ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 3, March 2025

A review of various heat mitigation techniques in Aluminium alloy fabricated by wire arc additive manufacturing

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ABSTRACT: This article provides a comprehensive review of metal arc additive manufacturing (WAAM) technology for the production of aluminium alloys. Various ways to control heat production and their associated problems are discussed, including cooling systems, climate control, thermal barrier coatings, and optimized processes. The performance, advantages and disadvantages of each machine are examined, as well as their impact on quality and performance. This review is designed to provide insight into current practices and future directions for the optimization of WAAM processes in aluminium alloy production, contributing to the advancement of manufacturing technology in aerospace, automotive and other industries

KEY WORDS: WAAM, Additive Manufacturing, Heat Mitigation

I.INTRODUCTION

Wire arc additive manufacturing (WAAM) is a cutting-edge technology revolutionizing manufacturing processes across industries. This method enables the fabrication of complex metallic components with exceptional precision and efficiency. By employing an electric arc to melt metal wire, layer by layer, WAAM achieves remarkable versatility and cost-effectiveness compared to traditional manufacturing methods[1]. WAAM's process begins with a computer-aided design (CAD) model that is divided into layers to guide the manufacturing process. A robotic arm or similar automated system deposits the metal line onto a substrate by precisely following a predetermined path [2]. At the same time, an arc is created between the metal and the substrate, heating the metal to its melting point. As the metal melts, it combines with the base layer and gradually forms the desired structure. One of the main features of WAAM is its ability to produce large quantities with very few materials. Unlike the manufacturing process, which involves cutting excess material from the block, WAAM reduces material consumption by adding material only where it is needed. This performance makes WAAM particularly suitable for producing lightweight products, reducing product costs and environmental impact [3]. In addition, WAAM has a unique design with the ability to create very complex geometries that are difficult or impossible to achieve with traditional methods. By layering data layer by layer, WAAM can create internal processes and similar features, creating new possibilities for product design and innovation. Furthermore, WAAM facilitates the use of a wide range of materials, including various metals and metal alloys. This versatility makes WAAM suitable for diverse applications across industries, from aerospace and automotive to healthcare and consumer electronics. Additionally, the ability to deposit multiple materials simultaneously opens up opportunities for creating hybrid structures with tailored properties, such as improved strength, conductivity, or corrosion resistance. In aerospace applications, WAAM has emerged as a game-changer, enabling the fabrication of lightweight, high-performance components for aircraft and spacecraft. By utilizing advanced materials and intricate geometries, WAAM enables significant reductions in weight without compromising structural integrity, leading to more fuel-efficient and environmentally friendly aircraft designs [4].

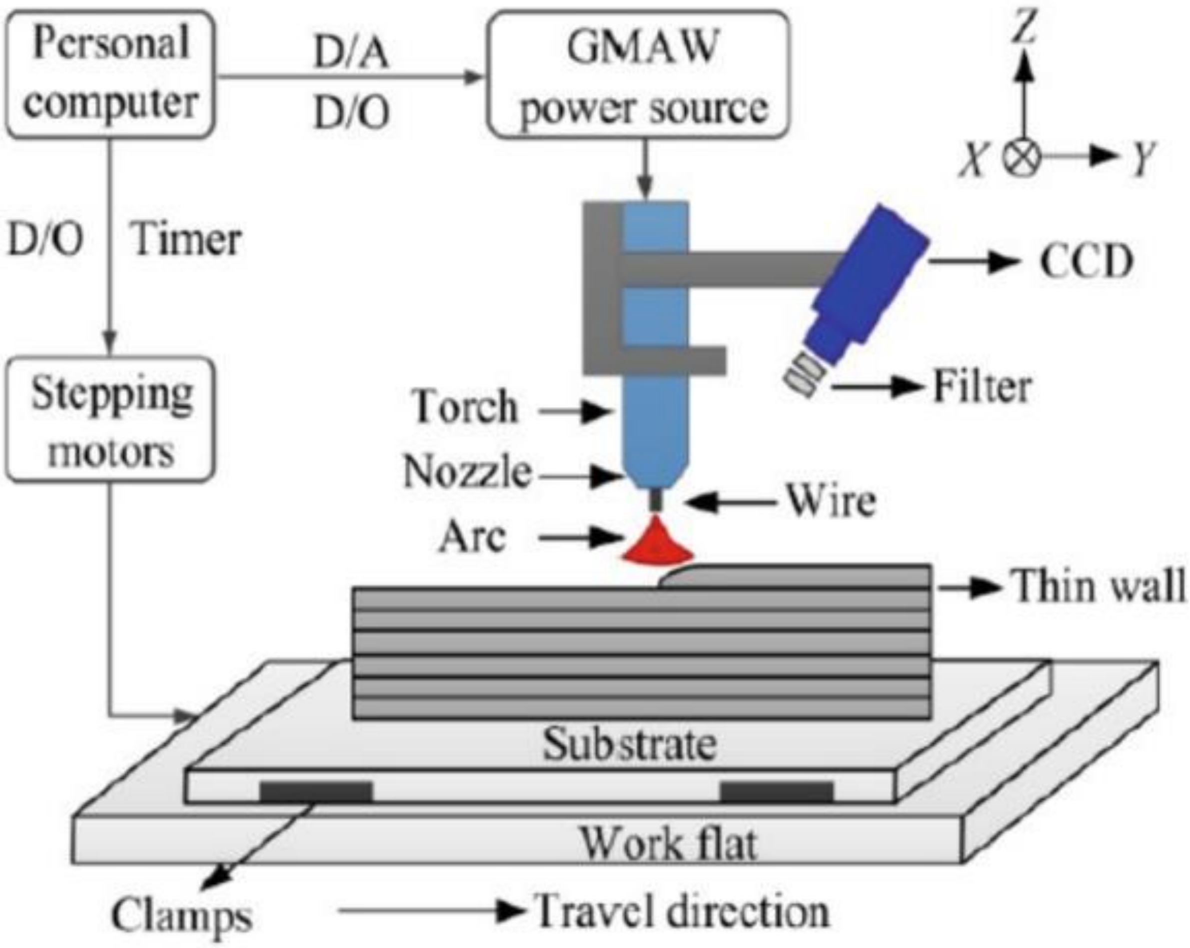

Figure 1. Schematic representation of WAAM system

Similarly, in the automotive industry, WAAM holds the potential to revolutionize vehicle manufacturing by offering cost-effective solutions for producing complex components, such as engine parts, chassis components, and custom prototypes. With WAAM, automakers can accelerate product development cycles, reduce production costs, and introduce innovative designs that enhance vehicle performance and efficiency. In the medical field, WAAM is enabling breakthroughs in patient care by facilitating the production of customized implants, prosthetics, and medical devices [5]. By leveraging the design flexibility and material versatility of WAAM, healthcare providers can create patient-specific solutions that improve treatment outcomes and enhance quality of life for individuals with medical conditions or injuries [6]. Additionally, WAAM leads innovation in the energy sector by supporting the development of technologies such as wind turbines, solar panels and energy storage. By optimizing the design and manufacturing of key components, WAAM can increase the efficiency, reliability and cost-effectiveness of renewable energy products, thus helping to create a sustainable and strong ecosystem. Although WAAM has many advantages, it also has some challenges and limitations [7]. A key challenge is the need to control process parameters, including arc voltage, wire feed rate, and discharge rate, to ensure consistency and quality of products. Post-processing steps such as machining, surface finishing and heat treatment also need to be performed to meet the quality and accuracy requirements of WAAM-produced parts.

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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Additionally, equipment, training and infrastructure, especially for small and medium-sized enterprises (SMEs). But as WAAM continues to grow and gain acceptance in production, advances in automation, optimization, and data enhancement will make it more accessible and less expensive [8]. Electric Arc Additive Manufacturing (WAAM) is the first choice in production today with its many advantages. Cost effectiveness of WAAM will require significant investments in is important because it reduces the amount of waste, which leads to significant savings in raw materials. Additionally, WAAM offers unique designs that allow the creation of sculptures and interior structures that are difficult to achieve using traditional methods. The product's versatility for many metals and alloys enhances its use in industry [9]. WAAM's rapid prototyping and manufacturing capabilities speed production and speed time to market for new products. It is also possible to create products by improving each product for better performance, while its scalability and efficiency streamline the production process. WAAM achieves environmental sustainability by using good information and reducing waste, based on changing sustainability goals. Personalization capabilities also support industries such as healthcare, where personalized solutions can improve patient outcomes. Finally, WAAM's affordability and availability democratizes advanced manufacturing technologies, allowing small and medium-sized businesses to compete effectively. Overall, the combination of WAAM's advantages makes it a revolutionary technology that enables innovation and improves the performance of different industries [10].

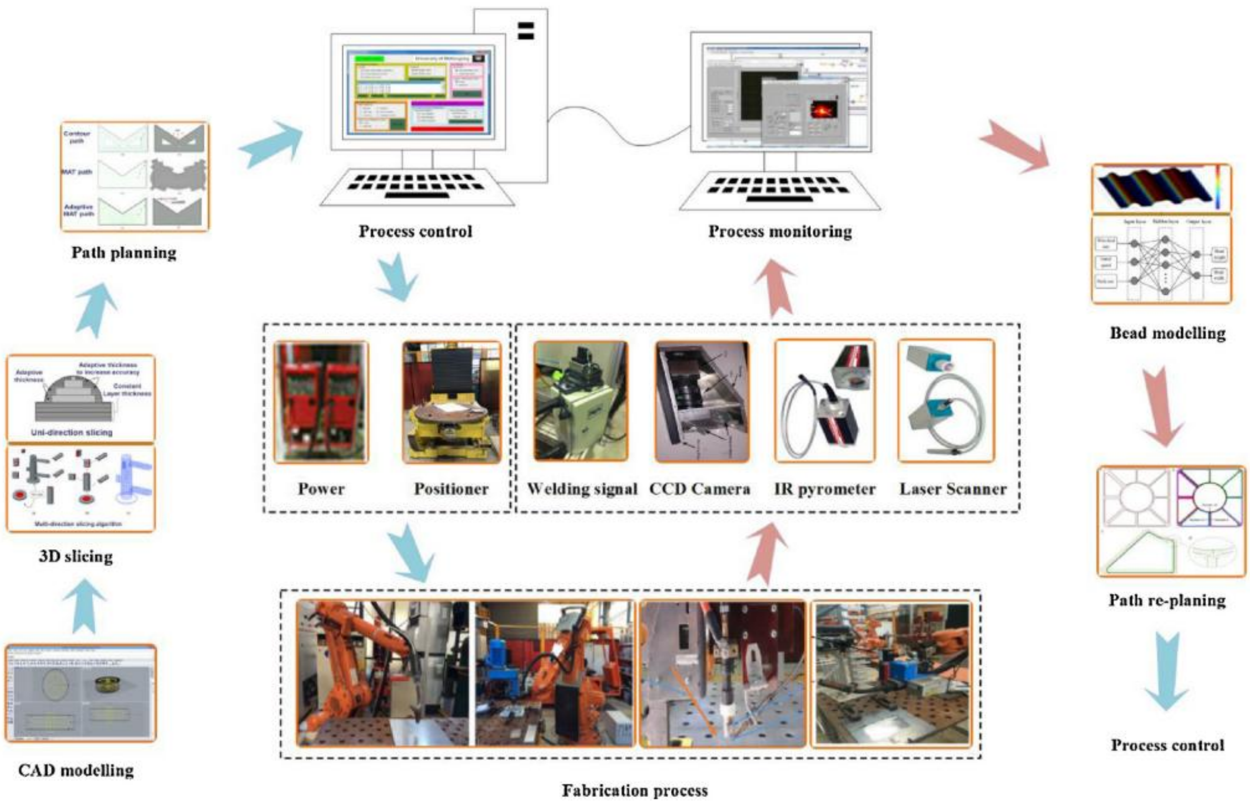

Figure 2 WAAM system design concepts, University of Wollongong

II. COMMON CHALLENGES IN COMPONENTS FABRICATED USING WAAM

Although wire arc additive manufacturing (WAAM) has many advantages, it also presents some limitations and challenges. The main disadvantage is the possibility of lack of availability in the product, especially in size. Rapid cooling of the deposited material can cause insufficient fusion of the layers, creating voids or defects that affect mechanical properties. Additionally, precise control of process parameters such as arc voltage and wire feed speed can be difficult to achieve, which can affect the accuracy and position of the WAAM-produced product. Post-processing requirements, including machining and heat treatment, can also add time and cost to the manufacturing process. Additionally, the need

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 3, March 2025

for specialized equipment and expertise may hinder adoption, especially for small and medium-sized businesses (SMEs). Despite these challenges, research and development continues to address these limitations and improve WAAM's capabilities, making it useful for broader use.

Table 1 Various Challenges faced in wire arc additive manufacturing

Challenges	Feature	Reference
Heat Accumulation	In wire arc additive manufacturing (WAAM), electrical components are an important factor affecting the manufacturing process and the final product. When arcs are used to place the finished product onto the product, the heat generated during the process is generated in the workpiece. Heating in this zone causes temperature gradients in the material, especially at the junctions of the layers. As each layer is deposited and cooled, thermal cycling occurs, creating residual stresses and distortions in the manufactured part. In addition, the stress zone continues in the previous process, changing the microstructural and metallurgical properties. Pore formation, material deformation, and residual stress development are characteristics of heat accumulation in WAAM; affects accuracy, mechanical properties and structural integrity. Controlling the heat produced poses a challenge for optimization; It requires careful replacement of waste material to reduce defects while ensuring proper fusion and good production. Understanding these resources is crucial to improving the WAAM process and realizing its potential in various industries.	[11][12] [13][14] [15]
Residual Stresses	Residual stresses are inherent in Wire Arc Additive Manufacturing (WAAM) due to the complex thermal history experienced by the fabricated components. As successive layers of material are deposited and cooled, rapid heating and subsequent cooling induce thermal gradients and differential expansion and contraction within the material. This uneven thermal cycling leads to the development of residual stresses, which can significantly influence the structural integrity and dimensional stability of the fabricated part. Residual stresses in WAAM are typically highest near the deposition zone and decrease gradually with distance from the weld interface. Additionally, the unique layer-by-layer deposition process of WAAM can result in alternating tensile and compressive residual stresses along the build direction, affecting material properties and susceptibility to deformation or cracking. Managing residual stresses in WAAM is essential for ensuring the reliability and performance of fabricated components. Strategies such as optimizing process parameters, controlling cooling rates, and implementing post-processing techniques such as stress relief annealing can help mitigate the adverse effects of residual stresses and enhance the quality of WAAM-produced parts. Understanding the features and origins of residual stresses in WAAM is crucial for optimizing manufacturing processes and maximizing the potential of this additive manufacturing technology.	[16] [17]
Distortion	Distortion is a notable characteristic in Wire Arc Additive Manufacturing (WAAM) processes, stemming from the complex thermal interactions and material deposition patterns inherent to additive manufacturing. As successive layers of material are deposited and cooled, localized heating and rapid thermal cycling induce uneven expansion and contraction within the workpiece. This non-uniform thermal history can lead to distortion or warping of the fabricated part, affecting dimensional accuracy and geometric fidelity. Distortion in WAAM is particularly prominent in large or complex components with intricate geometries, where differential cooling rates and thermal gradients exacerbate the deformation tendencies. Additionally, the accumulation of residual stresses during deposition further contributes to distortion, as internal forces seek equilibrium within the material. Managing distortion in WAAM requires careful consideration of process parameters, including deposition strategy, heat input, and cooling methods. Advanced modeling techniques and simulation tools can aid in predicting and mitigating distortion effects, enabling more	[18] [19]

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
Vol. 12, Issue 3, March 2025

	precise control over part geometry and dimensional tolerances. By understanding the features and mechanisms of distortion in WAAM, manufacturers can optimize process parameters and implement strategies to minimize deformation, ensuring the quality and integrity of fabricated components.	
Microstructural Changes	Microstructural changes are a key aspect of Wire Arc Additive Manufacturing (WAAM), resulting from the complex thermal cycles experienced by the deposited material during the fabrication process. As successive layers are added and rapidly cooled, the material undergoes significant transformations that influence its microstructure. The rapid heating and cooling rates inherent in WAAM can lead to fine-grained microstructures and non-equilibrium phases, affecting material properties such as strength, ductility, and toughness. Additionally, thermal gradients and residual stresses induced during deposition can promote microstructural heterogeneity and texture development within the fabricated part. The heat-affected zone (HAZ) adjacent to the weld interface exhibits distinct microstructural features, including grain refinement and phase transformations, due to the intense thermal exposure. Understanding and controlling microstructural changes in WAAM are crucial for tailoring material properties and optimizing component performance. Process parameters such as deposition temperature, cooling rate, and post-processing treatments can be adjusted to manipulate microstructure evolution and enhance desired characteristics. Advanced characterization techniques such as microscopy, diffraction analysis, and thermal modeling provide insights into microstructural evolution during WAAM, enabling informed process optimization and quality assurance. By effectively managing microstructural changes, manufacturers can tailor material properties to specific application requirements and realize the full potential of WAAM for producing high-performance components.	[20] [21]
Porosity and Void Formation	Porosity and void formation are significant features of Wire Arc Additive Manufacturing (WAAM), influenced by the complex interplay of process parameters, material properties, and deposition conditions. During WAAM, gas trapped within the molten pool or between deposited layers can become entrapped, leading to the formation of voids or porosity within the fabricated part. Factors such as arc stability, shielding gas composition, and wire feed rate can affect gas entrapment and bubble formation. Additionally, rapid solidification and cooling rates in WAAM can limit the escape of dissolved gases, exacerbating porosity formation. Porosity and voids within the material compromise structural integrity, mechanical properties, and surface finish of the fabricated components. They can act as stress concentration points, reducing fatigue life and susceptibility to cracking. Managing porosity and void formation in WAAM requires optimizing process parameters to minimize gas entrapment and promote efficient gas escape during solidification. Strategies such as adjusting arc voltage, optimizing shielding gas flow rates, and implementing post-processing treatments such as hot isostatic pressing (HIP) can help mitigate porosity and enhance part quality. Advanced non-destructive testing techniques, including X-ray computed tomography (CT) and ultrasonic testing, enable detection and characterization of internal defects, facilitating quality control and process optimization in WAAM. By understanding the features and mechanisms of porosity and void formation, manufacturers can implement effective measures to improve the integrity and reliability of WAAM-produced components.	[[22][23]
Overheating and Burn-Through	Overheating and burning are key features of metal arc additive manufacturing (WAAM), causing problems for the integrity and quality of manufactured products. The intense heat generated by the arc during the WAAM process can cause local heating, especially in thin or hard workpieces. Excessive pressure can exceed the melting point of the material, causing the substrate to burn or melt. Overheating and burning can be worsened by reasons such as improper arc voltage, too high a metal feed rate, or insufficient protective oil. The presence of overheating and combustion	[24][25]

	can affect the accuracy, surface finish and integrity of the product. It can cause material waste, geometric inaccuracies, and defects such as undercuts or weld spatter. Controlling overheating and combustion in WAAM requires control of critical parameters such as arc force, feed rate, and fuel flow prevention. Optimizing deposit and transfer strategies will help reduce the risk of overheating while maintaining fusion and build quality. Real-time analysis, temperature measurement and control strategies enable early detection and prevention of overheating events during WAAM. By understanding the characteristics and processes of overheating and combustion, manufacturers can take effective measures to increase process safety, reduce defects and improve all the advantages of WAAM-manufactured products.	
Inadequate Heat Dissipation	Inadequate heat dissipation is a critical feature in Wire Arc Additive Manufacturing (WAAM), contributing to various challenges in the fabrication process. As successive layers of material are deposited and rapidly cooled, heat generated by the electric arc accumulates within the workpiece. However, inefficient heat dissipation can occur due to factors such as insufficient coolant flow, poor gas coverage, or inadequate cooling mechanisms. This results in localized overheating and thermal gradients within the material, leading to issues such as residual stresses, distortion, and porosity formation. Inadequate heat dissipation can also affect the stability of the melt pool, compromising material fusion and deposition quality. Furthermore, uneven cooling rates can result in differential shrinkage and warping of the fabricated part, affecting dimensional accuracy and geometric fidelity. Managing inadequate heat dissipation in WAAM requires optimizing cooling systems, gas flow rates, and deposition parameters to ensure efficient heat removal and temperature control. Enhancing heat dissipation capabilities helps mitigate thermal issues and improves the overall quality and reliability of WAAM-produced components. Real-time monitoring and feedback systems enable early detection of heat-related anomalies, allowing for timely adjustments to optimize heat dissipation and enhance process performance. By addressing the features of inadequate heat dissipation, manufacturers can optimize WAAM processes, minimize defects, and achieve superior part quality.	[11] [12]
Layer-to-Layer Bonding	Interlayer bonding is important in metal arc additive manufacturing (WAAM) and determines the structural integrity and overall properties of the product. Since the arc is used to deposit the finished layer of the product, ensuring a good relationship between layers is important to achieve a consistent and flawless result. The quality of interlayer bonding in WAAM is affected by many factors, such as deposition parameters, materials and process conditions. Proper mixing of layers is important to prevent delamination, cracking or weak effects affecting the strength and durability of the part. Deposition requires precise control of deposition parameters such as arc voltage, wire feed speed, and feed rate to ensure adequate penetration and fusion of the layer. Additionally, maintaining proper gas and gas flow protection helps protect the pool from oxidation and pollution and promotes social harmony. Real-time monitoring and feedback identify synergies or inconsistencies in deposits, ensuring efficiency and allowing timely adjustments to be made effectively in the relationship. By addressing the specification of the connection, companies can improve the reliability and performance of WAAM-designed products and ensure they meet stringent standards and practices.	[26] [2]
Temperature Control Challenges	Temperature control presents significant challenges in Wire Arc Additive Manufacturing (WAAM), impacting process stability, part quality, and material properties. WAAM involves the deposition of successive layers of material using an electric arc, resulting in complex thermal interactions and rapid heating and cooling cycles. Maintaining precise control over temperature distribution throughout the fabrication process is essential to minimize defects such as distortion, residual stresses, and porosity formation. However, several factors contribute to temperature control challenges in WAAM. Variations in arc voltage, wire feed rate, and travel	[27] [28]

ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

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	speed can result in fluctuations in heat input and thermal gradients within the workpiece, affecting material fusion and deposition quality. Inconsistent cooling rates and inadequate heat dissipation can lead to uneven temperature distribution, exacerbating thermal stresses and distortion tendencies. Additionally, the large size and geometric complexity of WAAM components pose challenges in achieving uniform temperature profiles and mitigating localized overheating or cooling. Managing temperature control challenges in WAAM requires advanced process monitoring and control systems, as well as optimization of deposition parameters and cooling strategies. Real-time thermal imaging, temperature sensors, and feedback control mechanisms enable precise monitoring and adjustment of process conditions to maintain optimal temperature levels and minimize thermal anomalies. By addressing temperature control challenges, manufacturers can enhance process reliability, part quality, and dimensional accuracy in WAAM, unlocking the full potential of this additive manufacturing technology for a wide range of industrial applications.	
Cracking	Cracking is a significant challenge in metal arc additive manufacturing (WAAM), affecting the structural integrity and reliability of the product. Cracks can develop during deposition or post-processing depending on many factors, including thermal stress, microstructural changes and material composition. In WAAM, hot and cold air create thermal gradients and residual stresses in the material, making it prone to cracking. In addition, the unevenness of the cooling air and insufficient heating can cause thermal deformation and local stress, thereby causing the initiation and propagation of cracks. Microstructural changes such as boundary separation or phase transitions can cause WAAM-fabricated products to crack. Additionally, changes in composition or impurities can increase the effect, especially in strong materials or alloyed materials. Control of cracks in WAAM requires careful attention to the quality of the process, including the release strategy, cooling process, and post-treatment. Using preheating methods, stress relief, or various deposition methods can help reduce stress and reduce the risk of cracking. Real-time inspection and non-destructive testing equipment detect cracks or defects at an early stage, allowing timely intervention and quality assurance. By addressing critical features in WAAM, manufacturers can improve process reliability, part quality and performance to ensure WAAM products match industry application demand.	[29] [30]

III. CURRENT HEAT MITIGATION TECHNIQUES

A. Gas medium

It is important to minimize heat generation during the production of a variety of products in different media, including oil, solids and liquids. In this general research, we will take a look at the methods used to control heat in each environment with their effects, advantages and disadvantages. In gaseous environment processes such as laser cutting, welding and plasma cutting, controlling the heat produced is important to ensure that the product can be used. Use different methods to reduce heat: Gas cooling systems involve the use of compressed air or inert gases such as nitrogen or argon to cool the workpiece or machining area during machining. While air conditioning provides efficient heating, it reduces the use of cooling water and reduces the risk of environmental pollution. However, these machines will not provide heat as well as cooling, especially in hot applications. They also require a constant supply of compressed gas, which increases energy consumption and operating costs. Another way is to control airflow. It will adjust the speed and direction of airflow to control heat transfer and reduce heat generation in the workplace. Proper air management helps maintain stable cutting and prevent overheating of workpieces or tools, thus increasing process reliability. and the products are good. However, achieving good airflow patterns will require complex equipment and accurate measurements, additional installation time and laborious work. Next method is gas purging is the use of inert gas to create a protective environment around the workpiece, reducing oxidation and product degradation caused by heat. Gas scrubbing helps protect solid materials and surfaces, especially reactive metals and alloys that tend to oxidize at high temperatures. However, oil is expensive to

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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clean and may require specialized equipment, which may limit its effectiveness in certain applications. Optimizing the design of a fuel nozzle will configure the geometry and position of the nozzle to provide good heat dissipation and airflow distribution. Well-designed nozzles improve cooling and coat the oil, reducing heat generation and increasing process safety. Designing and manufacturing custom nozzles can increase production costs and lead time, especially for complex geometries or special applications. Air control with variable airflow to optimize cutting or welding performance and reduce heat generation. Quality management guarantees the same process and increases work accuracy and quality by preventing heat or material deformation. However, managing the correct management system will require complex management processes and regular adjustments, with complex tools and actions being added after the job. Heat management in gaseous media processes involves a combination of air conditioning, air flow control, cleaning, nozzle design optimization and pressure control. Although each method has unique advantages in terms of thermal dissipation and structural stability, it also brings associated problems and considerations.

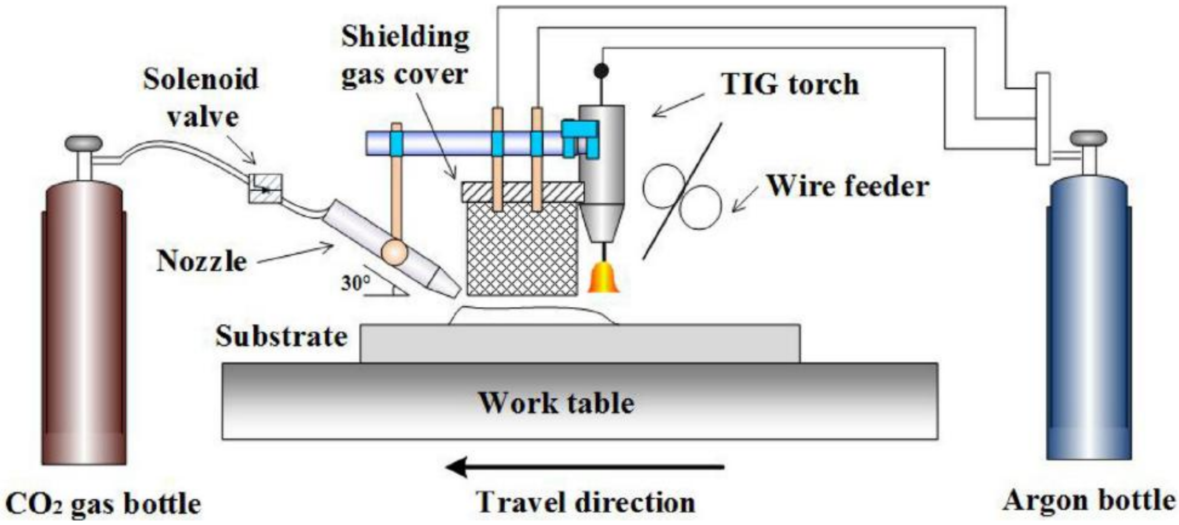

Figure 3 Schematic diagram of the combined WAAM gas cooling process

B. Solid medium

During processing environments such as machining, grinding and milling, electrical equipment may cause tool wear, deformation of the workpiece and decreased accuracy. Cutting fluids such as oils, emulsions and coolants are applied to the cutting surface to reduce friction, dissipate heat and lubricate the cutting tools. Cutting fluid helps extend the life of the tool, improves surface quality and prevents deformation by removing heat and chips from in-situ cutting. Additionally, some processes may require special or expensive fluids, thus increasing production costs. Heat sink and heat insulation material is used to absorb and dissipate the heat of the workpiece or tool cutting process, reducing thermal deformation and tool wear. Heat sinks and insulation help maintain stable operation, prevent overheating, and improve accuracy and surface finish.

However, the use of heat sinks and insulation can increase the number and complexity of equipment or tools, which will limit functionality and flexibility in some applications. Optimizing tool geometry including the design of edges, rake angles, and chip breakers to reduce heat during machining and improve chip escape. Well-designed tool geometry reduces cutting force, heat generation and tool wear, thus increasing productivity and product quality. However, the design and production of knives may require special knowledge and equipment, increasing production costs and production times. In summary, reducing heat generation during material processing involves a combination of fluid, coating, high-speed machining, coolant, thermal insulation and optimized tool geometry. Each method has certain benefits in terms of heat dissipation, tool life, machining accuracy, and productivity, but also brings associated problems and considerations.

C. Liquid medium

Controlling energy consumption in liquid processes such as chemical processing, heat treatment and surface finishing is important to ensure product homogeneity and process efficiency. A cold shower placed in the workplace or equipment to ensure rapid cooling of the coolant or refrigerant and to promote cooling. Cold showers provide good heating and

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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cooling. Temperature control ensures uniform cooling and minimizes deformation or stress on heat-treated equipment. However, cold showering requires a lot of cooling equipment and special equipment, as well as caution in the workplace to prevent heat contamination. Another widely used approach is quenching, which is the immersion of a part of the hot metal into a liquid medium (such as water, oil or polymer solution) for rapid cooling to obtain a certain product or hard products. Quenching can control the microstructure and mechanical properties of the product, increase the strength, hardness and wear resistance of the product. However, improper quenching can cause cracking, deformation, or stress in the work area, which can affect accuracy and performance. Heat exchangers transfer heat between a liquid medium and a coolant such as water or air to control process temperature and retain heat in chemical reactors, furnaces, or industrial products. Heat exchange equipment provides heat exchange and temperature control, clarifies the process and saves energy in heating and cold weather. However, different electronic products may require regular maintenance and cleaning to prevent scaling or corrosion, as well as proper insulation to reduce heat and increase energy. Cryogenic cooling is the use of liquefied gas, such as nitrogen or carbon dioxide, at low temperatures to cool materials or materials in order to achieve desired results, special or functional properties. Cryogenic cooling allows deep cooling of the heat treatment area, improving microstructures and improving mechanical properties such as increasing toughness and wear resistance. But refrigeration is expensive and requires special equipment and safety precautions to store and store liquefied oil safely. Thermal insulation materials such as ceramic fibers, refractory bricks and thermally conductive coatings are used to reduce heat transfer and maintain temperature in industrial furnaces, reactors and equipment. Thermal insulation can reduce heat, increase energy efficiency, prevent heating in hot areas, increase process reliability and can be created. However, the insulation will deteriorate over time due to thermal cycling, any corrosion, or chemicals; should be maintained or replaced regularly. Reducing heat accumulation in liquid media processes involves a combination of cooling baths, quenching, heat exchangers, cryogenic cooling and insulation. Each method has unique benefits in terms of heat removal, process control, and product quality, but there are also challenges and considerations. Good thermal management of process oil, equipment and fluid is essential to ensure operating performance, product quality and process performance. By using the combination according to the specific application and business needs, companies can reduce the negative heat generated in many business processes and achieve good results.

IV. IDENTIFICATION OF RESEARCH GAPS

The main issues identified in WAAM components include distortion, residual stress, porosity, cracks, and delamination. Potential solutions encompass post-process heat treatment, interpass cold rolling, interpass cooling, peening, and ultrasonic impact treatment, although their effectiveness varies depending on the material involved. A preliminary study has shown promising outcomes using forced interpass cooling with compressed CO_2 to manufacture Ti6Al4V, resulting in reduced surface oxidation, a refined microstructure, increased hardness, and enhanced strength. However, further exploration is needed to understand its effects on other materials. Research into air-cooling should expand to evaluate jet parameters for preventing heat buildup while maintaining deposition efficiency. Active interpass cooling influences the deposition process, necessitating consideration in path planning strategies for distortion control based on cooling times. Interpass cold rolling is feasible primarily for simple geometries, with complex components requiring specialized flexible tooling. While cold rolling effectively reduces residual stress, its impact on overall distortion warrants further investigation. Assessing the feasibility of replacing time-consuming interlayer rolling with single-step forming, particularly for aluminium alloys, is crucial. Understanding the interplay between heat accumulation, residual stress formation, and mechanical properties is essential. Residual stress mechanisms in fusion welding and WAAM are similar, with limited studies on aluminium AM products. Enhancements in process techniques via thermomechanical processing could improve microstructural and metallurgical similarities to wrought alloys. The environmental conditions during welding and additive manufacturing, including both heated and cooled environments, deserve more attention, as research often focuses solely on gas shielding. Heat treatments can significantly alter the microstructure and mechanical properties of WAAM 2024 alloy, emphasizing the importance of addressing porosity and property anisotropy in further research and application

V. CONCLUSION

In summary, wire arc additive manufacturing (WAAM) faces problems such as deformation, residual stress, porosity, cracking, and delamination. Processing measures such as post-heat treatment, cold rolling, cold working, injection forging and ultrasonic shock treatment have different effects on different products. Preliminary studies show that forced

ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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interlayer cooling using compressed CO2 on Ti6Al4V is promising but further research is needed. Particularly in complex geometries, attention should be paid to the control of conflict and the cooling process. It is important to understand the relationship between heat accumulation, residual stress, and mechanical strength, and thermomechanical treatment can improve the microstructure and metallurgical preparation. Investigating the effect of environmental conditions and heat treatment on the WAAM alloy deserves further study.

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ISSN: 2350-0328
International Journal of AdvancedResearch in Science, Engineering and Technology
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