Advances and Challenges of Aluminum Materials in Building Facades: A Comprehensive Review from a Chemical Perspective

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Abstract: This review article discusses the properties, advantages, and challenges associated with the use of aluminum materials in building facades from a chemical perspective. We present a comprehensive analysis of aluminum's material properties, alloy compositions, surface treatments, and environmental impacts. Additionally, we identify research gaps and provide recommendations for future studies to enhance the performance and sustainability of aluminum in building facades. The results contribute to a better understanding of aluminum materials for architects, engineers, and researchers working in the field of facade engineering and materials science.

Keywords: aluminum materials, building facades, alloys, surface treatments, sustainability, fire safety, environmental impact, chemical properties

Introduction

Aluminum materials have been widely used in building facades due to their unique properties, such as high strength-to-weight ratio, corrosion resistance, and recyclability (Baolong, H., Rusong, W., Liang, Y., Hongxiao, L. and Zhonghang, W., 2015).However, the application of aluminum in building facades is not without challenges, including concerns related to fire safety and environmental impacts(Anthony, Y., Timothy, C., Ao Li, Ivan, C., Luzhe, L., Hengrui, L., Anson, L., Qing, C. and Guan, Yeoh. , 2021) and (Aurelija, L., Raimondas, B., Arunas, B. and Tomas, M., 2019).These challenges have led to an increased focus on understanding the use of aluminum in building facades from a chemical perspective. The use of aluminum in building facades has been growing in popularity due to its ability to enhance the overall aesthetics of the building and provide energy efficiency(Kate, N., Pasindu, W., Priyan, M and Tuan, N., 2016). However, the use of aluminum in building facades is not without challenges, with the most significant concern being the fire safety issues that arise from the use of aluminum in building facades(Anthony, Y., Timothy, C., Ao Li, Ivan, C., Luzhe, L., Hengrui, L., Anson, L., Qing, C.

and Guan, Yeoh. , 2021). Additionally, the environmental impact of aluminum production and recycling has been a topic of concern(Jirang, C. and Hans, J, R., 2010). Therefore, there is a need to explore and examine the use of aluminum in building facades from a chemical perspective. This review paper aims to provide a comprehensive understanding of aluminum materials in building facades from a chemical perspective. The review paper will highlight the benefits and drawbacks of using aluminum in building facades, identify research gaps, and provide recommendations for future studies that will enhance the performance and sustainability of aluminum in building facades. The findings of this review paper will be valuable to architects, engineers, and researchers working in the field of facade engineering and materials science, as it will help them to make informed decisions regarding the use of aluminum in building facades.

Methodology

The methodology section of this review paper explains how the research was conducted. A comprehensive literature review was conducted using various databases, including Scopus, Web of Science, and Google Scholar, to gather information on aluminum materials in building facades. The search terms used included "aluminum," "building facades," "alloys," "surface treatments," "sustainability," "fire safety," and "environmental impact."

The literature reviewed was limited to peer-reviewed journal articles, conference proceedings, and books published within the last 20 years to ensure that the findings presented in this review paper are current and relevant. The selected studies were analyzed to extract relevant information, identify research gaps, and develop recommendations for future research.

The data collected from the literature review was then synthesized and analyzed to provide an overview of the current state of knowledge on aluminum materials in building facades from a chemical perspective. The analysis included a comparison of the advantages and disadvantages of using aluminum in building facades, as well as an examination of the fire safety and environmental impact issues associated with aluminum in building facades.

The methodology used in this review paper ensures that the findings presented are reliable, valid, and relevant. The rigorous approach taken in the literature review provides a comprehensive and up-to-date understanding of the use of aluminum in building facades from a chemical perspective. The recommendations developed from the analysis of the literature will help to guide future research in this area and inform decision-making by architects, engineers, and researchers working in the field of facade engineering and materials science.

Literature Review

3.1 Material Properties of Aluminum

Aluminum is an excellent material choice for building facades due to its unique properties, which include a high strength-to-weight ratio and low density. Aluminum is approximately one-third the weight of steel, but it has comparable strength, making it an ideal material for use in building facades (Petersen, 2012)and (Banhart, 2008). The lightweight nature of aluminum also makes it easier to handle and transport, resulting in lower transportation costs and reduced environmental impact.

In addition to its low weight, aluminum has excellent corrosion resistance, thanks to its natural oxide layer. This layer forms on the surface of aluminum when it is exposed to air, and it acts as a protective barrier against further corrosion(Rebecca, F. S. Carlos, F. J. C, Jason, E.T and Eric, J.S., 2017). The oxide layer is chemically stable and prevents the metal underneath from reacting with the environment, which helps to prolong the life of the material(I. Milošev and G. S. Frankel, 2018).

Although the oxide layer provides a certain degree of corrosion resistance, additional surface treatments can further enhance this property. For example, anodizing is a surface treatment process that increases the thickness and density of the oxide layer, making it more durable and resistant to wear and tear(Luca, P., Katya, B., Silvia, G., M. Magrini and Manuele, D., 2014). Anodized aluminum is commonly used in building facades as it provides a high level of corrosion resistance and durability.

Another advantage of aluminum is its excellent thermal conductivity, which allows it to transfer heat quickly and efficiently. This property is particularly useful in building facades, where it can help to regulate indoor temperatures and reduce energy costs. However, the thermal conductivity of aluminum can also be a disadvantage in certain situations, such as in colder climates where heat loss can be a concern (Abderrahim, B., Laurent, I., Magili, F., Evelyne, G. and Jean, C.M., 2004).

Overall, aluminum's material properties make it an excellent choice for building facades. Its low weight, excellent corrosion resistance, and thermal conductivity make it a versatile material that can be used in a variety of facade applications. By understanding the material properties of aluminum, architects, engineers, and researchers can make informed decisions regarding the use of this material in building facades.

3.2 Aluminum Alloys and Compositions

Aluminum alloys are created by adding other elements to pure aluminum, resulting in improved mechanical and chemical properties(Jagan, 2018). The addition of alloying elements changes the crystal structure of aluminum and can create new phases, resulting in a unique set of properties (Thomas, L., Martin, L., Thomas, M., Dagmar, D. and Thomas, L., 2017).Common alloying elements used in aluminum alloys include copper, magnesium, silicon, manganese, and zinc. These elements can improve strength, corrosion resistance, and other properties, depending on the specific alloy composition(R. Orozco, J. Genesca & J. Juarez-Islas , 2007).

Table (1) below provides a simplified overview of the main series of aluminum alloys, their primary alloying elements, common uses, and notable properties. While the table does not include every subcategory of aluminum alloys, it illustrates the diversity and range of properties that different alloying elements can introduce.

Table 1: Overview of Main Aluminum Alloy Series

Alloy Series	**Main Alloying Element**	**Common Uses**	**Notable Properties**
1xxx	Pure Aluminum	Electrical applications, chemical equipment	High corrosion resistance, excellent thermal, and electrical conductivity
2xxx	Copper	Aircraft structures, automotive parts	High strength but lower corrosion resistance
3xxx	Manganese	Cooking utensils, heat exchangers	Medium strength, good workability, formability, and corrosion resistance
4xxx	Silicon	Welding wires, heat-treating applications	Lower melting point, good fluidity
5xxx	Magnesium	Marine applications, automotive parts	High strength, good formability, excellent weldability, good corrosion

			resistance
6xxx	Magnesium & Silicon	Building facades, automotive parts	Good strength and corrosion resistance, excellent formability, and weldability
7xxx	Zinc	Aircraft structures	Very high strength, good machinability

The choice of alloy composition for building facades depends on the specific requirements of the application. For example, the 6xxx series aluminum alloys, containing magnesium and silicon, exhibit good strength and corrosion resistance, making them suitable for building facade applications. The 5xxx series alloys, containing magnesium, have excellent welding and formability properties, making them useful for complex facade designs(Polmear, I. J., StJohn, D. H., Nie, J. F., & Qian, M., 2018).

The alloy composition also affects the material's microstructure and, in turn, influences its mechanical and chemical behavior (Milan, H., Bryan, D. E., Timothy, M. S., Přemysl, B., Veronika, M., Tomáš, K., Jaroslav, P. & Michael, J. M., 2017). Aluminum alloys can be cast or wrought, which can also affect the final material properties. The use of aluminum alloys in building facades requires careful consideration of the specific alloy composition and manufacturing process to ensure that the material meets the required performance and sustainability criteria.

By understanding the role of alloying elements and their impact on the final material properties, architects and engineers can make informed decisions about the selection of aluminum alloys for building facades.

3.3 Surface Treatments for Aluminum Facades

To enhance the performance of aluminum materials in building facades, various surface treatments can be applied (Skuibida, 2022). These treatments may include anodizing, powder coating, and organic coatings (Sheng, W. & Pengcheng, L. , 2016). **Anodizing** is one of the most popular surface treatments for aluminum facades, as it creates a thicker oxide layer, offering increased corrosion resistance and a range of color options. The anodization process involves the electrochemical conversion of aluminum's surface into a durable oxide layer, which can be further modified by incorporating various metal salts or organic dyes(Junghoon, L., Wangryeol, K., Jo-Hyunbin, & Hyunsik, K., 2020). Anodized aluminum is commonly used in building facades due to its high level of corrosion resistance, durability, and aesthetic appeal.

Powder coatings are another popular surface treatment for aluminum facades, providing a protective and decorative finish, with excellent durability and color retention (Wang, Z. L., Li, Q., Han, X. R., Ju, C., Song, H. Q., Li, J. J., Sun, P. Z., & Zhang, F. Y., 2021). The powder coating process involves the electrostatic application of a polymer-based powder, followed by heat curing to create a tough, chemical-resistant layer (Golgoon, A., Aliofkhazraei, M., Toorani, M., Moradi, H. M., & Sabour Roughaghdam, A., 2017). Powder coatings are available in a wide range of colors, textures, and gloss levels, allowing architects and designers to achieve their desired aesthetic effect.

Organic coatings, such as polyvinylidene fluoride (PVDF) and fluoropolymer coatings, are also used for their high resistance to UV radiation, chalking, and fading. These coatings are typically applied using a coil-coating or spray-coating process, creating a thin, uniform layer that adheres to the aluminum surface (Robert, 2015). PVDF coatings are commonly used in high-performance building facades, as they offer excellent durability and color retention, even in harsh environments.

Surface treatments play a critical role in enhancing the performance and durability of aluminum materials in building facades. To provide a clearer understanding of the different surface treatment processes, their benefits, and potential drawbacks, the following table compares anodizing, powder coating, and organic coating processes:

Table 2: Comparison of Anodizing, Powder Coating, and Organic Coating Processes for Aluminum Facades

	Anodizing	**Powder Coating**	**Organic Coating**
Preparation Process	Cleaning, Acid etching, Desmutting	Degreasing, Etching, Chromating	Cleaning, Surface preparation
Application Process	Electrochemical Anodization	Electrostatic Application, Heat Curing	Coil-Coating or Spray-Coating
Main Benefits	Corrosion resistance, Aesthetic appeal	Durability, Color retention	UV resistance, Chalking and fading resistance
Commonly Used For	Building Facades	Building Facades	High-performance building facades
Drawbacks	Energy-intensive	Require specific conditions for application	Possible environmental impact

By understanding the available surface treatment options and their respective advantages and limitations, architects and engineers can make informed decisions about the selection of surface treatments to ensure that the material meets the required performance and sustainability criteria.

3.4 Environmental Impacts of Aluminum Materials

Aluminum production is energy-intensive and generates significant greenhouse gas emissions (Ning, D., Ning, L., Bin, L., & Jianxin, Y., 2021). The primary production of aluminum involves the electrolytic reduction of aluminum oxide, which requires a large amount of electricity and results in significant emissions of greenhouse gases, including carbon dioxide and perfluorocarbons(Bouzouni, M., & Papaefthymiou, S., 2021). However, aluminum's recyclability and long service life help offset some of these environmental impacts(Carlisle, S., & Friedlander, E., 2016).

Recycling aluminum requires only 5% of the energy used in primary production, resulting in a significant reduction of greenhouse gas emissions. Recycling also helps reduce the demand for primary aluminum production, thereby reducing the energy consumption and greenhouse gas emissions associated with primary production. The use of recycled aluminum in building facades can further contribute to the overall sustainability of a building project (Skuibida, 2022). The environmental benefits of using recycled aluminum in building facades include reduced energy consumption, greenhouse gas emissions, and the conservation of natural resources.

The chemical composition of recycled aluminum materials may vary depending on the source, and understanding the impact of these variations on the material's performance and environmental footprint is essential for optimizing their use in building facades (Nurul, F.M.J., Noradila, A.L., Sukri, M., Nur-Azam, B.,& Faisal, M., 2020). With proper sorting and processing, recycled aluminum can meet the required performance and sustainability criteria for building facades, providing an environmentally responsible and cost-effective material option.

The environmental impacts of aluminum materials in building facades must be carefully considered throughout the material's life cycle, from production to disposal. By understanding the environmental impact of aluminum materials and incorporating sustainable practices into the design and construction process, architects and engineers can reduce the environmental footprint of building facades.

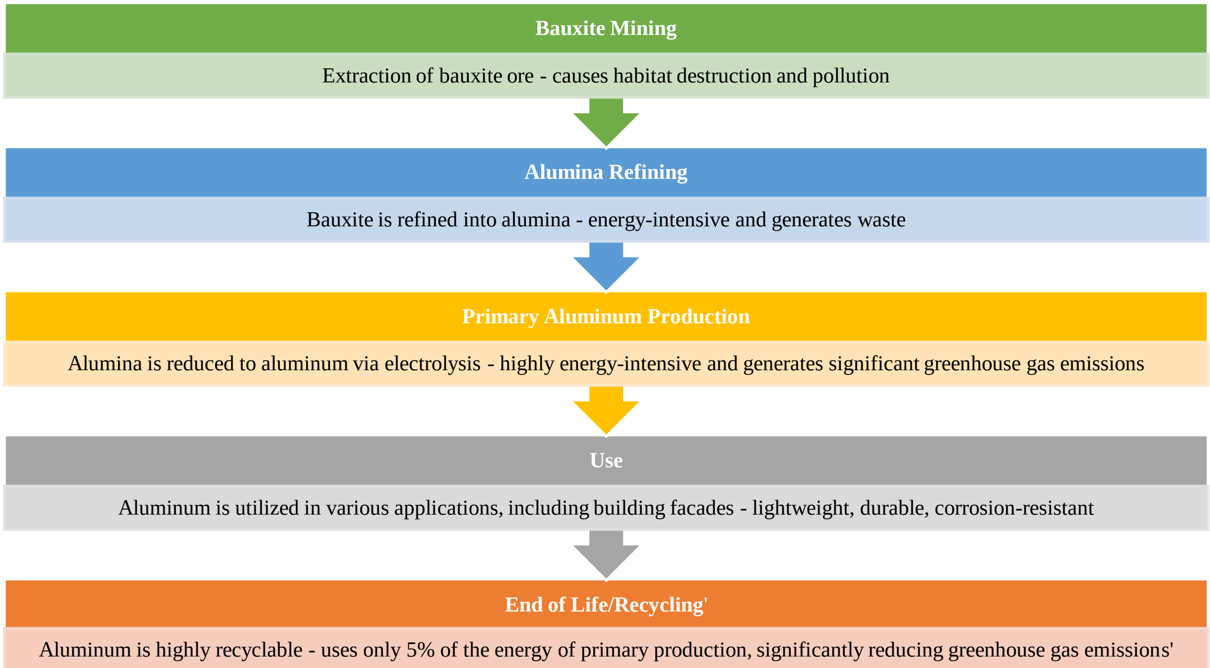

Figure 1: Environmental Impact of Aluminum Life Cycle

This flowchart outlines the key stages of the aluminum life cycle, from bauxite mining to alumina refining, primary aluminum production, use, and end-of-life treatment including recycling. It encapsulates the environmental implications at each stage, drawing attention to the energy-intensiveness of aluminum production and the significant benefits of recycling, including a notable reduction in energy use and greenhouse gas emissions.

The sequential stages represented in the flowchart include:

Bauxite Mining: At this initial stage, bauxite, the main source of aluminum, is mined from the earth. This phase has substantial environmental implications such as habitat destruction and pollution.

Alumina Refining: Here, bauxite is refined into alumina, or aluminum oxide, a process that requires significant energy and produces waste.

Primary Aluminum Production: This involves the electrolysis of alumina to produce aluminum. This step is highly energy-consuming and results in substantial greenhouse gas emissions.

Use: Aluminum is used in a myriad of applications, including building facades, due to its lightweight, durable, and corrosion-resistant properties.

End of Life/Recycling: At this stage, aluminum's high recyclability comes into play. Recycling aluminum consumes only 5% of the energy used in primary production, significantly reducing greenhouse gas emissions(Gang, L., & Daniel, B. M. , 2013).

The flowchart serves to illustrate and emphasize the environmental impact of each stage in the aluminum life cycle. It underscores the importance of understanding these impacts for architects and engineers when making material decisions for building facades, highlighting particularly the critical role of recycling in minimizing aluminum's environmental footprint.

3.5 Fire Safety of Aluminum Materials

Concerns about the fire safety of aluminum materials in building facades have arisen due to their potential involvement in the spread of flames in certain building fires (Chinnasami, S., Chidambaram, P.K., Ramachandran, M., & Ashwini, M., 2022). Although aluminum itself is non-combustible, its melting point is relatively low, around 660°C (1,220°F), which may contribute to structural failures in extreme heat (Hyun-Yong, L., Gun-Hong, J., Heon, K., & Jong-Bin, Y., 2017). In addition, some surface treatments and coatings, such as certain organic coatings, may contribute to the spread of flames and generate toxic fumes during combustion (Thirumal, 2017).

Table 3: Fire Safety Considerations for Aluminum Materials

Consideration	Description	Example Standard/Test
Melting Point	Aluminum melts at around 660°C, which can contribute to structural failures in extreme heat.	N/A
Flame Spread	Certain surface treatments and coatings can contribute to flame spread.	ASTM E84

Toxic Fumes	Certain surface treatments and coatings can generate toxic fumes during combustion.	ASTM E800
Fire Resistance	Evaluates the ability of a structural element to resist fire.	ASTM E119

The fire performance of aluminum materials, including their alloys and surface treatments, is crucial to ensure the appropriate selection and design of aluminum facades. Various tests and standards have been developed to assess the fire performance of building materials, including aluminum facades. For example, the American Society for Testing and Materials (ASTM) has developed a range of fire tests for evaluating the fire performance of building materials, including ASTM E119, which tests the fire resistance of structural elements(Kate TQ Nguyen, Pasindu, W., Mendis, P., & Ngo, T. , 2016). Similarly, the International Code Council (ICC) has developed the International Building Code (IBC), which sets minimum requirements for building design and construction, including fire safety measures(Marcelo, 2017).

To ensure the fire safety of aluminum materials in building facades, it is essential to consider the material's fire performance, along with other design factors such as building height, occupancy, and fire suppression systems. Additionally, the appropriate selection and installation of fire-rated assemblies and systems can help mitigate the potential risks associated with aluminum facades in building fires.

Further research is needed to develop more advanced testing methods and computational models for assessing the fire performance of aluminum facades, as well as to identify effective design strategies and fire protection measures for aluminum facades in building fires.

4. Research Gaps and Recommendations

Based on the comprehensive literature review, several research gaps have been identified which provide potential avenues for future investigations aligned with our study's aim and methodology:

1. The formulation of new aluminum alloys featuring enhanced mechanical properties, superior corrosion resistance, and improved fire safety. This involves modifying the alloys' chemical compositions and adjusting processing techniques. It is a key area that aligns with our aim to improve the performance of aluminum materials in building facades (Pfeiffer, O.P., Liu, H., Montanelli, L., Marat, I.L., Fatih, G.S., Vishwanath, H., Elsa, A.O., & Eric, R. H., 2022).
2. The development and optimization of innovative surface treatments and coatings. These not only enhance protection against corrosion, UV radiation, and fire but also take into account the chemical compatibility with various aluminum alloys. This area directly relates to our objective of enhancing the durability and aesthetic appeal of aluminum facades (Dong, G., Ma, F., & Wang, G., 2016).
3. The investigation into novel recycling techniques and strategies aimed at optimizing the usage of recycled aluminum materials in building facades, while preserving their performance and environmental advantages. This corresponds to our goal of promoting the sustainable use of aluminum in building construction (Skuibida, 2022).
4. The assessment of the long-term performance of aluminum facades, considering factors such as corrosion, material degradation, and environmental impacts (Elkhayat, Y., Hamada, M., & Wahba, M., 2023). This is critical to our methodology of examining the life cycle impacts of aluminum usage in building facades.

In light of these identified research gaps, we recommend the following actions for future studies:

1. Conduct research into new aluminum alloys with superior characteristics, keeping in mind the requirements of building facades.
2. Advance the development of novel surface treatments and coatings, considering their interactions with various aluminum alloys.
3. Promote the use of recycled aluminum in building facades, while devising strategies to minimize potential adverse effects due to variations in the chemical composition of recycled materials.
4. Foster collaboration among architects, engineers, and materials scientists to optimize the design and performance of aluminum facades, taking into account factors such as alloy selection, surface treatments, and environmental conditions.

By aligning the identified gaps with our research objectives and following the proposed recommendations, future research can substantially contribute to advancing the knowledge in the field of aluminum usage in building facades.

5.Conclusion

This research has critically examined the applications, challenges, and opportunities associated with the use of aluminum materials in building facades. It has become evident that aluminum, with its high strength-to-weight ratio, corrosion resistance, and recyclability, serves as a promising material for facade construction. Furthermore, tailoring the chemical composition of aluminum alloys and surface treatments opens the potential for enhanced specific properties, enabling their effective use in various building applications.

Nonetheless, our study identified significant challenges associated with the fire safety and environmental impact of aluminum materials, which warrant further research and development efforts. In addressing fire safety, future research should concentrate on developing new aluminum alloys and surface treatments to enhance fire resistance while preserving other beneficial properties. Understanding the fire performance of aluminum materials, inclusive of their alloys and surface treatments, will indeed be a crucial component in safe and effective aluminum facade design.

Regarding the environmental impact, our research underscores the need to explore innovative recycling techniques and strategies. The objective is to optimize the use of recycled aluminum materials in building facades while maintaining their performance and environmental advantages. Long-term performance evaluation of aluminum facades, considering factors such as corrosion, material degradation, and environmental impacts, also emerged as a key research necessity.

In conclusion, a thorough understanding of the chemical properties and behaviors of aluminum materials in building facades is paramount to ensuring their performance, safety, and sustainability. By addressing the identified research gaps and implementing the provided recommendations, our study contributes to the ongoing effort to optimize the use of aluminum in building facades. Ultimately, such efforts can significantly enhance the overall sustainability of building projects and shape the future of environmentally conscious architectural design.

Further Research

While this study has provided insights into the use of aluminum materials in building facades, certain areas warrant additional investigation to deepen our understanding and optimize their application.

1. **In-depth Study on Fire Safety**: Despite understanding the general fire safety concerns associated with aluminum materials, further studies focusing on real-world scenarios, and the effectiveness of different fire-suppression systems, would be beneficial.
2. **Investigating the Lifecycle Impact of Aluminum**: A holistic investigation into the life cycle impact of aluminum, including detailed environmental and economic impact analyses, could provide more nuanced insights for sustainable architectural design practices.
3. **Exploring New Material Combinations**: Combining aluminum with other materials might yield enhanced properties. Future research could focus on exploring such combinations and understanding their implications for building facade applications.

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References

Baolong, H., Rusong, W., Liang, Y., Hongxiao, L. and Zhonghang, W. (2015). Life cycle assessment of ceramic façade material and its comparative analysis with three other common façade materials. *Journal of Cleaner Production*, 86-93.

Anthony, Y., Timothy, C., Ao Li, Ivan, C., Luzhe, L., Hengrui, L., Anson, L., Qing, C. and Guan, Yeoh. . (2021). Evaluating the fire risk associated with cladding panels: An overview of fire incidents, policies, and future perspective in fire standards. *International journal of fire and materials*, 663-689.

Aurelija, L., Raimondas, B., Arunas, B. and Tomas, M. (2019). Dependencies of heat transmittance through the ventilated wall system on thermal conductivity of connectors crossing thermal insulation layer. *4th Central European Symposium on Building Physics (CESBP 2019)* (p. 02089). MATEC Web.

Kate, N., Pasindu, W., Priyan, M and Tuan, N. (2016). Performance of modern building façades in fire: a comprehensive review. *Electronic Journal of Structural Engineering, 16*, 69-87. doi: 10.56748/ejse.16212.

Jirang, C. and Hans, J, R. (2010). Recycling of automotive aluminum. *Transactions of Nonferrous Metals Society of China*, 2057-2063. https://doi.org/10.1016/S1003-6326(09)60417-9.

Petersen, R. (2012). *Handbook of aluminum: Vol. 1: Physical metallurgy and processes.* CRC Press.

Banhart, J. (2008). Aluminium alloys for structural applications. *Advanced Engineering Materials, 10(1-2)*, 26-33.

Rebecca, F. S. Carlos, F. J. C, Jason, E.T and Eric, J.S. (2017). The controlling role of sodium and carbonate on the atmospheric corrosion rate of aluminum. *NPJ Materials Degradation 1,20*, 1-8. doi:10.1038/s41529-017-0020-3.

I. Milošev and G. S. Frankel. (2018). Review—Conversion Coatings Based on Zirconium and/or Titanium. *Journal of The Electrochemical Society, 165(3)*, 127-144 . DOI 10.1149/2.0371803jes.

Luca, P., Katya, B., Silvia, G., M. Magrini and Manuele, D. (2014). Effect of process parameters of plasma electrolytic oxidation on microstructure and corrosion properties of magnesium alloys. *Journal of Applied Electrochemistry, 44*, 867-897. https://doi.org/10.1007/s10800-014-0695-x.

Abderrahim, B., Laurent, I., Magili, F., Evelyne, G. and Jean, C.M. (2004). Thermophysical properties of polypropylene/aluminum composites. *Journal of Polymer Science, 42(4),*, 722-732. https://doi.org/10.1002/polb.10713.

Jagan, N. (2018). *Aluminum Castings Engineering Guide.* ASM International.

Thomas, L., Martin, L., Thomas, M., Dagmar, D. and Thomas, L. (2017). The Phase Composition and Microstructure of AlxCoCrFeNiTi Alloys for the Development of High-Entropy Alloy Systems. *Metals, 7(5),*, 162. https://doi.org/10.3390/met7050162.

R. Orozco, J. Genesca & J. Juarez-Islas . (2007). Effect of Mg Content on the Performance of Al-Zn-Mg Sacrificial Anodes. *Journal of Materials Engineering and Performance,16*, 229-235. https://doi.org/10.1007/s11665-007-9037-z.

Polmear, I. J., StJohn, D. H., Nie, J. F., & Qian, M. (2018). *Light alloys: Metallurgy of the light metals.* Butterworth-Heinemann.

Milan, H., Bryan, D. E., Timothy, M. S., Přemysl, B., Veronika, M., Tomáš, K., Jaroslav, P. & Michael, J. M. (2017). On the origin of extraordinary cyclic strengthening of the austenitic stainless steel Sanicro 25 during fatigue at 700 °C. *Journal of Materials Research, 32*, 4342-4353.

Skuibida, O. (2022). Green Aluminium: Trends and Prospects. *Grail of Sceience, 18(19)*, 165-169. https://doi.org/10.36074/grail-of-science.26.08.2022.29.

Sheng, W. & Pengcheng, L. . (2016). The technology of preparing green coating by conducting micro-arc oxidation on AZ91D magnesium alloy. *Polish Journal of Chemical Technology, 18(4),* 36-40. https://doi.org/10.1515/pjct-2016-0068.

Junghoon, L., Wangryeol, K., Jo-Hyunbin, & Hyunsik, K. (2020). Low Temperature Sealing of Anodized Aluminum for Enhancing Corrosion Resistance. *The Electorchemical Society*, 3554. DOI 10.1149/MA2020-02683554mtgabs.

Wang, Z. L., Li, Q., Han, X. R., Ju, C., Song, H. Q., Li, J. J., Sun, P. Z., & Zhang, F. Y. (2021). Reaction mechanism of Ni-Al during thermal spraying. *Digest Journal of Nanomaterials and Biostructures, 16(4)*, 1295-1311.

Golgoon, A., Aliofkhazraei, M., Toorani, M., Moradi, H. M., & Sabour Roughaghdam, A. (2017). Corrosion and wear behavior of alumina-polyester nanocomposite coatings. *Polymer Engineering & Science, 57(8),* 846-856. https://doi.org/10.1002/pen.24461.

Robert, A. L. (2015). Polyvinylidene Fluoride-Based Coatings Technology. In B. Kenneth, *Protective Organic Coating* (pp. 80-87. https://doi.org/10.31399/asm.hb.v05b.a0006031). ASM International.

Ning, D., Ning, L., Bin, L., & Jianxin, Y. (2021). Life cycle greenhouse gas emissions of aluminum based on regional industrial transfer in China. *Journal of Industrial Ecology, 25(6)*, 1657-1672. https://doi.org/10.1111/jiec.13146.

Bouzouni, M., & Papaefthymiou, S. (2021). How to Design the Utilization of Larger Scrap Share in Aluminum Production. *Material Proceeding, 5(1)*, 5043. https://doi.org/10.3390/materproc2021005043.

Carlisle, S., & Friedlander, E. (2016). The influence of durability and recycling on life cycle impacts of window frame assemblies. *The International Journal of Life Cycle Assessment, 21*, 1645-1657. https://doi.org/10.1007/s11367-016-1093-x.

Nurul, F.M.J., Noradila, A.L., Sukri, M., Nur-Azam, B.,& Faisal, M. (2020). Physical Properties and Hardness of Treated Amorphous Silica as Reinforcement of AA7075 Recycled Aluminum Chip. *IOP Conference Series: Materials Science and Engineering, Volume 824, 10th International Conference on Mechanical and Manufacturing Engineering (ICME2019)* (pp. 012015. DOI 10.1088/1757-899X/824/1/012015). IOP Science.

Chinnasami, S., Chidambaram, P.K., Ramachandran, M., & Ashwini, M. (2022). Performance Analysis of Facade Materials using VIKOR Method. *REST Journal on Advances in Mechanical Engineering, 1(2)*, 41-49. DOI: https://doi.org/10.46632/jame/1/2/6.

Hyun-Yong, L., Gun-Hong, J., Heon, K., & Jong-Bin, Y. (2017). Evaluations of Sb20Se80-xGex (x = 10, 15, 20, and 25) Glass Stability from Thermal, Structural and Optical Properties for IR Lens Application. *Jounal of Korean Ceramic Society, 54(6)*, 481-491. DOI: https://doi.org/10.4191/kcers.2017.54.6.08.

Thirumal, M. (2017). Fire Retardant Coatings. In G. &. Carlos, *New Technologies in Protective Coatings* (p. 67675. DOI: 10.5772/67675). Intech.

Kate TQ Nguyen, Pasindu, W., Mendis, P., & Ngo, T. . (2016). Performance of modern building façades in fire: a comprehensive review. *Electronic Journal of Structural Engineering, 16,* 69-87. https://doi.org/10.56748/ejse.16212.

Marcelo, M. (2017). Procedures for development and revision of codes and standards associated with fire safety in the USA . *Fire and Materials, 41(8),* 1058-1071. https://doi.org/10.1002/fam.2449.

Pfeiffer, O.P., Liu, H., Montanelli, L., Marat, I.L., Fatih, G.S., Vishwanath, H., Elsa, A.O., & Eric, R. H. (2022). Aluminum alloy compositions and properties extracted from a corpus of scientific manuscripts and US patents. *Scientific Data, 9(128),* NA. https://doi.org/10.1038/s41597-022-01215-7.

Dong, G., Ma, F., & Wang, G. (2016). Effect of SiO2 Sol Sealing on Corrosion Resistance of Anodic Films of AZ31 Mg Alloy. *Rare Metal Materials and Engineering, 45(1),* 66-70. https://doi.org/10.1016/S1875-5372(16)30048-0.

Elkhayat, Y., Hamada, M., & Wahba, M. (2023). Visual Comfort as a Design Approach for Intelligent facades: A review. *Delta University Scientific Journal, 6(1),* 371-386. doi: 10.21608/dusj.2023.291086.

Gang, L., & Daniel, B. M. . (2013). Centennial Evolution of Aluminum In-Use Stocks on Our Aluminized Planet. *Environmental Science & Technology, 47(9),* 4882-4888. https://doi.org/10.1021/es305108p.