

Automotive Part Repair Using Metal Additive Manufacturing

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REVIEW

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ABSTRACT – Metal Additive Manufacturing (MAM) is one of the Additive Manufacturing (AM) technologies in which molten metal is deposited layer by layer to construct a 3D profile according to the programmed path and parameters. The technology has enormous potential in part repair applications due to its high deposition rate, low cost, and high flexibility characteristics offered. Those advantages make it preferable and have gained attention from industry and academia to promote circular manufacturing through part life span extension. Therefore, this paper will explore the potential of MAM in automotive parts repair, the current research and its application, and challenges in terms of standard compliance, end-user perception, and regulations that may limit the implementation of MAM in part repair. The outcomes of the work will support the agenda on Sustainable Development Goals (SDGs), especially SDG 8, 9, 11, 12 and 13.

KEYWORDS: Additive manufacturing, part repair, automotive parts

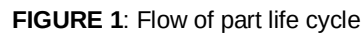
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1. INTRODUCTION

Additive Manufacturing (AM) plays a significant role in facilitating a circular economy by enabling the reconstruction and repair of parts, promoting reuse, extending parts' lives, and leveraging recycled materials (Zhao et al., 2024; Gordin, 2021; Mad Yusoh et al., 2020). This aligns with the circular economy's principles of keeping resources in use and minimizing waste as long as possible. AM can be used to repair damaged parts, create new parts from recycled materials, and even design for disassembly and reuse. For the typical part lifecycle, most of the time spent and cost involved occur during the manufacturing stage. Typically, as the part lifecycle ends due to being broken or damaged, it is then either repaired or replaced, depending on the seriousness of the damage. The easiest and preferred solution is to replace it with a new part; however, a new part may have a huge impact on the environment since it needs to go through all manufacturing stages. Even though the replaced part is sent for recycling, reuse, or even remanufacturing, there are relatively high costs involved and energy consumed compared to repair. Figure 1 summarizes the flow of part life.

Additive manufacturing offers part repair via layer-by-layer deposition of the material on the damaged area. In addition, the lifecycle impact of the extension needs to be assessed. A comparison made by Li et al. (2022) found that wire arc additive manufacturing (WAAM) offers lower cost and higher efficiency than other metal additive manufacturing technologies. The extension not only shortens the time to market but also uses less energy and material to manufacture new parts (Priarone et al., 2021; Dekis et al., 2025). Interestingly, recent studies focus more on environmental aspects but lack the economic and social dimensions, exclude AM part quality and its mechanical performance, and lack the life cycle assessment at stages after the part is repaired (Kokare et al., 2023; Reis et al., 2023).



Repair is a higher-value circular strategy than recycling because it preserves the product's functionality and the value of its original components (Psarommatis et al., 2025). By extending product lifespan, repair reduces the need for new raw materials, shortens products to market and decreases waste, which is essential for sustainability (Ipaki & Hosseini, 2025). Longer product lifetimes are not only ecologically beneficial but also economically attractive for manufacturers, especially in service-based models like leasing. Circular manufacturing requires a transition from a linear model to one that focuses on keeping products and parts in use for as long as possible through successive cycles of repair, refurbishment, repurposing, or remanufacturing. However, there are many challenges in implementing part repair, including the economics of part repair (Mad Yusoh et al., 2021). Another issue is the consumer perception of reconstructed or repaired parts in terms of safety and performance. This includes user education on the benefits of repair and sustainable design. In some cases, increased affordability through repair could lead to higher consumption, potentially offsetting some of the sustainability gains (Miliotis & Matsumoto, 2019).

The part repair via AM can be represented in three major stages: pre-repair, repair, and post-repair, as illustrated in Figure 2. At the pre-repair stage, firstly, the broken part or area to be repaired needs to be determined, and the material to be used for repair, either similar or dissimilar to the base material, needs to be identified. Optimal process parameters, including the welding speed, wire feed rate, and shielding

gas, were tested to see the effect on various outcomes such as width and height (Wani et al., 2022), tribological performance (Md Azlin et al., 2024), and mechanical properties, including hardness and tensile strength (Vasuthaven et al., 2023). In stage 2, a deposition strategy for a shorter time and minimum material consumption needs to be formulated. In the final stage, a suitable secondary process via machining needs to be employed (Senthilkumar et al., 2024). Finally, the most critical aspect is compliance with standards or regulations. Chioibasus et al. (2022) referred to the European Union Legislation for vehicle circulation in testing the repaired brake disc. The main aim of the testing is to ensure the safety and reliability of the reconstructed part before it is fitted to be used.

The aim of this paper is to explore the potential of WAAM application in automotive part repair. The discussion focuses on specific criteria to be met, including quality, performance, and compliance with standards, using a brake disc rotor as the case study.

TABLE 1: Recently published works on automotive parts repair

Reference	Automotive Part	Research/Findings
Way et al. (2023)	Brake caliper	Directed Energy Deposition (DED) method is recommended for the repair process.
Chioibasus, et al. (2022)	Brake disc	Laser-clad the disc made of GCI with powder-based IN718 and tested on Renault Megane. The result complies with European standards.
Kumaran et al. (2024)	Piston	A guideline was developed to be used in part repair using additive manufacturing.
Gray & Depcik, (2020)	Engine block	Repairing engine blocks through AM can cost 40% less than a new engine
Mad Yusoh et al. (2020)	Piston and alternator pulley	Suggested laser cladding as a suitable method to repair the parts.
Senthilkumar et al. (2024)	Gear	Repair using ER70S on an AISI 4340 gear was done and tested using a custom-made rig.

It is important to know the regulation/standard to be complied with, and all criteria taken into consideration in the assessment. This paper will comprehensively review all regulations and standards being implemented or to be implemented related to part repair using additive manufacturing.

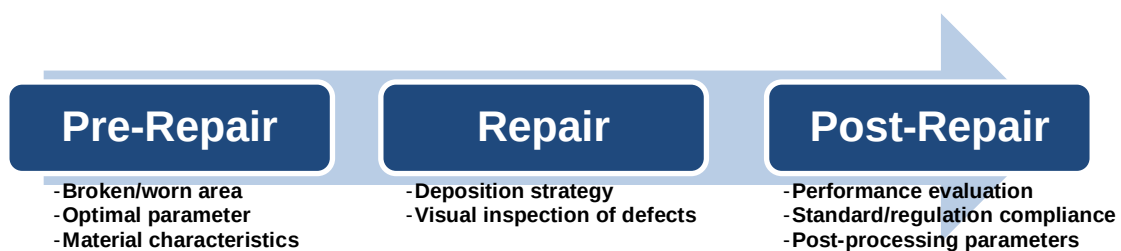


FIGURE 2: General flow process of the part repair using AM

This review focuses on the brake rotor disc; therefore, the standards and regulations referred to are limited to the product and its relevant components.

2. STANDARDS AND REGULATIONS

There are a few general standards and regulations to be followed in meeting the specification set and ensuring the safety of the vehicle user. Any modification made to any of the parts requires compliance with one of the standards or certification to convince the consumer (Milios & Matsumoto, 2019).

2.1 Malaysian Standard MS 1164:2015

In Malaysia, automotive safety regulations for brake disc rotors are primarily governed by Malaysian Standard MS 1164, which ensures compliance with quality and performance standards for brake friction materials. These regulations ensure that brake pads and shoes meet specific requirements for safety and reliability, including resistance to water, saline solution, oil, and brake fluid. The standard is equivalent to ECE Regulation 90.

2.2 ECE Regulation 90

ECE Regulation 90 is a United Nations regulation focused on the approval of vehicle braking systems and their components, specifically for aftermarket brake discs, brake drums, brake pads, and brake linings. It aims to ensure that replacement parts meet the same safety standards as original equipment. Based on this standard, Chioibas et al. (2022) evaluated a few criteria, such as braking coefficient and friction force.

For the case of brake disc rotors, there are three main criteria to be highlighted, which are the ability to withstand heat, wear, and pressure. They can be assessed through visual inspection or performance testing. García-León et al. (2023) constructed an experimental setup to analyze the heat distribution between the brake disc and pad. They found that these three criteria are interrelated and primarily influenced by friction. Other than due to the mode of the driver handling the vehicle (speed and size of the vehicle) and the braking system (number of brakes and brake force), the condition of the brake disc rotor, including geometry, balancing, and surface quality, also plays a role.

Practically, during brake disc rotor service, three main geometries to be measured are the lateral run-out, disc thickness, and thickness variation or parallelism (Mavrigian, 2024), which are considered defects by Febriani et al. (2020) in their study. The brake disc parallelism, or disc thickness variation (DTV), refers to the consistency of thickness across the braking surface of the rotor. Parallelism is diagnosed by measuring 8 different spots along the surface of the rotor with an outside micrometer, and the tolerance limit is 40 μ or less. The runout tolerance limit of this disc brake design specification is 25 μ or less at 5 mm from the outside diameter. Excessive movement of runout will result in vibration and pulsation in the steering wheel. However, Febriani et al. (2020) differentiate between parallelism and DVT. They defined DVT as a thickness variation when the brake disc has a difference in thickness across the surface. It is measured at more than 12 points along the circumference, with the management standard being 5 μ or less. Exceeding the value causes the two friction surfaces to no longer be parallel, leading to uneven wear. Furthermore, challenges to structural integrity, such as residual stresses, which are commonly encountered while using WAAM (Gurmesa et al., 2024), interfacial bonding when dealing with dissimilar materials (Shah et al., 2023), and lifecycle impacts at the pre-repair and post-repair stage in terms of material and energy consumption (Priarone et al., 2021), handling the excess material and optimum machining need to be considered.

In general, there are three main criteria in evaluating newly produced or reconstructed automotive parts: performance, quality, and compliance. Performance will ensure compliance with these regulations, ensuring that brake components are safe and reliable, reducing the risk of brake failure and accidents. Quality certification standards help maintain consistent quality and performance of brake components, ensuring they can withstand the demands of braking. Finally, compliance criteria, where non-compliance with these regulations can lead to legal consequences for manufacturers and distributors. The established standards are to ensure vehicle safety and reliability on the road.

Meanwhile, till now, a dedicated standard for additively manufactured parts still does not exist. There are a few generic standards, such as ASTM F2792 for standardizing the terminologies used in AM and ASTM F3187, that provide guidelines for using Directed Energy Deposition (DED), one of the classifications of metal additive manufacturing. For WAAM-based AM, standards for welding, such as AWS (American Welding Society), SAE International, and ISO (International Organization for Standardization) apply are referred to, including standard tests like the tensile test, hardness test, and shear test. However, there are efforts to develop standards for public reference around the globe. The standardization framework covers material qualifications from structural design to execution. This includes the definition and establishment of the material, quality of the WAAM process and the part, optimization of process parameters and toolpath strategy, integration of the CAD/CAM, and the most important aspect is that the application must be relevant to industry. Figure 3 illustrates the elements included in the framework.

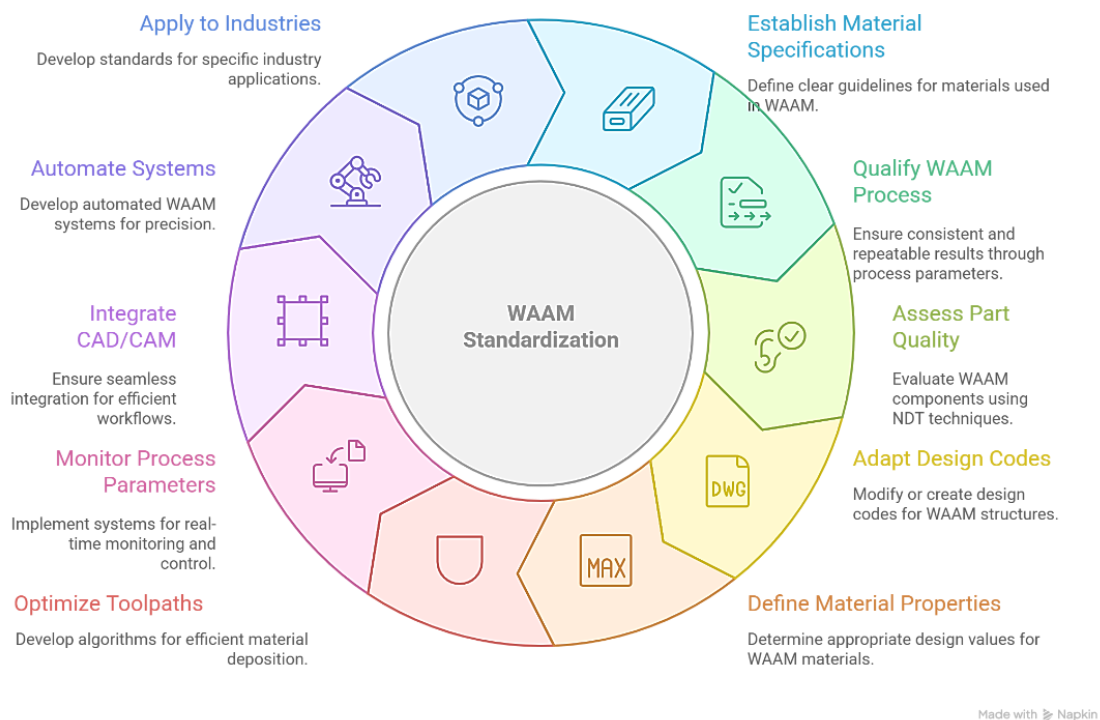


FIGURE 3: WAAM standardization framework

3. CONCLUSION

Additive Manufacturing shows a very promising approach to be used in part repair in various industries, including automotive. The main purpose of part repair is to extend its life cycle and to reduce the impact on the environment due to either the recycling process or the manufacturing of new parts. From the literature review, there are a lot of studies carried out recently. However, there is still a lack of physical evaluation. Therefore, in future work, by taking all these criteria into consideration, the reconstructed part performance evaluation via experimental work will be carried out.

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