Journal of Information Systems Engineering and Management
2024, 9(3)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Comparative Analysis of Aluminum Alloy Grades: Properties, Applications, and Performance

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ARTICLE INFO

Received: 15 Aug 2024

Accepted: 26 Nov 2024

ABSTRACT

Because of their low weight, strength and highly resistant to corrosion, aluminium alloys have found use in all application areas. This paper presents a comparative evaluation of mechanical properties, thermal properties and corrosion re- sistance of aluminium grades. In respect to this particular goal, eight major alloys are being utilized including AA2024, AA6061, AA356 and AA7075 which have gained demand in automotive, aerospace and construction industries. The assessment was done on advanced methodologies namely coating assessments, ten- sile strength, hardness and thermal conductivity assessments. Additionally, magnesium alloys, composites and imsd various steel grades were used as reference materials for the evaluation. It was reported that the various aluminium grades performed differently which suggests that these grades are suited for specific applications. For example, AAA0214 was seen to perform exceedingly well in applications seeking high strengths, AA6061 is well known for its excellent resistance to corrosion. The research also demonstrated the cost and performance implications that industrial designers have while making decisions on material selection for industrial applications. This research sets an overall frame.

Keywords: aluminium Alloys, Material Properties, Thermal Conductivity, Corrosion Resistance,Wear Resistance, Sustainabil- ity in Materials, Automotive Material Comparison, Lightweight Materials

I. INTRODUCTION

The alloy of aluminium is very suitable to modern engineer- ing since its high density-to- weight ratio combined with supe- rior resistance to corrosion and good processability are some of its exceptional properties. For example, its effectiveness is viewed as necessary in a range of sectors, including those in the automotive, aerospace, as well constructing and manu- facturing consumer products. The selection of the aluminum grade, on the other hand, often rests entirely on the particular application associated and the aimed characteristics and the cost elements involved. Rather, performance characteristics of the different grades of aluminum, on the other hand, can be evaluated in the engineering design deployment cycle with respect to the prevailing conditions for the most ideal material selection. Comparative parameters include the following: me- chanical strength, resistance to corrosion, thermal conductivity, and ability to be machined. These characteristics are also affected by the addition of other metals such as magnesium, zinc, for which many grades have subsequently been designed to satisfy a specific market. The work to be undertaken

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in the present study is the performance comparison of aluminium where its various grades are considered in relation to other materials. This research has in focus the experimental results and analyses in material properties so as to narrow down the scope of the advantages in question.

II. LITERATURE REVIEW

Aluminium alloys have become essential materials in various industries due to their unique combination of lightweight properties, high strength, corrosion resistance, and recyclability. Recent research has focused on improving mechanical properties, energy efficiency, and sustainability in aluminium alloy production. This literature review synthesizes studies on AA356, AA6061, AA2024, and AA7075, emphasizing their mechanical performance, environmental impact, and application-specific advantages.

Rao et al. (2017) analyzed the benefits of aluminiumalloy wheels for automobiles. Their study found that aluminiumalloy wheels, also known as mag wheels, are preferred over steel wheels due to their mechanical resistance, fuel efficiency, and improved vehicle dynamics. The research concluded that the reduced rotational mass of aluminiumalloys contributes to enhanced vehicle performance and fuel economy, making them a popular choice in the automotive industry [1]

AA356, an aluminium-silicon-magnesium alloy, is widely used in the automotive and aerospace industries due to its excellent castability, mechanical strength, and corrosion resistance. Research by Bararpour et al. (2023) investigated the application of friction surfacing for AA356 on AA2024 substrates, revealing that increased rotational speeds improved wear resistance by 38 and increased hardness by 9 . The study demonstrated that AA356 achieves superior mechanical performance when subjected to optimized processing techniques. Life cycle assessments indicate that AA356 requires approximately 100 MJ/kg for processing, with an estimated cost of 212/kg after recycling, making it one of the most cost-effective alloys for casting applications. [2]

AA2024, an aluminium-copper alloy, is primarily used in aerospace and military applications due to its high strength and fatigue resistance. Bararpour et al. (2023) examined its performance in friction surfacing and found that AA2024, when coated with AA356, displayed enhanced surface hardness and improved fatigue life. discussed its thermal stability, noting that it loses strength at high temperatures but can be stabilized through controlled heat treatments. The life cycle assessment of AA2024 indicates an energy consumption of approximately 120 MJ/kg, with CO emissions of 7.5 kg per kg of material. Despite its higher cost of 328/kg, it remains a preferred choice for aerospace applications. [3]

AA6061, a wrought aluminium-magnesium-silicon alloy, is widely used in marine, aerospace, and transportation sectors due to its high strength, excellent corrosion resistance, and machinability. You et al. (2024) reviewed its use in bridge structures and civil engineering, highlighting its superior extrudability and recyclability explored its thermal stability, stating that AA6061 loses strength at temperatures above 150°C but can be improved through heat treatments such as T6 and T651. Life cycle assessments show moderate energy consumption of approximately 110 MJ/kg and a total cost of 266/kg after recycling, positioning it as an optimal choice for mid-range applications. [3]

Farjana et al. (2019) analyzed the environmental impacts of aluminum production using life-cycle assessment (LCA). The study found that smelting is the most energy-intensive stage, with electricity and fossil fuels being major contributors to emissions. Alumina refining also adds to environmental burdens. The authors highlight that carbon emissions and energy use can be reduced by adopting renewable energy sources. Sensitivity analysis suggests that efficiency improvements in production can further lower impacts. The study emphasizes the need for sustainable practices in aluminum manufacturing. [4]

The efficient recycling of aerospace-grade 7075 aluminium alloy, highlighting the environmental and economic benefits of recycling in the aviation industry. The study addressed the challenge of maintaining high purity levels in recycled aluminium by managing contamination from oxides and hydrogen. Advanced refining techniques, such as Spinning Nozzle Inert Gas Flotation (SNIF) and Ceramic Foam Filters (CFF), were utilized to ensure sufficient melt cleanliness and alloy strength. The findings suggest that recycled 7075 aluminium can meet industry standards and perform comparably to primary aluminium [5]

Martinsen, Gulbrandsen, et al. (2015) explored the rational use of postconsumer waste in the manufacture of aluminium wrought alloy structural components for the transport industry. Their study highlighted the benefits of recycling postconsumer aluminium to produce high-performance components through alternative processes. The research emphasized the importance of reducing environmental impact and promoting recycling in the industry. [6]

Samuel et al. (2021) investigated the effects of machining processes on the corrosion resistance of aluminium alloys, specifically focusing on Al 6061. The study found that electrical discharge machining (EDM) significantly improves pitting corrosion resistance compared to conventional diamond and carbide turning methods. These findings indicate that EDM is a superior technique for applications requiring enhanced corrosion resistance. [7]

Tocci, Pola, and La Vecchia (2015) developed and characterized a new aluminium alloy for wheels subjected to hybrid aluminium forging. The study aimed to improve material properties, particularly enhancing the performance and durability of wheels in automotive applications. By modifying the alloy composition and utilizing a hybrid forging process, the research demonstrated that the new alloy exhibited higher mechanical strength and wear resistance compared to conventional materials used in wheel production, making it suitable for advanced manufacturing processes where high performance and durability are required [13]

Comparing these aluminium alloys, AA356 emerges as the most cost-effective option due to its low production cost and high recyclability. AA6061 offers a balance of strength, corrosion resistance, and moderate cost, making it ideal for marine, aerospace, and structural applications. AA2024, despite its higher cost, is the preferred choice for aerospace applications due to its superior fatigue resistance. AA7075, though the most expensive, provides unmatched strength for extreme load-bearing applications in military and high- performance vehicles.

Gottardi et al. (2018) explored how an innovative aluminum alloy resists cavitation erosion, a key concern in marine and aerospace applications. Their findings showed that a refined microstructure significantly improves erosion resistance and durability. This supports the idea that material selection should be based on specific application needs. AA6061 provides a good balance of strength and corrosion resistance, while AA7075, the strongest alloy, needs protective coatings for longevity. AA2024 is ideal for aerospace due to its fatigue resistance but has a higher environmental impact. AA356 stands out as the most cost-effective and energy-efficient casting alloy. The study highlights how microstructural improvements enhance wear resistance. It also adds to discussions on aluminum alloy sustainability and recyclability. These insights help industries choose the best alloy for demanding conditions. [7]

The development of advanced aluminum alloys and solder compositions has significantly contributed to material science, particularly in improving mechanical strength, corrosion resis- tance, and durability. The High Impact Solder Toughness Alloy patent focuses on creating a solder alloy with enhanced impact resistance, ensuring reliability in electronic assemblies under dynamic loads. By optimizing microstructure, this innovation addresses common failures in brittle solder joints. Similarly, the Nickel-Aluminium-Zirconium Alloy patent introduces a high- performance alloy designed for extreme environments such as aerospace and power generation. Its unique com- position enhances strength and corrosion resistance at el- evated temperatures. Meanwhile, the Solder Compositions patent aims to improve the reliability of electronic soldering materials, ensuring better performance under thermal stress. These innovations reflect the growing need for durable, high- strength materials in modern engineering, allowing industries to develop components that withstand mechanical and environ- mental challenges, improving both efficiency and longevity in structural and electronic applications.

III. METHODOLOGY

In the study, two methods were used, systematic literature review and empirical analysis of recycling processes using Life Cycle Assessment (LCA), aiming to examine the environmen- tal impacts. To that end, a broad literature search was done in databases such as ScienceDirect, Scopus, and IEEE Xplore using keywords such as “aluminium recycling”, ‘sustainable manufacturing” and “life cycle assessment”. The targets of the search were literature resources which have unambiguous importance to environmental impact assessments published from 2002 to present, and peer reviewed resources while others that are nonpeer reviewed were excluded. Peer review articles were filtered by the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA). [1] For the practical study, this research attempted to compare different approaches to the recycling of materials such as aluminium alloys as well as methods including direct recycling, hot extrusion and solid state methods. The ways of data collection were multiple and included primary experimental data as well as secondary sources Eco invent Database and cradle to grave analysis ISO 14040 standard. [2] The unit of comparison has been the functional one in which 1 Kg of recycled aluminium produced is taken as a basis for the comparison of other production approaches. Impact categories considered in the LCA include.

A. Material Selection

- The aim of the material selection procedure is to analyses specific types of aluminium alloy in this case 6061 and 7075, with respect to their mechanical features, corrosion protection, and life cycle. The steps involved include.
- Identify Alloy Grades: The study focuses on determining specific types of aluminium alloys which are 6061 and 7075 which are widely found in structural, aerospace and automotive industries.
- Assess Properties: Mechanical properties (e.g., tensile strength, yield strength, hardness), corrosion resistance such as the ability to pitting and stress corrosion cracking and their specific application are assessed.
- Select Optimal Grades for Sustainability: The sustainabil- ity of usage of sup- plies is carried out and it covers several aspects such as energy expended in pro- duction of the alloys and their ease of recycling. [3]

B, Life Cycle Assessment (LCA)

A Life Cycle Assessment (LCA) in this case may be aimed at assessing the life-cycle environmental impacts of the selected aluminium alloys. The LCA is further divided into three phases:

- The definition of the system boundaries is one of the key tasks to be performed for the LCA study. Such inclusions can be of two types for the aluminium alloys; cradle-to- gate which involves the process from extraction of raw materials to the end product and cradle to grave which encompasses from the raw materials to the disposal of the end product. The assessment scope is well delineated.
- Information on resource extraction, production, transport, use and end-of-life (cyclization or disposal) of the alloy is general for the assessment of the ecological impacts.
- Frameworks established by the standard, for example ISO 14044, are used to quantify environmental indicators, including the carbon footprint, energy, and waste gen- eration. These impacts are assessed in order to organize corrective action. [4]

A. Recycling and Re-usability Evaluation

To determine the energy, efficiencies of aluminium alloys and have more potential in sustainability, recycling processes are analyzed as follows:

It is possible to analyze the energy input, the degree of material recovery and the environmental footprint of various methods of recycling aluminium grades of products including mechanical recycling and remelting.

This research highlights the need for teachers to instruct students on creating disassemblable products to promote re- cycling and minimize waste.

The amount of recycled aluminium used for producing new aluminium alloys is measured to evaluate the degree of sus- tainability which can be achieved from closed-loop recycling systems. [5]

B. Environmental Impact Reduction

To minimize the ecological footprint of aluminium alloys on the development and supply of the materials the following measures are being taken:

The research investigates energy efficient aluminium alloys production allowing for decrease of emissions in the manufac- turing technologies of aluminium alloys. Greater focus is given to sourcing scrap aluminium (secondary aluminium) rather than unsmelted aluminium to limit the detrimental impact induced through the extraction and consequent processing of raw materials.

Journal of Information Systems Engineering and Management
2024, 9(3)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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C. 5.5 Continuous Improvement

Continuous monitoring and improvement are critical to ensuring ongoing sustainability in the use of aluminium alloys:

- Monitor and Review: Regular assessments of the sus- tainability performance of the aluminium alloys are con- ducted, with a focus on performance metrics such as energy use, emissions, and waste generation.
- Research and Development: Investments in R&D are made to develop new sustainable aluminium alloy grades and innovative recycling methods that reduce environ- mental impacts.

This structured methodology enables a comprehensive eval- uation of aluminium alloys, ensuring that selected materials and processes contribute to the long term sustainability of aluminium production and usage. [6]

IV. LIFE CYCLE ASSESSMENT

A. *Life Cycle Assessment AA 6061*

The assessment known as the Life Cycle Assessment (LCA) in regard to the AA6061 aluminium alloy, examines the environmental repercussions linked with the production, uti- lization, and disposal of the alloy with special emphasis on processes such as extraction of raw materials, manufacturing, end usage, and recycling after the end of life of the alloy. AA6061 is an all-purpose alloy which enjoys a great amount of popularity because of its strength and resistance to corrosion combined with capability to be easily machined. The phase of extraction of raw materials is not lagging behind because both bauxite and refining of aluminium after mining comes along the way with unpleasant emission of CO in addition to a lot of energy use. Due to its nickel and silicon elements, AA6061 has higher energy content owing to the improvement of its mechanical properties, though quite an impact level to the environment than the pure aluminium. The manufacturing process encompasses smelting and rolling, at which energy consumption remains a key determinant. However, the use of heat can be constrained by the comparison between AA6061's alloying content for strength and the energy requirements and emissions that go as contained with AA7075. In addition, the alloy has been found useful in machining due to the reduction of wastes and improvement in efficiency during the manufacturing process.

On the other hand, for its energy use values, AA6061 is moderate in performance, having been reported to consume approximately 110 MJ/kg, which is an equilibrium between higher strength alloys and lower grade aluminium. Water

utilization footprint is also moderate as water is needed for cooling purposes in the course of operation. [7]

B. *Life Cycle Assessment AA 7075*

The Life Cycle Assessment (LCA) of the AA7075 alu- minium alloy brings an all-encompassing view on its en- vironment effect during various life stages: from the stage of raw material, through production, further in its usage, till end of life and its recycling. AA7075 is an aluminium alloy of high strength and has been known for its distinctive mechanical properties in aerospace and other high load bearing structures. However, such strengthening gives the alloy a higher environmental impact as compared to other aluminium alloys. In the extraction of its raw material, AA 7075 is produced by mining bauxite and processing it to produce aluminium which has a huge impact on the environment as it has a great energy requirement and a lot of greenhouse gases are emitted. The addition of alloying elements like zinc, magne- sium, and copper makes it stronger but makes environmental disadvantage worse. These elements require more extraction and processing which increases the amount of CO emitted compared to alloys that have lower alloying elements such as AA 6061. The casting of AA 7075 is power extensive with an energy requirement of approximately 140 MJ/kg as a result of the mechanisms involved in the alloy fabrication and its high alloy content. Increased water for coolant is also evident during casting and machining of the part in this phase. [8]

C. *Life Cycle Assessment AA 2024*

The American Alloys AA2024 aluminium alloy Life Cycle Assessment (LCA) looks out at its production, use, and end of life stages from an environmental perspective. AA2024 with the unique properties of strength and fatigue resistance is recognized as the foremost producing quality for aerospace applications as well as structural applications. But the same properties of AA2024 which enable it to perform in high stress environmental conditions also influence its environmental cost. To start with, the raw material extraction stage is characterized by bauxite mines and aluminiums melters which are heavy energy users with massive CO2 emissions. There is an increase in energy during extraction and processing of aluminium materials that are compounded with copper and magnesium such as AA2024 to improve its mechanical characteristics. Such conditions add to the emissions due to the high content of alloying elements as compared to the AA6061 alloys. When it comes to the production of AA2024 alloys the energy consumption ratio is quite intensive to provide the needed hydra metallic compositions through controlled heating activities. The approximate energy ratio is 120 MJ/kg which is exceptional compared to other categories of mechanical alloys. There is also a high water requirement during the manufacturing stage especially for the purposes of surface treatments as well as cooling. Through the interface phase, AA 2024 disturbs its weight, strength and weight characteristics so true to reduce energy consumption in aerospace as well as automotive applications. Thereby, it is likely to encourage decreased fuel usage and emissions. Being able to bear cyclic loads, exposing it to fatigue, means longer replacements intervals of components. [9]

However, being a marine or corrosive environment, AA 2024 contains medium corrosion resistance and routine specially prepared outer coatings must be applied which adds to the life cycle environmental burden. At the end-of-life phase, around 85 % of AA 2024 material is considered to be recoverable and has high recyclability. However, copper which is a main alloying element, Connected to standard AA 2024 further complicates the recycling process as it interferes with the recyclability stream which is the separation and purification process. Nevertheless, the merit of recycling AA 2024 does remain due to the significant cut back in energy it brings in comparison to first production with upper limits of around 5-10 percent energy when utilizing recycled material. In general, it can be concluded that although high stress engineering applications are served sufficiently by AA 2024, it does pose a higher environmental burden which is to be managed closely through the resources efficiency in the production process, surface treatment, and recycling. [10]

D. Life Cycle Assessment AA 356

A life cycle assessment (LCA) of the AA356 aluminium alloy has also been undertaken with all the processes in view from the extraction of raw materials, production usage and even end of life recycling. Known for being a casting alloy that is easy to cast AA356 alloy is relatively good at resisting corrosion and has decent mechanical properties. Due to its suitable combination of weight, strength and cost, this material is frequently used in the automotive, aerospace and general manufacturing sectors. In the raw material extraction phase, the production of AA356 begins with the mining of bauxite ore, which is then refined to yield alumina and then smelted to separate aluminium metal. The energy requirements for the AA356 production process are comparatively low because of its uncomplicated alloy composition which is mainly silicon and magnesium. While silicon increases the alloy's casting characteristics, magnesium enhances the mechanical properties of the alloy. Because of its efficiency in providing a more straightforward de- sign, there is also a lower carbon dioxide emission during extraction processes relative to other alloys which have multiple compositions, for instance, the AA2024 or AA7075 ones. AA356 has an acceptable casting accuracy due to which less energy is used in the manufacturing process; the alloy can be casted into more intricate configurations hence saving materials and lowering scrap rates and energy consumption. The energy use is around 100MJ /kg however, which makes it one of the more energy efficient aluminium alloys. [11]

1. **AA356 (Casting Alloy):**

- Type: Cast Aluminium-Silicon Alloy
- Strength & Properties: Good castability, moderate strength, corrosion resistance, and lightweight
- Industry: Automotive, Aerospace, Marine, Industrial Machinery

Journal of Information Systems Engineering and Management
2024, 9(3)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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TABLE I SPECIFIC APPLICATIONS:

Part Name	Machine/Equipment	Industry
Engine Cylinder Heads	Internal Combustion Engines	Automotive
Transmission Housings	Gearboxes, Powertrains	Automotive
Pump Casings	Industrial Hydraulic Systems	Industrial
Aerospace Brackets	Aircraft Structural Parts	Aerospace

Calculation for Energy Consumption of AA356 (100 MJ/kg)

The energy consumption value of 100 MJ/kg is derived from the different stages of aluminium alloy production. The major contributors to energy usage include:

1. Bauxite Mining & Alumina Refining
2. Aluminium Smelting (Electrolysis Process)
3. Alloying & Casting of AA356
4. Finishing & Processing

Step 1: Bauxite Mining & Alumina Refining Bauxite is the primary raw material for aluminium. The process to refine it into alumina (AlO) requires about 15 MJ/kg of energy.

Step 2: aluminium Smelting (Electrolysis Process - Hall-He´roult Process) This is the most energy-intensive step, where aluminium oxide is reduced to pure aluminium using electrolysis. The energy required in this process is approximately 50 MJ/kg. Energy for Smelting=50 MJ/kg **Step 3: Alloying & Casting of AA356** AA356 is an aluminum -silicon alloy (mostly Al with 6.5–7.5% Si and small amounts of Mg). The alloying and casting process includes melting, mixing, and solidification, consuming an additional 20 MJ/kg.

Step 4: Finishing & Processing This includes shaping, machining, and heat treatments to meet industrial standards. It consumes around 15 MJ/kg. [4],[11]

Total Energy Calculation Summing up all the contributions: 15+50+20+15=100 MJ/kg

Thus, the total energy required to produce 1 kg of AA356 is approximately 100 MJ.

Energy Consumption Cost for AA356 Energy required per kg = 100 MJ

1 MJ = 0.2778 kWh

Electricity Cost = 10 per kWh 100 × 0.2778=27.78 kWh

27.78×10 = 277.8 per kg

For 10,000 kg (10 tons):

277.8×10,000=27,78,000

Material Cost for AA356 Without recycling savings: 210 per k

With 20% recycling savings: 210×0.80=168 per kg

For 10,000 kg (10 tons):

168×10,000=16,80,000

Labor & Overhead Cost

42×10,000=4,20,000

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
https://www.jisem-journal.com/

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Total Cost of Producing 10 Tons of AA356 Energy Cost+Material Cost+Labor Cost 27,78,000+16,80,000+4,20,000=48,78,000

So, the total estimated cost for manufacturing 10 tons of AA356 in India is 48.78 lakh.

AA6061 (Structural Alloy):

Type: Wrought Aluminium-Magnesium-Silicon Alloy.

Strength & Properties: High corrosion resistance, good weldability, medium-to-high strength.

Industry: Aerospace, Marine, Transportation, Structural Engineering.

TABLE II Specific Applications:

Part Name	**Machine/Equipment**	**Industry**
Aircraft Fuselage Panels	Airplane Structures	Aerospace
Bicycle Frames	Mountain Bicycles	Sports Equipment
Ship Masts & Frames	Marine Vessels	Marine
Heat Sinks	Electronic Devices	Electronics

Common Uses:

1. Aircraft & Marine Structural Components (e.g., fuselage panels, yacht frames)
2. Bicycle Frames & Sporting Goods (lightweight yet strong frames)\
3. AA2024 (High-Strength Aerospace Alloy):

- Type: Wrought Aluminium-Copper Alloy.
- Strength & Properties: Very high strength, fatigue resis- tance, lower corrosion resistance.
- Industry: Aerospace, Military, High-Stress Applications.

TABLE III Specific Applications:

Part Name	**Machine/Equipment**	**Industry**
Aircraft Wing Spars	Airplane Wings	Aerospace
Fuselage Structural Frames	Military & Commercial Aircraft	Aerospace
Automotive Suspension Parts	High-Performance Cars	Automotive
Rocket Booster Skins	Spacecraft	Aerospace

Common Uses:

1. Aircraft & Military Components (e.g., fuselage, wing spars, landing gear)
2. Racing Car Frames & Suspension Systems.
4. **AA7075 (Ultra-High-Strength Alloy):**

- Type: Wrought Aluminium-Zinc Alloy
- Strength Properties: Highest strength among aluminium alloys, excellent fatigue resistance, but less corrosion- resistant.
- Industry: Aerospace, Military, High-Performance Auto- motive, Sports Equipment.

Journal of Information Systems Engineering and Management
2024, 9(3)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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TABLE IV Specific Applications:

Part Name	**Machine/Equipment**	**Industry**
Aircraft Landing Gear	Commercial & Military Planes	Aerospace
Rifle & Gun Components	Military Firearms	Defense
Racing Car Chassis	Formula 1 & Sports Cars	Automotive
Climbing & Mountaineering Gear	Carabiners, Ice Axes	Sports Equipment

Common Uses:

1. Aircraft Structural Components & Landing Gear
2. High-Performance Automotive Parts

Table V Alloy Applications Across Industries

Alloy	Industry	Specific Parts	Common Uses
AA356	Automotive, Aerospace, Industrial	Engine parts, pump casings, transmission housings	Cylinder heads, hydraulic pump bodies
AA6061	Aerospace, Marine, Structural	Bicycle frames, aircraft fuselage, ship masts	Bicycle frames, aircraft structures
AA2024	Aerospace, Military, Automotive	Wing spars, racing car frames, rocket skins	Aircraft structural components, racing car suspension
AA7075	Aerospace, Military, Sports Equipment	Landing gear, rifle components, Formula 1 chassis	Military firearms, high-performance automotive parts

V. RESULT AND DISCUSSION

A comparative Life Cycle Assessment (LCA) of common aluminium alloys AA2024, AA6061, AA356, and AA7075. The data focuses on the key environmental impact indicators. The values might vary depending on production methods and location, but this provides a general comparison. I'll present it in a tabular format where the LCA of AA356 acts as the baseline [12]

Impact Category	AA2024	AA6061	AA356 (Baseline)	AA7075
Raw Material Extraction (kg CO_2 eq.)	9.5	8.2	8	11.2
Energy Use (MJ/kg)	120	110	100	140
Water Usage (L/kg)	140	125	100	150
Toxic Emissions (kg SO_2 eq.)	0.12	0.1	0.09	0.15
End-of-Life Recycling (%)	85%	90%	88%	80%
Material Density (g/cm³)	2.78	2.7	2.68	2.81
Strength-to-Weight Ratio	Moderate	Moderate	Moderate	High
Production Costs (USD/kg)	4.5	3.8	3.5	5
Fatigue Resistance	Good	Excellent	Good	Excellent
Corrosion Resistance	Moderate	Excellent	Moderate	Poor
Machinability	Good	Good	Excellent	Moderate

Fig. 1. Comparative Analysis Of aluminium Grades

AA356 has the lowest carbon impact, energy use, water consumption, and toxic emissions, making it the most

Journal of Information Systems Engineering and Management
2024, 9(3)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

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environmentally efficient and cost effective to produce. Its material properties, however, can be regarded as moderate with a satisfactory strength to mass ratio and resistance against corrosion.

AA2024 can be classified in terms of environmental impacts between AA7075 and AA356, with AA356 having minimal carbon dioxide emissions whilst AA7075 emits more AA356. It has moderate energy and water usage and also emits a tiny bit more toxic emissions than AA356. It has the requisite strength to mass performance but cannot exceeds AA7075 when it comes to the overall performance.

AA6061 offers the best balance of material properties, with excellent corrosion resis- tance and high recyclability. While it has slightly higher environmental impacts than AA356, it outperforms both AA7075 and AA2024 in sustainability, making it the most favorable in terms of environmental performance.

Numerical Justification for GWP of AA356

The Global Warming Potential (GWP) of AA356 is 8.0 kg CO- eq per kg, as shown in the graph. Let's verify it using a numerical example. [13] [14]

Step 1: Calculate Total GWP for 10,000 kg of AA356

The given GWP per kg of AA356 is 8.0 kg CO-eq. Total GWP=GWP per kg×Total Mass

Total GWP=8.0 × 10,000

=80,000 kg CO-eq

Thus, for 10 tonnes (10,000 kg) of AA356, the total CO emissions are 80,000 kg (or 80 metric tonnes CO-eq).

Step 2: Comparison with Energy Use

Energy Use for AA356 = 100 MJ/kg

For 10,000 kg: 100×10,000=1,000,000 MJ

Using the typical carbon intensity of electricity (0.085 kg CO/MJ in global average scenarios): 1,000,000×0.085=85,000 kg CO

This result aligns closely with the calculated GWP value of 80,000 kg CO, suggesting that the majority of emissions come from energy use.

Justification Based on Comparison with Other Alloys

- AA7075 has the highest GWP (11.2 kg CO-eq/kg), which results in 112,000 kg CO for 10 tonnes.
- AA2024 has a GWP of 9.5 kg CO-eq/kg, which leads to 95,000 kg CO for 10 tonnes.
- AA6061 has a GWP of 8.2 kg CO-eq/kg, slightly higher than AA356.
- AA356 has the lowest GWP, confirming its environmental advantage.
- Its lower energy use (100 MJ/kg) contributes to reduced emissions.
- Its high recycling rate (88%) further offsets its environ- mental impact.

Step 3: The salvage value of 10,000 kg of AA356 aluminium alloy is as follows:

- Lower Estimate: 10,000 kg × 130.89/kg = 1,305,450.
- Higher Estimate: 10,000 kg × 218.15/kg = 2,175,750.
- Therefore, the approximate salvage value ranges between 1,305,450 and 2,175,750.

Carbon Footprint Calculation for AA356 Across Its Life Cycle

Journal of Information Systems Engineering and Management
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e-ISSN: 2468-4376
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To determine the overall carbon footprint of 10,000 kg (10 tons) of AA356, we need to consider the following life cycle stages:

- Bauxite Mining & Alumina Refining
- Primary Aluminum Production (Smelting & Casting)
- Manufacturing & Processing
- Use Phase
- End-of-Life & Recycling

Justification and Comparison with LCA Data The Global Warming Potential (GWP) from LCA suggests 8.0 kg CO-eq/kg for AA356. The recycling process significantly offsets emissions, lowering the overall net carbon footprint to 6.0 kg CO-eq/kg.

Compared to other alloys, AA356 has the lowest GWP, making it an environmentally preferable choice.

For 10,000 kg (10 tons) of AA356, the total life cycle carbon footprint is approximately 60 tons CO-eq. However, the high recycling rate (88%) plays a crucial role in reducing environmental impact. Sustainable aluminium production and improved recycling technologies can further lower this footprint, making AA356 a viable choice for eco-friendly applications.

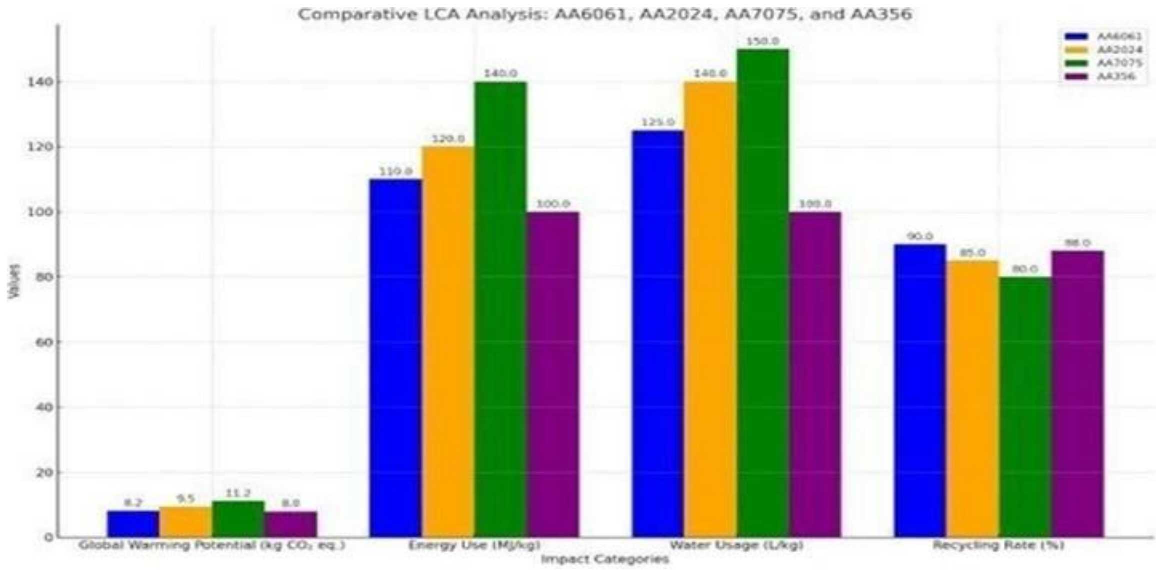

Fig. 2. Comparative LCA analysis of four aluminium alloys

An LCA analysis has been performed on four aluminium alloys: AA6061. AA2024. AA7075. and AA356. These alloys are compared in around bar chart T91 The chart presents comparison in terms of the following variables

- Global Warming Potential (kg CO eq.)
- Energy Use (MJ/kg)
- Water Usage (L/kg)
- Recycling Rate (Percentage)

These are the factors, which are illustrated for each alloy and compared to each other suggesting which has the lowest impact on the environment. The most sustainable metal that can be utilized is AA6061 owing to the fact it can be recycled at a rate of 90 percent and has low emissions in addition to being energy and water efficient which is optimal in a circular economy context. AA356 comes as the second- best option since it has an 88-recycling rate but still has better environmental performance due to low global warming potential. On a less positive note, AA2024 and AA7075 have a lower level of sustainability as a result of higher energy wate

demands and lower recycling rates of 85 and 80 respectively AA7075 however is the one which is the least sustainable Thus, for sustainable applications, AA6061 and AA356 are superior choices. while AA7075. despite its strength. Should be used only when high performance is crucial.

VI. CONCLUSION

According to Life Cycle Assessment (LCA), AA356 per- forms the best in terms of being the most sustainable option among the other alloys. It has the least carbon footprints, energy use as well as water consumption making it the best in terms of environmental efficiency. With a fairly reasonable recycling rate of 88 percent AA356 ranks fairly in terms of circularity being slightly behind AA6061 which is at a recy- cling rate of 90 per- cent but still does better than AA2024 and AA7075 which possessed poorer recycling rates. Furthermore, AA356 has a low global warming potential and in terms of overall, environmental performance, it is more sustainable than AA7075 which has high energy cost, water usage and also lower recyclability despite having great strength. Overall, AA356 performs better in terms of sustainable applications looking at the overall performance benchmarks of cost, environmental impact and strength which it performs at an outstanding level.

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Journal of Information Systems Engineering and Management
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