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Review

Metal Additive Manufacturing (MAM) Applications in Production of Vehicle Parts and Components—A Review

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Abstract: In this article, the significance of additive manufacturing techniques in the production of vehicle parts over the past several years is highlighted. It indicates the industries and scientific sectors in which these production techniques have been applied. The primary manufacturing methods are presented based on the materials used, including both metals and non-metals. The authors place their primary focus on additive manufacturing techniques employing metals and their alloys. Within this context, they categorize these methods into three main groups: L-PBF (laser-powder bed fusion), sheet lamination, and DED (directed energy deposition) techniques. In the subsequent stages of work on this article, specific examples of vehicle components produced using metal additive manufacturing (MAM) methods are mentioned.

Keywords: additive manufacturing; metal additive manufacturing; vehicle components

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1. Introduction

The Fourth Industrial Revolution, also known as Industry 4.0, has radically transformed the manufacturing sector [1]. Globally, there has been a shift to embrace the ongoing trend of mechanical automation in conventional production processes, resulting in the emergence of intelligent production [2]. This is one of the most extensively researched topics in modern times. Cyber-physical systems and the integration of physical processes, storage systems and manufacturing equipment that autonomously exchange information and monitor each other are at the heart of Industry 4.0 [3,4]. Additive manufacturing techniques are considered to be one of the components of modern production [4–7]. According to the ISO/ASTM 52900:2021 international standard, the definition of additive manufacturing is as follows: "the process of joining materials to make parts from 3D model data, usually layer by layer, as opposed to subtractive and formative manufacturing processes" [8]. The first mentions of 3D printing techniques date back to the 1980s [9]. From the beginning, this type of manufacturing has been used to produce a wide range of components. The graph in Figure 1 is taken from a report by Wohlers Associates, one of the largest organizations focusing on additive techniques, published in 2023 [10]. It illustrates the total cost of components and services produced using additive manufacturing techniques in recent years. It shows a significant increase in the importance of the manufacturing techniques under review. These products are used in a wide range of industries, from automotive to aerospace, medical, electronics, defense, etc. The breakdown described is shown in Figure 2 [11].

Based on the data provided, it is clear that additive manufacturing techniques are being used in a variety of production and manufacturing sectors. The wide variety of materials, flexibility in shaping geometries and material savings are some of the advantages that distinguish it from other manufacturing methods [12,13]. The growing interest and use of additive techniques in the design and manufacture of machine parts and components prompted the authors to undertake a literature review on the application of additive techniques in the manufacturing of vehicles parts and components. Due to the already extensive use of additive techniques and the focus, it was decided to present examples of metal parts. A comparison was made between additive and conventional manufacturing techniques in terms of the strength properties of the parts. The advantages and disadvantages of each technique were presented. This work is of great importance for the research development of the academy in which it was produced.

Figure 1. The use of additive manufacturing techniques over the past 15 years. Reproduced with copyright permission of Wohlers Associates from Reference [10].

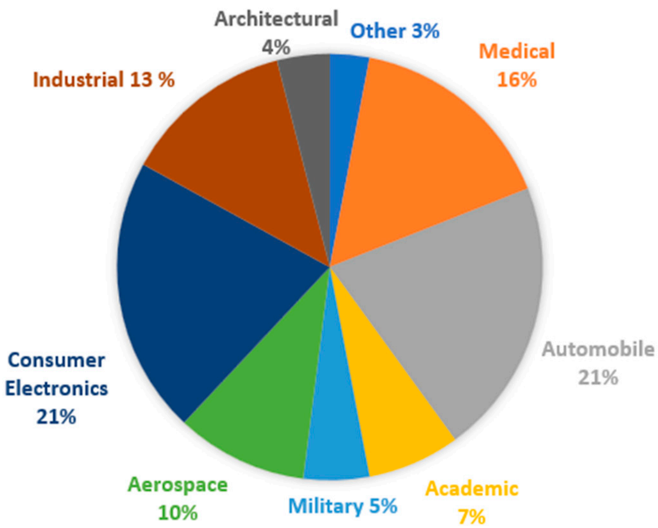

Figure 2. Application of additive manufacturing in various sectors. Reproduced from Reference [11].

2. Materials and Methods

A classification of additive techniques is presented based on data from scientific publications on additive manufacturing [14]. Additive manufacturing techniques are classified according to three criteria:

- methodology of the product formation,
- type of base material used,
- processing method.

According to the methodology of the product formation, the following can be distinguished:

- Material Jetting,
- Binder Jetting,
- Vat Photopolymerization,
- Powder Bed Fusion,
- Material Extrusion,
- Energy Deposition,
- Sheet Lamination.

Based on the type of base material used, a classification is made between:

- Solid-based (Laminated Object Manufacturing "LOM", Fused Deposition Modelling "FDM", Wire and Arc Additive Manufacturing "WAAM", Electron Beam Free Form Fabrication "EBFFF"),
- Powder-based (Selective Laser Sintering "SLS" and Direct Metal Laser Sintering "DMLS", Electron Beam Melting "EBM", Selective Laser Melting "SLM", Laser Metal Deposition "LMD"),
- Liquid-based (Stereolithography "SLS", Direct Light Processing "DLP", PolyJet printing).

In terms of the processing method, a distinction is made between:

- Laser beam,
- Ultraviolet rays,
- Thermal means.

The diagram presented in Figure 3 illustrates the categorization of additive manufacturing techniques [14].

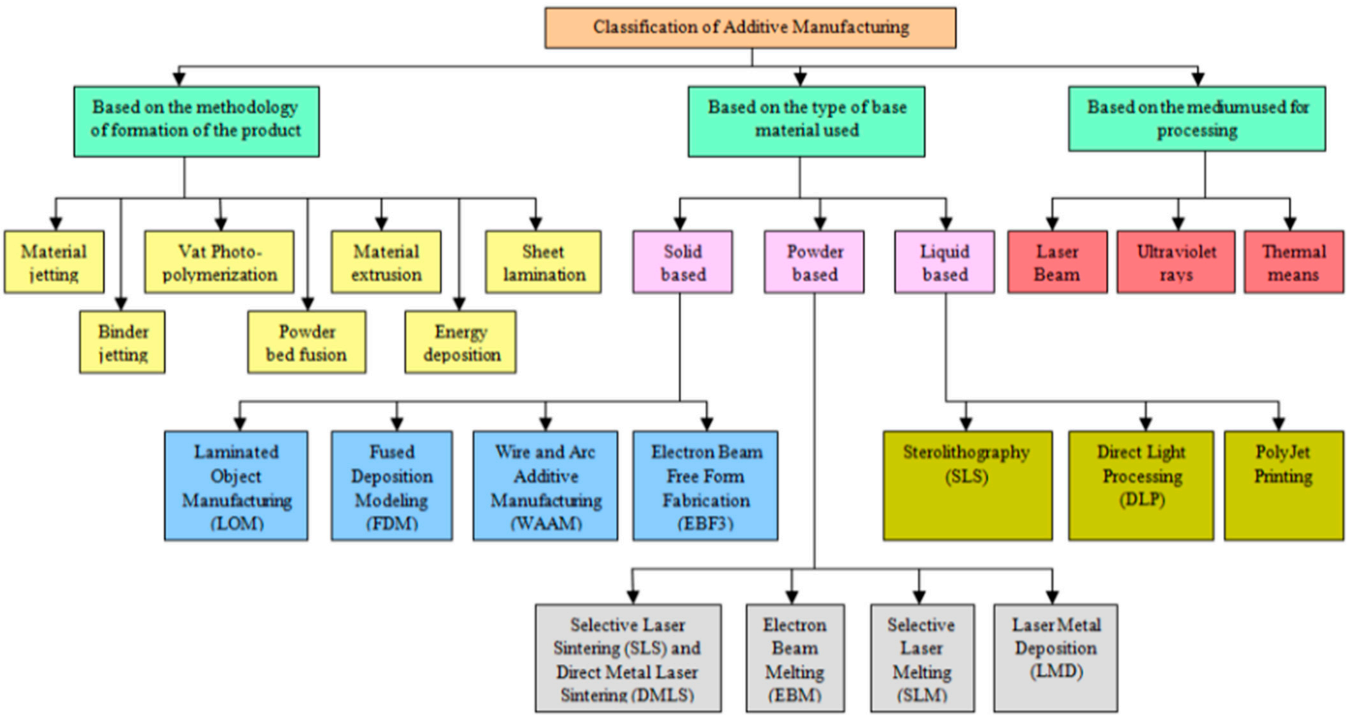

Figure 3. Classification of additive manufacturing techniques. Reproduced from Reference [14].

Today, the manufacturing of parts using polymers has become relatively common. These materials are frequently used in AM techniques due to their low weight to volume ratio, corrosion resistance, relatively high achievable mechanical and thermal properties, good electrical insulation and, in some cases, fire resistance, biocompatibility and biodegradability [10]. With the advanced development in the field of materials, polymers with previously unavailable properties have been introduced based on the research. As a result, polymeric materials that respond to external stimuli such as temperature, light, electric or magnetic fields, moisture or pH changes are being used to print structures that have the ability to change shape or physicochemical properties under the influence of certain environmental changes [11]. Due to their proven benefits, polymer-made objects have found applications in many industries such as automotive, aerospace, engineering or medical [15–17]. The most popular technique based on thermoplastic extrusion is FDM/FFF (fused deposition modeling/fused filament fabrication). It is based on the use of polymers or advanced composites doped with other types of materials such as carbon fibers, glass beads or metals and their alloys [18]. The nozzle of the machine heats the material to plasticize it and then, layer by layer, the printer builds up the expected product based on a previously generated CAD model [19].

Within the range of additive techniques operating in the field of non-metallic materials, ceramics should be mentioned. Compared to polymers and metals, ceramic materials also have advantageous properties [20,21]. A major advantage of this group of materials is the high hardness of the components and their ability to insulate heat and electricity. Taking into account the criterion of thermal resistance, ceramic materials are able to operate in the most extreme conditions, where the use of polymers or advanced metal alloys is impossible [22–25]. For this reason, additive manufacturing has extended to ceramics. Using the material in a form that can be additively molded, 3D printers are producing components and parts that are used, for example, in the aerospace industry to produce cooling components that reach an operating temperature range of 1200 degrees Celsius [26]. The properties of these materials also make it possible to produce medical implants, such as a teeth or part of a human skull [27]. By analyzing the research carried out, which shows that the structure of the material has a direct effect on the functional properties, it is possible to apply it in many sectors of the manufacturing industry.

3. Metal Additive Manufacturing

3.1. MAM Technologies

When manufacturing parts and components for machinery and equipment, metals or metal alloys are typically used by designers. However, with the development of additive manufacturing techniques, it is now possible to use non-metallic materials to create similar products with positive functional properties [28,29]. In the past thirty years, there has been a rapid development in additive techniques for working with metals. These techniques have resulted in the creation of various methods for forming metals, which differ mainly in the way in which the material is plasticized, and the energy source and form of the based material. Figure 4 shows the most common metal additive manufacturing techniques found in the literature [14]. There are also other, less well-known methods of additive manufacturing of metals, such as friction-stir additive manufacturing [30], cold spraying [31,32], direct metal writing [33] and diode-based processes [34].

Of the main additive techniques, sheet lamination is the least popular. It is a process that involves applying thin layers of material in succession. The layers are bonded to the previous ones either by heating the material (laminated object manufacturing) or by plasticizing it using high frequency waves (ultrasonic additive manufacturing) [35–37]. These methods are commonly used in the production of components with a larger surface area. Figure 5 shows the manufacturing process of an unmanned aerial vehicle wing using these techniques [38].

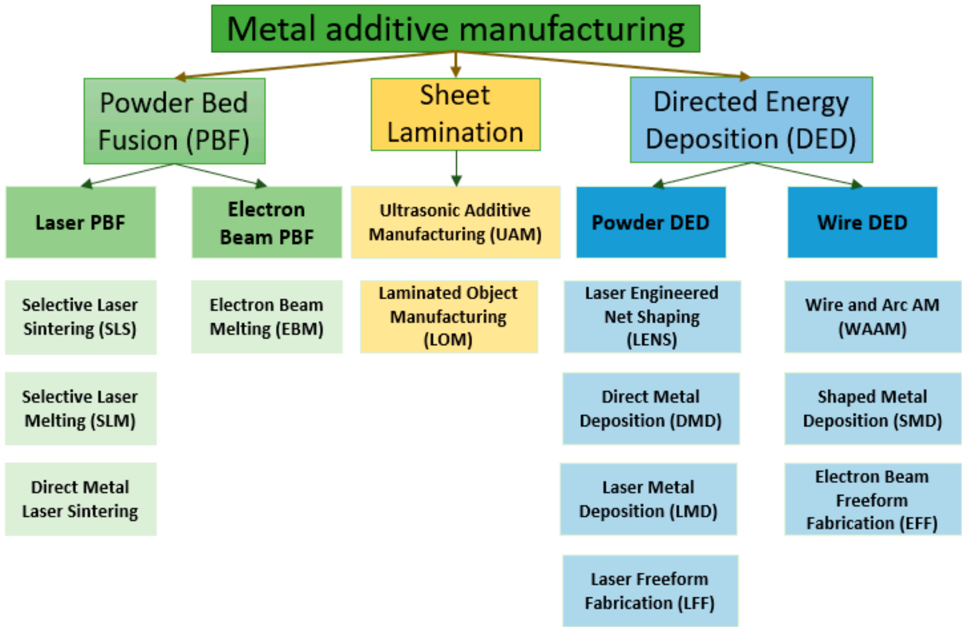

Figure 4. Metal additive manufacturing (MAM) classification.

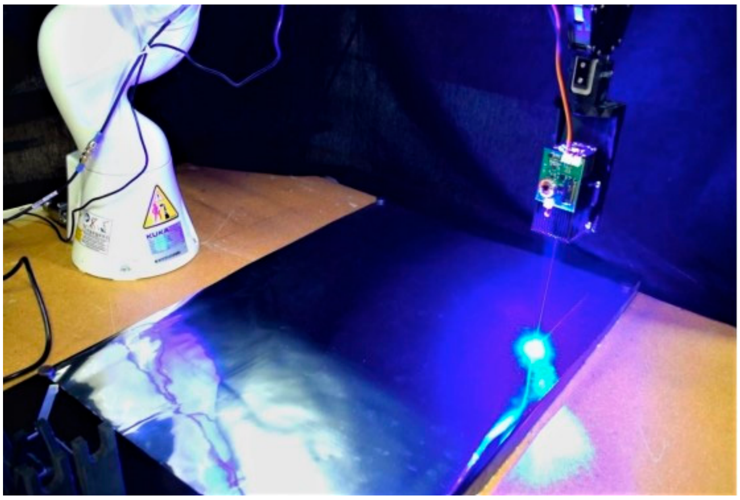

Figure 5. Steps of manufacturing aircraft wing using LOM technique. Reprinted with permission from Reference [38], 2019, Bhatt, P.

Directed energy deposition (DED) is another type of additive manufacturing technique that works with metals. DED covers 16% of the metal AM market [39]. The printing machine's head applies successive layers in the form of powder (powder DED) or wire (wire DED). With the help of a laser (LW-DED), electron beam (EB-DED), or electric arc (AW-DED), the material goes into a liquid state and deposits successive layers of the target part [40–42]. In most cases, a shielding gas (usually argon) is used to prevent the atmosphere from reacting with the liquid metal and forming metal oxides, which could negatively affect the structure of the material [43]. These techniques enable the production of large parts using advanced materials, such as stainless steels, titanium, or Inconel alloys, which have favorable performance properties. The mentioned techniques not only enable the complex production of components from basics, but also allow for equipment regeneration and damaged component repair [44–47]. The primary goal of a specific procedure is to reproduce a component's original geometry and properties using only an additive manufacturing process [48]. A laser is used to weld the material and determine the material structure, which affects the mechanical properties of the product.

Figure 6 presents an example of the remanufacturing process for repairing a key part of a jet engine rotor, specifically its blades. Despite the high degree of freedom in remanufacturing the components in question, in many cases post-processing is required. This is due to the high surface roughness.

Figure 6. The process of regenerating jet engine rotor blades. Reproduced from Reference [48].

The original parts are made of titanium alloys, which are highly sensitive to chemical reactions with atmospheric air components, mainly oxygen and nitrogen [49]. Remanufactured parts must regain their initial aerodynamic and strength properties during repair to be put into service. To minimize the negative effects of atmospheric gases, a common solution is to inject protective gas together with the surface material or to conduct the entire manufacturing process in a special chamber filled with gas.

Metal additive manufacturing called PBF (powder bed fusion) cover 54% of the metal AM market [39]. Similar to the DED techniques mentioned previously, these methods use a high-powered laser (sometimes multiple lasers in advanced machines) to melt or super-melt the material and fuse it together [50]. The process involves a powder reservoir, and the laser beam exposes thin layers to create a CAD model [51]. The process occurs in a chamber filled with protective gas. The printer operator determines the parameters, such as laser speed, exposure path scheme, or material layer thickness, during the print preparation phase [52]. These parameters may be significantly different for each material (various types of steel, aluminum and other metal alloys). The techniques used include selective laser powder melting (SLM), selective laser sintering (SLS), and direct metal laser sintering (DMLS). PBF techniques enable the production of parts and components using a variety of materials, such as aluminum alloys, steels, copper alloys, nickel alloys, and titanium alloys. Compared to DED techniques, PBF techniques result in smaller product sizes due to the need to fill the entire working chamber with powder, which significantly increases costs. However, the powder can be reused in subsequent processes after having been sieved. The final components have a high manufacturing accuracy, typically within the range of 0.2–0.4 mm, and can have total dimensions of up to 300–400 mm. Larger devices with working chambers of up to 500 $\times$ 280 $\times$ 850 mm are slowly entering the industrial market, providing greater production capabilities [53]. The technique has some disadvantages, including the structure's porous nature, high surface roughness, and high internal stresses that occur immediately after the manufacturing process. Post-processing is necessary to remove these issues.

Each of these techniques has advantages and disadvantages. These are mainly due to the manufacturing characteristics. Table 1 lists the main advantages and disadvantages of each technique mentioned, the materials used and their application.

Table 1. Specification of the most important types of production techniques [36,50,52,54–56].

Metal Additive Manufacturing Technique	Advantages	Disadvantages	Mainly Used Materials	Application
Powder Bed Fusion (PBF)	fabricating complex structures, lattice structures, high strength combined with lower weight large components, no support structures required, saving and re-use material, reduction of material waste and fuel consumption	part size limitation, production time, cost of machines and materials, number of available materials, need for post-processing (porosity, surface roughness, cracks and residual stresses)	aluminum alloys, magnesium alloys, titanium alloys, steels, Ni-based superalloys, nitinol based alloys, Zn-based, pure copper or copper alloys	manufacturing complex parts for aerospace, automobile, aeronautic, biomedical implants, industrial parts,
Sheet Lamination	process high speed, low cost, ease of material handling, multi-material process	strength and integrity largely rely on the adhesives used, material preparation before process	aluminum sheets, steel sheets	large surface components (aircraft wings)
Directed Energy Deposition (DED)	freedom in the materials domain, enabling fabrication of multi-material structures, build environment's freeform with 5-axis to free axis deposition heads, more possibilities to repair damaged parts	production time, need for post-processing (surface roughness, cracks, delaminations and residual stresses)	titanium alloys, steels, Ni-based superalloys, aluminum alloys	repair or manufacturing parts for aerospace, automobile, aeronautic, biomedical implants, industrial parts

3.2. *Examples of Vehicles Parts Produced via Metal Additive Manufacturing*

Additive manufacturing techniques are increasingly used to produce components of motor vehicle subassemblies and parts [57–65]. In the common cases, the manufacturing process only requires a 3D printer or a finishing machine (grinding or polishing). The lowest costs are obtained when producing parts with relatively small sizes (volumes) and complex geometries. The use of additive techniques in the production of machine components has become increasingly clear due to the addition of one of the most important issues of recent years: reducing CO_2 emissions. According to the work of M. Rupp et al., emissions can be reduced by more than 50% [66]. Following to available publications, major automotive companies such as Daimler, Volvo Construction Equipment, and Deutsche Bahn have started implementing additive manufacturing techniques to produce machine parts [67]. Modern manufacturing technology has been incorporated into almost every aspect of machine production, including the engine, drivetrain, and styling components. To account for the unknown mechanical properties of manufactured components, various tests are conducted to demonstrate the material behavior under different loads and high temperatures [68–71]. The subsequent paragraphs offer examples of components produced using additive techniques and the advantages of the application of these techniques.

3.2.1. Combustion Engines Components

Although there are increasing restrictions on vehicles powered by internal combustion engines, they remain a fundamental part of modern automobiles. The primary focus of development is reducing weight while maintaining the required strength properties and minimizing the production costs. These objectives are being achieved by manufacturing subassembly components using additive manufacturing techniques. The study by C. Ding et al. analyzed a material for the additive manufacturing of diesel camshafts. The material produced using additive techniques was heat-treated, resulting in favorable strength properties [72]. BMW (Munich, Germany), a leading automotive company, is increasingly using components produced with additive techniques in the production of handheld tools that are used to attach bumpers and license plates [73]. The S58 engine head used in BMW M-series sports cars was made with an additive manufactured core [74]. Wuhan Binhu Mechanical, Wuhan, China and Electrical Technology Industry Co., Ltd., London, UK used the SLM technique along with casting to reduce the production time of the iron cylinder head of a six-cylinder engine [75]. The crankshaft is a crucial component that converts the reciprocating motion of the engine's pistons into rotary motion. Honda designers collaborated with Autodesk to create a model of the crankshaft using Netfabb and Fusion 360 programs [76]. The use of additive manufacturing and reverse engineering allows for the creation of natural shapes for elements that were previously unattainable through conventional techniques. This procedure allowed a significant reduction in the crankshaft weight of 30%. Additive techniques can even replicate the capabilities of vehicles produced in the early 20th century. A paper by E. Dalpadulo et al. presents several examples of this process, including the restoration of a Steyr 220 car's carburetor [77]. Figure 7 displays the results of the work. The use of additive techniques reduced the cost and production time of the component by 30%.

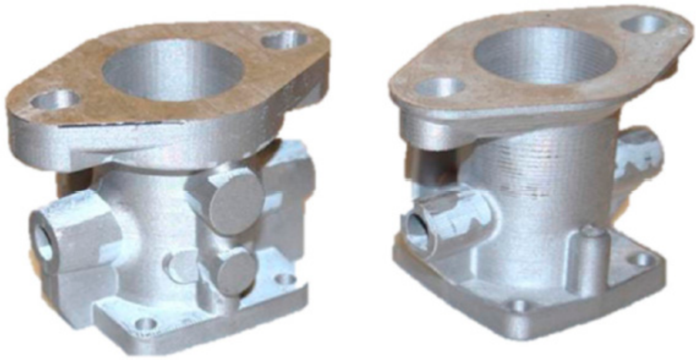

Figure 7. Steyr 220 carburetor manufactured using additive techniques. Reproduced from Reference [77].

D.L. Bourell presents an example on fabricating a basic internal combustion engine component [78]. The piston model was created using generative design techniques to reduce the weight, volume, and material usage. The lower mass of the piston generates lower inertia forces, resulting in slower wear of the piston-crank system. Porsche attempted to produce internal combustion engine pistons using a similar approach. Innovative pistons, created using additive manufacturing in a 3D printer, have passed their first endurance test in the 911 GT2 RS engine. The piston structure was optimized to match the load conditions, and a cooling channel was integrated, resulting in a 10% weight reduction compared to forged pistons. The modifications made to the engine allowed for an increase in speed, reduced temperature load on the pistons, and optimized combustion. Consequently, it is possible to achieve a power increase of up to 30 hp in the 515 kW (700 hp) Porsche 911 GT2 RS. The pistons were created through a collaborative project between Porsche, its supplier and development partner Mahle, and Trumpf, a company specializing in additive technologies [79]. By utilizing generative design and additive manufacturing techniques, it is now possible to produce parts with complex geometries. B. B. Milner and others have demonstrated a complex internal structure in an F1 sports car radiator [43]. The high-performance drive units of these vehicles require efficient cooling. Thin fluid flow channels with cellular structures enable better heat dissipation compared to heat exchangers manufactured using other methods. Figure 8 shows the view of a radiator containing thin channels generated using topology optimalisation and manufactured using additive techniques.

Figure 8. Sports car radiator manufactured using L-PBF technology. Reproduced from Reference [43].

Most vehicle engines are equipped with turbochargers, which consist of rotors that operate under difficult conditions due to the high temperature of the exhaust gas and the speed of the turbocharger shaft. The complex geometry of the rotor makes its manufacture difficult using traditional machining methods. Additive techniques enable significant material savings during the production of rotor blade geometries. Jia. D et al. in their work presented the design and fabrication of a specific component using L-PBF techniques. The element is shown in Figure 9 [80]. Due to the surface roughness of additive manufactured components, finishing is necessary in many cases. In their work, A. Yaghi et al. performed a process to produce two pieces of a turbocharger rotor with the L-PBF technique and 316-L steel. One was subjected to finish machining. Accuracy measurements carried out with GOM Inspect ATOS triple scan optical software showed that the component immediately after printing had dimensional differences of 200 μm compared to the nominal dimensions. A finishing treatment in the form of a 5-axis milling machine reduced these values by 50% [81]. In some cases, the authors of the papers carry out simulations on the process of additive manufacturing impellers. Such an exercise was undertaken by J.M. O'Brien et al. In their study, they simulated the manufacturing process of a turbocharger impeller. By using computer analyses, they were able to predict the effects of heat treatment. According to the calculation results, it reduced the component's stress values by 75% [82].

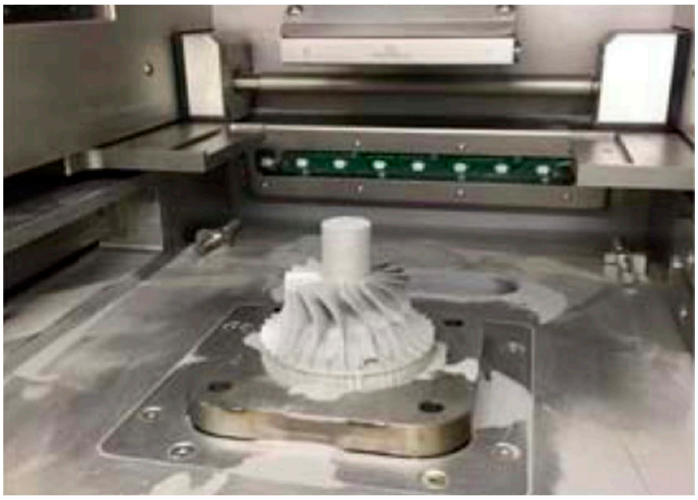

Figure 9. Turbocharger rotor directly after L-PBF process. Reproduced from Reference [80].

EOS GmbH, a company based in Krailling, Germany, is attempting to introduce new materials and manufacture components using them. They have used Al_2139 aluminum alloy, which is known for its high temperature strength (up to 200 °C), corrosion resistance, and tensile strength of up to 500 MPa. By using additive techniques, the manufacturing time of components was reduced by 88% compared to other techniques [83]. The unmanned vehicle sector has experienced significant growth. Additive manufacturing techniques are frequently used to produce small components. J. Gray and colleagues created a computer model and fabricated the engine head and crankcase of an internal combustion engine for small UGVs. The results are presented in Figure 10. The computed tomography analysis showed that the low porosity of the material had a direct impact on the favorable mechanical properties of the component. The engine underwent tests that demonstrated nearly identical operating conditions to those of an engine using conventionally made components [84].

Figure 10. The crankcase (**top**) and the head of the internal combustion engine (**bottom**) of the unmanned ground vehicle. Reproduced from Reference [84].

3.2.2. Electric Motor Components

Due to emission restrictions for vehicles with internal combustion engines, hybrid and electric vehicles are becoming increasingly common. In both cases, an electric motor is the primary power source. As a result, additive technologies are also being introduced in the sector for the production of components [85]. A paper by A. Selem et al. describes the advantages of using additive techniques in the manufacture of electric motor components [86]. The L-PBF technique allows for easier fabrication of geometries that are more favorable to the electric motor core. This improves heat dissipation during work and reduces weight, directly enhancing device efficiency. Figure 11 presents an example of the electric motor core. Designers are continuously seeking new solutions to enhance the final product. D. Schuhmann et al. propose mounting an electric motor in the hub of a vehicle wheel [87]. The authors intend to use additive techniques to manufacture the housing for the motor shown in Figure 12 with channel cooling applied. The channels' structure and geometry enable optimal heat dissipation during the motor's operation.

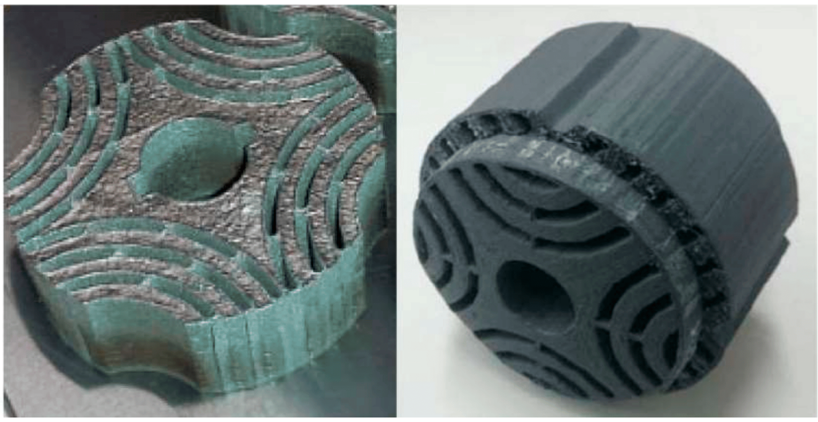

Figure 11. Electric motor core fabricated using L-PBF technique. Reproduced from Reference [86].

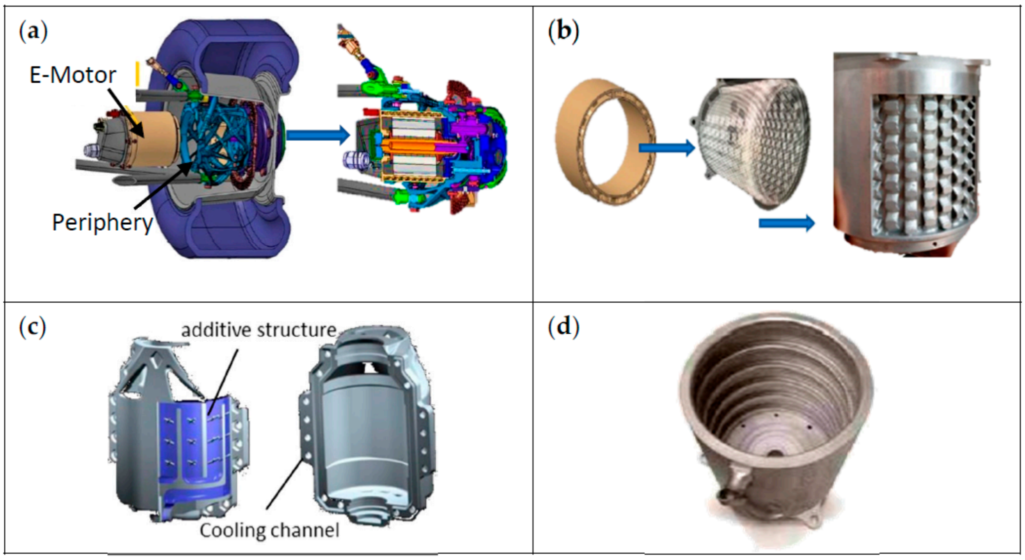

Figure 12. The application of Additive techniques in the production of electric motor components (**a**) electrical motor mounted in wheel hub; (**b**) electrical motor housing with integrated cooling; (**c**) housing with integrated cooling; (**d**) housing with helix structured cooling channels; Reproduced from Reference [87].

3.2.3. Drivetrain Components

Several studies also discuss the implementation of components and parts manufactured with additive techniques in vehicle drivetrains [88]. Upon analysis of the available literature, a significant number of articles focuses on gear manufacturing [89–94]. Various machining techniques are commonly used to manufacture gears, which can generate significant waste. Additive techniques can significantly reduce material consumption and waste compared to conventional machining techniques. Moreover, additive manufacturing allows for the production of gears using high-strength metal alloys, for example 16MnCr$_5$ steel [90]. By using appropriate structures, it is possible to produce lightweight gears while still maintaining the required strength properties [95,96]. Additive manufacturing techniques can facilitate the production of internal channels, which may enhance heat dissipation and ensure sufficient lubrication of friction surfaces [97,98]. Figure 13 shows an example of a gear produced using the SLM technique and SS-316L steel [89]. Hyundai Motors, based in Seoul, Republic of Korea, has started testing for manufacturing gearbox components using low-alloy steel DM 4140. This material is specifically designed for heat treatment, resulting in favorable mechanical properties such as high hardness and corrosion resistance [83].

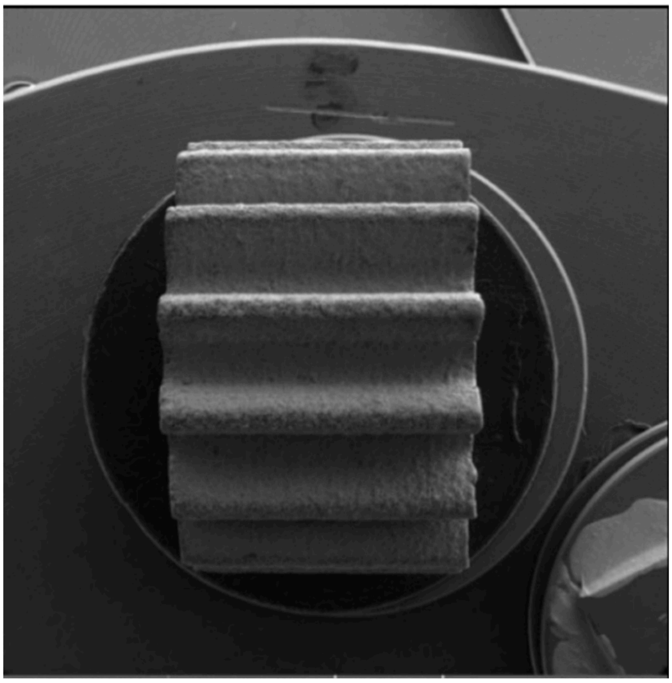

Figure 13. Example of gear produced via SLM/L-PBF techniques. Reproduced from Reference [89].

3.2.4. Other Components

Eplus3D (China, Hangzhou) has created a prototype exhaust system component for the Ford Mustang. The designers aimed to improve the vehicle's performance and reduce engine noise. The internal structure ensures adequate exhaust gas flow without causing excessive resistance, resulting in no loss of power to the drive unit. This allows for higher speeds while driving [83]. The brake caliper of the Bugatti Chiron sports car provides an example of the use of additive techniques [99]. The component is made of high-strength titanium alloy Ti_6Al_4V and has been tested under actual operating conditions, demonstrating its high resistance to the high temperatures that occur during proper brake operation. In their work, M. Lien et al. demonstrated the benefits of additive techniques and optimized topology for the fabricated components. They used the example of a brake caliper to showcase these advantages [100]. The implemented optimization methodology can reduce the total weight of calipers by approximately 668 g, resulting in a 41.6% weight reduction compared to traditionally produced parts. Additionally, the maximum caliper displacements in the *y*-axis were reduced by 50% and 17.5% for the front and rear calipers, respectively. Although the manufactured calipers have not been tested yet, they are expected to outperform their commercial counterparts. The weight reduction has a positive impact on the car's performance, as well as generating lower fuel consumption, resulting in reduced vehicle operating costs and less environmental impact. The parts from Figure 14 were manufactured using the SLM technique and high-strength titanium alloy Ti_6Al_4V.

Metal additive manufacturing (MAM) enables the production of designs created using CAD programs in the field of generative design. These solutions feature irregular model geometries that provide favorable properties while minimizing the weight and material consumption [101]. Numerous publications have addressed the topic of generative design and additive manufacturing [102–108]. Artificial intelligence (AI) is a major contributor to the field. The mathematical algorithms used by software at the component design stage make it possible to optimize the geometry and compensate for structural defects that have a significant impact on the strength properties of components. Similarly, T. Briard et al. proposed a scheme for producing an automobile seat belt holder [109]. The publication by E. Bassoli et al. is an example of DfAM (design for additive manufacturing). In this publication, the authors aimed to optimize the topology of an electric motor handle and manufacture it [110]. The component's stiffness needed to be increased while maintaining its required strength and weight. Figure 15 displays the successive stages of manufacturing the component using the $AlSi_{10}Mg$ material and SLM 250 device in the given process.

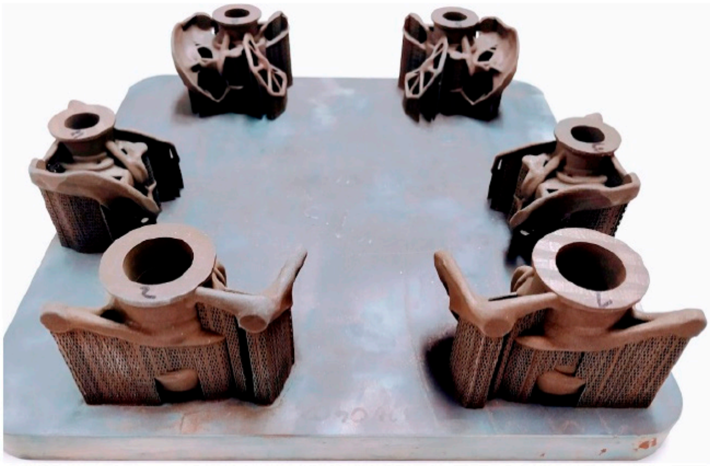

Figure 14. Test car brake components made using SLM technique. Reproduced from Reference [100].

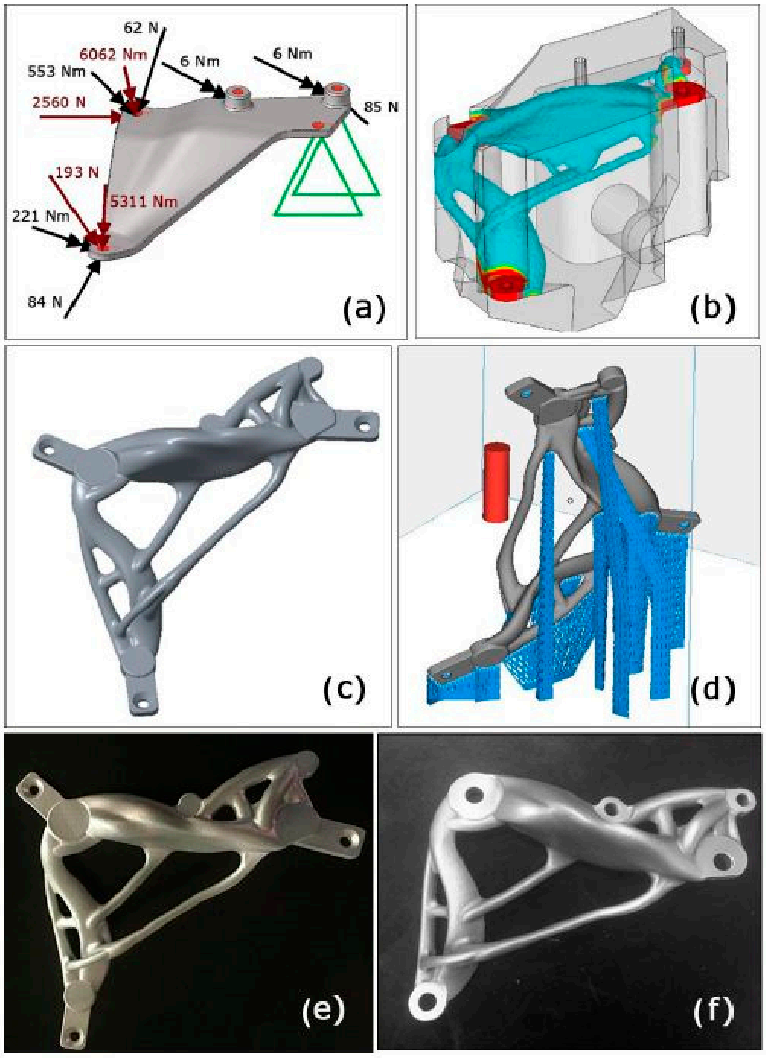

Figure 15. Process of manufacturing electric engine bracket: (**a**) original bracket load cases, (**b**) geometry from the topology optimalization process, (**c**) final geometry, (**d**) part in SLM 125 machine software, (**e**) stock part after L-PBF process, (**f**) finished part. Reproduced from Reference [110].

Continuous technological development has led to the implementation of numerous new solutions. Divergent 3D, based in Torrance, CA, USA, has designed a car for the future. The vehicle, named ”Chinger 21C”, is based on components manufactured using 80% additive techniques [83]. The project developers focused on using a generative design for the vehicle’s components. The authors suggest that additive techniques will become the primary method of manufacturing components due to their numerous benefits. Supporting this idea, attachment parts for the drive unit and accessories were fabricated. Additionally, N. Zhao et al. demonstrated the design of a Nissan brand sensor mount using additive manufacturing [111]. This mount controls the proper traction of a car while it is on the road. The use of generative design and additive manufacturing techniques resulted in a 42% weight reduction compared to conventional manufacturing methods. BMW is currently developing a roof attachment for the i8 Roadster. Through generative design, the component’s geometry has been optimized to ensure stable and secure attachment to the remaining body components. By use modern design and manufacturing techniques, the weight of the component was reduced by 44% compared to a component produced using conventional methods [112].

Analyzing the examples of using additive techniques to manufacture vehicle components, Table 2 lists the main advantages and weaknesses of the techniques in question compared to other manufacturing techniques.

Table 2. Main benefits (+) and weaknesses (−) of additive manufacturing processes compared to conventional manufacturing processes.

+	−
better working conditions	lower dimensional accuracy
mass customization and personalization	lower surface quality
reduced time to market	more expensive part manufacturing
flexibility for design changes	limited part dimensions
possibility to produce more complex parts	high requirements for input metals
shorter process and assembly chains	higher failure tests
fewer spare parts	higher specific energy demand
no need for complex tooling	need for support structures
on-demand manufacturing	
higher material efficiency	
improved remanufacturability	
less waste production	
weight reduction	

4. Discussion

After a thorough analysis of scientific publications, it has been identified that metal additive manufacturing techniques have been used to produce various vehicle components. Metal additive manufacturing techniques are employed in the manufacturing of components for a range of applications, including internal combustion engines, electric motors, power transmission systems, and other vehicle parts. The most common materials used in these cases are various types of steel (316 L, Maraging M300, $16MnCr_5$, $20MnCr_5$, $42CrMo_4$), aluminum alloys ($AlSi_{10}Mg$) or titanium alloys (Ti_6Al_4V). These techniques are also used in the electric industry with pure copper or its alloys (CuCP, CuCrZr). While additive techniques have numerous advantages for producing vehicle components, it is important to consider their disadvantages as well. One major drawback is the high cost of the machines and materials, typically powders, used in these technologies. Additionally, the size of the working chambers in PBF machines limits the maximum dimensions of the components that can be produced. While there is a wide variety of materials available, it is important to note that not all of them are suitable for atomization. One of the main drawbacks of this technology’s material structure is its inherent porosity, which is a result of the closed gas vapors used in the process. Furthermore, cracks may occur due to incorrect melting temperatures, and the structure may appear rough. Porosity and cracks can be removed through heat treatment, and roughness can be eliminated by machining, such as lathing or milling.

One of the fastest growing trends related to adventurous techniques is their combination with systems based on artificial intelligence (AI). A number of scientific publications report on the possibility of better predicting the properties of parts manufactured using additive techniques as early as the modelling stage and in preparation for the printing process. Complex computer simulations make it possible to prepare the printing process accordingly. The field of generative design is well suited to the issue. The shape and geometry of the parts are based on irregular shapes that provide good mechanical properties with low material consumption and weight. In many cases, additive techniques are the only available option for producing these designs. AI makes it possible to generate all sorts of out-of-the-box component geometries, which in most cases can only be produced using additive techniques. Appropriate geometry optimization makes it possible to achieve the intended properties of the components resulting in low material consumption. The combination of MAM and AI techniques opens up a wide range of possibilities in terms of the design, manufacture and implementation of new construction solutions and represents a major development path for incremental technology issues.

5. Conclusions

1. Additive techniques enable the production of components with intricate geometries that are often impossible to manufacture using other conventional techniques. This includes components with internal cellular structures designed in the CAD software like Solidworks, CATIA (Dassault Systemes, Vélizy, France).
2. Additive techniques enable the creation of the manufacturing topology optimization model, for example with software like Fusion 360 (Autodesk, San Francisco, CA, USA). This results in significant material savings while maintaining appropriate mechanical properties.
3. Additive manufacturing is associated with Industry 4.0 due to its ability to produce a component using a single machine, for example the EOS company (Krailling, Germany) or SLM Solutions Group AG (Lubeka, Germany). The direct operation of large and complex machines is avoided to ensure human safety.
4. In the additive manufacturing process using powdered material, a small amount of waste is generated, in contrast to other manufacturing techniques like milling. Any unused powder can be reused in subsequent processes, provided it has been properly sieved and dried. This reduces the cost per element.
5. Additive techniques enable the production of parts using a variety of metals and alloys, ranging from steel and its variants to aluminum, copper, and their alloys, as well as high-strength titanium alloys or Inconel.
6. Typically, items produced through additive manufacturing exhibit a high strength-to-weight ratio. Thus, additive techniques are widely used in the mechanical industry to produce components such as pistons, crankshafts, valves, spur gears, camshafts, brake calipers, seat belts mount, movable roof mounts, etc.
7. Additive techniques have been found to offer advantages over conventional methods for producing single-piece components with complex geometries.

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