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Overview of Thermit Welding Process for Railway Applications: A Mixture of Iron Oxide and Aluminium Powder Joining Techniques

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Abstract

The welding of rails and metal components is essential for ensuring the structural integrity and safety of railway infrastructure. Traditional welding techniques often fall short in providing the required strength and durability to withstand heavy loads and harsh environmental conditions. Thermit welding, utilizing a mixture of iron oxide and aluminum powder, offers a robust and efficient alternative. This study evaluates the suitability of Thermit welding for railway applications through a comprehensive literature review, examining critical parameters, principles, environmental sustainability, and practical applications in railway engineering. The findings reveal that Thermit welding produces strong, durable welds with superior mechanical properties, including high tensile strength, ductility, and resistance to fatigue and corrosion. Performance comparisons indicate that Thermit welding is equal to or surpasses other conventional welding methods used in railway maintenance and construction. Moreover, its environmental advantages—lower energy consumption and reduced emissions—highlight its sustainability compared to traditional methods like arc welding. To enhance its applicability, further research on the long-term durability and reliability of Thermit welds under diverse environmental conditions is recommended.

Keywords: Thermit welding, Railway applications, Iron oxide, Aluminium powder.

1 | Introduction

Thermit welding is a joining technique commonly used in railway applications to bond two pieces of metal together. This process involves the use of a mixture of iron oxide and aluminum powder, which is ignited to produce a high-temperature reaction that melts the metal and creates a strong bond between the two pieces [1]. Thermit welding has been widely used in railway applications for over a century due to its ability to create strong and durable bonds between metal components. This process is particularly well-suited for joining

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railway tracks, as it can withstand the heavy loads and vibrations that trains exert on the tracks. In addition, thermit welding is a cost-effective and efficient method of joining metal components, making it a popular choice for railway maintenance and repair projects [2].

Thermit welding involves the use of a special mixture of iron oxide and aluminum powder, known as thermit, which is placed in a crucible and ignited using a magnesium strip. The thermit reaction produces intense heat, reaching temperatures of up to 2500 degrees Celsius, which melts the metal components to be joined. The molten metal is then poured into a mold that holds the two pieces together, creating a strong and seamless bond between them [3]. It was first developed in the late 19th century by german chemist hans goldschmidt as a method of joining metal components in a railway track. Since then, thermit welding has become a widely used technique in railway maintenance and repair, as well as in other industries such as construction and manufacturing.

The process has evolved over the years to become more efficient and versatile, with new formulations of thermit being developed to suit different types of metal and applications. This welding approach is a highly effective joining technique for railway applications, offering a strong and durable bond between metal components [4]. Its cost-effectiveness and efficiency make it a popular choice for railway maintenance and repair projects. With its long history of use and ongoing development, thermit welding continues to be a valuable tool for joining metal components in a variety of applications [5].

2|Recent Advancements in Thermit Welding Processes

In recent years, there have been several key advancements in the thermit welding process that have improved its efficiency and effectiveness in railway applications.

The development of new formulations of thermit mixtures that have been optimized for specific applications, these new formulations have been shown to produce stronger welds with fewer defects, leading to improved performance and longevity of the welded joints [6], [7].

The development of automated welding systems that can be used to perform welds quickly and accurately, these automated systems use computer-controlled equipment to precisely control the welding process, resulting in higher quality welds and increased productivity [8]. Additionally, these systems can be used in remote locations or hazardous environments, making them ideal for railway maintenance and repair work.

Advancements in the design of thermit welding equipment have led to the development of portable and lightweight systems that can be easily transported and set up on-site. This has made thermit welding more accessible and cost-effective for railway maintenance crews, allowing them to quickly and efficiently repair damaged rails and other components [9].

Overall, these recent advancements in thermit welding technology have significantly improved the efficiency and effectiveness of the process in railway applications. By using optimized thermit mixtures, automated welding systems, and portable equipment, railway maintenance crews can now perform high-quality welds quickly and accurately, leading to safer and more reliable railway infrastructure.

3|Operation Principles of Thermit Welding

The operation principles of Thermit welding are based on the exothermic reaction between iron oxide and aluminium powder. When these two materials are mixed and ignited, the aluminium reduces the iron oxide, releasing a large amount of heat in the process. This heat is sufficient to melt the metals being joined, allowing them to fuse and form a strong bond [10]. The operation principles of thermit welding are as follows:

I. The first step involves preparing the rail tracks to be joined by cleaning and aligning them properly. The next step is to place the Thermit welding crucible on top of the rail joint and secure it in place [11].

II. Once the crucible is in place, the iron oxide and aluminium powder mixture is poured into the crucible and ignited using a magnesium strip. This ignition process initiates a chemical reaction that produces intense heat, melting the mixture and forming molten steel [12].

III. As the molten steel is formed, it flows into the mold and fills the gap between the rail tracks, creating a strong and durable joint. The molten steel solidifies quickly, forming a seamless bond between the rail tracks.

IV. Thermit welding is a highly effective joining technique for rail tracks due to its ability to create a strong and reliable bond. The high temperature generated during the welding process ensures that the joint is able to withstand the heavy loads and stresses experienced by rail tracks [13].

Thermit welding is a proven and reliable technique for joining rail tracks in railway applications. The operation principles of this process ensure that a strong and durable joint is created, providing a safe and efficient railway infrastructure.

4 | Classifications of Thermit Welding in Railway Operations

Several classifications or types of Thermit welding processes are commonly used in railway applications. These classifications are based on the specific requirements of the welding job and the materials being joined. The following is a breakdown of the different types of Thermit welding processes in railway operations:

Rail Welding: One of the most common applications of thermit welding in railways is the joining of rail tracks (*Fig. 1*). This process involves the use of a specially designed mould that is placed around the two rail ends to be joined. The thermit mixture is then ignited, producing a molten metal that fills the mould and creates a seamless bond between the two rail ends [14].

Fig. 1. Thermit railway welding [15].

Joint Welding: in addition to rail welding, thermit welding is also used to join various metal components in railway infrastructure, such as switches, crossings, and joints (*Fig. 2*). This process involves the use of a different type of mould that is designed to accommodate the specific shape and size of the components being joined [16].

Fig. 2. Thermit joint Weld [17].

Repair Welding: thermit welding is also commonly used for repairing damaged or worn-out rail tracks and components (*Fig. 3*). This process involves the removal of the damaged section of the rail or component, followed by the application of the thermit mixture to create a new bond between the two pieces [18].

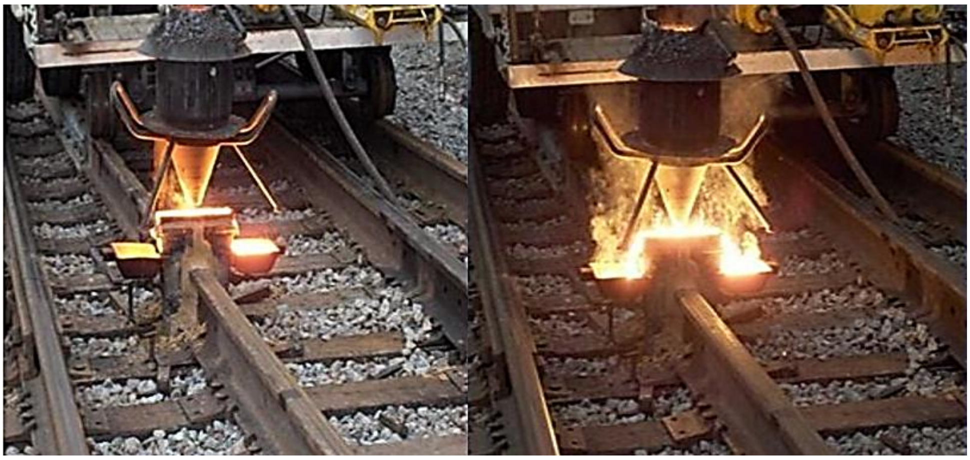

Fig. 3. Repair using thermit welding [19].

Continuous Welding: in some cases, thermit welding is used to create continuous welds along the length of a rail track or component. This process involves the use of a continuous mould that allows for the seamless joining of multiple sections of metal.

Thermit welding is a versatile and effective joining technique that is widely used in railway applications. By understanding the different classifications and types of Thermit welding processes, railway engineers and technicians can choose the most appropriate method for their specific welding needs. This ensures the creation of strong and durable bonds that meet the high standards of safety and reliability required in the railway industry.

5 | Iron Oxide and Aluminium Powder Content in Thermit Welding

The composition of the thermit mixture plays a crucial role in the success of the welding process. The mixture typically consists of iron oxide (Fe2O3) as the oxidizing agent and aluminium powder (Al) as the reducing agent. The ratio of these two components is critical in determining the efficiency and effectiveness of the reaction as well as the quality and strength of the weld [20]. The iron oxide serves as the source of oxygen in the reaction, while the aluminium powder acts as the fuel.

When the mixture is ignited, the aluminium reacts with the oxygen from the iron oxide to produce aluminium oxide and molten iron. This exothermic reaction generates temperatures as high as 2500°C, hot enough to melt the iron and create a strong bond between the two pieces of metal. The composition of the thermit mixture must be carefully controlled to ensure a successful weld [21]. A mixture with too much iron oxide will result in insufficient heat generation, leading to a weak weld.

On the other hand, a mixture with too much aluminium powder can produce excessive heat, causing damage to the surrounding metal and compromising the integrity of the weld. Excessive content of iron oxide in thermit welding can lead to a number of negative effects [22]. When there is too much iron oxide present, it can result in a slower reaction time and a weaker weld. This is because the excess iron oxide can act as a barrier, preventing the aluminium powder from fully reacting and producing the necessary heat to create a strong bond between the metal parts. Additionally, an excessive amount of iron oxide can also lead to the formation of slag, which can weaken the weld and compromise its integrity [23].

On the other hand, a moderate content of iron oxide and aluminium powder is ideal for thermit welding. When the ratio of these two components is balanced, it allows for a controlled and efficient reaction that produces a strong and durable weld. The moderate content ensures that the reaction occurs at the optimal temperature and speed, resulting in a high-quality bond between the metal parts [24].

Conversely, low iron oxide and aluminium powder content can also have negative effects on thermit welding. When there is not enough iron oxide present, the reaction may not reach the necessary temperature to create a strong weld. This can result in a weak bond between the metal parts and a weld that is prone to failure under stress.

The content of iron oxide and aluminium powder in thermit welding plays a crucial role in determining the quality and strength of the weld. While excessive and low content can lead to negative effects such as weak bonds and slag formation, a moderate content is ideal for producing a high-quality weld [19]. It is important for welders to carefully consider the ratio of these two components in order to achieve the desired results in thermit welding.

6 | Thermit Welding Processes in Railway Applications

The following highlights the steps involved in the effectiveness and efficiency of thermit welding in railway applications:

I. The preparation of the thermit mixture is a crucial step in the welding process. The mixture is typically composed of iron oxide (Fe_2O_3) as the oxidizing agent and aluminium powder (Al) as the reducing agent. The ratio of these two components is carefully controlled to ensure the desired reaction and heat generation during the welding process [25].

II. Thermit welding process requires a special crucible to contain the Thermit mixture and facilitate the controlled ignition. The crucible is placed on top of the rail joint to be welded, and a special igniter is used to initiate the reaction between the iron oxide and aluminium powder.

III. The intense heat generated by the Thermit reaction melts the metals at the rail joint, allowing them to fuse and form a strong bond. The molten metal is then poured into the prepared mold to shape the weld joint according to the desired specifications [26].

IV. The Thermit welding process is known for its ability to produce high-quality welds with excellent mechanical properties. The resulting weld joint is free from defects such as porosity and slag inclusions, which are common in other welding methods [27].

V. The Thermit welding process is also highly efficient and cost-effective compared to other welding techniques. The simplicity of the equipment and the ease of operation makes Thermit welding a preferred choice for railway applications where quick and reliable repairs are essential.

Thermit welding is a highly effective and efficient welding technique for railway applications. The step-by-step characteristics of this welding process highlight its simplicity, reliability, and cost-effectiveness, as shown in *Fig. 4*. With its ability to produce high-quality welds and strong bond joints, Thermit welding continues to be a preferred choice for railway maintenance and repair projects.

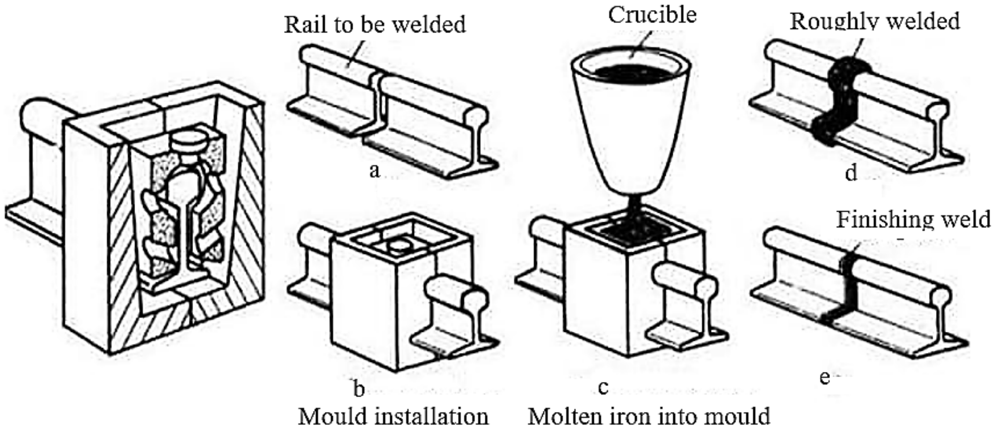

Fig. 4. Rail welding process [13].

7 | Key Components of the Thermit Welding Process

In the thermit welding process, a mixture of iron oxide and aluminium powder produces a high-temperature reaction when ignited, resulting in the formation of molten iron. This molten iron is then used to fill the gap between the two rail ends, creating a strong and durable weld. The components used in Thermit welding can be broken down as follows:

I. Iron oxide: this serves as the oxidizing agent in the reaction. Iron oxide is a compound that is commonly found in nature and is typically in the form of rust or hematite. In Thermit welding, iron oxide is used to provide the oxygen necessary for the combustion of the aluminium powder [28].

II. Aluminium powder: aluminium powder is a fine, granular substance that is highly reactive and combustible. When ignited, the aluminium powder reacts with the iron oxide to produce a vigorous exothermic reaction, generating intense heat and molten iron [29].

III. Crucible: this is required to contain the reaction. The crucible is typically made of a heat-resistant material such as clay graphite or silicon carbide and is designed to withstand the high temperatures generated during the welding process [30].

IV. Mould: the process also requires a mold to shape the molten iron into the desired weld profile. The mold is typically made of sand or ceramic material and is placed around the rail ends to contain the molten iron as it solidifies.

Thermit welding is a complex and precise process that requires careful attention to detail and proper handling of the components involved. By understanding the various components used in Thermit welding, railway engineers and technicians can ensure the successful completion of welding projects and the long-term integrity of railway infrastructure.

8 | Procedure for Preparing Thermit Welding for Railway Applications

The various procedures for preparing thermit welding for railway applications are as follows:

I. Prepare the joint to be welded: this involves cleaning the surfaces of the rail tracks to remove any dirt, rust, or other contaminants that could interfere with the welding process. It is essential to ensure that the surfaces are clean and free of any debris to achieve a strong and durable weld [31].

II. Assemble the thermit welding kit, which includes the Thermit mixture, a crucible, a mould, and an ignition system. The Thermit mixture is a combination of iron oxide and aluminium powder, which is carefully measured and mixed according to the manufacturer's instructions. The crucible is used to contain the thermit mixture during the welding process, while the mold is used to shape the molten metal into the desired form [32].

III. Ignite the thermit mixture: this is done using an ignition system, which typically consists of a magnesium strip that is ignited with a spark or flame. The ignition system is carefully positioned over the Thermit mixture, and once ignited, it produces a high-temperature reaction that melts the metal and creates a molten pool.

IV. As the Thermit mixture melts, it flows into the mould and fills the joint between the rail tracks. It is essential to ensure that the Thermit mixture is evenly distributed and that the molten metal fills the entire joint to create a strong and seamless weld. The welding process typically takes a few minutes to complete, after which the molten metal cools and solidifies, forming a solid and durable bond between the rail tracks [27].

Thermit welding is a highly effective technique for joining rail tracks and repairing defects in railway applications. By following the step-by-step key parameters outlined in this paper, railway engineers can ensure that Thermit welding is performed correctly and produces strong and durable welds. This process is essential for maintaining the integrity and safety of railway tracks, and it is crucial to follow best practices and guidelines to achieve successful results.

9 | Design Parameters for Thermit Welding in Railway Applications

When designing parameters for Thermit welding in railway applications, several factors must be considered to ensure the quality and integrity of the weld. These design parameters include the composition of the thermit mixture, the preheating of the rail ends, the size and shape of the mold, and the post-welding heat treatment, which are presented as follows:

I. The composition of the thermit mixture is crucial in determining the quality of the weld: The ratio of iron oxide to aluminium powder must be carefully controlled to ensure a complete reaction and the formation of high-quality molten steel [33]. A mixture with too much iron oxide may result in a weak weld, while a mixture with too much aluminium powder may produce excessive heat and spatter.

II. Preheating the rail ends is another important parameter in Thermit welding: Preheating helps to reduce the risk of cracking and distortion in the rail ends during the welding process. Proper preheating also ensures that the Thermit mixture reaches the required temperature for a successful weld [34].

III. The size and shape of the mould used in Thermit welding also play a significant role in the quality of the weld: The mould must be designed to contain the molten steel and shape it into a strong and durable weld. A properly designed mold will help to prevent defects such as porosity and incomplete fusion in the weld [35].

IV. Post-welding heat treatment is essential to relieve residual stresses and improve the mechanical properties of the weld: Heat treatment helps to ensure that the weld is strong, durable, and resistant to fatigue and corrosion [36]. Proper heat treatment can also help to prevent cracking and distortion in the welded rail.

Designing parameters for Thermit welding in railway applications requires careful consideration of several factors, including the composition of the Thermit mixture, preheating of the rail ends, mold design, and post-welding heat treatment. By carefully controlling these parameters, railway engineers can ensure the production of high-quality welds that meet the stringent requirements of the railway industry.

10 | Control Measures for Thermit Welding Process in Railway Applications

Controlling the Thermit welding process is crucial to ensure the quality and integrity of the weld. This can be achieved through the following means:

I. One key method for controlling the thermit welding process is to measure and mix the iron oxide and aluminium powder carefully. The ratio of these two components must be precise in order to achieve the desired temperature and reaction. Any deviation from the correct ratio can result in a weak or defective weld

[37]. Therefore, it is important to use accurate measuring equipment and follow the manufacturer's guidelines for mixing the Thermit materials.

II. Another important method for controlling the thermit welding process is to preheat the rail or component to be welded properly. Preheating helps to ensure that the metal is at the correct temperature for the thermit reaction to take place. This can be done using a preheating torch or other heating equipment. Without proper preheating, the Thermit reaction may not be successful, leading to a weak weld [38].

III. It is also important to carefully monitor the welding process itself: this includes ensuring that the Thermit reaction is taking place evenly and that the molten metal is flowing properly into the joint. Any irregularities or issues during the welding process should be addressed immediately to prevent defects in the weld [39].

Controlling the Thermit welding process in railway applications requires a combination of careful measurement, proper preheating, and vigilant monitoring of the welding process. By following these key methods, railway engineers and technicians can ensure that Thermit welds are strong, durable, and reliable for the safe operation of trains and other railway equipment.

11 | Key Areas of Thermit Welding in Railway Applications

Thermit welding is a versatile and widely used process in railway applications. The process offers numerous benefits, including strong and reliable welds, quick and efficient welding times, and cost-effective solutions for joining and repairing metal components [40]. The applications of thermit welding in railway components such as tracks, bridges, structures, joints, and switches are essential for ensuring the safety, efficiency, and reliability of railway systems.

The use of this technique provides a strong and durable bond between metal components, ensuring the smooth operation of trains and the safety of passengers and railway personnel. Thermit welding has become an indispensable tool in the railway industry, and its applications continue to play a crucial role in the construction and maintenance of railway infrastructure. The key areas of application of thermit welding in railway are presented in *Table 1*.

Table 1. Key areas of thermit welding applications in railway.

Thermit Welding Application In Railway	Description
Repair and maintenance of railway tracks	Railway tracks are subjected to heavy loads and constant wear and tear, leading to the need for regular maintenance and repairs. Thermit welding provides a strong and durable bond between the rails, ensuring the smooth and safe operation of trains. This technique is particularly useful in repairing cracked or damaged rails, as it allows for a seamless and reliable repair that can withstand the stresses of train traffic [41], [42].
Construction of railway bridges and structures	The process is used to join steel beams and other structural components together, creating a strong and durable connection that is able to support the weight of trains and other heavy loads. The use of thermit welding in the construction of these bridges ensures a strong and reliable connection between the various structural components, ensuring the safety and stability of the bridge [43].
Manufacturing of railway components	The process is able to produce high-quality welds (in rail joints and switches) that meet the strict standards and specifications required for railway applications [44]. Thermit welding is also used in the fabrication of railway components, as it provides a cost-effective and efficient method for joining and assembling metal parts [45].
Construction and maintenance of railway joints	Railway joints are used to connect two sections of track, allowing for expansion and contraction due to temperature changes [46]. Thermit welding provides a secure and durable connection between the rails at these joints, ensuring smooth and uninterrupted train operations.

12 | Iron Oxide and Aluminium Powder in Thermit Welding

Iron oxide, also known as rust, is a compound that consists of iron and oxygen atoms. It is commonly found in nature as a reddish-brown powder and is used in thermit welding as an oxidizing agent [47]. Aluminium powder, on the other hand, is a fine granular material that is produced by grinding aluminium metal into a powder form. It is used in thermit welding as the reducing agent, which reacts with the iron oxide to produce a highly exothermic reaction. When the iron oxide and aluminium powder are mixed and ignited, the aluminium reduces the iron oxide, releasing a large amount of heat in the process [48].

The reaction between iron oxide and aluminium powder in thermit welding is highly exothermic, meaning that it releases a significant amount of heat. This heat is used to melt the metal pieces being joined, allowing them to fuse. The resulting weld is strong and durable, making thermit welding a popular choice for joining large metal pieces in industries such as construction, railway maintenance, and shipbuilding. Iron oxide and aluminium powder are commonly used in thermit welding due to their simplicity and cost-effectiveness. The materials are readily available and relatively inexpensive, making thermit welding an attractive option for many applications.

Additionally, the high temperature generated by the reaction ensures a strong bond between the metal pieces, resulting in a reliable and long-lasting weld. The process can be difficult to control, and the high temperatures involved can pose safety risks if not handled properly. Additionally, the reaction between iron oxide and aluminium powder produces a significant amount of slag, which must be carefully removed to ensure a clean weld [49].

The use of iron oxide and aluminium powder in thermit welding offers a cost-effective and efficient method for joining metal pieces. The exothermic reaction between the two materials generates high temperatures that melt the metal pieces, creating a strong and durable weld. While thermit welding has its limitations, it remains a popular choice for a variety of industrial applications due to its simplicity and effectiveness.

13 | Environmental Impact of Thermit Welding Technique

While the thermit welding technique offers several benefits in terms of efficiency and effectiveness, its environmental sustainability has been a subject of debate and is highlighted as follows:

I. Energy efficiency: Unlike traditional welding processes that require the use of electricity or gas, thermit welding relies on a chemical reaction to generate heat. This means that thermit welding has a lower carbon footprint compared to other welding methods, making it a more sustainable option for railway applications [50].

II. Thermit welding produces minimal waste and emissions: The only by-products of the reaction are aluminium oxide and small amounts of other gases, which can be easily captured and disposed of in an environmentally friendly manner [51]. This makes thermit welding a cleaner and more environmentally friendly option for railway maintenance and repair.

III. Thermit welding is a long-lasting and durable welding method. The resulting welds are strong and resistant to wear and tear, reducing the need for frequent repairs and replacements. This not only saves time and money but also reduces the environmental impact of railway maintenance activities.

IV. Proponents of thermit welding argue that it is a more environmentally friendly option compared to traditional welding methods, such as arc welding, due to its lower energy consumption and reduced emissions. The high temperatures generated during the thermit welding process result in a cleaner and more efficient weld, which can lead to less material waste and a longer lifespan for the welded components [52]. Additionally, the use of thermit welding can help reduce the overall carbon footprint of a project by minimizing the need for additional materials and resources.

V. Critics of thermit welding point out that the process involves the use of potentially hazardous materials, such as aluminium powder, which can pose risks to both human health and the environment. The production and disposal of these materials can contribute to pollution and environmental degradation, particularly if proper safety measures are not followed. Furthermore, the high temperatures generated during thermit welding can release harmful fumes and gases into the atmosphere, further exacerbating air quality issues.

Thermit welding offers a number of environmental benefits and contributes to the sustainability of railway applications. Its energy efficiency, minimal waste production, and long-lasting results make it a preferred welding method for railway maintenance and repair. By choosing thermit welding over traditional welding processes, railway operators can reduce their carbon footprint and contribute to a more sustainable future for the industry.

14 | Conclusion

Thermit welding is a highly effective and reliable process for joining metal components in railway applications. Its ability to create strong and durable joints, its cost-effectiveness, efficiency, and environmental friendliness make it a preferred choice for railway maintenance and repair activities. As such, it is likely to continue playing a crucial role in ensuring the safety and reliability of railway tracks in the future. Thermit welding offers environmental benefits compared to other welding processes, as it does not require the use of external gases or fluxes that can be harmful to the environment.

This makes it a more sustainable option for railway maintenance and repair activities. It is a cost-effective and efficient method for repairing and maintaining railway tracks. It can be performed quickly and with minimal disruption to train services, allowing for timely repairs and upgrades to be carried out without causing significant delays or downtime. Based on the findings of this study, the following recommendations are made to improve the efficiency and effectiveness of the thermit welding process in railway applications. These include:

I. It is important to ensure that the iron oxide and aluminium powder mixture is properly prepared and mixed in the correct proportions. This will help to ensure a consistent and reliable reaction when the mixture is ignited.

II. It is essential to carefully control the ignition process to ensure that the reaction occurs at the desired temperature and rate. This can be achieved by using a suitable ignition source and closely monitoring the temperature of the reaction. Proper ignition will help to ensure that the molten iron produced is of the correct quality and consistency for welding applications.

III. It is important to carefully prepare the surfaces to be welded to ensure a clean and smooth joint. This can be achieved by removing any rust, dirt, or other contaminants from the surfaces using appropriate cleaning methods. Proper surface preparation will help to ensure a strong and durable weld that will withstand the rigors of railway applications.

IV. The Use of high-quality thermit welding materials and equipment to ensure the best possible outcome is recommended. This includes using high-purity iron oxide and aluminium powder, as well as high-quality molds and crucibles for pouring the molten iron. Using high-quality materials and equipment will help to ensure a reliable and consistent welding process that produces strong and durable welds.

By properly preparing the welding materials, controlling the ignition process, preparing the surfaces to be welded, and using high-quality materials and equipment, it is possible to achieve strong and durable welds that meet the requirements of railway applications. Following these recommendations will help to ensure the success of Thermit welding in railway applications.

Author Contributions

Imoh Ime Ekanem conceptualized the study and conducted the literature review. Aniekan Essienubong Ikpe contributed to data analysis and methodology refinement. Ndifreke Etebom Itiat reviewed the findings and prepared the manuscript. All authors reviewed and approved the final version of the manuscript.

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Data Availability

Data supporting the findings of this study are available within the article. Additional details can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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