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Laser metal deposition technique: sustainability and environmental impact

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Abstract

Additive manufacturing (AM) is a term used in describing a set of manufacturing techniques that employs layer upon layer production of parts and components through the application of 3D model data and inputs of raw material. The technology easily comes to mind in the recent times as processing complexities during production is partly responsible for the high cost of parts and components. Industries such as the heavy machinery consumers, aerospace and casting industry now employs the technology as a way of prolonging service of faulty parts through repair and remanufacturing technology. AM has the tendency to change many production set ups through reduction in cost of production, material wastage, energy usage, component lead time etc. AM technologies also have their own challenges despite numerous advantages associated with them. This paper looks at some of the laser metal deposition techniques, their sustainability and environmental impact.

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Keywords: Additive manufacturing; laser metal deposition technique; sustainability; environmental impact;

1. Introduction

Additive Manufacturing (AM) technology is a technology that is developing and usually employed in the production of near-net shape components through layer by layer build-up from the information supplied by 3D CAD model. AM technology emanates from 3D printing and showing a great potential in changing the manufacturing sectors

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through reduction in material waste, component lead time, energy usage, cost, carbon footprint etc. [1]. AM technology also has the ability of producing sophisticated parts that ordinarily could not have been produced using the traditional manufacturing processes such as machining. This technology has also proven to be useful in the repairs of in-service parts. AM technology now finds application in the development of lightweight structures with unique properties that are now employed in areas such as the aerospace, medicine, surgery, automotive, oil and gas etc. The fastest-growing industrial sectors using AM technology include the aerospace, medical and dental and automotive [2]. The technology has been established as a manufacturing process with the ability of providing sustainable advantages [3].

The principle of additive manufacturing and conventional subtractive manufacturing is shown in figure 1. Additive manufacturing method uses powder as a form of major raw material in the building of part through selective addition of the powder. Convectional subtractive manufacturing method begins by working on a bulk material that mostly involves the removal of material until a finished product is formed. The scrap material in additive manufacturing route is so little compared to the one obtainable in convectional manufacturing route. The application of additive manufacturing technology is seen in the building of customized parts, complex shapes, high value and low volume components. Table 1 highlight some of the qualities of additive manufacturing that differentiate it from the conventional manufacturing technology and their implications on product offerings and supply chains of companies.

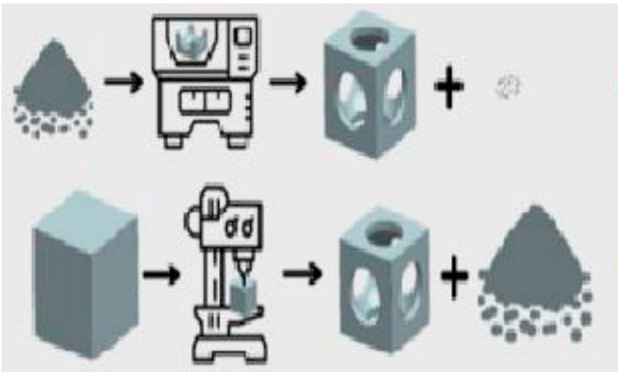

Fig.1 (A) principle of additive manufacturing and (B) convectional subtractive manufacturing [3]

Table 1: Impact of additive manufacturing on company's product offerings and supply chain [4]

Additive manufacturing qualities compared to conventional manufacturing	**Impact on product offerings**	**Impact on supply chains**
Manufacturing of complex design products	Very high	High
New products that remove present design and manufacturing restriction	Very high	High
Product customization to meet customer requirement	Very high	High
Ease and flexibility of design variation	High	Medium
Part simplification/sub-parts reduction	Medium	Medium
Reduced time to market	Medium	Medium
Waste minimization	Medium	Medium
Weight reduction	Medium	Low
Production near/at point of use	Medium	Very high
On-demand manufacturing	Low	Very high

The environmental impacts of manufacturing industries are extraordinary. These environmental impacts are seen in various forms as in waste, carbon emissions, energy and toxic chemicals. The industry is a serious user of water and cases of soil, water and air contamination have been associated with the industry [5]. Protecting the environment and achieving economic growth is now a thing of concern as stiffer environmental standards are enacted.

Industries such as the aerospace, automotive, medical etc. are now embracing AM technology because of the sustainability aspect of it, being less wasteful and reduced weight. The continuous development of the technology and general acceptability of the technology as a major manufacturing process will be able to ensure shorter value chain and provide notable advantages such as reduction in carbon footprint, energy and production cost. Although, there are some short comings that need to be addressed to make it possible for small and medium scale industries to adopt. Commercial availability of the technology, raw material, and cost slows down the adoption of the technology.

Laser metal deposition, one of the techniques of additive manufacturing technology is proving to be very viable not only in the manufacturing of new parts but also in the repair and cladding of parts. This technique involves the deposition of metal powder shielded by an inert gas onto a melt pool created by well-focused laser beam [6]. The development and commercial availability of the technology is currently limited and still at an early stage but has the ability of providing high deposition rate and finished product of high accuracy and good surface finish [7].

2. Laser metal deposition technique

This is a manufacturing technique that uses a laser supplying the energy required and a nozzle in depositing metal powder on a desired surface where it finally solidifies. The process is proving to be effective in the repair and manufacturing of parts using material such as titanium aluminide composites that found applications in industries like the aerospace, medicine, automotive, etc. Different companies and research institutes continue to develop this approach of additive manufacturing using different method but with similar working principle. Some of the benefits of additive manufacturing include: Improve innovation, part consolidation, lower energy consumption, light weighting, less waste, reduced time to market and agility of manufacturing operations [4].

2.1 Laser powder injection

This technique involves the injection of powder via a nozzle that is then melted and deposited. The powder may be injected through a gravity feed or using inert gas. Shielding gas is normally supplied to the system to prevent the molten weld pool formed from possible oxidation. This technique is very useful in the sense that it can be employed in adding material to an existing part especially when it comes to repair and cladding. However, shortfall of the technique is it inability to deposit same amount of material.

2.2 Optomec Laser Engineered Net Shaping (LENS)

This is a powder injection technique that was first developed by Sandia National Laboratory and licensed to Optomec for further development and manufacturing [1]. Using high power (500W to 4KW) laser as an energy source, metal powder is deposited onto a molten pool of metal. Machines using this technique have been developed to operate with most of the commercial powders. The technique has high cooling and solidification rate but has problem of serious overhangs because the supporting structures are not of different material [8].

2.3 Accufusion Laser Consolidation

General Electric (GE) global Research and Integrated Manufacturing Technologies Institute of National Research Council, Canada, collaborate in the development of the metal powder injection approach referred to as laser consolidation. This approach has been licensed to Accufusion for subsequent development. The process (as shown in figure 2) is closely related to the LENS approach, where metal powder is deposited onto a molten metal pool with laser providing the required energy. Corresponding Movement between the laser beam and substrate is controlled by numerical control system [9]. Pre-designed part from the CAD model ensures the movement of the laser beam and the powder feed nozzle that produce layer by layer bead of molten material on substrate, that get solidifies quickly. However, the process has a lower deposition rate but produce better surface finish than the LENS system [1].

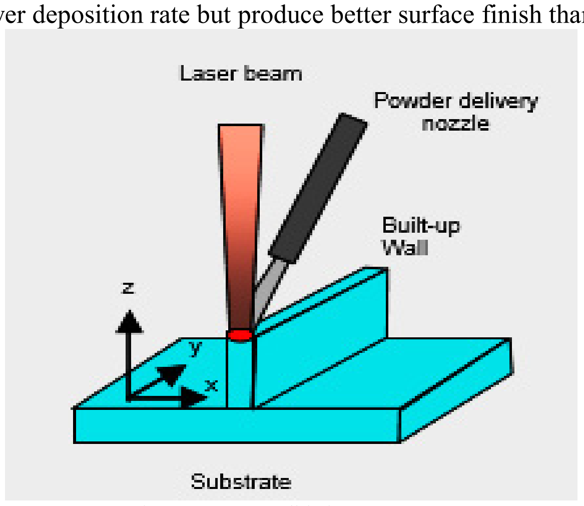

Fig.2: Laser consolidation process [9]

2.4 Precision Optical Manufacturing (POM) Direct Metal Deposition

The precision Optical Manufacturing Company developed the Direct Metal Deposition (DMD) technology. This technology is also based on powder metal injection approach but combined with a robotic arm installed with a fibre laser. The technology is applicable to parts repair, feature addition to existing large parts and manufacturing of new parts.

3. Sustainability and Environmental Impact

The development, cost, material availability and commercialization of the laser metal deposition additive manufacturing technology might still be growing and as such limiting the commercial use of the technology in the laboratories, small and medium scale industries. However, the technology has made it able to censure the activities of the tooling industry resulting in environmental pollution mainly during the repair and manufacture of tools and other parts. Not only has the technology show to be effective in the repair, cladding and manufacturing of parts giving good structural, physical and mechanical properties but have also show that parts can be manufactured from metal powders using advanced means from computer aided design (CAD) model and laser.

Sustainable manufacturing is the production of prudent products through processes that reduces undesirable environmental impacts, manage natural resources and energy, safe for workers, consumers, communities [10]. Sustainability of AM processes is an area researchers are continuously working on [10,11,13]. As clean and sustainable production become paramount in manufacturing processes where huge sum of materials and energy are utilized [14], the conventional manufacturing technique of tooling are sometime seen as time consuming requiring skilled and unskilled labour, specialized materials and means of manufacturing. One of the problems often associated with tooling production especially when it comes to large complex tools is the production lead time. This method is sometime seen to be expensive, time consuming and difficult in the design and manufacture of tooling. Manufacturing industries are now being monitored to reduce negative environmental impact as they produce and deliver quality products [15]. Some of the tooling industry in the developed countries faces economic challenges as more consciousness on environmental impact of the tooling industry increases. The challenges are making the companies to exploit other options of low production and labour cost and making them relocate to foreign countries with low environmental standards. The conventional technique such as machining, casting and forging are now seen as unsustainable due to the atmospheric, terrestrial and aquatic pollution caused by the processes, coupled with the use of finite material and energy resources [16].

Interdisciplinary panel for the International Assessment of Environmentally Benign Manufacture Technology set up, takes a look at problems facing companies in developing an environmentally benign manufacture (EBM), visiting Europe, US and Japan. These regions have different method of developing the strategy with different drivers. In Europe, drivers are recycling mindset, high population density and take-back provisions. In US, cost-savings and environmental benefit are major drivers. While in Japan, high population density, export economy and ISO 1400 are major drivers. The group highlight that major success in EBM is achievable not only with technology but with collaborative effort between government, industry and academia in science, engineering and policy [5].

Mahesh et al. [17] proposed an outline for sustainable characterization guide (see figure 3) that will help give a measurement framework to improve the sustainability of manufacturing processes and for comparing various manufacturing methods for sustainability. The proposed guide is made up of four steps. The first part involves the understanding of physics and collection of important data related to the process. The second step involves the actual performance of the sustainability characterization. The third step is applying manufacturing process data as evidence to support the information model and metrics computed. This process will give life cycle inventory (LCI) data. Action plan is then developed in step four based on outcome in step three.

Morrow et al. [16] performed an investigation to determine the rate to which Direct Metal Deposition (DMD) based production of dies and molds can be used to obtain minimal energy consumption and environmental pollution with respect to the conventional manufacturing technique (such as stamping, forging and injection molding). The outcome of the studies revealed that the Direct laser deposition advancement in reducing environmental impact of die and tool production can be achieved in it remanufacturing ability. Cost reduction and environmental impact as the size tool production increases are some of the merit associated with laser-based remanufacturing of tooling (dies, tools and molds).

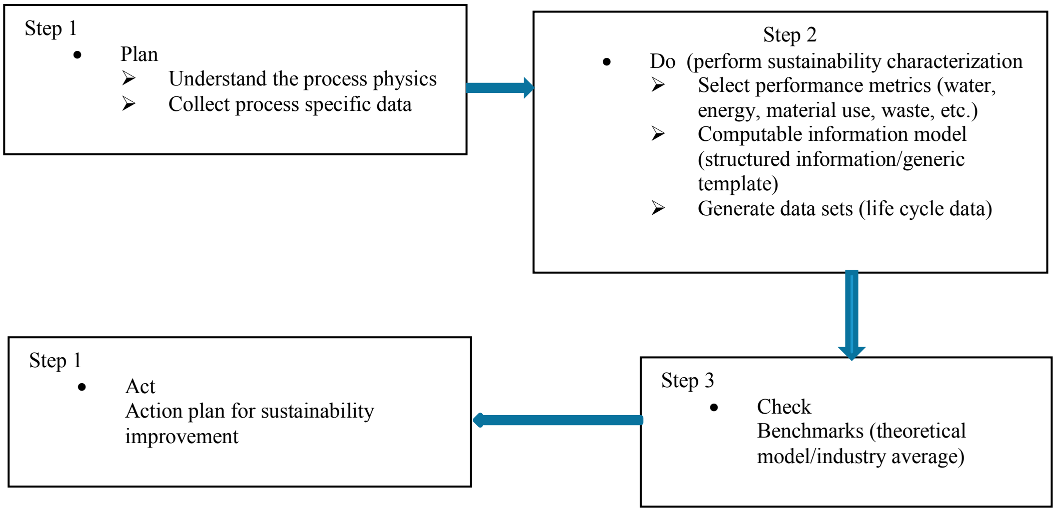

Fig.3 Sustainability characterization guide [17]

Additive manufacturing with the ability of building complex shapes can ensure components are designed with less materials and equal in functional specifications like the conventional components. AM provide business leaders in the industries opportunity to improve current processes and designs [18]. In aeronautic industry, not less than 40% mass reduction in aircraft part production with additive manufacturing is achievable. The adoption of additive technology (such as the laser metal deposition) can ensure energy savings of about 115.7 TBtu/year including about 7600 ton/year of titanium alloys, 4000 ton/year of aluminium alloys and 8100 ton/year of nickel alloys weight reduction in U.S. fleet by 2050 [4].

Laser metal deposition techniques among other additive manufacturing technology are developing and finding useful need in different industry applications. The technique is highly useful in the production of low volume complex geometrical parts. Market of product and services of additive manufacturing continues to grow over the years; this is proven in the 2014 Wohlers Associates report. The report shows that a survey was conducted on 82 service providers and 29 manufacturers of industrial additive manufacturing systems. The companies where questioned on the industries they provide services to and percentage revenues gotten from the services, the outcome is shown in figure 4, with industrial/business machines, consumer products/electronics, motor vehicles, mechanical/dental and aerospace taking larger percentages than architectural, government/military and academic institutions that are also adopting the technology gradually.

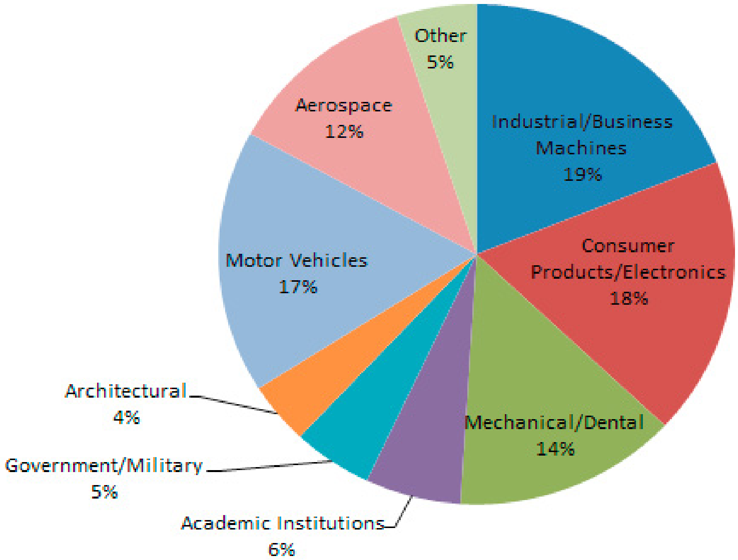

Figure 4: Estimates of industries serviced by AM manufacturers and service providers [19]

The accuracy of analysis between manufacturing processes is cantered mainly on availability of needed life cycle inventory (LCI) data, which still remain a challenge [12]. Globally, conventional manufacturing using milling machines, melting machines and heavy presses consume more energy than AM systems [20]. For same production ability, AM only needs a single machine. Details to material (powder) processes are well reported but atomization processes are yet to be properly documented. As regard to waste generation, AM has a comparative environmental edge as only needed material are used up and in some cases where powder waste is generated, the processes are highly efficient as regards to material reusability. Whereas, subtractive manufacturing route produces chips that need to be recycled to be reusable or cause environmental waste.

4. Way Forward

The certainty in quality (durability, strength, toughness, etc.) of the final product that can be obtained can increase the adoption of the technology. Ability to model and simulate metal deposition process by varying the process parameters (such as the laser power, laser scanning speed, powder deposition rate, preheating temperature, etc.) can assist manufacturers in obtaining optimum process parameters that may help in reducing deformation and residual stresses. Microstructure model of Ti-6Al-4V composite using finite element code was illustrated in the work of Lundback and Lindgren, 2016 [3].

No doubt, fabricated components of AM technologies such as laser metal deposition have challenges such as residual stresses occurring during manufacturing processes which can cause part failure and distortion of fabricated parts final shapes. These challenges are being looked at with development of new approach. Development in the fundamentals and approach for the analysis of AM technological processes revealed that AM fabricated components possess exemplary properties that allow them to display additional mechanical outcome [21]. Bourhis et al. [14] worked on component production taking into account electrical, fluids and material consumption on environmental impact assessment. The methodology formed was based on analytic and experimental models with the hope of automatically generating manufacturing method that will help minimized components environmental impact.

The space of the technology should also be broadened to accommodate low and medium scale industrial sector though research and development, producing low-cost technology and ease of accessing of raw materials (metal powders). This will increase the adaptation of the technology, increasing its sustainability and reducing environmental impacts currently witness with some of the conventional method of production.

5. Conclusion

Additive manufacturing techniques produce near-net-shape, light weight and high strength components which is making it gradually revolutionizing the manufacturing sector. The use of the technology is now providing sustainable production benefits, as ability to repair and manufacture components can now be employed to increase product life circle. Because of the additive method and high build-up rate involved, Laser metal deposition technique reduces waste and therefore optimized material usage in production of components. This makes the technique a viable option in sustainable manufacturing.

Additive manufacturing technology is adjudged as a technology that possesses the ability to reduce material, energy usage and environmental worries when compared to conventional manufacturing process. Ability to repair, coat and build lightweight functional parts, low or absence of specialized tooling and less waste gives the laser metal deposition technique sustainable manufacturing advantage.

Light weight and high strength components produced using laser metal deposition technique makes it possible to reduce fuel consumption and lower carbon emissions during product service life. The possibility of producing better light weight complex systems will ensure that emissions are drastically reduced thereby providing positive environmental impact. Modelling and simulation of the process can help predict microstructure evolution that might help ensures that more sustainable and environmentally friendly materials with exemplary properties are developed.

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