Advanced Manufacture of Compositionally Composite Graded Materials: An Overview

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Abstract

Compositionally graded composite materials are advanced materials that consists of inhomogeneous composition as well as structure that varies across the entire volume and with changing properties. Functionally graded materials are produced through different manufacturing processes which include centrifugal method, powder metallurgy method, and additive manufacturing technology. Additive Manufacturing (AM) is an advanced manufacturing process used to produce three dimensional objects simply by adding materials in layers using the digital image of the component. In this chapter, the production of compositionally graded composite materials using an advanced manufacturing method, laser additive manufacturing technologies, which include selective laser melting/sintering and laser metal deposition/laser material deposition (LMD) processes are reviewed and the recent research progress are also presented.

Keywords - Additive Manufacturing, Functionally Graded Materials, Laser Material deposition Process, Selective Laser Melting, selective laser sintering.

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1. INTRODUCTION

Functionally graded material are made up materials with varying elemental properties as a result of varying quantities of materials mixture or changing microstructural characteristic across the depth of the bulk material. The idea of functionally graded material which presents the compositional and structural gradients in the material microstructure was initially proposed by researchers in Japan in the mid 1980 [1]. These researchers were confronted with the problem of delamination of a composite material that was used in a hypersonic space plane project that requires a thermal barrier which should have an outside temperature of about 2000K and an inside temperature of about 1000K across a less than 10 mm thickness [1]. The composite materials they were using kept failing as a result of the composite materials delaminating. They noted that the failure was happening at the interface between the composite materials due to mismatch between the properties of these materials at the interface. They concluded that if it was possible to eliminate this sharp interface, then the problem would be solved. The researchers developed this novel compositionally graded composite material that was called functionally graded materials which has a graded composition thereby eradicating the sharp interface in the initial composite material.

Compositionally graded materials have different properties both in composition as well as in structure throughout the entire volume of the material so as to achieve desired properties and to satisfy the intended service requirements [1-3]. Functionally graded materials has provided solutions to various engineering problems that is completely different from the application it was initially meant to solve such as in wear resistance applications. Functionally Graded Material is being used as an interface layer for connecting two incompatible materials in order to enhance the bond strength between the two materials. It provides the opportunity to combine different material systems such as ceramics and metals that has the ability to control properties such as deformation, dynamic response, wear, and corrosion. There are different approaches used in producing bulk compositionally graded material as well as for producing thin compositionally graded surface coating. The methods include centrifugal method, Physical Vapour Deposition, additive manufacturing, Chemical Vapour Deposition (CVD) process, and Powder metallurgy,. [4].

Additive manufacturing method is an advanced manufacturing process that is used to produce three dimensional (3D) objects through the addition of successive layers of materials [5]. Some additive manufacturing technologies are able to handle multiple materials simultaneously and hence they are able to produce 3D part that is made of compositionally graded composite materials in one manufacturing process. The most important advantage of using additive manufacturing process for the fabrication of compositionally graded graded materials is that the part can be made directly with the required graded material composition in one manufacturing run [3]. This is not possible in the past using the traditional manufacturing process that involves first producing the functionally graded materials and then make the part by cutting the bulk material into the desired shape. The additive manufacturing process can make each layer during the building process to contain the intended desired properties along the cross section of the entire object formed or created. Additive Manufacturing is able to produce the 3D object by using the 3D computer aided design (CAD) model representing the intended part, accepting the CAD data and process it to form the object through series of materials addition in layers, following the description of the CAD data until the part building is complete [6]. This helps to build customized and personalized part with functionally graded materials without any need for special tools that was not possible with the traditional manufacturing process.

Additive manufacturing technology has developed rapidly and it has seen increasing industrial applications in the last few decades. Additive manufacturing process is attractive for its ability to shorten cycle times and the rapid transition of product concepts into physical products. Production process which usually takes weeks or months can now be produced in hours with higher accuracy. Additive manufacturing can be used to solve problems arising from production of complex parts that are often needed to be broken down into various parts when produced using the conventional manufacturing processes. By effective process control the products made of functionally graded materials can be produced using 3D CAD model with variation of material properties that are controlled to achieve desired. Functionally Graded Materials are built up with varying properties which has inhomogeneous compositions. Some additive manufacturing processes are able to incorporate various materials that made them suitable for the production of FGMs [7, 8]. The major additive manufacturing processes that are capable of producing the functionally graded materials are sheet lamination, directed energy deposition and powder bed fusion classes of additive manufacturing technologies [4, 9, 10].

In this chapter, review on some of the recent research efforts in the production of functionally graded materials with laser additive manufacturing processes namely: selective laser melting, selective laser sintering and laser material deposition process. Some of the challenges that are overcome by using this laser additive manufacturing processes for fabrication of compositionally gradient materials are discussed. The rest of the chapter is organized as follows: section II of the paper presents the some research works on manufacturing of functionally graded materials using selective laser sintering and selective laser melting. Compositionally graded materials produced using the laser material deposition process is presented in section III. The summary and future research direction of production FGM using these laser additive manufacturing technologies are presented in section IV.

2. Production of Functionally Graded Materials with Selective Laser Sintering/Melting

Selective laser sintering (SLS) belongs to the powder bed fusion class of additive manufacturing technology based on the recent grouping made by committee of international standard organization on additive manufacturing (committee F42) [11]. SLS produces three dimensional parts made directly from the 3D CAD model representing the part by fusing the powder spread on the build platform using the energy from the laser [3]. The laser is used to fuse the powder while following the path dictated by the CAD data information. At the end of each cycle, the building platform is then lowered by one layer thickness, the powder is spread on the platform and the laser scans the required area according to the data for the CAD model. The powders are sintered together with the laser and the 3D part produced is further heat treated to increase the density of the part produce. One of the important advantages of this technology is that it does not require any support structure for building the part. The un-used powder serves provide the needed support for the part as the building progresses. Selective laser melting (SLM) is another technology that is similar to the SLS process, the only difference is that instead of sintering the powder in the SLS, the laser fully melt the powder in the process. Also the parts produced with SLS are porous which are useful in a number of applications such as biomedical industry. SLS and SLM are used for producing prototypes, end used parts and art products. SLS and SLM are also capable of producing functionally graded materials because the technologies allow the use of multiple materials simultaneously.

A number of research works has been reported in the literature on this exciting technology on functionally graded materials since its invention and the more recent ones are reviewed in this section. The feasibility study on the production of functionally graded tissue scaffold for medical implant application has been conducted by Sudarmadji et al. [12]. Scaffolds with different graded porosity and structural configuration were produced with Polycaprolactone (PCL) using SLS process. Compression test was conducted on the samples and the degree of porosity was mapped with the resulting properties. The study showed that the compressive stiffness, the yield strength and the porosities, obtained from the scaffolds produced to be closely related to that of the cancellous bone (maxillofacial region). This study has proved that SLS is feasible for the production of compositionally graded scaffolds without causing toxicity to the non-proprietary PCL material. This is an important result for tissue engineers because designing and producing suitable scaffolds has always been a great challenge. The capability of using SLS to produce tissue scaffolds will make the designing of tissue scaffolds with suitable mechanical properties possible and porosities. Functionally graded scaffolds, with graded porosity and variable stiffness across the scaffold section are crucial in this field and SLS will make it achievable. Traini et al. [13] also use selective laser sintering to produce functionally graded porous titanium alloy implant. The roughness, microstructure, chemical composition, mechanical properties and fractography were investigated from the samples produced. The results showed that the SLS is suitable for fabrication of functionally graded porous titanium implant with the resulting properties similar to that of the human bone. This study showed that implant with functionally graded materials can be produced with better elastic properties that are close to the properties of human bone which will reduce stress shielding effect which results when there is modulus of elasticity mismatch between the human bone and the implant. This will help to extend the life of the implant. In another study, selective laser sintering was used to produce 3D structure of functionally graded polymer nano-composite material by Chung and Das [14]. Functionally graded Nano-composites made of Nylon-11 that is filled with between 0–10 vol. % fumed silica nanoparticles. Different processing parameters were used for producing each layer in the functionally graded structure based on the result of initial experiment performed using design of experiment. The properties of the FGM structures produced were investigated. The mechanical properties were found to vary with the graded composition. The results indicate that particulate-filled compositionally graded nano-composites can be produced by SLS process to produce 3D FGM components made of spatially varying mechanical properties. Two different 3D parts were produced to demonstrate the suitability of using SLS process for the fabrication of 3D FGM structures, they are: a compliant gripper and a rotator cuff scaffold. Similar study was conducted with the SLS to fabricate functionally graded Nylon-11 composite that is filled using different volume fractions of glass beads of up to 30 vol. % [15]. The study involves experimental, theoretical modeling and the numerical methods of analysis. The optimal SLS processing parameters for the FGM composition were obtained through theoretical modelling as well as through experiments. The results obtained from experimental study were compared with the results predicted by the numerical modeling and were found nave a close agreement. The tensile strength and compressive modulus were found to increase as the volume fraction of the glass bead was increased but the strain at the yield region and break point decreased. This study also demonstrates the feasibility of producing functionally graded structure using selective laser sintering process. Salmoria et al. [16] studied the influence that hydroxyapatite (HA) content has on the properties of high-density polyethylene (HDPE)/ HA composites using SLS. The result was used to fabricate functionally graded scaffold of HDPE/HA. The result of the investigation showed that SLS is suitable to fabricate HDPE/HA functional graded scaffold of controlled microstructure as well as mechanical properties which can be used for biomedical applications, for example, bone and cartilage tissues. Leite et al. [17] produce 3D functionally graded polymer blends of polyamide 12 with high density polyethylene using selective laser sintering with compositionally gradient material in two directions. The density, microstructure and mechanical study of the specimens produced showed that the microstructure and the mechanical properties varied as the compositions. The results showed the capability of manufacturing advanced polymeric functional gradient material parts using the selective laser sintering. A number of researches have also been reported in the literature on the capability of using selective laser melting for the fabrication of functionally graded materials.

Maskery et al. [18] use selective laser melting process to produce lattice structure of aluminium alloy with graded density. They performed mechanical tests on the as-deposited samples and heat treated samples. The results showed that the mechanical properties of the produced structure can be improved with appropriate heat treatment. Selective laser melting process has also been established to be able to manufacture functionally graded material of CoCrMo femoral stem that is lighter and flexible than the fully dense stem [19]. Hazlehurst et al. [19] also modelled the cellular structure as continuum part and determine the compressive elastic modulus using finite element method. The result obtained showed that there is good agreement between the experimental data and the model. However, SLM has been found to be limited in terms of its inability to repeatedly manufacture femoral stems cellular structures which incorporate strut sizes that are 0.5 mm or less. Mumtaz and Hopkinson [20] presented a method of producing functionally graded nickel alloy- ceramic composite material using selective laser melting. The functionally graded material of Waspaloy- Zirconium composited was fabricated from 100 vol. % Waspaloy to 10% Zirconium and 90% Waspaloy. The specimens produced were studied and found to contain an average of 0.34 % porosity and without any major interfacial defects.

All these research works show that, the selective laser sintering/melting are suitable for the fabrication of functionally graded material coating and bulk FGM materials. They can also be used to fabricate the required part consisting of compositionally graded materials directly from the CAD model of the part. Fabrication of compositionally graded material using the laser material deposition process is also more documented in the literature and is some of them are presented in the next section.

3. Manufacturing of functionally Graded Material using Laser Metal deposition Process

Laser material/metal deposition (LMD) technology is an important advanced manufacturing technology based on laser cladding principle. It in the class additive manufacturing named directed energy deposition [11]. LMD create a 3D object directly from the 3D CAD data of the object by adding materials layer by layer [3]. The laser beam is used to produce a melt pool on the substrate where the material that is located coaxially with the laser is deposited. The melt pool solidifies and forms a bead upon solidification [3]. Series of beads form a long track that is seen left on the laser path. The path generated by the CAD data is followed by the laser beam to generate the 3D object by repeating the deposition layer after layer until the building of the object is complete. LMD can handle more than one material simultaneously making it useful for building part that is made up of composite materials and functionally graded materials [3]. Another important characteristic of the LMD process is its capability to repair high valued Engineering component as well as for product remanufacturing [21]. The literature is rich on the LMD process for manufacturing of compositionally graded material both as a surface coating and as a bulk material. Some of the recent research works on LMD process for manufacturing of compositionally graded materials are presented in this section.

Thivillon et al. [22] demonstrated the potential of using the LMD process to fabricate compositionally graded coating of commercial metal powders of Co-based Stellite 6 and Ni-superalloy Inconel 625 deposited on the a substrate of S235 steel. The result revealed that LMD can be used to produce FGM coating and with properties that is comparable to wrought materials. Biomedical application of FGM coating requirement is one of the driving factor of research in this area. In the research work conducted by Tanaskovic et al. [23], compositionally graded material of hydroxyapatite (HAP) and bioglass (BG) was produced on titanium substrate. The study showed that the introduction of BG interlayers in the FGM resulted in a considerable increase in the multistructures adherence to the substrate and it also improved the crystallinity of the HAP overcoating. The surface morphology of the FGM was also found to consist of adjacent spherical droplets which are was expected to promote cell growth and proliferation. Syed et al. [24] use copper powder and nickel wire to produce a functionally graded material on H13 tool steel substrate with LMD process. By analyzing the produced sample the results showed that by varying the powder feed rates of the copper powder and the nickel wire, the compositional gradients and varying properties could be achieved without the need for multipass of laser. The mechanical behaviour of functionally graded Alumina/Titanium nano layered thin coatings produced through LMD was studied by Bertarelli et al. [25]. The homogeneous nanocrystalline aluminium coating was produce in order to compare it with the functionally grade coating of Titanium alumina. The FGM was produced by varying the percentage of alumina from 0% to 100% on the titanium substrate. The result showed that the mechanical properties of the FGM are comparable with that of the homogeneous material at low depth micro indentation. Wilson and Shin [26] investigated compositionally graded material of titanium carbide and Inconel 690 using laser metal deposition process. The compositionally graded material was produced by placing the pure Inconel 690 in one powder feeder while a pre-mixed Inconel 690 powder and 49 vol. % TiC powder was placed in another powder feeder. The powders from the two feeders were deposited on AISI 1018 steel substrate to produce the functionally graded material. The FGM produced was found to be fully dense. The microstructure was found to be refined and a finely dispersed crystalline phase was also observed. Different vol. % of Inconel 690 and titanium carbide functionally graded material was produced in this study and a significant improvement in the microhardness and wear resistance was seen as the percentage titanium carbide was increased. In a similar study conducted by Wang et al. [27], compositionally graded material of titanium alloy grade 5 (Ti6Al4V) reinforced with titanium carbide (TiC) was produced using the LMD process and characterized. The functionally graded material was fabricated with TiC powder and Ti6Al4V wire which were deposited on Ti6Al4V substrate. The TiC particles were found to be uniformly distributed in the Ti6Al4V matrix of up to volume fractions of about 74% TiC. After 74% TiC volume fraction unmelted TiC particles were observed. The wear resistance behaviour of the FGMs was seen to be improved when compared to that of the substrate. The influence of the processing parameters on the properties of functionally graded material of stainless steel SS316L and Inconel 718 produced using LMD process was studied by Shah et al. [28]. It was found that the tensile strength was increased when the powder flow rate was increased while it was found that tensile strength was inversely proportional to the laser power. The Fe2Nb phases were seen to be formed during the deposition process. Secondary dendritic arm spacing was also found to depend on the laser power as well as the powder mass flow rate. The NbC that was observed at higher Inconel percentage ratio provide the opportunity to selectively control the mechanical properties of the compositionally graded material. The study concluded that functionally grading of stainless steel SS316L and Inconel 718 was feasible using the LMD process. Another investigation carried out by Mahamood and Akinlabi [29] also showed that functionally graded materials can be fabricated using laser metal deposition process. They investigated the influence of producing FGM materials at constant processing parameters and at changing parameters based on the compositional ratio. Two compositionally graded material of titanium alloy grade 5 and titanium carbide composite was produced using laser metal deposition process. One was produced at constant process parameter while the other was produced at optimum set of process parameters for each layer based on the compositional ratio. These optimum process parameters were gotten from the model that was patented by the authors. The study showed that the FGM produced using the varying processing parameters has improved wear resistance properties when compared to the one produced at constant processing parameters [29]. Ren et al. [30] produced functionally graded material of Ti–6Al–4V and Ti–6.5Al–3.5Mo–1.5Zr–0.3Si on Ti6Al4V substrate using the LMD process. They study the physical chemical and the mechanical properties of the deposited functionally graded material. The results revealed that there is good metallurgical bonding in gradient zone with large columnar grains seen growing epitaxially in the microstructure. The alloying elements' chemical composition were found to remain unchanged in the interior of one layer, but change abruptly in between layers which shows that there was no chemical compositional change during the melting process. The microhardness value was found to increases as the layers were increased from the substrate to the surface. The functionally graded material was also found to have an improved tensile property. The study concludes that LMD is suitable for producing functionally graded materials. Muller et al. [31] carried out process modeling for the manufacturing of FGM parts using the laser metal deposition technology The model would be able to choose an appropriate manufacturing strategy as well as to also be able to control the processing parameters in order to obtain the desired properties as well as the desired part geometry. The modelling was performed based on experimental data and the model makes it possible to control the process in a closed-loop form. Carroll et al. [32] conducted thermodynamic studies on a functionally graded component that was built from 304L stainless

Steel and Inconel 625 using laser metal deposition technology. The results revealed that secondary phase's particles were found in small amounts in the gradient zone. These secondary phases' particles were shown by the experimental results and thermodynamic calculations by transition metal carbides. The presence of these micro sized secondary phase particles were found to be responsible for the development of cracks seen in these zones. The study showed that laser metal deposition technology can be used to fabricate compositionally graded materials and also highlights the possible formation of secondary phases which could cause micro cracks in the FGM and the need the FGM to cater for these developments as it has the potential to alter the developed properties. In a similar study, Liu and DuPont [33] created a crack-free compositionally graded composite material of pure titanium as well as titanium carbide composite using the laser metal deposition technology. The FGM was fabricated by changing the composition from pure titanium to about 95 vol. % of TiC. The two powders were placed in a separate powder feeder and through proper process control. The result of this study showed that in comparison to homogeneous Ti/TiC composite which contains cracks, the FGM composite does not contain any form of crack. The FGM was attributed to elimination of the crack formation. It was concluded that the LMD process can be used to manufacture FGM based on the ease with which the constituent materials can be delivered and the proper process control. In a similar study conducted by Balla et al. [34] also showed that functionally graded material with desired properties can be produced using the laser metal deposition technology. Functionally graded material of yttria-stabilized zirconia coatings were manufactured using laser metal deposition process. Fine microstructure seen in the coating with higher hardness was attributed to the high thermal gradients and high cooling rates produced as a result of rapid heat loss through the substrate. The substrate acts as a heat sink that resulted in the directional grain growth to be seen during the deposition process. The segmentation cracks and columnar grains observed along the coating direction were seen to be of advantage in thermal barrier application. The cracks were believed to increase the life of coatings because of expansion and contractions that will be taken place during operation. Also, the functionally graded coatings have proved to be better than the homogeneous coatings because of the higher bonding strength between the coating and the substrate. Krishna et al. [35] were able to fabricate compositionally graded material of Co–Cr–Mo alloy on Ti–6Al–4V alloy using the laser metal deposition process. A crack-free compositionally graded coating of Co–Cr–Mo / Ti–6Al–4V composite coatings from 0% to 86% Co–Cr–Mo were deposited on Ti–6Al–4V substrate was successfully produced with optimal processing parameters. The FGM coating deposited on the surface of Ti6Al4V alloy was found to increase the hardness significantly. The result of human osteoblast cells in vitro cultured test showed the biocompatibility of the coatings with better bone cell proliferation. The best wear resistance and biocompatibility was seen with the FGM at 50% Co–Cr–Mo alloy. This study also concludes that the LMD process can be used to manufacture functionally graded material. Balla et al. [36] produced functionally graded material of Ti–TiO2 on porous Ti substrate using laser metal deposition process. A fully dense compositionally graded of up to 50% TiO2 ceramic was deposited on porous Ti substrate.

The application of a dual structure with one side of porous structure and the other side of fully dense and hard surface is seen in medical implant such as hip prostheses. The hard side will provide the needed low friction and better surface wettability. The higher wettability will promote the formation of chemisorbed lubricating films that can help to reduce wear rate between the implant and polyethylene liner. The functionally graded coatings were also found to be biocompatible. The probability of extending mould life in the die casting industry by producing functionally graded coating on the mould using the LMD process was pursued by Ocylok et al. [37] through experimental investigations. The study showed that functionally graded coating can be build on the mould with a smooth transition from different compositions and with no cracks and low porosity can be achieved with LMD process.

Shishkovsky et al. [38] demonstrated the possibility of producing functionally graded material consisting of intermetallic phases in Ti-Al powder systems using LMD process. The result of this research work showed that the LMD process has the potential to form the heterogeneous - phase of TiAl intermetallic when implemented under argon environment. The properties were found to be improved significantly. Han et al. [39] investigated the possibility of producing compositionally graded properties in gear using LMD process. The influence of processing parameters on the resulting properties was also explored. The results revealed that functionally graded properties can be achieved using the LMD process and by varying the processing parameters. In a similar study by Abioye et al. [40], compositionally graded material of Ti/Ni on Ti6Al4V substrate using Ni powder with commercially pure titanium wire was fabricated using the LMD process. The formation of intermetallic NiTi was found to be increased with increase in Ni content and the microhardness was also found to be decreased with increase in NiTi content. The highest microhardness was observed in the region where the $NiTi_2$ intermetallic precipitates are seen to be more. A number of other research works on the manufacturing of compositionally graded material using the LMD technology was reported by Jiang et al. [41] and Qian et al. [42] and a host of other researchers. The importance and the capability of manufacturing compositionally graded materials of bulk and functionally graded coatings have been demonstrated in this section. A number of studies has also been conducted on the study of properties of compositionally graded materials which is important in the further development of FGM [43].

An important characteristic of manufacturing components with functionally graded materials using additive manufacturing technology is that, this component can be produced directly from the 3D CAD data of the part, and also with the required gradation which can be achieved in a single manufacturing process. This is not possible to be achieved using the traditional manufacturing process where a number of manufacturing processes are involved. There will be need to first make the functionally graded material in one process and then use the stock FGM material to manufacture the required structure using series of other manufacturing processes depending on the complexity of the component. The additive manufacturing process that are reviewed in this research are not on.ly capable of manufacturing functionally graded coating on an existing component but can also manufacture component no matter the complexity with graded composition, directly from the 3D CAD data of the component and in one manufacturing process. This has a number of ripple effect on the way products are designed and manufactured which is capable of manufacturing product at much cheaper rate and faster too. This important technologies are still been developed and more research work is still required in order to expand the current application of this technology. The summary and the future research need are presented in the next section.

4. Future Research Direction

Compositionally graded material, an advanced form of composite material, found its application in a wide range of industries. FGMs are found in nature such as in human body like the teeth and bone; this can be seen as the major drive for research on functionally graded material. It has been seen that making the medical implant as close as possible to the human tissues goes a long way to increase the life of the implant as well as removing some of the problem associated with the properties mismatch between the implanted material and the surrounding human tissues. Most of the reviews presented in this study were aim at biomedical implants. The importance of achieving medical implant with functionally graded materials through the additive manufacturing route provide the opportunity of making highly customized components such as implants which are patient specific in a timely and cost effective manner. Apart from the medical field, automobile and aerospace industries are also few of the industries that are in dear need of this technology because of the inherent potentials of this technology in helping to reduce the carbon foot print by these industries. A lot of research is still needed to address the repeatability issue that surrounds this technology. This challenge is one of the reasons why this technology is not fully accepted especially in application that demands proper material properties with high precision. Additive manufacturing is seen as a manufacturing process that will revolutionize the way products are designed and produced but the technology is still regarded as a niche technology because of some of the unresolved issues about this new technology. In order for the technology to gain better acceptance not only for the manufacturing of functionally graded materials but for other components, there is need for more research works in the areas of materials characterization and process repeatability, and in the areas of process modeling and control. Understanding the physics of this important process will further help in the development of the process model that can truly represent the process which will in turn result in the proper controller design for the process. On till this is achieved, the repeatability issue is less likely to be resolved. Also more material characterization is still needed to be done which will enable the properties resulting from this process to be adequately predicted and controlled. All these research needs will be able to instill more confidence in industries that are still skeptical about the technology and also expand the application area for the industries that have already accepted the technology. Although some of the aerospace parts are now produced using this technology but with achieving more confidence about the parts produced such that it has the required properties that is able to meet the requirements of specific application requirement will help to expand the use of this technology for the production of more critical parts. A number of research works have established the influence of processing parameters on the evolving properties of LMD materials [44-51]. By changing the processing parameters, it is possible to change the properties of materials can be varied across the volume of the material. This method of producing compositionally graded material should be developed through research to produce functionally graded materials.

5. Conclusion

Some recent research works has been presented in this chapter to show the main research effort in the fabrication of compositionally graded materials with the laser additive manufacturing process. The laser additive manufacturing technologies that are used to produce compositionally graded parts that were reviewed in this chapter are: the laser metal deposition process and the selective laser sintering/melting. A number of the research works are seen to have established the capabilities of these technologies to produce of compositionally graded materials in form of coatings as well as for 3D solid parts. The future research direction has also been presented.

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