

Incorporating 3D Metal Printing with Artificial Intelligence in Meeting Aerospace Demands

Aneez Syuhada^{1,2}, M S Shamsudin^{1,2,3}, M F Omar², S K Ghoshal^{1,2}, S W Harun⁴,
M S Aziz*^{1,2}

¹ Laser Centre, Ibnu Sina Institute for Scientific and Industrial Research, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor D.T., Malaysia

² Department of Physics, Faculty of Science, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor D.T., Malaysia

³ School of Engineering, Faculty of Engineering and Physical Sciences, University of Southampton Malaysia (UoSM), 79200 Iskandar Puteri, Johor D.T., Malaysia

⁴ Photonics Engineering Laboratory, Department of Electrical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia

Corresponding author: safwanaziz@utm.my

Abstract. 3D metal printing and aerospace industry is an ideal combination where 3D metal printing offers unmatched advantages over the conventional method in terms of its rapid prototyping, rapid tooling, easy maintenance and repairs. With the provision and implementation of 3D metal printing onto aerospace sector, leading manufacturers are now enjoying great benefits as this exciting technology reduces the lead-time, increases production flexibility as well as cost-effective. However, we are now left with a big question: whether or not this 3D metal printing technology has arrived to its maximum capacity where the system operates with no flaw. Previous studies have shown that 3D metal printing is battling with its consistency, repeatability and traceability due to many independent variables that need to be controlled in a single run. Adoption of Artificial Intelligence onto the 3D metal printing has been viewed to be a promising step and therefore, serves as a cornerstone towards a better development of 3D metal printing technology.

1. Introduction

3D printing has taken the world by storm and a lot of industries are now growing fervour over this thrilling technology. With the 3D printing market reaching USD 772.1 million in 2019, the trend is expected to increase dramatically with CAGR of 27.8% from 2020 to 2027, according to the report by Grandview Research. This prediction is supported by market research from Technavio, which suggest that the 3D printing industry will be in full bloom by USD 1.59 billion at CAGR of over 26% between 2020 and 2024. Conclusively, the overall 3D printing industry is evolving rapidly and healthily by both estimates. A number of established industry players and newcomers are expected to invest in this technology with a lot more innovations are going to be made in various industries including the aerospace industry, defence sector, medical industry, and automotive industry even in the footwear industry. While plastics remains the most prominent materials used by various industries, metal powders such as Inconel, Stainless Steel and Titanium alloys has been widely utilised especially in the aerospace industry. Ti6Al4V is the most common and most widely used titanium alloy in the



aerospace industry due to high strength, strong and structurally efficient for jet engine parts and airframe components [1, 2].

Simply put, 3D metal printing is a process where a solid metallic object is fabricated directly from the computer-aided design (CAD) model by adding materials layer by layer with the involvement of high power laser [3]. Generally, there are two ways on how metal objects are fabricated through 3D metal printing; powder bed fusion (PBF) and directed energy deposition (DED). 3D metal printing serves many benefits towards the aerospace industry; however, it also greatly suffers in terms of the repeatability and traceability of the whole system. This review paper discusses on the overview of the aerospace industry, the challenges and limitation of 3D printing in coping with aerospace demands and how the implementation of data improves the 3D printing environment.

2. Aerospace Industry Overview

3D printing, also known as Additive Manufacturing, unlocking possibilities in today's new era for digital design and manufacturing. This technology has been around for nearly three decades when aerospace application took advantage of it in the late 1980s. In the early stage, the main focal point of 3D printing was the rapid prototyping [4]. This process was limited to building prototypes by creating complex geometries and features that cannot be produced economically using traditional methods. Manufacturing of aerospace components requires a high degree of supply chain management, together with the large work force and machinery.

With the introduction of 3D metal printing, the whole process is now automated by turning the CAD drawing into the solid metallic object, thus drastically reducing the amount of supply chain management [5]. A type of free-form end-user product with precise specifications using lesser material can now be easily fabricated to suit the demands in aerospace application. The market value for rapid prototyping in the aerospace application is expected to reach USD 105 million by 2026. This is further supported by the demands in aerospace application for strong, flexible, lightweight [6], low waste and cost effectiveness components. Nowadays, the application for aerospace industry is no longer limited to build prototypes, rather involves the rapid tooling, maintenance, repairs and part consolidation. Through part consolidation, simplification of parts can be made as part pieces can now be molded together to form a component in a single run. From the manufacturer's point of view, more cost and time production can be realised as waste material can be avoided and time needed for assembly can be greatly reduced.

The most common techniques employed in 3D metal printing for aerospace application are powder bed fusion (PBF), electron beam melting (EBM) and direct laser metal deposition (DLMD). DLMD is a famous technique as it can easily repairs components that are considered non-repairable before. This technique is best applied to the turbine blades and vanes repairs [7, 8] as compared with the welding process as the low heat input along with the clamping flexibility are valuable treats for aerospace components [9]. Aerospace manufacturing companies have already integrated 3D metal printing into their business. Most notably, NASA has successfully developed and hot fire test the thrust chamber assembly for its rocket propulsion application through 3D metal printing [10]. By its Zero-G Technology program, NASA planned on having the 3D printer on ISS to study the effects of consistent microgravity on melt deposition and therefore, seeking an opportunity to start printing parts and tools in space [11, 12]. This fantastic effort will definitely becoming a huge advantage in terms of instant part production and assembly or even for repairing damage parts.

3. Challenges and Limitations

The implementation of 3D metal printing in the aerospace industry is considered to be the century's leading breakthrough as it opens up new possibilities for the optimization of parts and systems. Despite the improvements and capabilities it brings to the table, 3D metal printing possessed its own fair share of challenges and limitations. An important issue that is frequently addressed is the repeatability and reproducibility of the system to produce the parts with constant quality control [13, 14] coming from the printer in every batch of production. This barrier of industrialization has been in

the constant spotlight, especially in the aerospace industry where the reliability and quality assurance of the printed product is highly needed.

3D metal printing is a complex process where at least 50 parameters affecting the quality of the print [15]. The relationship between process parameters such as metal types, laser power, powder feed rate, shielding gas speed and transverse speed, to name a few [16] need to be fully understood in order to control the performance of the printed components in terms of its deposition microstructure, mechanical properties, porosity, surface finishing, residual stress and distortion. For many decades, metallurgists have been studying the relationship between these parameters, yet there is no simple way to tune in the individual parameters together, to date [17]. Different metal powder gives different challenges, and the biggest challenge appears when multi-material printing are involved. Now we are talking about different temperature-time history, solidification rate and temperature gradient which will subsequently affect the phases that formed, morphology of grains, scale of the microstructure and also the nature of defects [18, 19] for each types of metal powders involve just to print a single component. 3D printing involves those numerous complex variables to be constantly keep track of in order to achieve the desired level of accuracy in the printed components.

In this current state, trial and error testing is the most common practice to optimize the structure, properties and mitigation of defects. This practice might be applicable for printing components made up of plastics or polymers which are naturally inexpensive; however, it is totally a different story with metal printing. The high-price of feedstock material and the metal printer itself has made the trial, and error testing appears expensive and no longer effective. Aerospace manufacturing companies have been constantly battling in between time consumption and cost for the production of the metal components. A single CAD design might require up to 200 times trial and error testing to produce the desired flawless component. These kinds of practice is irreversible and the only way to know if the material fused perfectly or not is when the whole procedures are finished as illustrated in Figure 1.

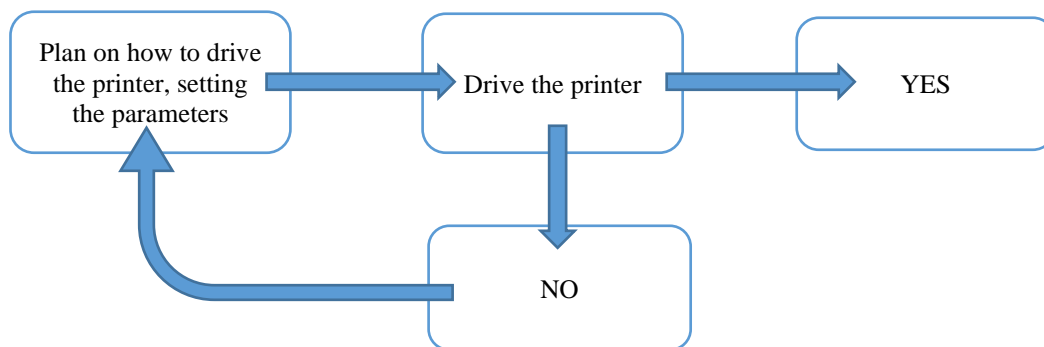


Figure 1. The workflow of 3D Metal Printing

4. How Artificial Intelligence Escalates 3D Metal Printing Performance

Artificial Intelligence or Big Data technology is now the talk of the town. The applications of Artificial intelligence is everywhere, and it is no longer a futuristic view of the world. 3D printing, genetic engineering, virtual reality, robotics and Artificial Intelligence are among the most important technologies in recent human history [20], and these kinds of technologies will continue to evolve over time. Starting from the first industrial revolution in 1760s where the invention of steam engines was introduced, the industrial transition entered the second phase with the introduction of internal combustion engines. This is the era when human learnt how to maximise the usage of oil and electricity to power mass production. The third industrial revolution began in the year 1960s where electronics and information technology were implemented in the automation production. We are now reaching the fourth industrial revolution, where computer generated product design and 3D printing dominate the industry [21-25].

In this era, computers are connected with the manufacturing machines and ultimately making decisions with less human intervention. Artificial intelligence aims to achieve a state in which the system is becoming aware of its surrounding; consequently, it can take action towards increasing the chance of success [26]. The 3D printers get smarter when they acquire more data; hence they are able to make smart predictions and assembling accurate parameters for 3D printing based on the existing data. This is known as machine learning algorithm. Through this approach, the challenges in maintaining the repeatability, traceability, connectivity and automation can now be solved with the existence of data storage as illustrated in Figure 2.

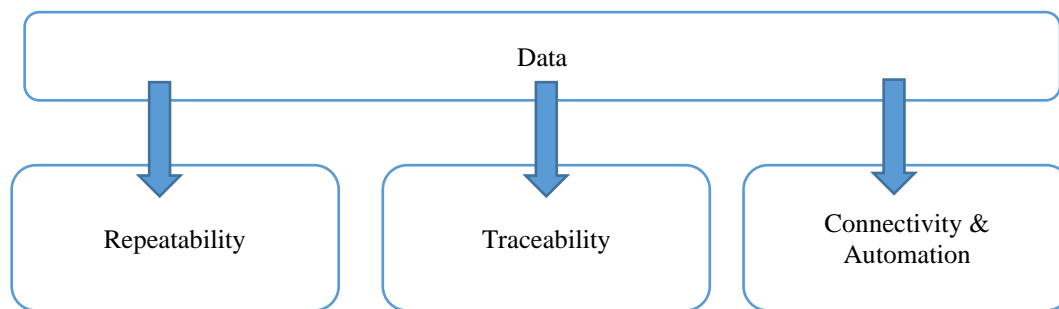


Figure 2. Data underpins the solutions in 3D printing.

By incorporating of 3D printing with artificial intelligence, the system enables aerospace manufacturing companies to produce a more precise and accurate aero parts with greater design flexibility, cost effective and low waste. To allow the in-process monitoring and control to happen, sensors and cameras are placed inside a 3D printer, usually at the nozzle where powder feedstock and laser beam are fused together to form a solid layer. The data are then supplied to the specialised software where it measures and analyses the multiple build in real-time. The printers learn as it goes by understanding the problem and focusing the power of Artificial Intelligence to solve it. Once it controls the whole system and understands how each parameter link from one to another, the system will decide on the best printing parameters to suit the desired outcome [27]. The whole build process is documented while the system is constantly making adjustments to ensure the requirements are met. The system is also learning on how the parameters vary with different input of powder feedstock, thus printing a multi-material component is no longer a hard task to do. Artificial intelligence has made it possible for the gathering of data patters and incorporates the printer with cumulative learning ability so that a more accurate, comprehensive, robust and faster decision-making system can be realised.

Today, aerospace manufacturing companies are slowly acknowledging the advantage of Artificial Intelligence with the third-party solutions are starting to appear in the market. There has been a report on June 4, 2019, on a 3D printer powered by machine vision and artificial intelligence. It has been developed by a group of people from Inkbit, an MIT startup company who offers 3D printing experience not only with high speed, yet also with high precision and high-quality output parts. Through pairing of the multi-material inkjet 3D printer with machine-vision and machine-learning system, their vision system made it possible to comprehensively scans each layer of the object in real-time. The system uses the information stored as existing data to predict the warping behaviour of the material; thus a more accurate final product is realised. Another company which managed to steal the limelight is Markforged, a multi award-winning company for 3D printing provider. The company has introduced a new Artificial Intelligence technology named Blacksmith, a cloud platform to further improve the dependability of the system, not only for 3D printing application but for all sorts of manufacturing machines. Through this platform, the system collects data from three parts of the

fabrication process which are scanning/inspection, hardware and software with the goal to improve the way a part is manufactured.

5. Conclusion

A comprehensive study of 3D metal printing integrated with Artificial intelligence has been presented. The current major drawback of 3D metal printing has been discussed, covering the inconsistent repeatability and traceability of the system. With the advantages of Artificial Intelligence to predict the probability of success in printing metal object, the efficiency of the whole system can be upgraded, involving cost and time reduction. Artificial intelligence is now the key to improve the prefabrication printability checks and lowering the complexity in 3D metal printing processes.

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