



A REVIEW AND REFLECTION OF THE POTENTIAL USES OF NEW GRADE TITANIUM ALUMINIDES IN THE ELECTRICAL INDUSTRY

Pranav Ravindrannair, Research Scholar, Department of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad

Dr K. Kishore, Professor, Department of Mechanical Engineering, Vasavi College of Engineering, Hyderabad

Dr P. Laxminarayana, Senior Professor, Department of Mechanical Engineering, University College of Engineering, Osmania University, Hyderabad

ABSTRACT

Titanium aluminides (TiAl) have garnered considerable interest across multiple industries owing to their remarkable mechanical properties, low density, and resistance to high temperatures. The present study aims to investigate the potential applications of newly developed-grade titanium aluminides in the electrical industry. The goal of this research is to elucidate the advantages that these materials offer in comparison to conventional materials currently used in the industry. Titanium aluminides are known for their exceptional properties, including a high strength-to-weight ratio, corrosion resistance, and electrical conductivity. These characteristics make them highly suitable for various applications, such as electrical components, conductive materials, and protective coatings. Furthermore, the advancements in manufacturing techniques and the development of new alloy compositions have significantly improved the suitability of titanium aluminides for electrical applications, thereby facilitating their wider acceptance and utilization. The present review aims to provide a comprehensive analysis of the challenges and opportunities that arise when integrating titanium aluminides into electrical designs. The discussion encompasses a variety of factors, including cost considerations, processing methods, and material properties optimization. In addition, this study delves into current research efforts and possible future avenues for maximizing the advantages of these groundbreaking materials. The ultimate objective is to enhance the effectiveness, functionality, and environmental friendliness of electrical systems.

Keywords: Titanium Aluminides, Electrical Industry, Conductive Materials, Protective Coatings, High-Temperature Stability

I. Introduction

The pursuit of advanced materials with enhanced performance, durability, and sustainability is a perpetual endeavor within the electrical industry. Titanium Aluminides (TiAl) have garnered significant attention as potential materials for various applications, primarily due to their remarkable mechanical and thermal properties. These properties make them highly attractive for use in industries such as aerospace, automotive, and energy. The combination of titanium and aluminum in TiAl alloys results in a unique microstructure, which contributes to their desirable characteristics. The exceptional strength-to-weight ratio, excellent high-temperature stability, and outstanding corrosion resistance exhibited by TiAl alloys make them suitable for demanding environments. Furthermore, their low density and high melting point make them more appealing for lightweight structural applications.

Researchers continue to optimize processing techniques and alloy compositions to enhance the performance of TiAl alloys and broaden their applications. The present section aims to offer a thorough analysis of the diverse potential applications of titanium aluminides in the field of electrical engineering, with a specific emphasis on their comparative advantages over conventional materials like copper and aluminum. People widely recognize titanium aluminides for their exceptional strength-to-weight ratio, outstanding resistance to corrosion, and remarkable stability at high temperatures. These unique properties make them extremely well-suited for a wide range of electrical applications. In addition, the

advancements in alloy compositions and manufacturing processes have greatly improved their suitability for large-scale manufacturing.

The objective of this study is to conduct an analysis of the various opportunities and challenges that arise from the incorporation of titanium aluminides in electrical designs. Specifically, this research will concentrate on examining the impact of cost, processing techniques, and the optimization of material properties. Conducting an examination of the existing body of research and exploring potential future directions is of utmost importance in order to fully exploit the benefits provided by these cutting-edge materials. The ultimate goal is to improve the efficiency, performance, and sustainability of electrical systems.

II. Properties and Advantages of Titanium Aluminides

Titanium aluminides possess a distinctive array of characteristics that render them highly appealing for application in the electrical industry. These materials' high strength-to-weight ratio offers significant advantages in terms of weight reduction for electrical components, potentially enhancing their overall efficiency and performance. Furthermore, it is worth noting that the remarkable corrosion resistance exhibited by titanium aluminides plays a crucial role in guaranteeing prolonged durability even in the presence of harsh environmental conditions. This, in turn, leads to a reduction in maintenance expenses and a significant improvement in the overall reliability of electrical systems.

Titanium aluminides possess excellent high-temperature stability, rendering them highly suitable for a wide range of applications that entail significant thermal loads. These applications include using titanium aluminides as conductive materials and protective coatings for electrical components. In addition, it is worth noting that titanium aluminides exhibit electrical conductivity levels that, although not on par with copper, are deemed satisfactory for specific applications where their unique set of properties presents notable benefits. The characteristics of titanium aluminides position them as superior alternatives to traditional materials in a variety of electrical applications.

III. Electrical components manufactured using Titanium Aluminides

3.1 Conductive Materials

Researchers have found that titanium aluminides exhibit a unique combination of electrical conductivity and remarkable mechanical properties, making them suitable for specific electrical applications. While they may not possess the same level of conductivity as conventional materials such as copper, their inherent characteristics make them a promising alternative. The application of power transmission lines, connectors, and terminals can potentially offer numerous advantages.

Power Transmission Lines: Power transmission lines, commonly used for transmitting electrical energy over long distances, are typically constructed using materials with high conductivity, such as aluminum or copper. We choose these materials because they efficiently carry electrical current and minimize power losses during transmission. Applications that require a combination of reduced weight and enhanced mechanical strength can potentially utilize titanium aluminides. As an illustration, it is worth noting that in the context of overhead power lines, the utilization of titanium aluminide cables with reduced weight can potentially lead to a decrease in sag and a reduction in mechanical stress exerted on support structures. The weight reduction has the potential to facilitate the installation process and result in lower maintenance costs. Furthermore, it is worth noting that the cables in question possess a remarkable strength-to-weight ratio, which makes them exceptionally capable of enduring various environmental pressures, including but not limited to wind and ice loads.

However, the challenges encountered in the manufacturing of power transmission lines are numerous and diverse. These challenges can arise at various stages of the manufacturing process, from the initial design and engineering phase to the actual production and assembly of the transmission lines. One of the primary challenges is ensuring the structural integrity and reliability of the transmission lines. Power transmission lines

The optimization of conductivity in titanium aluminides poses a significant challenge because it requires striking a balance between achieving sufficient electrical conductivity and preserving the material's desirable mechanical properties. The alloy composition should be carefully optimized.

Processing techniques are methods or procedures used to transform raw materials or data into a desired form or output. These techniques entail a systematic series of steps or operations. Long, uniform cables necessitate the utilization of advanced processing techniques. Ensuring uniformity in the characteristics of the cable throughout its entire length poses a significant challenge.

Compared to conventional materials commonly used in power transmission infrastructure, titanium aluminides tend to have a higher price point. This higher cost can potentially lead to an increase in the overall expenditure associated with the development and maintenance of such infrastructure.

Connectors and Terminals: Connectors and terminals, when fabricated using titanium aluminides, can derive advantages from the material's exceptional strength and resistance to corrosion. To get these parts to work at their best, they often need to be in a delicate balance between how well they conduct electricity and how long they last, especially when they are in harsh environments. Researchers have found that titanium aluminides exhibit advantageous characteristics such as enhanced durability and dependability, which reduces the need for frequent replacements and maintenance activities. The robust mechanical strength of connectors and terminals ensures that a reliable and steady connection is maintained even when subjected to mechanical stress and vibration.

The manufacturing of connectors and terminals presents numerous challenges. Within the field of precision manufacturing, it is imperative to maintain a high level of precision in order to guarantee the proper fit and electrical integrity of connectors and terminals. Surface treatment plays a crucial role in improving conductivity and corrosion resistance. To achieve optimal results, it is essential to employ sophisticated techniques and maintain strict quality control measures. The higher cost of titanium aluminides compared to conventional materials such as copper or brass may pose a significant obstacle to their widespread adoption.

3.2 Protective Coatings

Titanium aluminides, intermetallic compounds composed of titanium and aluminum, possess unique properties such as high strength, excellent oxidation resistance, high-temperature stability, and corrosion resistance. These properties make them highly suitable for protective coatings on a wide range of electrical components, offering a barrier against environmental degradation, thermal stress, and electrical arcing.

Environmental Degradation Protection: Electrical components exposed to outdoor environments are vulnerable to corrosion and weathering, which can significantly impact their performance and longevity. Titanium aluminide coatings provide an effective barrier against oxidation and corrosion, significantly enhancing the durability and longevity of components such as switchgear, transformers, and outdoor junction boxes. Benefits include enhanced reliability and reduced maintenance costs.

Challenges in Coating Production: Producing protective coatings involves several challenges, including issues with coating formulation, selecting suitable raw materials, and optimizing manufacturing processes. Achieving uniform coating on intricate geometries requires meticulous control of the coating procedure. Ensuring strong adhesion between the coating and the substrate is crucial for maintaining the integrity and longevity of the coating. Additionally, advanced coating processes and the use of titanium aluminide materials can be expensive.

Thermal Stress Resistance: Titanium aluminide coatings are effective in protecting components in power generation and high-power electrical systems against thermal degradation and distortion. For example, in high-voltage circuit breakers, these coatings prevent thermal damage to critical components, ensuring consistent performance and safety. Challenges include ensuring consistent thickness to prevent cracking or delamination due to thermal expansion mismatch and maintaining precise control over coating thickness and composition for effective thermal protection.

Electrical Arcing Protection: Electrical arcing can cause extensive damage to electrical components. Titanium aluminide coatings, resistant to high temperatures and thermal shock, safeguard underlying components, maintaining system integrity. Challenges in manufacturing these coatings include maintaining the desired level of electrical resistance and ensuring that coatings withstand extreme temperatures generated during electrical arcing.

3.3 High-Temperature Insulators

Titanium aluminides are promising materials for high-temperature insulators due to their high melting point and excellent thermal stability. They are ideal for applications in power generation and distribution equipment, preventing electrical shorts and maintaining safety. The production of high-purity materials is essential to maintain consistent insulating properties, but achieving this level of purity can be challenging. Minimizing thermal expansion to prevent mechanical failure is crucial, as is managing the high costs associated with producing high-purity titanium aluminide insulators.

Titanium aluminides offer significant benefits as protective coatings and high-temperature insulators for electrical components. However, the production process faces numerous challenges, including achieving coating uniformity, ensuring strong adhesion, maintaining electrical resistance, and managing costs. Addressing these challenges is crucial for leveraging the full potential of titanium aluminides in industrial applications.

3.4 Magnetic Shielding

Titanium aluminides have been found to possess exceptional properties that render them highly suitable for utilization in magnetic shielding applications. Specifically, these materials have demonstrated remarkable effectiveness in safeguarding delicate electronic components against the detrimental effects of electromagnetic interference (EMI).

Importance of Electrical Enclosures and Housings: Electrical enclosures and housings play a critical role in protecting sensitive electronics from electromagnetic interference (EMI) in environments characterized by high electromagnetic fields. These environments, which may include areas in close proximity to large transformers or high-voltage transmission lines, pose a significant risk to the proper functioning of electronic devices. Shielding electronics from EMI is of utmost importance in order to maintain their performance and prevent any potential damage or malfunction caused by the disruptive effects of electromagnetic fields. The protection offered by titanium aluminide enclosures and housings is attributed to their unique capability to both absorb and reflect electromagnetic waves. By implementing this measure, the stable operation of sensitive equipment, including control systems, communication devices, and sensors, is guaranteed.

Challenges in Manufacturing Magnetic Shielding: The challenges in manufacturing magnetic shielding are numerous and require careful consideration. Magnetic shielding is essential in various industries, including electronics, aerospace, and medical devices, to protect sensitive equipment from the effects of magnetic fields. However, the manufacturing process of magnetic shielding poses several challenges that need to be addressed. One significant challenge is optimizing the material composition to maximize magnetic shielding effectiveness while ensuring that mechanical properties are maintained. Additionally, manufacturing complex shapes and enclosures with uniform shielding properties can pose significant challenges in the manufacturing process. The exorbitant cost associated with titanium aluminide materials and the utilization of advanced manufacturing techniques can also pose a significant obstacle to the widespread adoption of these materials.

Electronics in Harsh Environments: In the context of electronics employed in challenging environments, such as industrial settings or military applications, the implementation of titanium aluminide shielding can effectively mitigate the risks posed by both mechanical and electromagnetic threats. The reliable operation of these devices is ensured by the combination of mechanical strength and electromagnetic interference (EMI) shielding, even in challenging conditions. The challenges associated with manufacturing shielding for harsh environments are numerous and complex. These

challenges arise due to the extreme conditions that the shielding materials need to withstand, such as high temperatures, corrosive chemicals, and intense mechanical stress.

Durability and Integration: Regarding durability, it is crucial to ensure that the shielding material has the ability to withstand various harsh environmental conditions. These conditions may include temperature extremes, moisture, and physical impacts. It is important to assess the material's resilience and ability to maintain its protective properties under such circumstances. The focus of this study is on the integration of the shielding material with other components while ensuring that the performance is not compromised. The production and implementation of titanium aluminide shielding materials are accompanied by high costs, which can influence their adoption.

IV. Manufacturing techniques for Titanium Aluminides

The production of titanium aluminide components for the electrical industry encompasses a range of sophisticated manufacturing techniques. The implementation of these methods guarantees that the various components exhibit the essential characteristics required for consistent and dependable performance in challenging and rigorous settings. Below is a comprehensive elucidation of these methodologies in relation to electrical components.

4.1 Casting and Forging

The production of high-strength titanium aluminide components often involves traditional techniques such as casting and forging. Casting involves the utilization of molds to facilitate the pouring of molten titanium aluminide, resulting in the formation of specific shapes. On the other hand, forging is a technique that involves the application of compressive forces to shape the material. The effectiveness of these methods is frequently augmented through secondary processes such as hot isostatic pressing (HIP). HIP subjects cast or forged parts to elevated temperatures and pressures, ensuring uniform application and eliminating internal voids within the parts. Consequently, the mechanical properties and density of the parts are significantly enhanced. For electrical components, this results in the production of durable parts capable of enduring mechanical strains and elevated temperatures, which are crucial for applications such as switchgear and transformers.

4.2 Powder Metallurgy

The process of powder metallurgy entails the meticulous blending of fine powders of titanium aluminide, followed by the compaction of these powders into a desired shape. Subsequently, the compacted powders are subjected to high temperatures during the sintering process, resulting in the formation of a solid component. This method enables precise control over the alloy composition and microstructure, yielding titanium aluminide components of exceptional quality with uniform properties. In electrical applications, powder metallurgy is highly advantageous for fabricating conductive materials and developing protective coatings. The meticulous management of the material's characteristics guarantees optimal electrical conductivity and improved surface protection, crucial for components subjected to challenging operational conditions.

4.3 Additive Manufacturing

Additive manufacturing, more commonly referred to as 3D printing, presents notable benefits in fabricating intricate shapes and minimizing material inefficiencies. Techniques such as electron beam melting (EBM) and selective laser melting (SLM) are highly efficient in producing complex titanium aluminide parts. EBM and SLM involve layer-by-layer melting and fusing of titanium aluminide powder to fabricate components with exceptional precision. This capability is particularly advantageous for electrical components that require intricate geometries and internal configurations, such as heat sinks and enclosures designed for delicate electronic devices. The high precision and material efficiency of additive manufacturing contribute to reducing production costs and accelerating prototyping processes.

4.4 Surface Treatments



Various surface treatment techniques, including anodizing and thermal spraying, are utilized to improve the surface characteristics of titanium aluminide components. Anodizing is an electrochemical technique that enhances the thickness of the inherent oxide layer on the surface of titanium aluminide, improving its resistance to wear and corrosion. Thermal spraying involves applying a coating substance onto the surface of a component by heating it to a molten or semi-molten state and then spraying it onto the substrate. These treatments enhance the wear resistance, corrosion resistance, and electrical performance of titanium aluminide components, increasing their suitability for electrical applications. For instance, enhancing the surface properties of connectors and terminals that require both low electrical resistance and high durability in corrosive environments is crucial.

The utilization of advanced manufacturing techniques in the production of titanium aluminide components ensures that these materials meet the rigorous demands of the electrical industry. By leveraging techniques such as casting, forging, powder metallurgy, additive manufacturing, and surface treatments, manufacturers can produce components with enhanced mechanical strength, electrical conductivity, and resistance to environmental degradation. Titanium aluminides possess exceptional characteristics that make them highly suitable for a diverse array of electrical applications.

V. Cost analysis and economic viability

The economic feasibility of utilizing titanium aluminides in the electrical industry is contingent upon various factors, such as the costs associated with the material itself, expenses related to the manufacturing process, and the overall lifecycle costs. Although the initial material and manufacturing costs associated with titanium aluminides are generally higher compared to traditional materials, it is important to consider their long-term advantages. These include enhanced durability, reduced maintenance requirements, and improved overall performance. Consequently, the potential benefits of titanium aluminides can outweigh the initial investment costs. Furthermore, it is anticipated that the progress in manufacturing techniques and the realization of economies of scale will lead to a decline in production costs, thereby enhancing the economic viability of titanium aluminides for widespread implementation. Conducting a comprehensive cost analysis that takes into account factors such as material costs, manufacturing processes, and lifecycle costs is crucial in order to evaluate the economic feasibility of utilizing titanium aluminides in electrical applications.

VI. Environmental impact and sustainability

Titanium aluminides have been found to possess notable environmental advantages, such as improved recyclability, diminished material waste, and decreased emissions of greenhouse gases. The high strength-to-weight ratio of these materials plays a significant role in the reduction of energy consumption during the manufacturing and transportation processes of electrical components. Moreover, the enhanced durability and corrosion resistance exhibited by titanium aluminides contribute to a reduction in the frequency of replacements and maintenance requirements. This, in turn, results in a diminished environmental impact throughout the entire lifespan of the product.

The implementation of sustainable manufacturing practices, such as the utilization of additive manufacturing and powder metallurgy techniques, serves to effectively reduce the overall environmental impact associated with the production of titanium aluminide components. The utilization of titanium aluminides within the electrical industry is in accordance with the overarching objectives of global sustainability, thereby facilitating the advancement of environmentally friendly and highly efficient electrical systems.

VII. Future research and development

Future research and development in the field of titanium aluminides for the electrical industry will primarily concentrate on the improvement of alloy properties, the advancement of manufacturing techniques, and the exploration of novel applications. These areas of focus are crucial for furthering the understanding and utilization of titanium aluminides in the electrical industry. By enhancing the

properties of these alloys, such as their electrical conductivity and thermal stability, researchers aim to optimize their performance in various electrical applications. Additionally, the development of more efficient manufacturing techniques will enable the production of titanium aluminides with enhanced precision and reduced costs.

Exploring new applications for titanium aluminides in the electrical industry will expand their potential uses and contribute to the overall growth and innovation in this field. Overall, future research endeavors will be dedicated to pushing the boundaries of knowledge and technology in titanium aluminides for the electrical industry. One of the primary areas of research will involve the development of novel titanium aluminide alloys that exhibit enhanced electrical conductivity, mechanical strength, and corrosion resistance. The production of high-quality components with complex geometries and optimized properties will be driven by advancements in additive manufacturing and powder metallurgy. Moreover, the incorporation of titanium aluminides in conjunction with other cutting-edge materials, such as ceramics and composites, has the potential to yield hybrid structures that exhibit enhanced performance characteristics.

Collaborative research initiatives that involve academia, industry, and government have the potential to expedite the development and commercialization of titanium aluminides. This collaboration is crucial in ensuring the successful adoption of titanium aluminides in the electrical industry.

VIII. Conclusions

The examination of the potential applications of newly developed titanium aluminides in the electrical industry has brought attention to the remarkable characteristics of these materials and their appropriateness for various uses. Titanium aluminides are characterized by their exceptional properties, including high strength, low density, excellent high-temperature stability, and corrosion resistance. These attributes make them particularly appealing for applications in the electrical industry. The aforementioned materials exhibit notable advantages when utilized in applications necessitating robust and dependable components that can endure adverse environmental conditions.

Within the domain of conductive materials, titanium aluminides exhibit noteworthy advantages in terms of reduced weight and improved mechanical strength, despite their lower electrical conductivity when compared to conventional materials such as copper. The suitability of these materials for various applications, including power transmission lines, connectors, and terminals, stems from their favorable strength-to-weight ratio and durability. As a result, their utilization can potentially result in decreased maintenance expenses and enhanced overall performance.

The utilization of titanium aluminides as protective coatings has been found to offer efficient barriers against various forms of environmental degradation, thermal stress, and electrical arcing. The application of these coatings has been found to significantly improve the durability and dependability of electrical components, including switchgear and transformers. This is achieved through the provision of exceptional safeguarding against the detrimental effects of oxidation and corrosion. Nevertheless, the manufacturing process of these coatings presents significant obstacles pertaining to the formulation of the coating, the attainment of consistent thickness, and the establishment of robust adhesion.

Titanium aluminides have been found to exhibit promising characteristics as insulating materials for high-temperature applications. This is attributed to their remarkable thermal stability and low thermal expansion properties. The consistent insulating properties of these materials under extreme conditions make them highly suitable for use in power generation and distribution equipment.

Moreover, it is worth noting that titanium aluminides have exhibited exceptional efficacy when utilized in the realm of magnetic shielding applications. This particular application involves safeguarding delicate electronic components against the detrimental effects of electromagnetic interference (EMI). The stable operation of control systems, communication devices, and sensors in high electromagnetic field environments is ensured by the ability of these materials to absorb and reflect electromagnetic waves.



Despite the numerous advantages of titanium aluminides, their widespread adoption in the electrical industry is impeded by various challenges. These challenges primarily revolve around the high costs associated with both the material itself and its manufacturing. Additionally, the achievement of desired properties necessitates the utilization of advanced processing techniques. Continual research and development endeavors are imperative in order to tackle these challenges, enhance alloy compositions, and refine manufacturing processes. The utilization of additive manufacturing and powder metallurgy techniques is anticipated to have a substantial impact on improving the economic feasibility and overall performance of titanium aluminide components.

Conclusively, it can be stated that titanium aluminides possess considerable potential in terms of enhancing the efficiency, performance, and sustainability of electrical systems. Through the strategic utilization of their distinctive characteristics and the diligent resolution of the accompanying production obstacles, the electrical sector stands to gain substantial and enduring benefits from the incorporation of these cutting-edge materials.

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