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Data Analysis of Steel and Aluminum for Industrial Shed Construction: Structural, Environmental and Economic Perspectives: A Comparative Review

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***Abstract*—The present paper reports and compares the performance of steel and Aluminum in the construction of industrial sheds with respect to their material properties, structural behavior, costs, and environmental impacts. The objective of this study is to analyze the merits and demerits of each material in performance, durability, and sustainability so that informed recommendations can be made regarding the selection of that material most applicable for different construction requirements. Some of the key findings show that while steel, with its much higher strength, is best suited to large structures that need to carry weight loads, it will need constant maintenance because it rusts. Aluminum, on the other hand, possesses better resistance to corrosion, weighs far less than steel, and as such, is only applicable to smaller or coastal structures; it also costs more in the initial phases. This study also analyses the cost-effective aspect in which steel is more upfront cheap; however, Aluminum, at first expensive, is long-lasting and hardly needs maintenance. Furthermore, both are recyclable and Aluminum has less carbon footprint during its production phase. This paper concludes that the selection of the material should depend on specific project requirements, environmental conditions, and life-cycle costs. Future studies should look into hybrid material approaches and further improvements in sustainability practices.**

***Index Terms*— Aluminium, Construction, Corrosion, Durability, Steel, Sustainability.**

I. INTRODUCTION

A. Overview of Industrial Sheds and Their Significance in Construction

They are large structures whose purpose is primarily storage, manufacture, warehousing, and other industrial processes. Industrial sheds are indeed important structures for manufacturing, logistics, agriculture, and construction industries. It can cater to diverse operational needs from assembly lines to massive open storage areas, designed to provide large areas or spaces for operations. [1] Several factors must be addressed in the building of the shed, including load-bearing capacity, durability, safety, and functionality.
Designwise, simple yet effective forms and wide spans, large roof areas, and minimizing interior supports characterize industrial sheds.

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This ensures that usable space and structural integrity are maximized. The materials that can be used in constructing industrial sheds significantly impact the overall performance, longevity, and cost efficiency of a building [2].
Among the many materials available, steel and Aluminum are still commonly used because of their high strength, flexibility, and durability.

B. Importance of Material Selection in the Design and Construction of Industrial Sheds

The nature of these materials considers the performances of the industrial shed in terms of making costs and the service life possible for industrial sheds. There have to keen specifications for the material regarding its required strength and resistance to environmental factors such as corrosion and extreme temperatures, along with the overall structural performance of the materials. Preferred materials are steel and Aluminum as they possess very beneficial characteristics. Each material has its properties with which they are characterized to suit specific applications [3].

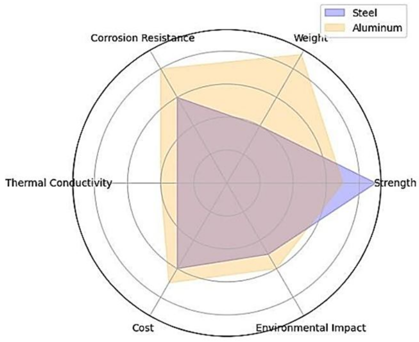

Fig. 1. Comparison of Steel and Aluminium for Industrial Shed Construction

Steel has a high tensile strength and load-bearing capacity, making it suitable for architecturally large structures for carrying heavy loads. It can also fit into any design as it easily shapes itself into many sizes and shapes according to the structural need. Steel has a high tendency to undergo corrosion, especially in humid or coastal environments, which further adds up to the maintenance requirements to increase the lifespan of steel. Fig. 1 provides a view of comparison difference based on some key factors such as strength, weight, corrosion resistance, thermal conductivity, cost, and environmental impact between steel and Aluminum [4]. An ideal way could be to show these features in a side-by- side bar chart or radar chart to allow readers immediate performance comparison of these materials on different attributes.

II. LITERATURE REVIEW

A. Historical Development and Evolution of Industrial Shed Construction Using Steel and Aluminum

The construction of the industrial sheds has come off much from the earlier decades with the incorporation of materials that answered the price, strength, and endurance demands. Steel has mainly been used due to its high strength-to-weight ratio, excellent endurance, and withstand severe atmospheric conditions. With time, the use of Aluminum in building industrial sheds has been gaining prominence because Aluminum is light and resistant to corrosion and the environment and is sustainable. Steel still holds a strong position in the construction of large industrial buildings; on the other hand, Aluminum is often employed in constructions around small or specialized areas.

B. Key Studies Comparing Steel and Aluminium Structures

Comparative evaluations of the performance of steel and Aluminum applications in the construction of industrial sheds have been conducted in several studies. For instance, Jiang et al. (2021) compared two Aluminum alloy joint systems, stating that the new Aluminum alloy penetrating (AAP) joint system showed better stiffness and bearing capacity over the conventional systems (AAT joints) [5]. The findings mean that Aluminum is probably more useful than steel where lightness and corrosion resistance are required.
Dani et al. (2022) analyzed carbon emitted throughout the life cycle of light steel and timber buildings [6]. It came out that even if manufacture of steel construction emits relatively high carbon, it is counterbalanced at the end of a structure's life through its recyclability. This, however, denotes that steel is more sustainable in the long term than timber.

The same authors, Ostapska et al. (2024), worked on implementing DfD principles in industrial construction, stating that in this way steel structures could be disassembled more easily and recycled instead of generating waste in the construction sector [7]. Hence, their findings emphasized the environment under which steel would fit well in the structures for future flexibility and disassembly.

C. Review of Methodologies for Structural Analysis and Design in Existing Research

There is a significant divergence between the methodologies used in the study and development of steel and Aluminum commercial sheds. The standard tool for simulating and analyzing how materials act on varying loading conditions is Finite Element Analysis (FEA). For example, Paul and others (2024) used FEA to explore the moment capacity of cold-formed Aluminum channels. Their study translated into greater knowledge of how variations in design and material properties influence the performance of Aluminum structures subjected to bending load forces [8]. It was compared with design guidelines of several standards, with some methodologies being found conservative in their predictions for moment capacity.

Another method described by Cucuzza et al. (2024) was to optimize steel trusses adopting a strategy of dynamic grouping [9]. Focusing on constructability, however, made such a design not only structurally efficient but also relatively simpler in construction level and cost. Their approach to optimization was cost-effective and could thus be applicable in most realistic design for industrial shed.

D. Identification of Research Gaps and Areas Requiring Further Exploration

A large amount of research work has been done on the comparative analysis of steel versus Aluminum for industrial sheds construction, but much still remains for the literature. One of those areas includes the environmental impact of different materials throughout their entire life cycle. Even though works like those of Dani et al. (2022) and Ullah et al. (2024) address the aspect of carbon emissions, there can be much more wide-ranging research that addresses long-term maintenance and disassembly stages of structures [10][11]. A suggestion for future research would probably be comparing how Aluminum recyclability fares against steel recyclability when applied under large-scale industrial applications and how embodied energy from both materials would affect overall sustainability.

Another gap the research has found is that there is no standardization in the methodologies for design of Aluminum structures. While methodologies for steel design are well established and accepted, the standards for Aluminum designs are still under development [12]. Research concerning the behavior of Aluminum against various loading conditions and environmental factors at an industrial level is scarce and needs further investigation [13].

And finally, there is much work to be done on hybrids integrating Aluminum and steel to harness the benefits that accrue from both materials [14]. Such systems can optimize the cost, performance, and sustainability of industrial sheds, yet very little work has been done toward investigating such integration in construction.

III. Material Properties

When comparing steel and Aluminum in construction, understanding their mechanical and physical properties, advantages, and limitations is essential for selecting the most suitable material for specific applications. Additionally, factors like cost, availability, and environmental impact play a crucial role in the decision-making process.

A. Mechanical and Physical Properties of Steel and Aluminium

Steel is used widely in construction because of its strength, durability, and versatility. It possesses mechanical properties such as high tensile strength, which may range from 250 MPa to 2000 MPa depending on the specific grade of steel. Steel has high resistance to fatigue, which makes it highly recommended for use in structural applications subjected to dynamic loads. The modulus of elasticity of steel is about 200 GPa, which contributes to its rigidity and strength under stress [15].

$$\sigma = E \cdot \varepsilon \qquad (1)$$

where σ is the stress, EEE is the Young's modulus, and ε is the strain.

As a solid rule, the density of steel remains typically around 7.85 g/cm³. This is dense enough for high strength and weight, which can be disadvantageous in some applications, mainly where weight reduction is important. Aluminum, on the other hand, is synonymous with being lightweight. Its tensile strength usually varies between 70 MPa to 700 MPa according to alloy types [16]. While Aluminum strength is lesser than steel, it is also much lighter (2.7g/cm³). Aluminum can increase strength to a certain limit through various alloying such as with copper, manganese, or silicon, thus making them applicable where both low weight and strength are required. The Young's modulus for Aluminum would approximately equal 70 GPa, lower than that of steel but qualifying for most structural applications.

B. Advantages and Limitations of Each Material

Steel Advantages

- The strength-to-weight ratio of steel is very good, making it possible to achieve thinner sections for structural elements.
- Steel suits many environments and can be formed into complex shapes for numerous applications.
- Steel can be recycled again and again without any compromise in quality and thus qualifies as an environment-friendly material.

Steel Limitations

- In fact, steel is much heavier than Aluminium, which means it can lead to higher transportation costs and complications in handling large-scale constructions [17].
- If steel is not coated or treated properly, it tends to rust in extreme environmental conditions.

Aluminium Advantages

- The low density of Aluminium allows to transport and to handle costs decreased by labour time and supports the possibility of large constructions without compromising strength [18].
- Aluminium has naturally an oxide layer, which protects it from further corrosion, and as such, is applicable for use in marine environments.
- The lightweight property of Aluminium can translate into energy savings in the structures it builds, especially in transportation and aerospace industries.

Aluminium Limitations

- Aluminium's tensile strength is less than steel, thereby making it a poor choice for applications that require high load bearing capacity.
- Aluminium tends to cost more than steel because of production costs and raw material costs.

C. Cost, Availability, and Environmental Impact

Steel is far more common and relatively cheaper than Aluminum, as the price of steel ranges between $500 and $1,500 per ton depending on the type and market conditions, while an Aluminum price that ranges from $2,000 to $3,000 per ton makes it more expensive, though it is gradually decreasing with the advancements in extraction and recycling technologies [19].

TABLE I. COMPARATIVE PROPERTIES OF STEEL AND ALUMINUM

Property	Steel	Aluminum
Tensile Strength (MPa)	250 - 2000	70 - 700
Young's Modulus (GPa)	200	70
Density (g/cm³)	7.85	2.7
Corrosion Resistance	Moderate (needs treatment)	High (self-protecting)
Cost ($ per ton)	500 - 1500	2000 - 3000
Recyclability	100%	100%

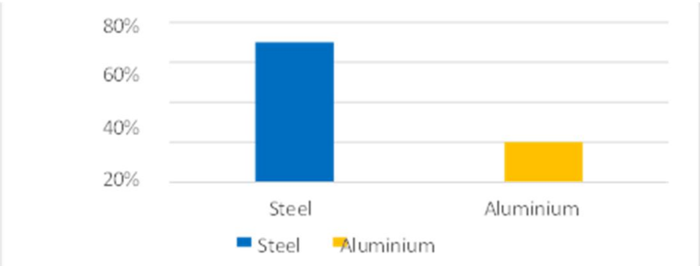

Fig. 2. Comparison of Strength-to-Weight Ratio of Steel and Aluminum

Steel making is said to have a greater carbon footprint compared to the other processes for environmental implications, taking into consideration the very energy- intensive processes involved in extracting iron from ores. Aluminum production, however, is very much energy-fueled; in recent years, recycling technologies have improved greatly, thereby reducing emissions. Aluminum is said to be recyclable, and up to 95% energy can be saved when recycled Aluminum is used instead of the commonly used raw material.

The graph along fig. 2 elaborates a comparison between steel and Aluminum in terms of their weight-to-strength ratios. Although steel has generally higher strength than Aluminum, the lightweight property of Aluminum makes it suitable for specific applications.

It is thus clear that the selection as to whether steel is used or Aluminum depends on the specific requirements of a particular project. Steel is superior to Aluminum in terms of strength and durability, while Aluminum has better qualities in lightweight applications and in benefiting from ideal corrosion resistance. Both are sustainable and recyclable materials, thus making them apt for environmentally friendly construction.

IV. CONCLUSION

This explains the benefits of steel and Aluminum together with some disadvantages while constructing industrial sheds. It is steel that has higher strength and is used mainly in large- scale structures weighing heavy loads. Corrosion is usually a problem with steel; that is why it uses protective coatings and maintenance at regular intervals. Aluminum, however, is lightweight, excellent in corrosion resistance, best ideally under conditions of moisture or at the coast, where weight and durability matter. Although the initial cost of Aluminum is relatively high, sustainability of maintenance and long life can turn it into a more economical long-term option.

Steel is the material of choice in the construction of large industrial sheds because these attributes are main in it. However, Aluminum is advocated in smaller structures or those constructed in warm, moist environments due to its resistance to corrosion and lighter weight, which also aids in decreased transport cost.

Future studies could focus on improving the cost- effectiveness of Aluminum through innovative manufacturing techniques or exploring hybrid designs that combine the strengths of both materials. Modernized coatings and surface treatments for steel will also be critical in improving corrosion resistance, so steel can be more widely used. More importantly, this research will contribute to sustainability practices and recycling options for both materials as aligned with environmental standards.

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