributes of traditional alloys like steel and aluminum but also delves into the potential of emerging materials such as titanium, magnesium, and advanced composites. Each alloy brings its unique set of advantages and challenges to the automotive manufacturing arena, influencing decisions in component design, structural integrity, and overall vehicle performance.

Moreover, this investigation aims to provide insights into the applications of these alloys within the automotive sector, examining their roles in critical components like chassis, body panels, engine parts, and safety features. By understanding the strengths and limitations of each alloy type, engineers and researchers can make informed decisions that contribute to the development of vehicles with improved fuel efficiency, enhanced safety profiles, and reduced environmental impact.

As we embark on this comparative journey across engineering alloys, the overarching goal is to offer a valuable resource for professionals and researchers engaged in the intricate task of selecting materials that drive the automotive industry towards a future characterized by innovation, efficiency, and sustainability.

1. Literature Review

The automotive industry is prioritizing the use of lightweight constructions and high strength materials, such as high strength steels and aluminum alloys, to meet customer demands and legal requirements, resulting in thinner sheets, reduced mass, lower consumption, and increased environmental protection. However, this can also decrease formability. This paper focuses on recent material developments in the automotive industry, specifically the use of high strength steels and aluminum alloys in sheet metal forming for body-in-white manufacturing [1]..

The study evaluates the corrosion performance of Al-Si automotive alloys in deep seawater using electrochemical impedance spectroscopy and potentiodynamic polarization techniques. Results show that corrosion resistance improves with increasing Si concentrations near the eutectic level, but deteriorates after. Higher Si concentrations show higher polarization resistance and open circuit potential, while corrosion current and rate values decrease. The study also reveals the presence of films after corrosion, including pits and pinholes [2].

This paper highlights the potential of chemical engineers in non-traditional technical areas in the automotive industry, such as vehicle thermal management. Chemical engineers have made significant contributions in areas like fuels, lubricants, and emission control. However, stringent emissions and fuel economy improvements have made automotive thermal management more challenging. This requires temperature management of vehicle components, systems, materials, and fluids. Chemical engineering education often focuses on chemical process industries, but real-life examples from automotive applications can help students understand the significance of these applications. Examples include vehicle instrumentation and testing, exhaust after-treatment systems, fuel system thermal management, and kinetics of material thermal degradation. The paper also discusses the importance of thermocouple dynamics and distillation problems in the automotive industry, such as estimating fuel temperature and fuel vapour emissions. The paper recommends developing an undergraduate course in automotive thermal management, offering elective options for senior undergraduate and graduate students [3].

The study investigates the use of lightweight materials like aluminum in automotive suspension parts to achieve weight targets and reduce fuel consumption. The research uses computer-aided engineering methods, such as Abaqus and nCode, to analyze the strength and fatigue of the aluminum suspension bracket. The study also investigates the redesign of the front suspension bracket made of ductile cast iron in commercial vehicles, aiming to reduce weight and fuel consumption. The fatigue performance of the existing ductile cast iron front suspension bracket was examined using the finite element method. The design, computer analysis results, and low-pressure aluminum casting manufacturing process have been continuously improved, with a 30% weight reduction target achieved with material change [4].

Technological innovations are essential for progress in many areas, including uses of titanium alloy. Expanding the uses of titanium alloy requires new design and material applications. Biomedical devices employ metallic biomaterials such as cobalt-chromium alloys and 316L stainless steel, however the discharge of these materials from prosthetic implants might have harmful consequences. Titanium alloys provide superior corrosion resistance, a unique strength-to-weight ratio, and mechanical qualities at high temperatures. By improving the surface characteristics of titanium alloys, surface engineering techniques can reduce fuel consumption and CAFÉ penalties. Without causing surface deterioration, surface modification can raise the operating temperature [5].

Due to growing rivalry and environmental consciousness, the car industry is embracing lighter materials and energy-saving designs more and more. The low density, high strength, and corrosion resistance of aluminium alloys make them the preferable material due to their ease of recycling. This method lowers the weight, fuel consumption, and emissions of the vehicle, saving 5–10% of gasoline each km and cutting emissions. It is imperative for the environment that designs become lighter and use less energy [6].

Understanding organizational problems in the automotive industry and offering remedies for enhancements are the goals of this research project. The method collects qualitative data through semi-structured interviews and literature review. The results emphasise people skills, organizational culture, and communication and cooperation challenges. Model-Based Engineering approaches should be the main focus of future research to improve theory development and industry implementation [7].

2. Engineering Alloys classification on the basis of uses

Cast aluminium alloys are becoming increasingly popular for use in electro automotive parts due to their unique properties, such as mechanical and thermophysical properties, dimensional stability, corrosion resistance, electromagnetic compatibility, and crashworthiness. The automotive industry is shifting towards electrification due to factors like the oil crisis, air pollution, and global warming. Cast aluminium alloys like EN AC-47000, EN AC-44300, EN AC-43500, and EN AC-42100 are available for mass production using casting processes like HPDC, LPDC, and CPS. However, concerns about the addition of alloying elements and their impact on corrosion and cost may limit their use in electro automotive parts production [8].

The comparison table above encapsulates a diverse array of engineering alloys and their applications within the automotive industry, shedding light on the multifaceted landscape of material selection. As the automotive sector undergoes profound shifts towards lightweight constructions, high-strength materials, and environmental sustainability, the choice of alloys becomes a critical factor influencing vehicle design, performance, and compliance with regulatory standards.

One prominent theme emerging from the comparison is the strategic utilization of high-strength steels and aluminium alloys in body-in-white manufacturing. The automotive industry, driven by customer demands for fuel-efficient vehicles and regulatory requirements to curb carbon emissions, is increasingly favouring materials that offer a balance between strength and reduced mass. The use of high-strength steels and aluminium alloys allows for thinner sheets, contributing to lower vehicle weights and improved fuel consumption. However, the trade-off involves potential decreases in formability, a factor that demands careful consideration in the manufacturing process.

Corrosion resistance emerges as a pivotal aspect in the evaluation of Al-Si automotive alloys. The study on the corrosion performance of these alloys in deep seawater provides valuable insights into their behaviour under extreme conditions. The findings indicate a nuanced relationship between silicon concentrations and corrosion resistance, highlighting the intricate nature of alloy composition in influencing material properties. Such insights are crucial for manufacturers striving to enhance the durability and longevity of automotive components, especially those exposed to harsh environmental conditions.

The exploration of lightweight materials, specifically aluminium, in automotive suspension parts showcases a concerted effort to achieve weight reduction targets and mitigate fuel consumption. Computer-aided engineering methods, such as Abaqus and nCode, facilitate a meticulous analysis of the strength and fatigue of the aluminium suspension bracket. Additionally, the study extends to the redesign of front suspension brackets made of ductile cast iron, exemplifying the industry's commitment to continuous improvement. The results demonstrate a significant achievement with a 30% weight reduction target through material changes, underscoring the potential for innovation in material selection to drive efficiency gains.

Beyond traditional automotive applications, the table reveals the role of titanium alloys in biomedical devices. While these alloys present unique properties ideal for load-bearing applications in implants, there are concerns about their toxic effects due to the release of nickel, chromium, and cobalt. This highlights the delicate balance required in material selection, particularly in industries where biocompatibility is paramount. The automotive sector's exploration of alternative alloys and materials signifies a broader trend in industries seeking not only performance but also environmentally conscious and health-compatible solutions.

The overarching trend in the automotive industry is a shift towards lighter materials and energy-saving designs, driven by both market competition and environmental consciousness. Aluminium alloys, with their low density, high strength, and recyclability, emerge as a preferred choice, resulting in significant fuel savings and reduced emissions. This shift aligns with global efforts to address environmental concerns and demonstrates the industry's commitment to sustainable practices.

The automotive industry is increasingly seeking materials to reduce energy consumption and air pollution. This paper discusses the application of magnesium and aluminium alloys in the automotive industry, focusing on material properties, machinability, and cost comparison. Magnesium alloys offer advantages over aluminium due to their mechanical and physical properties, making them suitable for various automotive components. The market for magnesium alloys is predicted to rise, with magnesium alloys showing potential for lightweight, environmentally friendly, safer, and cheaper cars. However, the application of magnesium profiles depends on whether established forming processes can be applied to magnesium. Further research is needed to improve processing, machinability, and mechanical properties, as magnesium has the potential to ignite if not handled properly. Cost-effective production and application technologies are crucial for making magnesium alloys an economically viable alternative to aluminium alloys [9].

The increasing demands for fuel economy improvement and greenhouse gas emission control have led to the production of lightweight automobiles. This has led to the development of lightweight yet high-performance materials as alternative solutions for conventional automotive materials like cast iron and steel. A systematic review of available lightweight materials for next-generation automobiles is provided, including light alloys, high-strength steels, composites, and advanced materials. The review discusses the entire life cycle of automotive materials, their physical/mechanical properties, characterization, manufacturing techniques, and potential applications. The advantages and drawbacks of the reviewed materials are summarized, yielding appropriate application scenarios for different lightweight materials. The review also provides general guidelines for material selection in different components and offers effective strategies for enabling extensive usage of different lightweight materials in the automotive market [10].

This study focuses on the use of a composite material with 4% WC particulates as reinforcement in an aluminium alloy matrix for a roll cage chassis of an off-road vehicle. The composite material showed improved impact resistance, high strength to weight ratio, and design safety compared to the conventional aluminium alloy. The composite material had no effect on heat treatment and showed proper distribution of WC particulates in the matrix. The CAE analysis of the composite and alloy chassis revealed that the composite material was a better choice for the roll cage chassis than the conventional A-356 alloy. The composite material also showed improved performance in front, roll over, and side impact [11].

Solid crankshafts are in growing demand since diesel engines need to operate at higher outputs while using smaller dimensions. Manufacturers are working to enhance these crankshafts' fatigue strength, quality, and dependability. New fillet hardening techniques, steel-making methods, and materials with increased strength are some of the latest developments in crankshaft production. Continuous Grain Flow (CGF) forging serves as the foundation for the design of most crankshafts. The fillets, which are the most crucial components of a solid type crankshaft, have undergone several changes to achieve greater fatigue strengths. Until around 1960, carbon steels in the 450 MPa class were in use. Low-alloy steels (≤800 MPa) and super-high strength steels (950 MPa class) came next. The application of additional technologies to increase fatigue strength includes cold rolling, induction hardening, nitriding, and shot-peening. The upward strength trend [12].

In order to choose and use materials in power transmission systems in the automotive industry more efficiently, researchers are developing material optimisation approaches. In order to guarantee ideal operating conditions during power transfer, engine shafts are essential. The study looks at the usage of three different types of materials: homogeneous, composite, and functionally graded materials (FGM), as well as their effects on crankshaft performance. According to research, FGM is the best material for best results. Functionally graded materials enhance the performance of stainless-steel crankshafts, according to the study, which used ANSYS to develop a finite element model of the crankshaft and perform modal and harmonic analysis. The paper proposes additional studies utilizing more traditional and functionally graded material types for modal and harmonic analysis of engine crankshafts [13].

The crankshaft is a crucial component of an Internal Combustion (I.C.) engine, responsible for rotary motion and the primary operation in automobiles. The optimal design should have low Noise Vibration and Harshness levels, as these levels determine the quality of output and affect the environment and other components of the automobile. This paper presents a methodology for determining the best material composition for a given crankshaft, which is essential for a structure's longevity. The methodology used is a good substitute for traditional experimental methods, as it reduces time and has good accuracy. Chemical tests were performed on Tata Nano and Mahindra Maxximo crankshafts, revealing that the Tata Nano crankshaft had a chemical composition of Carbon 0.43%, Sulphur 0.024%, Phosphorous 0.021%, Manganese 1.66%, and Silicon 0.35%, while the Mahindra Maxximo crankshaft had a chemical composition of Carbon 0.38%, Sulphur 0.045%, Phosphorous 0.021%, Manganese 1.57%, and Silicon 0.60%. This methodology can be applied to design crankshafts according to specific applications, reducing time and expenses compared to traditional methods [14].

Environmental concerns have led to a rise in the need for weight reduction in crankshafts, an essential component of internal combustion engines. Existing techniques, including hot forging and drilling, have drawbacks in terms of product stiffness and manufacturing costs. It is now possible to reduce weight while maintaining enough stiffness thanks to innovative design and production techniques. In order to maintain stiffness while lowering weight, the new design has a thicker outer border and a narrower pin shoulder. The production process minimizes temperature variance during forging by increasing thickness with a bent section. Osaka Steel Works evaluated the procedure on a 5000-t press line to ensure the required stiffness and validate formability.

Conclusion

Automotive industry is looking for lightweight materials with low cost without affecting the performance requirement.

This review paper discusses about various types of engineering alloys, high strength steels, Al-Si automotive steels, and lightweight materials in automotive suspension used in automotive industry. Table 1. discusses about various aspects of materials used in automotive industry. Aspects such as application area, performance criteria, challenges if material used, Evaluation techniques, analysis or evaluation methods etc. are discussed.

Table 1. Comparison of materials with different aspects

Aspect	High Strength Steels	aluminium Alloys	Al-Si Automotive Alloys	Chemical Engineers in Automotive Industry	Lightweight Materials in Automotive Suspension
Application Area	Sheet metal forming for body-in-white manufacturing	Sheet metal forming for body-in-white manufacturing	Corrosion resistance in deep seawater	Vehicle thermal management	Automotive suspension parts
Materials Discussed	High strength steels	aluminium alloys	Al-Si automotive alloys	Lightweight materials (e.g., aluminium)	aluminium, ductile cast iron
Performance Criteria	Lightweight, high strength, environmental protection	Lightweight, high strength, environmental protection	Corrosion resistance, Si concentration effects	Thermal management, fuels, lubricants, emission control	Weight reduction, fuel consumption
Challenges	Decreased formability	Corrosion, formability challenges after increased Si concentrations	Corrosion, pit and pinhole formation	Stringent emissions, fuel economy improvements	Achieving weight targets, maintaining strength and fatigue performance

Aspect	High Strength Steels	aluminium Alloys	Al-Si Automotive Alloys	Chemical Engineers in Automotive Industry	Lightweight Materials in Automotive Suspension
Evaluation Techniques/Methods	Not specified	Electrochemical impedance spectroscopy, potentiodynamic polarization	Electrochemical impedance spectroscopy, potentiodynamic polarization	Not specified	Computer-aided engineering (Abaqus, nCode), finite element method
Recommendations/Solutions Proposed	Recent material developments in high strength steels and aluminium alloys	Optimal Si concentrations near eutectic level for improved corrosion resistance	Developing an undergraduate course in automotive thermal management	Real-life examples from automotive applications in chemical engineering education	Material change to aluminium, continuous improvement in design and manufacturing process
Targeted Goals/Achievements	Thinner sheets, reduced mass, lower consumption, increased environmental protection	Corrosion resistance improvement with optimal Si concentrations	Advancements in chemical engineering education for automotive applications	Improved understanding of automotive thermal management	30% weight reduction achieved with material change
Analysis/Methods Used for Evaluation	Not specified	Electrochemical impedance spectroscopy, potentiodynamic polarization	Electrochemical impedance spectroscopy, potentiodynamic polarization	Not specified	Computer-aided engineering (Abaqus, nCode), finite element method
Significant Findings/Results	Not specified	Corrosion resistance improves with increasing Si concentrations near eutectic level, deteriorates after	Presence of films after corrosion, including pits and pinholes	Significant contributions of chemical engineers in non-traditional technical areas	30% weight reduction achieved with material change, continuous improvement in design
Key Takeaways/Contributions to the Industry	Advancements in lightweight constructions using high strength steels and aluminium alloys	Corrosion performance insights for Al-Si alloys in deep seawater	Importance of chemical engineers in automotive thermal management	Application of chemical engineering education in automotive industry	Use of lightweight materials (e.g., aluminium) in automotive suspension for weight reduction and fuel efficiency

Use of light weight material assures over all weight reduction, less power consumption, more fuel efficiency. Use of computer aided analysis for analyzing the materials without using protypes, thus helps in predicting the possible failure mode and stress-strain analysis. This review concludes that use of light weight materials such as aluminium and others in suitable automotive components for weight reduction and fuel efficiency.

Funding: This study was not supported by any agency or university.

Declaration of Competing Interest The authors declare that they have no known competing of interest.

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