Additive Manufacturing Spray Powder Process A Review

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Abstract

According to a report by reports and data, in today's fast-paced growing world, all technologies are continuously advancing in every field to improve performance. One such advancement in the manufacturing sector is additive manufacturing, which is a relatively new technology that is expected to have a market reach of 26.68 billion dollars by 2027, growing at a rate of 14.4%. The method of mixing materials to create items through layer addition from a 3D CAD model is known as additive manufacturing. It is the polar opposite of subtractive manufacturing and can yield more precise items. In this paper, we will briefly discuss the spray powder additive manufacturing process, which includes 3D printing and direct energy deposition (DED), as well as the various metals and alloys that can be used in this process, how these processes work, mechanical properties of the product, various applications, and its future use.

Keywords: *3D printing(3DP), Computer aided design(CAD), Additive manufacturing(AM), Direct Energy deposition(DED)*

INTRODUCTION

Additive manufacturing(AM) is the process in which first the computer takes the information from a CAD (Computer-aided design) fileand then convertit into STL(Stereolithography) file, in which the 3D CAD design in CAD software is approximated by triangles and then it is sliced layer by layer with every layer containing information to be printed. Liquid, molten/filament, powder, and solid layer processes are examples of additive manufacturing techniques. In additive manufacturing, there are two types of powder processes: powder bed and spray powder. Direct energy deposition (DED) and 3D printing are both used in the Spray powder technique.

DEFENSE "An additive manufacturing technique in which directed heat energy is employed to fuse materials by melting as they are deposited," according to ASTM(F2792).

A focused energy source, such as an electron beam, plasma arc, or laser, is used to melt a material, which is then concurrently deposited by a nozzle in direct energy deposition, blown powder additive manufacturing. It employs two distinct methods: 3D cladding and 3D welding.

To make a molten pool, DED usually feeds wire through a nozzle using plasma, laser, or electron beam. Rougher surfaces and complicated geometries make it more difficult to distribute the wire, which restricts its applicability in a variety of applications. As a result, powder is chosen and utilised often as a material in the Direct energy deposition technique.
Because of its potential to print any metal or metal-alloy device, mainly functionally gradient materials, it has sparked a lot of attention.

It's also used to remanufacture and repair items in order to increase their lifespan and reduce their environmental impact. DED laser engineered net shaping (LENS) and laser deposition are two examples of DED laser engineered net shaping (LENS) and laser deposition.

The 3D printing technique requires spraying a water-based liquid binder over a starch- based powder in order to print data from a CAD drawing. It is an MITlicensed process. The different advantages of 3D printing are less expensive equipment, more cost-effective procedure, no resins to cure, no chemical post-processing required.

There are two primary techniques in 3D printing (1) material jetting 3D printing and binder jetting 3D printing. Material jetting is a method of 3D printing that utilises droplets that are then poured by sending UV light across each layer.

Binder jetting involves spraying and imprinting a binder in fluid form over a powder bed using an inkjet head to bind the powder particles layer by layer, as seen in Figure 2. The choice of binder has a considerable impact on the mechanical strength and other qualities of the finished product.

Metal extrusion, which is currently employed in 3D printing, is a process in which a product is formed from a material by a mechanical head, similar to how inkjet printers extrude ink onto paper. Inkjet 3D printing is another name for it.

PRINTING PROCESS

Direct Energy Deposition

In direct energy deposition, control and direction of the heat source and feedstock include in the primary process and it mostly depends on the energy and melts dynamics.

Electron beam, electric arc, laser, and plasma are some of the heat sources that use indirect energy deposition. The feedstock is directed at the deposition site by the heat source, which is why it is termed direct energy deposition, as depicted in Figure 1.

The feedstock, which can be powder or wire, is then fed into the path where the heat source melts it, causing the heat source to spray or drip into a relatively large melting pool. Meltpool is controlled by moving the feedstock and heat source along the toolpath, where it freezes and solidifies into a solid metal bead.

The bead size in wire-based DED is often substantially greater than the input material. The melting mechanism is similar to traditional welding in that it requires a lot of energy to form a melt pool and a successful bond between the deposited material and the part.

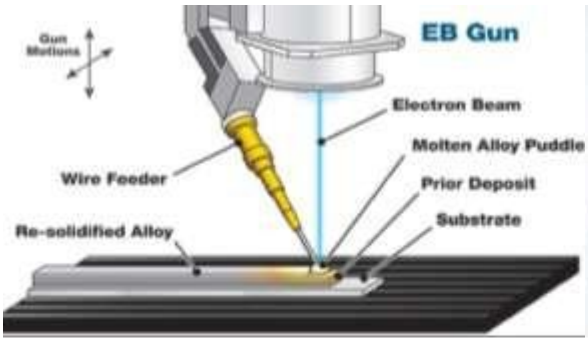

Fig.1:- Wire feed DED

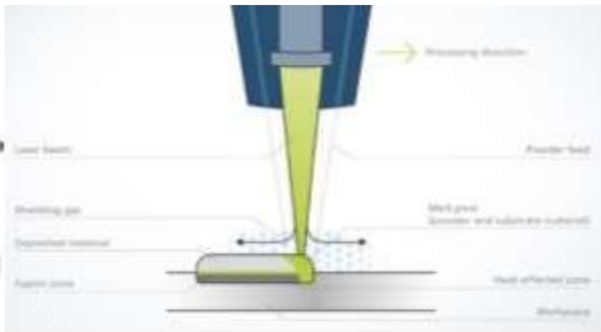

Fig.2:- Powder feed DED

3D PRINTING

3D printing is a method of producing three-dimensional objects.

The 3DP method entails converting a digital CAD file into a concrete 3D object over a long period of time. In Figure 3, the procedure is broken down into four steps:

Step-1 CAD files

To begin, a 3D CAD model is being created. This application generates a file containing all of the data, which is then delivered to the 3D printer. The software cuts the design into thousands of horizontal layers throughout this procedure. After this these layers are printed one on top of each other till the 3D item is being produced. AutoCAD, Solidworks, and other design applications such as Google Sketchup are among the programmes utilised.

Step-2 Motoring

The operation of 3D printing necessitates the use of a high-precision, low-torque stepper motor. The stepper motor's job is to transform digital pulses into mechanical shaft rotation in the motor. It offers excellent durability at a low cost, as well as strong torque at low speeds. They are a sort of synchronous motor that spins to a specific degree when it receives an electric impulse from its control unit. A 3D printer typically requires four stepper motors, three for X, Y, and Z movements and one for moving the bedplate.

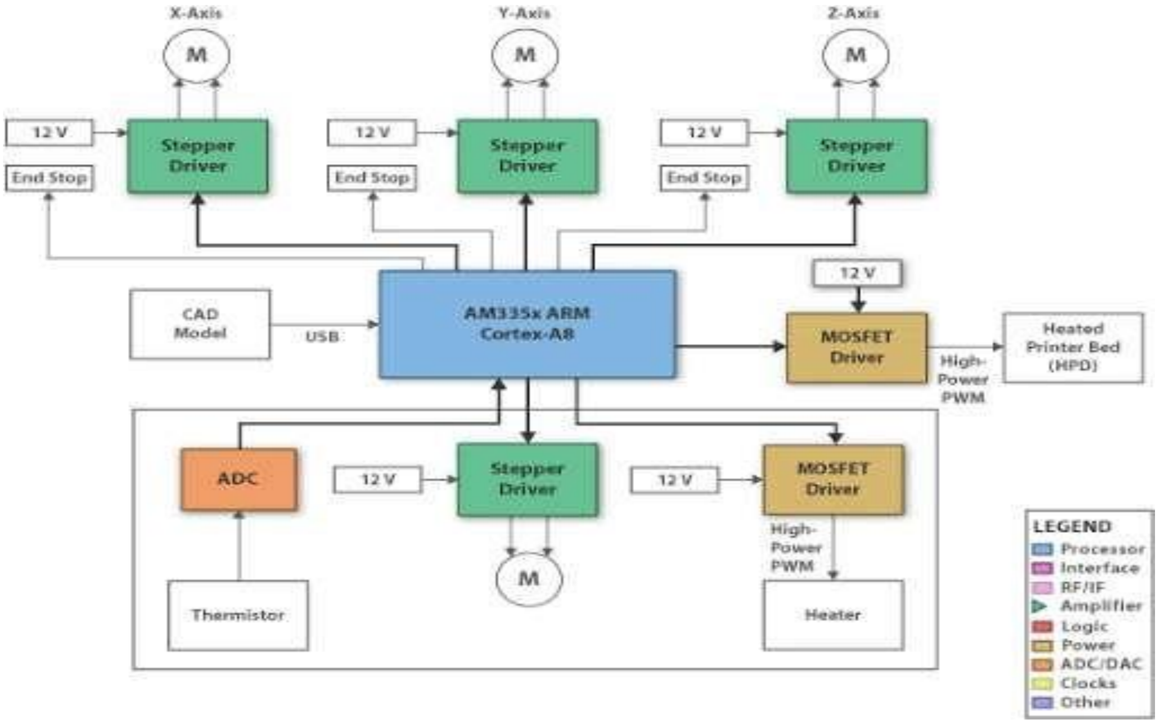

Fig.3:- 3D printing process[6]

Step-3 Processing

An AM335x microprocessor, which comprises of 1) a microprocesso runit 2) a Graphics accelerator subsystem for 3D graphics to support the display, is employed for autonomous operation, improved efficiency, and flexibility. It can operate at speeds ranging from 600MHz to more than 1 GHz.

Step-4 MOSFET drive

Because the stepper motor is an open-loop system, it necessitates a high-accuracy component to print in precise locations, so a MOSFET drive with a bipolar stepper motor is used, which allows the motor to move in both directions while operating at a high frequency.

MECHANICAL PROPERTIES DED

Tensile Strength

The microstructure of the material and the numerous process parameters in DED determine the ductility and tensile strength of the printed item. In other circumstances, a changing trend of ductility and tensile behaviour for the same material printed by direct energy deposition was seen, such as the tensile strength of Ti-6Al-4V created by DED being found to be relatively similar to wrought Ti-6Al-4V, with a drop in ductile power. In another study, it was discovered that the Ti-6Al-4V made by DED had a finer microstructure than wrought Ti-6Al-4V, but the ductilite power was still lower than wrought Ti-6Al-4V due to a combination of internal flaws and finer microstructure.

Due of micro-structural anisotropy, another study component produced from DED demonstrated tensile behaviour and anisotropic porosity in three distinct orientations.

Hardness

Microhardness values may vary along the build path due to variations in build direction. The centre layer has a lesser microhardness than the final and first layers, which have a greater microhardness. Heat is built up in the core layer as a result of the process's thermal history, resulting in decreased microhardness values. Because the addition of substrate mass leads to a quicker heat sink, greater hardness and finer microstructure was discovered when the substrate thickness was increased. Hardness reduced when the substrate was increased due to a reduction in cooling rate and thermal gradient, resulting in a coarser microstructure. As shown by Zuback et al., post-processing of additively manufactured components (such as heat treatment or ageing) or alloy selection can give better control over hardness than modifying process parameters in direct energy deposition.

Fatigue

The formation of flaws and microstructure are the most visible signs of fatigue. One of the most critical criteria in determining the structural integrity of a direct energy deposition printed object is fatigue. We can predict the fatigue life of the component treated by DED by evaluating the likely fatigue start point and fatigue crack propagation. The plane was the most common location for fatigue fracture growth, with some cracks travelling in the direction of tensile strain. The crack development rate was discovered to be location-dependent and to change with various directions. The tiredness results were not uniform, according to multiple writers. For example, Ti-6Al-4V treated by LENSTM exhibited a longer fatigue life than cast Ti-6Al-4V. DED processed Ti-6Al-4V has qualities similar to cast Ti-6Al-4V, while heat-treated DED Ti-6Al-4V has attributes similar to wrought Ti-6Al-4V, according to one study. The fatigue life of the DED processed was increased by hot isotactic pressing because it closed the pore sites inside that component.

Residual Stress

During DED or any other additive manufacturing process, residual stresses are formed due to the presence of a steep temperature gradient between the surrounding material and the heat source. Residual stress can damage printed parts due to cracking and distortion. Compressive stresses were discovered in the centre of the study, whereas tensile stresses were discovered towards the surface. Residual stresses were found to be higher in dissimilar metals in general. The length scale on the microscale and nanoscale, as well as the macroscale, can be used to classify residual stresses in additive manufacturing. The following are some of the most common methods for reducing residual stresses: using in-situ processes in which process parameters are monitored with a feedback loop to tune them; decreasing the thermal gradient by preheating the initial substrate; and post-processing methods such as heat treatment.

3D Printing

Tensile Strength

Several investigations have found that the tensile strength of 3D printed materials is heavily influenced by the mass of the specimen. A two-step procedure can be used to calculate tensile strength.

To begin, the outside of the printed material is visually inspected for sub-optimal layers produced by under and excess extrusion. The mass of the samples is then recorded in order to assess whether or not the material is being extruded. ABS, Nylon 618, HIPS, PC, T-Glass, Semiflex, and Ninjaflex were studied. With a tensile strength of 49Mpa, polycarbonates were determined to be the strongest. Ninjaflex was discovered to be the most flexible, since it did not shatter until an extension of 800 percent, and had a tensile strength of 12 MPa at that point. Nylon has been discovered to be stronger than Ninjaflex and more flexible than other materials, resulting in a healthy balance of strength and flexibility.

Residual Stresses

During the printing process of 3D printing, materials are subjected to repetitive contraction and expansion due to chilling and heating. This causes residual stresses in the printed material, resulting in fractures, warpage, and other types of deformation.

Figure 4 illustrates the effects of residual stresses in 3D printed parts: (a) separation and deformation from the base plate; (b) fracture development. As a result, a variety of strategies are employed to adjust for residual stresses, including modelling print scenarios to get ideal print circumstances and altering post-processing treatments to lessen the influence residual stresses. Ultrasonic waves can be employed both during and after the construction process. Short pulses of ultrasonic waves are emitted, which aid in the detection of internal flaws.

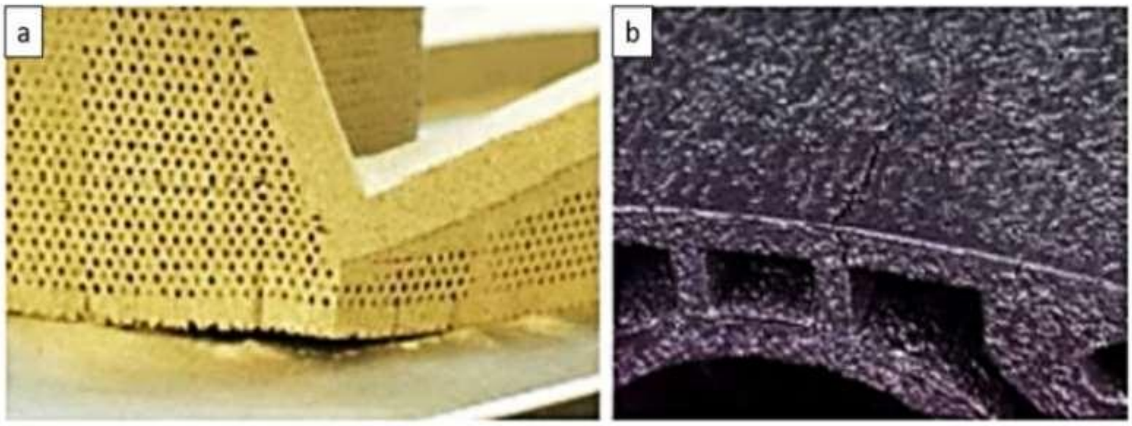

Fig.4:- The results of residual stresses in 3D printed parts[23] (a) distortion and separation from the base plate (b) crack formation

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Surface Finish

3D printed metals have rougher surfaces than traditional machining techniques due to a variety of factors, including the layer by layer deposition mechanism, which yields rougher surfaces, the use of metal powder as a raw material, and the presence of partially melted particles in 3D printed metals, which leads to rougher surfaces.

Machining, polishing, and different surface hardness treatments such as shot peening and high-frequency mechanical impact treatment can improve the surface quality of 3D printed metals[25].

Fatigue Behaviour

As illustrated in Figure 5 [26], fatigue in polymeric 3D printed materials is influenced by a variety of parameters, including ambient conditions, physical qualities, and mechanical loading factors. Fused deposition modeling-based fibre composites outperformed neat polymers in terms of bending and tensile strength. The fiber characteristics of FDM produced composites may aid in fatigue life extension. In the case of 3D printed metals, variables such as appropriate heat input, right construction direction, improved surface smoothness, and various heat treatment techniques contribute to improve fatigue life.

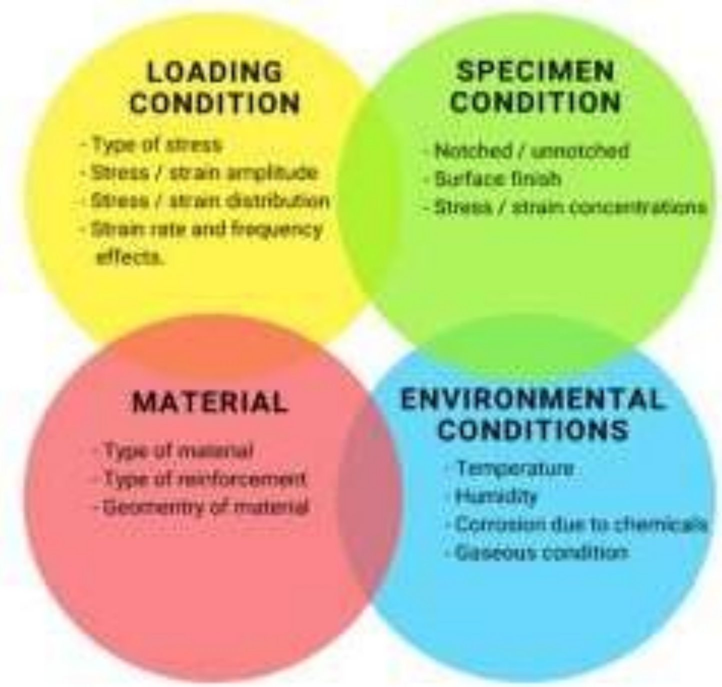

Fig.5:-Factors which effect the fatigue life of polymeric materials.

APPLICATIONS DED

In Repairing Components

One of the most significant activities for extending the life of parts and improving their functioning is repair. Repairing helps to reduce environmental impact by decreasing waste of materials and energy. DED is a regular mending procedure in gas turbines, where Ni-based superalloy is delivered through coaxial powder feeder, and in thermal power plants, where Co-based alloys are deposited on steam circuit elements to maintain high temperature bearing thermal characteristics.

Traditional casting produces primitive structures (homogeneous microstructure) in building materials, whereas DED tailored microstructure is feasible, which may have improved mechanical qualities. DED in construction might help greatly in reducing greenhouse gas emissions, as the construction industry accounts for 30% of greenhouse gas emissions, which could be reduced by partially adopting DED for specialized parts.

In part cladding and welding

Traditional welding creates large residual stresses at the interfaces when welding different materials, which can lead to early failure and be unsafe. In DED, on the other hand, the composition is a function of position, resulting in a smooth transition from one joint to the next. This can help to reduce residuals and improve joint mechanical integrity. Multi-axis cladding is achievable with the aid of DED, which allows material to be delivered at any angle point.

Biomedical applications in a variety of fields

DED modifies a material's mechanical characteristics by changing the geometry or orientation of the printed pieces. When compared to conventional casting, Direct energy deposition is a better way to manufacture porous implants. In the dentistry and implant industries, it has become a top focus. Co-based alloys, Ni-Ti based alloys, Ti and its alloys, and 316L stainless steel are the most common. DED is employed in the biomedical industry because it allows users to combine different materials to get ideal characteristics and makes it simpler to create personalized implants that meet the needs of patients. Biocompatibility experiments on porous Ti-6Al-4V using LENSTM revealed that it can support cell growth on implants with pore sizes of 200 micrometers or larger.

Medical Applications of 3D Printing

Some of the key uses of 3D printing in this discipline are as follows: Organs can be printed and utilized as a replacement for genuine body components like titanium jaws and pelvic bones.

Tissue engineering has made significant progress, including the ability to create 3D blood vessels. Additive manufacture of stem cells must lead to numerous possibilities in printing artificial organs, and we may conclude that 3D printing has opened up a limitless universe of possibilities.

Figure 6 depicts a 3D printed human heart created by bioprinters capable of printing human tissues. Prole now uses 3D printed teeth that may be tailored according to the needs of the patient, as well as 3D printed hearing aids.

Automobile and Aerospace Industries

In the aerospace sector, 3D printing has a lot of potential since it can be utilized to make lightweight parts with complicated geometry. At the same time, it can lower the amount of material used, resulting in a reduction in fuel use. It may be used to print automobile parts, as demonstrated by a local company that produced the world's first electric 3D printed vehicle, as well as the world's first 3D printed bus, the OLLI, which is a driverless, recyclable, electric 3D printed bus. Ford has also utilized 3D printing to produce protoengine components and automobile prototypes, while BMW has used 3D printing to print hand tools for automotive testing.

Fig.6:- 3D printed human heart which is made by bioprinters which can print human tissues

Industry of Food

In the food business, 3D printing has a bright future since it can be used to manufacture personalized foods that remove extraneous ingredients and boost the presence of essential nutrients.

As a result, cuisine may be tailored to suit individual tastes. Food can also be of greater quality while being less expensive. It may be beneficial in a future where individuals can eat a diet that does not need them to exercise.

- 3D printing is being utilized in industries such as the electric and electronic industry to manufacture structural electronic devices such as electrodes, electronic materials, and other materials. It can aid in the mass manufacture of products at a lower cost and with a faster turnaround time.

- 3D printing has made its way into the fabric and fashion industries, allowing for the production of 3D printed shoes and jewelry. Large corporations such as Nike and Adidas, for example, have used 3D printing to mass produce sporting shoes.

- 3D printing technology may be utilized in the construction sector to produce entire structures or specific pieces.

They also erected 10 single-story houses in a day in China, which would take months to finish using traditional methods. As a result, 3D printing is a more efficient, cost-effective, and secure method.

CONCLUSION

The above work is an effort to explore various spray powder additive manufacturing and learn about the process and how 3D printing and DED operate, as well as examine the mechanical qualities of both DED and 3D printing made items such as fatigue, residual stresses, and hardness. We've also attempted to describe the different uses of DED and 3D printing across a variety of domains. As a result of all of this, we may conclude that these methods will revolutionize the production of numerous components in the future, resulting in more efficient components. Apart from machine component manufacture, 3D printing and DED have a bright future in industries such as building, medical, fashion, and even the food business. We have attempted to discuss all of these areas in a clear and concise manner so that the reader can grasp them.

And they can conduct more research in the precise subject of their choice.

REFERENCES

1. Díaz, E., Amado, J. M., Montero, J., Tobar, M. J., & Yáñez, A. (2012). Comparative study of Co-based alloys in repairing low Cr-Mo steel components by laser cladding. Physics Procedia, 39, 368-375.
2. M. Petch, "Audi gives update on use of SLM metal 3D printing for the automotive industry," 3D Printing Industry, 2018. [Online]. Available: https://3dprintingindustry.com/news/a udi-gives-update-use-slm-metal-3d- printing-automotive-industry-129376/. [Accessed 2019].
3. Buchanan, C., & Gardner, L. (2019). Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges. Engineering Structures, 180, 332-348.
4. The Daily Telegraph, "3D printing of human organs,"timeslive.co.za, 2 September, 2013 [Online]. Available: Joshi, S. C., & Sheikh, A. A. (2015). 3D printing in aerospace and its long- term sustainability. Virtual and Physical Prototyping, 10(4), 175-185.
5. Shanmugam, V., Das, O., Babu, K., Marimuthu, U., Veerasimman, A., Johnson, D. J., ... & Berto, F. (2020). Fatigue behaviour of FDM-3D printed polymers, polymeric composites and architected cellular materials. International Journal of Fatigue, 143, 106007.
6. 3DPrint.com | The Voice of 3D Printing / Additive Manufacturing. 2021. Using Ultrasonic Waves to Analyze Residual Stress in 3D Printed Metal Parts - 3DPrint.com | The Voice of 3D Printing / Additive Manufacturing. [online] Available at: <https://3dprint.com/269334/reviewin g-am-3d-printing-residual-stress- analysis-ultrasonic-waves/> [Accessed 2 March 2021].
7. Xue, W., Krishna, B. V., Bandyopadhyay, A., & Bose, S. (2007). Processing and biocompatibility evaluation of laser processed porous titanium. Acta biomaterialia, 3(6), 1007-1018.
8. Shannon Stapleton "'Critical challenge': Doctors can now 3D-

print blood vessels," rt.com, June 01, 2014 [Online]. Available:

9. http://rt.com/news/162848-3d-print- blood-vessels/. [Accessed: June. 18, 2014].
10. Lee, J., Kim, H. C., Choi, J. W., & Lee, I. H. (2017). A review on 3D printed smart devices for 4D printing. International Journal of Precision Engineering and Manufacturing-Green Technology, 4(3), 373-383.
11. Kistler, N. A., Corbin, D. J., Nassar, A. R., Reutzel, E. W., & Beese, A. M. (2019). Effect of processing conditions on the microstructure, porosity, and mechanical properties of Ti-6Al-4V repair fabricated by directed energy deposition. Journal of Materials Processing Technology, 264, 172-181.
12. Zuback, J. S., & DebRoy, T. (2018). The hardness of additively manufactured alloys. Materials, 11(11), 2070.
13. Shin, Y. C., Bailey, N., Katinas, C., & Tan, W. (2018). Predictive modeling capabilities from incident powder and laser to mechanical properties for laser directed energy deposition. Computational Mechanics, 61(5), 617- 636.
14. Pinkerton, A. J., Ul Haq Syed, W., & Li, L. (2006). An experimental and theoretical investigation of combined gas-and water-atomized powder deposition with a diode laser. Journal of Laser Applications, 18(1), 73-80.
15. Beese, A. M., & Carroll, B. E. (2016). Review of mechanical properties of Ti- 6Al-4V made by laser-based additive manufacturing using powder feedstock. Jom, 68(3), 724-734.
16. Sandgren, H. R., Zhai, Y., Lados, D. A., Shade, P. A., Schuren, J. C., Groeber, M. A., ... & Gavras, A. G. Characterization of fatigue crack growth behavior in LENS fabricated Ti-6Al-4V using high-energy synchrotron x-ray microtomography, Addit. Manuf.(2016).
17. Prabhu, A. W., Vincent, T., Chaudhary, A., Zhang, W., & Babu, S. S. (2015). Effect of microstructure and defects on fatigue behaviour of directed energy deposited Ti–6Al– 4V. Science and Technology of Welding and Joining, 20(8), 659-669.
18. Shamsaei, N., Yadollahi, A., Bian, L., & Thompson, S. M. (2015). An

overview of Direct Laser Deposition for additive manufacturing; Part II: Mechanical behavior, process parameter optimization and control. Additive Manufacturing, 8, 12- 35.

19. Kistler, N. A., Corbin, D. J., Nassar, A. R., Reutzel, E. W., & Beese, A. M. (2019). Effect of processing conditions on the microstructure, porosity, and mechanical properties of Ti-6Al-4V repair fabricated by directed energy deposition. Journal of Materials Processing Technology, 264, 172-181.
20. Nalla, R. K., Ritchie, R. O., Boyce, B. L., Campbell, J. P., & Peters, J. O. (2002). Influence of microstructure on high-cycle fatigue of Ti-6Al-4V: Bimodal vs. lamellar structures. Metallurgical and Materials Transactions A, 33(3), 899- 918.
21. Tanikella, N. G., Wittbrodt, B., & Pearce, J. M. (2017). Tensile strength of commercial polymer materials for fused filament fabrication 3D printing. Additive Manufacturing, 15, 40-47.