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Additive manufacturing and acoustic emission: A brief review

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Abstract

The additive manufacturing (AM) process is the next-generation manufacturing technique that replaces traditional manufacturing. Based on applications, environments, installations, vibrations, fatigue, and the type of motion, such as static or dynamic, the material properties of objects fabricated by AM can change from day to day. Due to the exponential growth of AM items, it is imperative to monitor structural health to ensure the safety of users and quality control of the AM products to save material as well as manufacturing time. To ensure the future manufacturing process is successful and to avoid accidents, the AM parts must be monitored consistently and regularly. So, it is essential to monitor the health of such objects or parts carefully to ensure safety. Structure health monitoring (SHM) refers to methods and techniques that detect and monitor structural or parts health non-destructively. There are many SHM methods, including radiographic, ultrasonic, electromagnetic, X-ray CT, acoustic, and thermographic. When it comes to in-situ monitoring, independent of materials type and radiation effects on human health, acoustic emissions (AE) are the preferred method. By analyzing sound waves, an AE system can identify cracks in modern structural health monitoring systems (SHMs). In this study, AM and AE have been discussed. An overview of AM is provided, along with a brief description of AM. Furthermore, this study utilized data from different search engines to demonstrate the usefulness of AE as SHM in the AM process.

Keywords: Additive Manufacturing (AM), 3D Printing, Structural Health Monitoring (SHM), Acoustic Emission (AE).

1. Introduction

Currently, the world is experiencing a fourth industrial revolution. The focus of research and education is shifting from manual to automatic tasks. As a result, it has profound impacts in all fields, including manufacturing. As an example, additive manufacturing is replacing conventional manufacturing, and artificial intelligence is used in a wide range of industries [1], [2]. With its ability to fabricate parts with complex features, AM has gained a lot of attention from a variety of fields due to its popularity in the manufacturing industry. It is being applied to improve the design, in-situ monitoring, cloud serving, and other tools by using Machine Learning [3]. Since AM products bond metallurgically with the base materials instead of mechanically as conventional manufacturing processes do, they generate a reduced heat-affected zone, a cause of the system failure. It is also an excellent method for replacing items that require longer manufacturing processes and specific suppliers to manufacture. In addition, with AM, a part can now be repaired near-net-shape, particularly if only a minor portion has been damaged [4]-[6]. Moreover, medical science uses AM products to replace or repair parts of the body, like facial prostheses [7].

The same, or even greater, technical performance can be achieved by using lightweight materials. For instance, in the aerospace industry, aluminum, steel, and composites are mostly used, with composites having higher tensile strengths than steel. Furthermore, advanced optimization techniques can be used to maximize structural stiffness and minimize mass by optimizing geometrical parameters and the layout of structural elements. Topology optimized models and composite structures manufactured by additive manufacturing are often not feasible using conventional fabrication processes such as casting, forming, stamping, and machining [8]. Structures or systems that use AM parts need to be checked regularly for safety and to save resources and time. SHM, which uses a nondestructive method, is a good option in that case. Acoustic emission techniques are used in structural health monitoring to monitor the health of a complex structure [9].

Section 3 describes acoustic emission's use in AM products or printing process, while section 2 describes the basics and classification of additive manufacturing.
2. Additive Manufacturing

2. Additive Manufacturing

During the fourth industrial revolution, additive manufacturing has become a major research topic. From the home to the industry, it can be used to manufacture metals, polymers, and even concrete structures. Aside from the advantages of AM, known as 3D printing, it also has limitations, risks, and disadvantages.

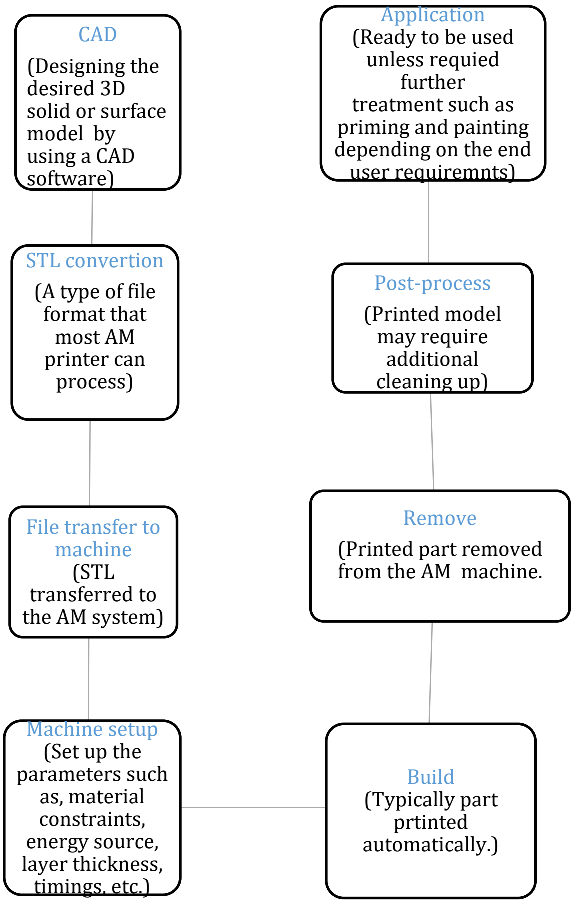

Fig 1. A flowchart to represent the basic steps of additive manufacturing [15], [23].

This innovative Additive Manufacturing can be compared with old-fashioned manufacturing, where an assembly is built with many parts with screwing or welding. Usually, an object made out of an AM is a three-dimensional object with one layer stacked up with another [10]. AM started almost 150 years before, with roots in topography and photosculpture [11]. The topography terminology is used to represent an area's physical and artificial features. Blanther, in 1890, introduced a layered method where wax plates were used to make a mold for topographical relief maps [12]. After that, many scientists proposed and developed these methods [11], [12]. Photosculpture, on the other hand, uses many cameras to take a picture of an object to construct a replica. It started in the 19th century as an attempt to produce a 3D replica model of any object. It was somewhat successfully developed by François Willème in 1860, where 24 cameras were used to take simultaneous pictures from an object that was placed in a circular, and the camera position was equal distance as the circumference of the room [11], [13]. This technique was the precursor to AM, and scanning introduced some fundamental characteristics of AM process, such as slicing an object or model to understand it [14].

2.1. Basic Steps of AM process

Additive manufacturing has different stages of production. Basic steps are shown in Fig. 1, which briefly describes a computer-aided design to its application [15]. Fig. 2 illustrates a schematic of the basic steps of AM process [16].

2.2. Classification of AM

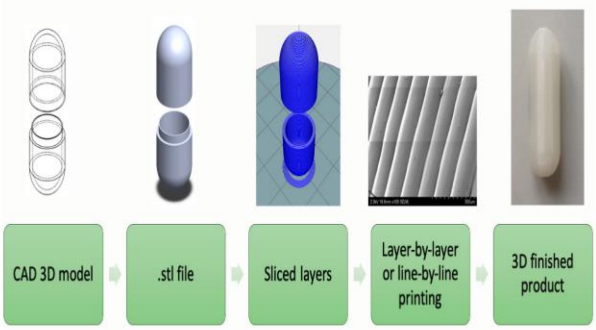

Fig 2. Basic steps of an AM process [16].

Polymers, metals, ceramics, and composites are typically used as materials in AM. Fig. 3 shows the classification of AM and typical materials used by each process [17], [18]. The material deposition process to make an AM model is one of the critical ways to classify the types of AM. Either melting the material or solidifying powders, or liquidizing materials makes the desired model of the shape, where basic processes are Sheet Lamination, Vat Photopolymerization, Powder bed Fusion, and Material Extrusion [19].

Additive manufacturing will revolutionize manufacturing, as well as a range of other industries. For AM to develop rapidly and significantly, it must be applied in a way that allows for its rapid and significant growth, for example, size limitations. An object can only be produced by a 3-D printer if it is smaller than its casing. As a result, the size of objects that can be manufactured is limited. Larger printers do exist, but they require a large space to accommodate their size. A product's components can sometimes be manufactured in segments without a large enough printer, but this requires additional time to assemble the parts, which detracts from its advantages [20].

2.2.1. Direct Energy Deposition

An Additive Manufacturing process called Direct Energy Deposition (DED) involves melting material, usually metallic powder or wire, during layer-by-layer depositions with the use of a focused thermal source. It also repairs and rebuilds damaged and worn parts,

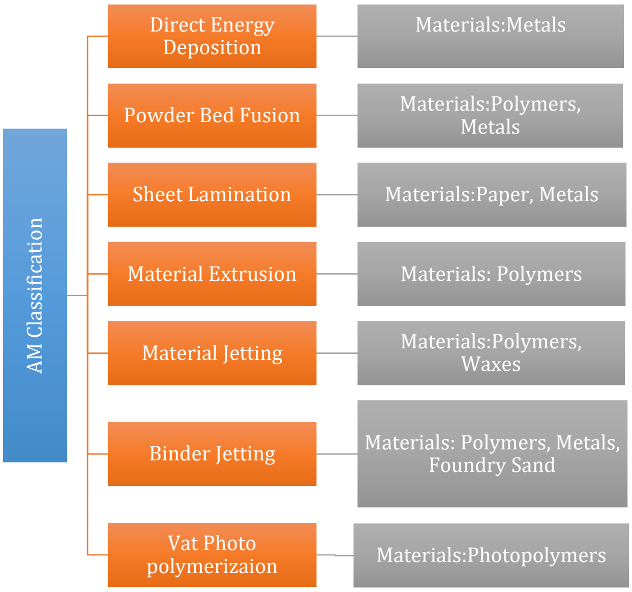

Fig 3. Classification of additive manufacturing [6], [17], [18], [23].

making new metallic components from a substrate [21]-[23]. This AM can produce good quality objects by doing a high degree of control of grain structure [24]-[26]. Fig. 4 shows two types of metal DED schematics [27]. In comparison with other AM processes, DED offers a number of unique advantages, including site-specific deposition and repair, as well as alloy design. Parts manufactured by DED will have different characteristics and quality depending on the type of technology (including feedstock and heat source); the build environment (vacuum, inert gas, or ambient); beam-material interactions; parameters for deposition (mainly laser powder, laser scan speed, hatch spacing, powder feed rate, laser scan strategy); and characteristics of feedstocks. Due to the local temperature variations, shrinkage, residual stress, and deformation can occur. It is important to note that different powder delivery mechanisms influence the complexity of parts, the support requirements, the flexibility of material usage, and the surface roughness of the deposited parts. In addition, DED deposited parts are subjected to rapid heating–cooling cycles during layer-by-layer deposition, resulting in unique microstructural characteristics, non-equilibrium phases, solidification cracks, directional solidification, residual stresses, porosity, delamination, and warpage. DED samples typically exhibit anisotropy in mechanical properties and heterogeneous microstructures because of the directional deposition process [28].

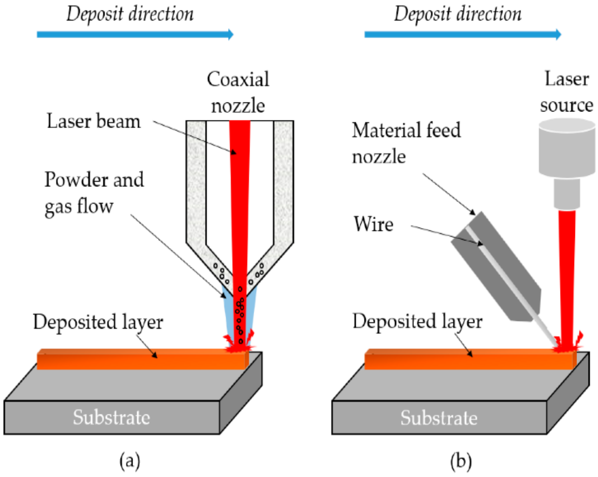

Fig 4. (a) Metal DED with a coaxial nozzle, and (b) Metal DED with a material feed nozzle[27].

2.2.2. Powder Bed Fusion

This AM method uses either an electron beam or laser to melt or fuse the powder. The types of powder bed fusion include selective heat sintering (SHS), selective laser sintering (SLS), selective laser melting (SLM), and electron beam melting (EBM). Ceramics, polymers, composite and hybrid, and metals are usually used for printing [23], [26], [29]. Different defects in the laser powder bed fusion (LPBF) process can be caused by a variety of reasons, and the same defect can also be caused by a variety of reasons. Low scan speed combined with high laser power can produce a large melt pool, resulting in balling. The powder can be affected by this and develop defects such as cracks, porosity, grain growth, oxidation, and shrinkage. It is also important to consider the machine parameter in LPBF because some issues are related to the machine, and an issue occurring in one machine may not necessarily occur in another [30]-[32]. One of the reasons for defective parts in SLM is stress. Cracks appear on the surface when the stresses trapped inside the component are suddenly released, affecting its performance and life. During the SLM process, thermal stresses are also induced by powder melting. As a result of this stress, the component cracks and eventually deforms [33], [34].

2.2.3. Sheet Lamination

This method is used for sizeable 3D model production where the materials are cut, stacked, and bonded using different materials, such as ceramics, paper, and polymer [23], [35]. Ultrasonic consolidation and laminated object manufacturing (LOM) are two categories of sheet lamination [36]. LOM is one of the first commercialized AM, a layer-by-layer lamination of material paper sheets cut using a CO2 laser. The bonding mechanism between layers can be performed in different ways, such as ultrasonic welding, gluing or adhesive bonding, thermal bonding processes, and clamping [15]. In the LOM process, warping is the most significant problem. The phenomenon often occurs at the beginning of the fabrication process, especially when the laminated part is cold, the heating temperature is low, or the prototype is large. Generally, warping starts at the top corners and curves of the part. Intra-laminar thermal forces are also responsible for warping, which is a result of a non-uniform distribution of temperatures at the interfaces of layers of the part. Cutting process also may cause defects in the 3D printed parts. In the laser cutting process, when the hot roller is removed from the laminated layer of the part, the temperature of that layer rises and falls[37], [38].

2.2.4. Material Extrusion

Material Extrusion technology typically uses heat to melt material before or during forcing materials into the 3D printer nozzle [23], [39] and this AM process is a powerful 3D technology applied in research and manufacturing fields due to raw materials' availability and ease of use [40], [41]. Fig. 5, a fused deposition modeling 3D view, an example of a material extrusion introduced in early 1990 [42]. Fused deposition modeling (FDM) builds a 3D model from bottom to top layer-by-layer by heating and extruding the polymer material known as a thermoplastic filament [26], [43], [44]. In FDM, voids can occur between the layers, resulting in an anisotropic mechanical property and delamination. As a result of reduced bonding between layers, this type of problem occurs [45]-[49]. Also, depending on the direction in which an AM part is built, its mechanical properties may vary. If a plate is manufactured by FDM technology from the Z-direction, its strength in x, y will be greater than in the Z-direction [49]-[51].

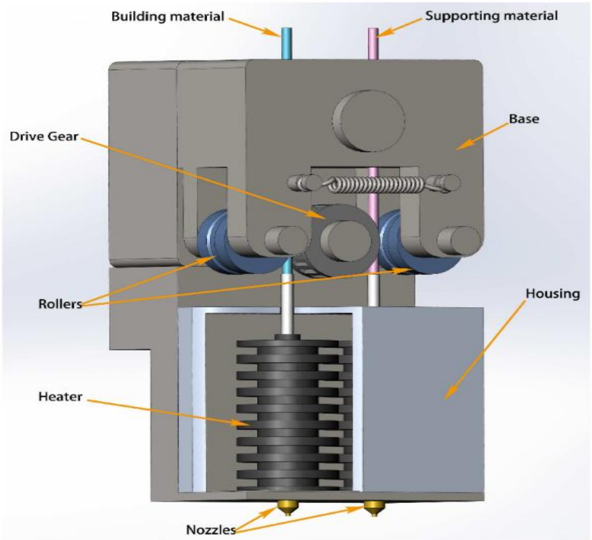

Fig 5. A 3D Model of fused deposition modeling [42] .

2.2.5. Material Jetting

As per the ASTM Standards, this AM process utilizes drop-by-drop selective deposition to build material. In material jetting (MJ) method of AM, to create a 3D model, a printhead is used to dispense droplets of a photosensitive material that solidifies layer-by-layer under ultraviolet (UV) light [23], [26], [52]. This AM method selectively cures liquid photopolymer to make functional parts [53]. The parameters influencing the mechanical properties and dimensional accuracy of MJ printed parts in the MJ process. In MJ manufactured parts, the location of the tray, the thickness of the layer, the build orientation, the surface finish, the type of material, and the post-processing affect mechanical properties, surface roughness, and dimensional accuracy. A tray's location can be defined along the X, Y, and Z axes. The jetting head moves along the X-axis and along the transverse Y-axis, along which jetting orifices are located in parallel. With each layer, the build plate moves along the Z-axis. It is important to note that where the part is located along the X or Y axis of the build tray in MJ has a significant impact on the mechanical properties and surface roughness of the final product. Additionally, the orientation of a part within a build tray affects both its surface roughness and its mechanical properties [54]-[57].

2.2.6. Binder Jetting

Primarily developed at MIT in the early 1990s, Binder Jetting (BJ) is a process in which part cross-sections are formed [23]. A binder is printed onto a powder bed [58]. It is a simple, fast, and cheap AM process where a liquid binding agent is selectively deposited to join powder particles to form the layer. This method can also print a 3D model with various materials, such as ceramics, polymers, and sands [26], [59]. The BJ process does not involve melting and is primarily consolidated by sintering, so porosities are always possible, and their volume, size, and shape may vary between parts made from the same batch due to the lack of melting. Furthermore, the parts are expected to have a coarse microstructure since the binder must be cured, sintered, and annealed after printing. As a result, BJ parts are not as strong as SLM parts [60], [61]. Several process-related parameters affect binder deposition, including binder saturation, printing speed, and binder drying time. Part quality, dimensional accuracy, density, and mechanical properties are affected by binder saturation. Binder deposits on a part are influenced by powder bed density and particle size. In general, fine and irregular-shaped particles require a higher binder saturation due to their lower powder bed density. In addition, the presence of localized density variations may result in cracking or non-uniform shrinkage. Metal BJ faces several challenges, one of which is the high-level part shrinkage in contradiction of full densification [62], [63].

2.2.7. Vat Photopolymerization

This AM method is most prevalent where ultraviolet (UV) light is used to form chains between molecules of liquid light-curable resin, crosslink them, and as a result, harden the resin. The types of these methods include digital light processing (DLP), stereolithography (SLA), and continuous digital light processing (CDLP) [23], [64]. Essential parameters for this process are wavelength, time of exposure, and the amount of power supply. The materials initially used are liquid, and later they will harden when the liquid is exposed to ultraviolet light. This Photopolymerization is suitable for making a premium product with good details and high surface quality [26], [65]. A typical SLA machine contains the following components (Fig. 6): 1- the printed part, 2- the liquid resin, 3- the building platform, 4- the UV laser source, 5 - the XY scanning mirror, 6- the laser beam, 7- the resin tank, 8- the window, and 9- the layer-by-layer elevation [66]. Photopolymers with high viscosities are more likely to damage printed features during recoating. In addition, the solvent removal process may cause shrinkage in the final product. Also, geometry affects printing parameters, shrinkage, and warpage. Photopolymers also lose mechanical properties over time, which is another concern hindering their use in industry. Due to potential photoinduced chain-scission, 3D printed parts exposed to UV light may show reduced mechanical performance [67], [68].

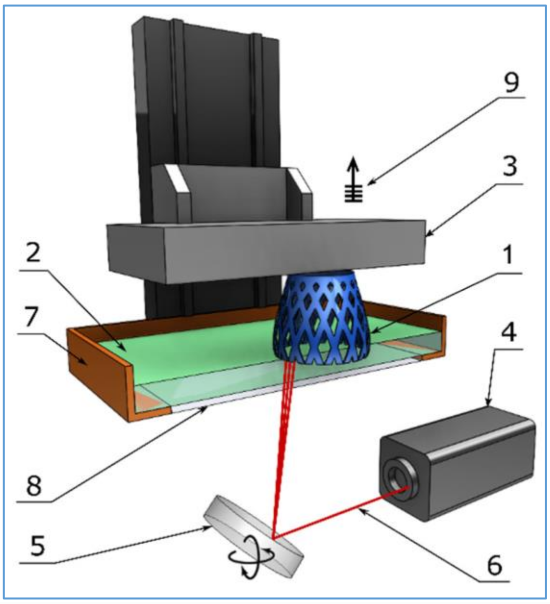

Fig 6. A typical SLA machine [66].

2.3. Defects of and Cracks AM products

Due to advanced research and development, innovative and high-performance AM materials are now utilized to print complex 3D objects, even a home. These object quality and mechanical performance are affected by different internal defects such as porosity, powder agglomeration, cracks, balling, and thermal or internal stress. Due to this reason, producing highly dense objects is the key to maintaining the quality of AM products. It has been observed that a highly dense (more than 99.8%) part is possible to make with a very controlled system. To improve the overall quality of AM products, in-situ quality control techniques are very important for detecting different issues that might arise during the printing process [69]-[76]. The following sections will discuss a recent study of health monitoring of AM products with a type of SHM, AE.

3. AM process defect detection with structural health monitoring

Different technology has been used to detect defects during or after the manufacturing process. For example, sensors like photodiode pyrometers are being used for the quality control of AM production, which are based on temperature or higher resolution images [77]. Followings are some of the NDT methods that have been applied to AM.

3.1. Dye penetrant testing

A dye penetrant was used to detect surface defects that cannot be seen visually. This method is multipurpose; it can be easily adapted to different part sizes and geometries, requiring short inspection times at a low cost. Through capillary action, the penetrant liquid penetrates superficial defects by seeping into their cavities. However, it is difficult to detect defects automatically [78].

3.2. Radiographic

By passing radiation energy through a material, a homogeneous image is formed except for areas with defects or density differences, making it possible to identify potential defects. Different thicknesses and materials require different voltages, currents, and exposure times to obtain adequate radiography images [79], [80].

3.3. Thermography

An electric current source was used in the thermography tests to heat volumes by using the Joule effect. Thermal signatures are left by the resultant temperature field due to the continuity of the material. An IR thermographic camera can detect heterogeneity if it alters the thermal conductivity of the specimen [78]. It is impossible to detect the defect at all locations of an AM object using this technique.

3.4. Eddy currents testing

Surface and subsurface defects can usually be detected with eddy currents based on a local change in electrical conductivity. Cracks, inclusions, and pores can be detected using it. Furthermore, it can also be used to determine whether materials are homogeneous or dissimilar from one another [78]. This NDT technique can only be applied to a limited number of materials.

X-ray computed tomography is also used in AM object defect detection, though it has a risk of radiation effects on humans. This study discusses acoustic emission monitoring, which has no radiation risk and is not limited to material types or locations. SHM is a system for identifying damage or any change in materials or geometrical properties for different engineering fields. It is an excellent method for detecting and identifying defects of an object or structure before it fails. This detection process can save time and money before an object undergoes a complete failure. A material level defect is typically the source of an object's damage, and consequently, these changes affect its present function as well as its future function. The level of defect or damage determines whether the state is safe or dangerous [81].

3.5. *Acoustic Emission-A type of SHM technique*

It is impossible to get a solid without cracks, and maximum stress developed during crack propagation is experienced at the tip of those cracks. Besides, a brittle fracture occurs as the 3D stress increases due to crack propagation in the objects [82]. It is important to detect crack propagation early. Using nondestructive techniques such as AE, the SHM system monitors cracks in materials [82].

Fig. 7 shows a typical setup to detect the desired output with the AE technique. Where AMP indicates the maximum amplitude in dB unit, DUR is the duration of the period during the first and the last threshold crossing. RT or "rise time," the time between the first threshold crossing and the point of maximum amplitude in µs [83]. A threshold works as the acceptable limit of AE signals.

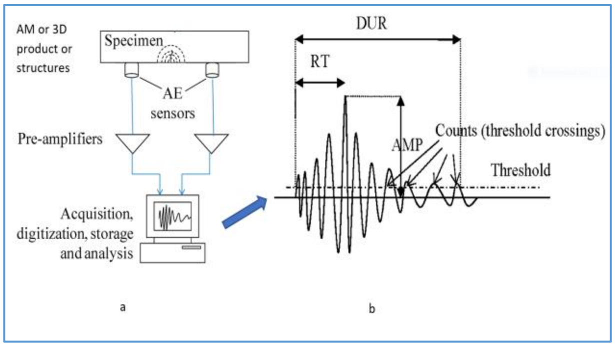

Fig 7. Basic AE techniques, (a) a typical setup, (b)AE signals [83].

There are several sources that can emit signals during the printing or construction of AM products, including cracking, dislocations, delamination, fiber breakage, and friction. These signals are detected by AE sensors, which may be electrostatic, piezoelectric, resonant, or broadband. AE sensors based on micro-electromechanical systems are also being developed and used to detect active defects in different materials through transduction mechanisms such as piezo resistivity, capacitance, or voltage [84], [85].

Due to the release of energy from the crack initiation, transient elastic waves are generated. These waves have frequency content between 20 kHz and 5 MHz. They can propagate into the material and be detected away from the source by piezoelectric-type sensors [86]. The waves' origins are plastic deformation, crack propagation, wear, friction, thermal stress, stress build-up, fiber breakage, and fiber-matrix debonding in composites. AE is different from other NDT techniques, like ultrasonic and eddy current testing. It detects damage occurring inside the material and eliminates the need to scan the whole structure, thus reducing cost. It can also predict incipient damage and prevent catastrophic failure of a system in advance [87].

3.6. *AE in AM*

The use of SHM is becoming increasingly important for monitoring AM processes. Currently, many researchers are conducting research in this field. Strantza et al. [62] proved that AE shows a similar trend to AM components with conventional metal components [88]. A real-time part was warping deformation or distortion of AM monitoring method based on AE developed by Li et al., which could identify distortion defects and realize the condition of the distortion region [89].

A research study performed in situ monitoring of an AM process, the fused deposition modeling (FDM). Where an AE sensor was placed on the hotbed inside the 3D printer, then AE data were analyzed to detect significant failures and failure modes. The different k-means algorithm was applied, which showed a similar consistency of frequency analysis. The experimental data were classified into four categories. In brief, k-means is a process to organize the k sets of data from the n-dimensional population considering the basis of the sample. However, this study did not detect effective failure monitoring, and there might have minor failures that might lead to significant loss [90], [91]. K-means algorithm is also used to classify core cracking, matrix cracking, and fiber/matrix debonding after post-processing the AE signals with unsupervised pattern recognition algorithms [92]. Another study developed an alternative method for filament breakage identification in the FDM AM process based on AE signals from filament breakage signals. This study showed that the AE from the filament was not from the crack or damage from the 3D printed object [42].

Wu et al. [93] developed an online monitoring method for the AM process on the fused filament fabrication (FFF) process based on AE signals. They considered two types of printing for the data analysis: failed FFF printing and normal printing process. AE signals were collected as the hits instead of the waveform of data due to more efficient data processing. Data were recorded from both time and frequency domains for the good and bad printing process.

Experiments were conducted in a research study to detect the damage mechanisms from an additive manufacturing material known as a carbon-fiber-reinforced polymer based on acoustic emission. Damage mechanisms included matrix cracking, debonding, fiber break, and delamination [94].

The laser-based powder bed fusion (LPBF) additive manufacturing (AM) process offers some benefits, including a high degree of design optimization due to shape complexity, relatively high resolution, confined by the laser beam size and powder properties, and the reusability of powder materials. However, LPBF has some disadvantages, including poor surface finishing, size and design limitations, and thermal gradients that can cause residual stress, resulting in internal cracks and deformations during processing; LPBF parts can be porous due to scanning and building strategies or inhomogeneity in powder layer delivery; as a result, this type of defects can significantly deteriorate performance properties [95], [96]. Kouprianoff et al. [95] developed a method for monitoring AE online, which uses indicators for detecting porosity forming phenomena such as lack of fusion during metal LPBF. As part of Ludwig's project, Ludwig developed the in-situ monitoring of the LPBF AM process. The testbed is equipped with an instrumented build plate where an ultrasonic sensor attached to the bottom is used to detect acoustic emissions while the laser beam scans over the powder bed. Experimental results with single powder layers indicated a clear distinction in AE signal between environmental noise, the laser actively scanning, and cracking [97].

It is essential to monitor as well as control the material delivery rate in powder directed energy deposition (DED) to ensure a reliable and repeatable additive manufacturing process. Whiting et al. [98] developed a novel mass flow monitoring system and calibration method for DED using acoustic emission. The system can measure a wide range of mass flow rates in a powder fed DED process. Earlier attempts to monitor metal powder mass flow lacked the necessary calibration process or were not able to be used in situ, which limited their utility. For in situ monitoring of metal DED AM processes was demonstrated by Taheri et al. by AE. That study also used a new approach, the K-means statistical clustering algorithm, to classify different process conditions and to assess the classification performance in terms of cohesion and isolation. The study shows the potential of acoustic techniques for monitoring DED in situ [99].

AE and artificial intelligence (AI) are also being used by researchers for AM. According to Shevchik et al. [100], they conducted a 3D in situ quality monitoring using acoustic emission, machine learning, and AI. A sensor was attached directly inside the chamber to get high-quality signals, which were further classified into two datasets, training and testing. Separating datasets into these two sets was the beginning step of image processing. To provide the input data of Machine Learning (a branch of AI), intentional pores have been made in the workpiece. Then, spectral, and conventional convolutional neural networks were used to classify the features from different AM qualities. The results show up to 83, 85, and 89 percent accuracy for high, medium, and poor object qualities using SCNN [100]. Also, a machine learning method, self-organizing map (SOM) was utilized to formalize the diagnosis procedure of failure modes. The research outcomes showed the feasibility of diagnosing the detection and identification of typical failures. However, this data showed only for the FFF process [93].

A key element to assessing the failure probability of a part produced via laser metal deposition (LMD) is detecting defects. An effective way to detect LMD defects is through acoustic emission. By Gaja et al. [101], a systematic experimental investigation was conducted to detect and classify defects in LMD using AE techniques. A logistic regression (LM) model and an artificial neural network (ANN) were used to determine if AE could detect and identify defects generated during LMD. Several AE features, such as peak amplitude, rise time, duration, energy, and the number of counts, as well as statistical features were extracted and analyzed. On the AE signal, fast Fourier transformation was also used for frequency analysis. This study shows that AE can be used to monitor LMDs for assessing the overall deposition quality and identifying defects that can adversely affect the strength and reliability of deposited materials, increasing component failure risks.

Environmental or background noise is the greatest challenge in differentiating defects from the AE that arises while monitoring the quality of AM products. For example, malfunction noise may be weak compared to environmental noises that are difficult to identify. Yang et al. [77] developed a method to overcome that challenge and tested filament breakage detection to disclose the effectiveness of this method. However, this method was perfect when the amplitude of the target malfunction AE signal was less than the stationary environmental AE signals [102]. In the AE technique, noise may create false-positive signals. Sometimes preload is applied to find out the threshold limit of stress to ignore this noise. Moreover, many AM products can be used to improve the overall efficiency of the SHM technique. Munasinghe et al., for example, developed a 3D printed sensor and tested it for loading and unloading conditions to determine the hysteresis effect, which can be directly printed onto gravity separation spirals. They used a carbon-based conductive filament to print a strain gauge on top of a polylactic acid-base material during their testing process. The researchers found a near-linear relationship between strain and measured resistance with minor hysteresis [103].

To overcome the challenge of a large amount of data, Liu et al. [104] performed a linear discriminant analysis after feature extraction to combine the frequency and time domains of AE data. Studies showed that the developed approach could identify the machine state effectively. The machine states were blocked, semi-blocked, loading of material, unloading of the materials, out of materials, and normal extruding [104].

4. Conclusion

During the AM process, materials are deposited incrementally, providing a unique opportunity to analyze the quality of the material at each stage of the process. Assessment of process performance and understanding of defect formation requires the development of in situ monitoring methodologies. Using in situ monitoring, process defects and faults can be detected early. As AM processes are sensitive to different factors, such as lasers and materials, any changes to aspects of the process could affect the quality of the part. Therefore, AM parts must be monitored in-process to ensure quality, integrity, and safety. Monitoring in situ processes has been accomplished using a variety of sensors and techniques [99]. AE is one of the SHM tools that have been used by researchers for the development of monitoring techniques. In this study, both AM and AE in AM have been discussed.

This study started by depicting the AM process, classification, and defects. Later, a presentation of the quality control of AM with AE is provided. However, AE is not the only way to monitor the SHM. There are many other NDT techniques for SHM, and researchers have been performing many studies to overcome the difficulties of AM. For example, design, material tuning, process optimization, real-time monitoring, and cybersecurity with the image processing and machine learning (ML) approach [74]. However, the challenges are not yet completely solved. As the demand for using the AM in different fields is increasing, problems are arising the same way.

One of the drawbacks of utilizing AM in recent days is the environmental impact. Some studies have examined the variety of environmental impacts of additive manufacturing. So, more research is needed to utilize AM process more efficiently by keeping in mind the world's future. However, potential benefits over conventional manufacturing include the following in brief, according to Scott et al. [6].

- Efficient use of raw materials: Conventional processes scrap rates can be as high as 80–90 percent, whereas AM scrap rates are 10 percent or less.
- Energy efficiency: Inefficient processes such as casting and CNC machining need more energy.
- Fewer fixed assets: AM processes need fewer pieces of specialty capital equipment.
- Fuel efficiency: As AM products are usually lighter, it saves fuel in different forms.
- Dramatically reduced the inventory and warehousing

Why is SHM important for AM? In AM, different materials are used than in conventional manufacturing. To protect and maintain the property when AM parts or structures are used, SHM is crucial. This also can save time for reconstruction or repair if the cracks or defects can be detected before leading to a catastrophic disaster. Researchers or engineers may verify AE sensors with other NDT or SHM technology when used in an AM process for quality control. Also, they can use the AI algorithm to predict and verify AE sensors for that type of environment. This study can be extended by comparing other SHM techniques with AE in the future.

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Author's statement

Conflict of interest: the authors declare no conflict of interest. Informed consent: Informed consent has been obtained from all individuals included in this study. Ethical approval: n/a.

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