ADDITIVE MANUFACTURING: A COMPONENT OF SUSTAINABLE TECHNOLOGY DEVELOPMENT FOR GREEN ECONOMY

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ABSTRACT

Additive Manufacturing (AM) is one of the pillars of the fourth industrial revolution that is becoming embraced globally. AM comprises of producing objects layer by layer from a three-dimensional computer-aided system. It also is a disruptive technology that offers sustainability through improved productivity and resource-efficient processes. These are key elements of a green economy and competitive manufacturing. A green economy refers to industrial processes with low carbon emission, minimum waste of resources and social practices that do not degrade the environment. In the context of this paper, the green economy is defined as production technologies that are aimed at reducing environmental risks while promoting resource efficiency. This paper provides a review of AM as a viable industrial technology for a green economy. It explores possible AM strategies for metal production to point out that AM technologies can be more sustainable than traditional metal casting technologies.

Keywords: Additive manufacturing ,Green Economy, Sustainable technology

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1 INTRODUCTION

Additive manufacturing (AM) has proven to be a viable technology to solve real-world problems through its ability to provide customized parts with complex geometries at shorter lead times. Due to these advantages, AM has been applied in many industries among which are the aerospace, automotive and medical industries [1]. The continued expansion of AM technology is driven by the need to manufacture lightweight parts with intricate shapes without the need for tooling as compared to conventional subtractive manufacturing. AM is the production of parts from a computer-generated model normally layer by layer [2]. It is a disruptive technology that offers sustainability through improved productivity and resource-efficient processes. According to Gibson, Rosen and Stucker [2], a disruptive manufacturing technology such as AM presents a smart way of producing objects with advanced product quality features that are nearly impossible to manufacture using conventional manufacturing methodologies. The significance of AM as a disruptive technology lies in the applied methodology and its capabilities in transforming raw materials into functional parts required by the industry. The sustainability and benefits of AM depends on the understanding of the technology usually known as process knowledgeAccording to Sithole et al [3], process knowledge is defined as the determination of process variables, their collection method, formulation and analysis approach to determine the varying process variables that are related with product characterization for specific objects/parts. Process knowledge is important for improving technology, product quality and also ensures sustainability. Process knowledge is one of the elements that can be used for improving manufacturing technologies and thus influences sustainability [4]. Sustainability is a phenomenon that is described in many ways and possesses different meanings for different industries. However, sustainability is generally defined as the ability to meet current needs without compromising the capability of the future generation to meet their needs. Meanwhile, sustainable technology refers to technologies that minimizes negative social and environmental impacts. It is governed by factors such as efficient resource and energy consumption, waste reduction and cost effective processes. Thus sustainable technologies are able to improve organizational productivity and comparativeness.

This paper provides an overview of AM in terms of sustainable technology development. It aims to explain why AM is a good choice for sustainable manufacturing when compared to traditional manufacturing. This work seeks to highlight why the industry needs to embrace this change. This paper also covers the sustainability of AM, resource efficiency, environmental impact and finally, explains the quality improvement in AM.

2 SUSTAINABLE TECHNOLOGY DEVELOPMENT FOR GREEN ECONOMY

AM has advanced from a prototype and tooling technology to also enable direct manufacturing in different sectors such as automotive, aerospace, architectural, construction, medical, jewellery, furniture, etc. Furthermore, the application of AM continues to grow [5]. The development of AM as a disruptive technology is embedded in the proficiency of the process to produce parts of complex geometries without the need for tooling and to make parts that are difficult to manufacture using conventional manufacturing technologies [2]. As a result, AM technology shortens lead times, production costs, energy consumption and improves material efficiency [6]. AM technologies as categorized by ASTM F2792 standard are Powder bed fusion, Direct energy deposition, Material extrusion, Vat photopolymerization, Binder jetting, Material jetting and Sheet lamination [7]. AM technologies mostly used for direct metal part manufacturing are Powder bed fusion and Direct energy deposition. Figure1 illustrates the technologies applied in metal manufacturing.

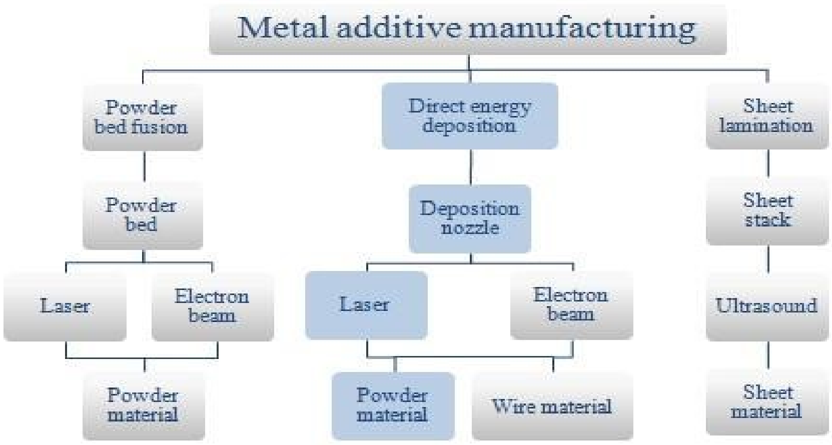

Figure 1: Schematic overview of Metal AM technology [8]

The principle in AM is that parts can be fabricated straight from a computer-generated model without the need for tooling [9]. Manufacturing improvements like production of complex objects in conventional manufacturing technologies require additional operations which then increases manufacturing costs [10]. In subtractive machining processes, increasing production of parts with intricate geometries increases process steps, tool paths and sometimes requires expensive customized tooling. According to Abdulhameed et al. [11], the current market competition in manufacturing requires the production of cost-effective complex shapes, at short lead times, with good quality and processes that require less-skilled workers [10]. AM can meet the current market needs without increasing production costs.

Sustainability in the production environment is influenced and driven by a cleaner, efficient resource utilization and improved manufacturing processes. Sustainable development is fundamentally engulfed in the green economy [12]. Green economy generally refers to industrial processes with low carbon emission, minimum waste of resources and social practices that do not degrade the environment. Peng et al. [6], discussed the sustainability of AM by focusing on energy demand and environmental impact. Figure 2 illustrates the dimensions of sustainability in relation to AM as discussed by Peng and colleagues. This figure summarises the sustainability of AM as a technology development for the green economy. It addresses the three fundamental aspects of sustainability which are economy, environment and society. AM has demonstrated great potential to be one of the leading sustainable manufacturing technologies when compared to conventional manufacturing.

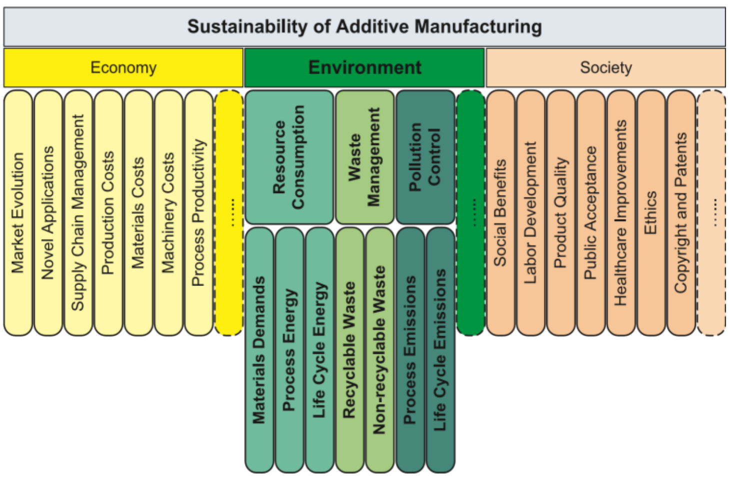

Figure 2: Sustainability of AM [6]

According to Resen and Kishawy [4], technology advancement can enhance the environmental impact and thus improve sustainability. Few studies have listed and studied the sustainability potential of AM. In AM, energy and material consumption are the main resources used in the technology [13]. Resource efficiency in AM depends somewhat on the size of the part being fabricated, the material used and the required properties of the part. Energy consumption for isolated processes can be low. However, when the total feedstock is taken into consideration, energy consumption can be high. At this stage, it is important to note that the determinants of a sustainable technology or green economy differ based on the nature of the manufacturing process and products being fabricated. However, the factors that determines a sustainable technology remains the same. The next sections describe the resource efficiency and environmental impact of AM to further outline the sustainability of the technology.

3 RESOURCE EFFICIENCY AND ENVIRONMENTAL IMPACT OF AM TECHNOLOGIES

AM is considered a green economy technology development due to its nature of production, state-of-the-art capability and potential in fostering sustainability [14]. The nature of production in this manufacturing technology is "additive" rather than "subtractive" as in conventional manufacturing [15]. In this process material is selectively deposited layer upon layer to form an apart/object [9], depending on the technology being used, a substantial energy source is passed after every layer of material deposition for fusion [2]. This process ensures that only the material required to make the part is used and the material not used can be recycled back to the system [15]. Figure 3 shows the nature of production in both subtractive and additive processes. As observed in this diagram, in a subtractive process denoted by the letter "A" a billet of material is shaped into the desired object by removing the material using a technology like CNC machining. While in Additive manufacturing, denoted by letter "B", material is selectively added to form the desired object. Although CNC machining can produce three dimensional (3D) objects, the process becomes increasingly difficult with increasing geometric complexity and can result in a significant amount of waste material.

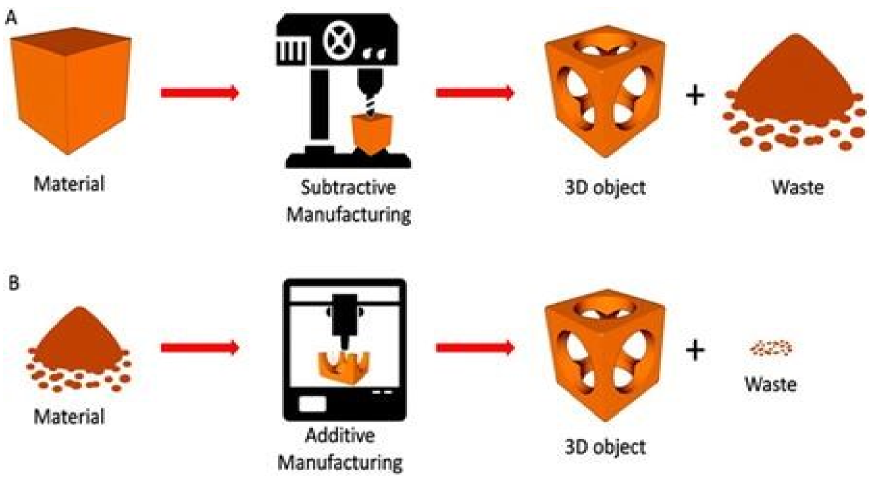

Figure 3: A. Subtractive vs B. Additive manufacturing [16]

Thus, the nature of production in AM promotes resource efficiency with increasing geometric complexity and in particular producing minimal waste. Comparing the nature of production in AM to subtractive manufacturing points out that AM is more sustainable with regards to environmental impact. However, AM has some drawbacks in its nature of production such as increased manufacturing times, high capital investment and low volume production [17]. According to Inovar Communications Ltd [5], AM is not yet suitable for mass production but rather for mass customization. Mass customization is defined as the production of not identical but comparable parts with features personalized by the customer [10]. Literature also shows that AM is a manufacturing technique that influences the production of customized products for a specific need in an industry or sector.The nature of production in AM fosters sustainability when compared to other manufacturing technologies. AM technology has the potential to be more sustainable in terms of environmental and social effects. The next section covers the state of the art capability of AM to point out its advantages that leads to sustainability

3.1 State – of – Art capability of AM

AM enables production of complex lightweight parts through the use of techniques like topology optimization, which in turn reduces the material and energy required to make such parts. According to Ma et al [15], AM has the potential to save energy and carbon emissions through production of lightweight parts for the aerospace and other heavy-duty industries, thus making AM an environmentally friendly process. Additionally, AM processes can be optimized to further reduce material utilization while producing lightweight and complex parts with hollow features [16]. Resource efficiency can be high in AM including the energy used to transform the input material into the output form. A study by Baumers et al [13], looked at energy consumption in AM and it was concluded that energy efficiency increases with improved productivity. Productivity in AM is influenced by process optimisation and process knowledge for improving designs and the technology performance. AM also shortens the supply chain by eliminating the tool-making process which is inevitable in traditional manufacturing for making complex shapes. AM also has the potential and capability to improve cost performance by reducing the number of supply chains and spare parts [18].

The nature of production in AM with regards to the number of process steps involved can also be compared with other traditional processes for metal manufacturing such as sand casting. Figure 4 shows the typical sand casting manufacturing process steps. A typical sand casting process possesses many interlinked and complex stages (Processes) [3]. In contrast, AM for metal production possesses a much shorter production chain when compared to a typical sand casting process which can result in lower manufacturing cost.

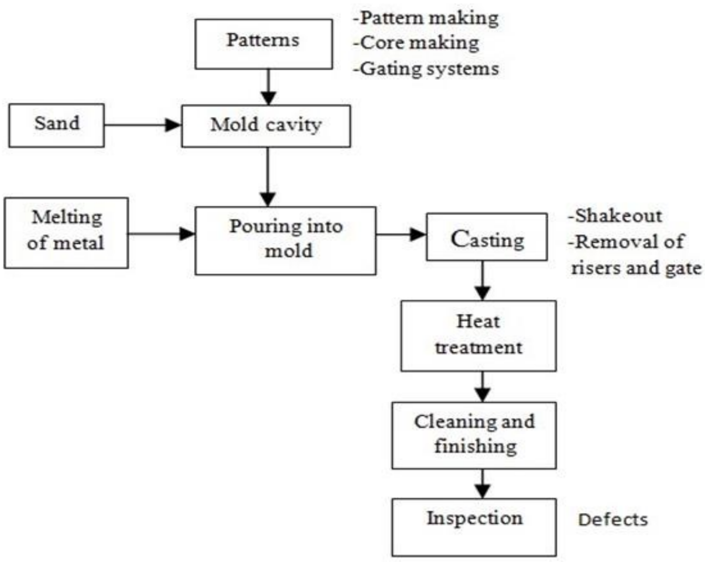

Figure 4: Sand casting process [19]

AM is also more sustainable when compared to the typical sand casting process because of shorter supply chains which minimizes resource consumptions. Reduction in the use of material saves energy and so minimizes carbon emissions. Direct metal manufacturing through AM reduces the number of process steps including removing the pattern making, sand mixing, metal melting and mould making stages. The reduction of these steps enhances resource efficiency, improves manufacturing cost and minimizes material wastage. In conventional manufacturing techniques such as sand casting, sustainability is in the material recyclability, which is mainly the sand [3]. However, the potential of AM in fostering sustainability is great when compared to other manufacturing technologies. The next section expands further on the sustainability of AM.

3.2 Potential of AM in fostering sustainability

The nature of production in AM fosters its sustainability by printing (mostly) only the material required for the part, which in turn reduces waste production. However, some additional material may be required to assist in the build process. Waste reduction in AM can be achieved through process optimization and part orientation on the build plate to reduce the number of support structures, which are removed and scrapped as soon as the building process ends.

According to Peng et al, AM can improve on waste production by up to 90% compared with subtractive manufacturing [6]. Albeit, AM produces less waste when compared to subtractive manufacturing, it is not a complete exception to waste production. Waste in AM is in the form of support structures, extensively used in metal manufacturing for example, as well as scrap produced during failed builds and materials that cannot be reused [6]. However, there is opportunity in the form of optimisation of complex parts and techniques for reduction of supports in AM to promote savings in waste and carbon emissions.

The sustainability of AM also lies in the shipment and inventory of parts. If parts are printed onsite, then no transport is required and therefore the overall carbon footprint can be reduced. In terms of inventory, AM reduces costs by ensuring we only print (spare) parts on demand. In particular, this minimises manufacturing and storage costs with less waste of material. The next section discusses quality management in AM, which is another aspect that fosters sustainability in manufacturing.

4 QUALITY MANAGEMENT IN ADDITIVE MANUFACTURING

Quality management in a production environment is meant to ensure that products are fabricated with maximum quality at minimum cost and ensure that they meet or exceed customers' requirements. Quality improvement is also essential for sustainability in manufacturing. Due to the capability and market demand of AM, quality plays a crucial role in this technology development. Quality control of AM parts must ensure that fabricated parts are fit for use in any form [17]. Although AM is a competitive manufacturing technology, it still possesses limitations in terms of surface quality, dimensional accuracy and lack of data repeatability in the process [18]. However, there are standards such as ISO and ASTM that govern AM technology to foster quality and also to ensure that AM parts are fits for use [20]. Apart from ensuring that fabricated parts are fit for use, these standards also ensure the sustainability of AM processes. Quality is a built-in feature of the process in AM technology. Understanding the process, the parameters and their correlation is important for ensuring quality of builds and reduction of failed builds. Process optimization is by far the most important feature for controlling and improving quality in AM. This reduces waste of material, minimises build failures and ensures maximum quality.

5 CONCLUSION

AM is a disruptive technology that has great potential for sustainability when compared to traditional manufacturing technologies. This technology can reduce material required in a supply chain and utilise less energy while minimising waste due to improved productivity. Despite of the well-known benefits of AM, this paper has outlined the efficiency of this technology in fostering sustainability. It has focused on the sustainability of AM, outlining the importance of AM in improving resource efficiency and environmental impact as green technology development.

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