FABRICATION OF STAINLESS STEEL BASED FGM BY LASER METAL DEPOSITION

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Abstract

Recent advancement in materials processing has resulted in the evolution of advance composite known as Functionally Graded Materials (FGMs). FGMs are multi-layered structures with composition and/or microstructure that vary spatially across the volume of the material. This chapter presents an overview of the concept of functionally graded materials in terms and its history. The present and potential applications of FGMs are briefly described, as well as various classification methods. Processing of FGM using laser metal deposition (LMD) is also discussed as well as the influence of LMD process parameters on the quality of laser processed materials. Studies that have been conducted on metal-metal FGM produced LMD are presented. Finally, a study on the microstructure and microhardness of laser deposited compositionally graded 316L/17-4PH was also presented.

Keywords: Advance composite, Functional graded material, Laser metal deposition, Microhardness, Microstructure

1 Introduction

There is a continuous search for new materials that are multifunctional or have better properties compared to conventional materials for modern engineering applications. Two different approaches can be adopted in the development of new materials; one way is to synthesize a unique material that is totally different from any material available or by combining two or more existing materials with dissimilar properties to form a composite. Composites have been employed for decades to successfully solve many engineering problems [1]. However, they are susceptible to stress concentration at each material interface which typically leads to delamination or debonding. To overcome this limitation, a different category of composite called Functionally Graded Material (FGM) was developed. FGMs exhibit gradual space variations in their composition and/or microstructure from one end of the component to the other. The gradient can vary in one or several dimensions [2]. Functionally graded materials can be generally tailored at nano to micro scale compared to traditional composite which are tailored macroscale materials. Functionally graded material concept is applicable to practically all industries because of the ability to tailor materials for a specific purpose. The wide scale use of FGMs at the moment is hinder by factors such as production cost, limited and reliable production technique. Hence, manufacturing technology is a key area of interest of many researchers.

1.1 Development of FGM

Biological systems have long exploited the concept of material grading to improve their performance and material usage. This type of materials is plentiful in nature and exist in the form of bone, tooth, bamboo to mention a few. The bone has a unique and complex structure, the centre of the bone is denser than the outer layer. The middle layer which has lower porosity is optimized for strength, while the spongy or a more porous outer layer contains blood vessel and tissues within the cavities. Another good example is the dental crown of the tooth, the outer shell has good tribological properties, while the inner structure is brittle and ductile. For bamboo, the volume fraction of vascular bundles increases from the centre of the structure to the edges, while the size decreases. This gradation is responsible for their enhanced mechanical properties. The human skin does more than providing structure and protection to the body. It is composed of several layers of cells and tissues which serve various other purposes.

The concept of material grading was first theorized by Bever and his associates in 1972 [3]. They published two manuscripts describing possible properties, application and processing of gradient materials. However, very little progress was made in the field until the space plan project in Japan around 1984 when the first FGM was manufactured [4]. Some Japanese scientist involved in a space project required a thermal barrier coating capable of withstanding extreme surface temperature and temperature gradients of about 2000 K and 1000 K respectively over cross-section of around 10 mm. Since there was no homogenous or inhomogeneous material with the required heat resistance property to withstand the temperature gradient experienced during re-entry of a spacecraft. To solve this problem, the Japanese scientist designed a new type of thermal barrier by improving the surface functionally of the metallic base material by applying a top layer of ceramic, both components were gradually graded thereby eliminating the sharp interface found in laminated composite. The thermal resistance of the ceramic ensured the structure was capable of withstanding high temperatures, while the metallic material provides the tensile strength, toughness and thermally conductivity required in the structure.

Other important benefits of gradient material design include increased chances of successfully bonding materials with very different coefficient of thermal expansion (CTE), reduction in residual thermal stresses, improved bond strength by elimination of sharp interfaces between constituent materials and reduction in thermal shock cracking [2], [5]-[7].

1.2 Applications of Functionally Graded Materials

As stated earlier, gradient materials were originally developed to eradicate the interface in traditional composites that causes large thermal stresses in the material and which can ultimately lead to delamination or cracking when used in high temperature applications. Recent research has extended the FGM concept to different areas of applications in different industries and also has potential applications in the future [2], [8]-[10]. Figure 1 shows some applications of FGM.

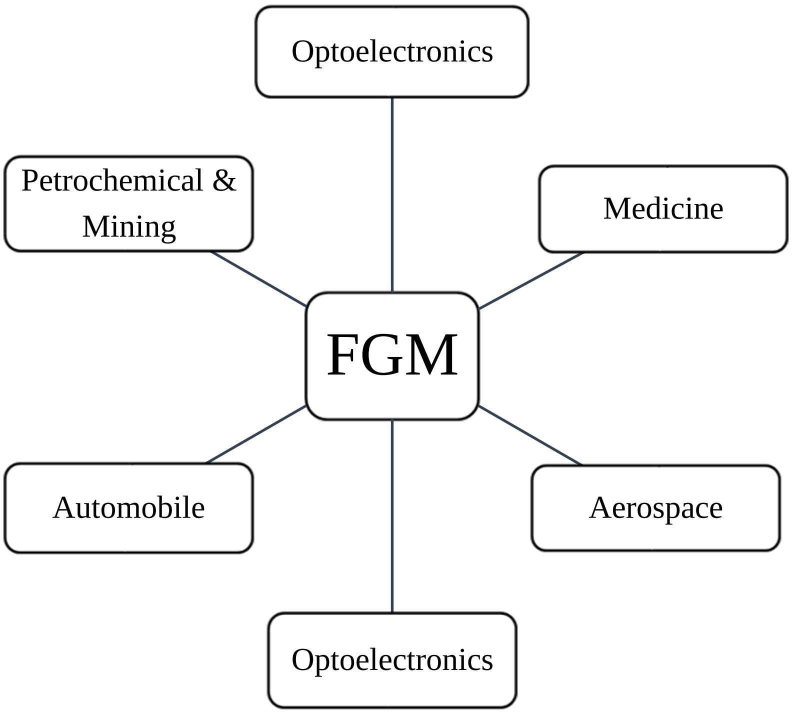


Figure 1: Application for FGMs

Medicine: The use of FGM has gained increased attention in the medical field and leading to major advances in the development of biomaterials for use in different areas of the human body. As mentioned earlier, some tissues and biological structures in the human body are functionally graded in order to optimize their functionality and material usage. When such material need to be replaced because of medical emergencies, implants must be biocompatible, non-toxic and meet other functional requirements in order to serve its intended purpose. Functionally graded biomaterials can better satisfy such multiple requirements than convention materials. FGMs have been successfully used for dental implant and orthopaedic applications.

Defence: The FGM concept has also received great attention in the defence industry because of the potential of producing light weight components which still meet the specified functional requirements. Ballistic protection for military vehicles and aircraft are component where this concept is being applied.

Aerospace: FGMs are being used in both military and commercial aircrafts to reduce thermal stress generated and also to enhance thermal resistivity. They are used as thermal barrier coatings (TBCs), in fuselage coatings, rocket nozzles, turbine wheels and propulsion systems.

Automobile: Functionally graded ceramic are now utilized as replacements for brake disc in race cars braking systems. Other areas of applications include, Diesel engine pistons, gas turbine engines Drive shafts, Shock absorbers, power transmission and exhaust system.

Petrochemical and mining: gradient materials show great potential in fabricating boring and cutting tools used for applications where high strength, fracture and wear resistance is required such as petroleum industry and mining industry. Functionally graded tungsten carbide and cobalt (WC/Co) have been developed to meet such functional requirement.

Optoelectronics: semi-conductors, piezoelectric devices, refractive index materials, and magnetic/optical storage devices are now being manufactured using the FGM concept. These devices are generally for advance applications in data storage and electronic industry.

1.3 Classification of Functionally Graded Materials

The classification of functionally graded materials vary amongst researchers. FGMs have been classified based on their structure as continuous graded or stepwise graded [2]. In continuous gradation the property of the material gradually changes from one direction to the other. While in stepwise gradation, the property changes are discontinuous thus producing a structure comprising of several layers having discreet. FGMs have also been categorized based on the type of gradient into three namely porosity, microstructural, and chemical composition gradient [10]-[12]. Porosity gradient FGMs have variable porosity across the volume of the material and typical application is in the medicine. This type of FGMs can be designed to have pores with different shapes, sizes and porosity distribution [10]. Microstructural gradation implies that FGMs has variable microstructure, this type of gradient are produced in metals through surface hardening processes such as nitriding and carburation have been employed to [10], [12][13]. Chemical composition gradient can be applied to either single or multiphase materials, however, single phase materials with such gradation are rare. In multiphase material, the volume fraction of the reinforcement phase is progressively varied in the bulk material. Common examples of chemical composition FGMs include ceramic-metal [14], [15], and metal–metal FGM [16], [17]. Furthermore, functionally graded materials have been classified according to the method of fabrication. Wessel [18], groups FGM into two types; functionally graded material produced by constructive processes and transport based processed FGM. Similarly, functionally graded materials according to fabrication methods as bulk and interfacial FGMs [10].

1.4 Manufacturing Techniques

A number of the manufacturing methods used in the production of FGMs are based on modifications of traditional material processing techniques. The selection of an appropriate manufacturing process depends on several factors such as materials, geometry, FGM structure (i.e. stepwise structure, continuous gradation or thin films) and the final properties of the structure. Powder metallurgy (PM), chemical vapour deposition (CVD), centrifugal casting, thermal spraying, friction stir welding (FSW), Gravity sedimentation and additive manufacturing technique used to manufacture FGMs include: powder metallurgy (PM), chemical vapour deposition (CVD), centrifugal casting, thermal spraying, friction stir welding and additive manufacturing (AM) are common manufacturing methods for graded materials [12], [19], [20].

Additive manufacturing is a very attractive method for joining dissimilar materials and fabricating compositionally graded materials because fully dense parts can be created in a single step. Furthermore, AM allows for freedom in design of component and as such component with complex shapes can be manufactured relatively quicker than most FGM processes. However, AM still lags behind when compared to conventional processing methods with regards to build speed, volume, accuracy, standardization and cost. These factors have limited its adoption in the manufacturing sector for mass production of parts. At the moment, AM is used for low volume productions, especially where bespoke parts are required.

1.5 Additive manufacturing technologies

Additive Manufacturing is a process where a component is fabricated from the bottom up in layers from a 3D computer model. Additive manufacturing encompasses several technologies and each of them is suitable for specific requirements and/or materials. These AM technologies have similar working principles but often differ in the way successive layers are stacked and type of heat source utilized. The available additive manufacturing technologies have been categorized differently by various authors. For example, AM technologies have been classified based on the type raw material utilized into polymer, metal and ceramic [21]. Another classification method differentiate the technologies based on nature or phase of the feedstock into liquid, powder and solid phase [21]. Most recently, the various technologies and terminologies has been standardized in the ISO/ASTM 52900:2015 [22], which proposed seven distinct process types namely vat-photo polymerization, material jetting, binder jetting, material extrusion, powder-bed fusion, sheet lamination, and directed energy deposition.

Laser Metal Deposition (LMD) is one of the process types which falls under the direct energy deposition (DED) category. LMD have several benefits which differentiate it from the other metal additive manufacturing processes like powder bed and sheet lamination. Major benefits include multi-material feeding and relative ease of controlling or varying material ratio [14]. Other advantages of LMD include better thermal control; minimum base metal dilution; has a relatively wide process window; can be used for repair works; easy operation in an inert environment; ability to manufacture functionally graded products; and material flexibility [23], [24]. Laser metal deposition systems uses a focused laser to create a melt pool on a substrate into which the metal feedstock is supplied [22]. LMD systems can be further sub-divided into powder and wire fed system, however, hybrid systems having both wire and powder feeding have been developed [25]. The wire or powder metal can be fed using either a lateral or coaxial nozzle arrangement as shown in Figure 2.

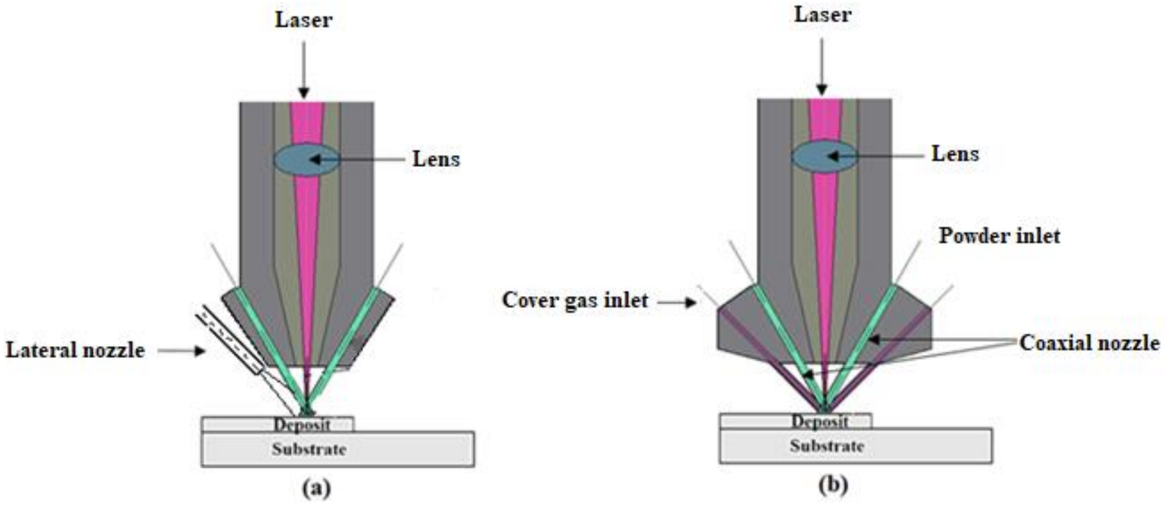


Figure 2: Nozzle types used in powder fed LMD systems (a) Lateral, and (b) coaxial

Typically powder fed system are more versatile as they can utilize either the lateral and coaxial nozzle arrangement. Material delivery in wire based system are achieved mainly with lateral nozzles.

1.6 Process parameters

LMD is a very sensitive and complex process because the quality of the fabricated components is influenced by different processing parameters that interact with each other. The interaction between these variables must be well understood to correctly select the appropriate parameters to successfully manufacture parts with the preferred properties. There are three main group of process parameters namely, input parameter, process parameter and output parameter respectively [26]. However, according to the literature, powder feed rate, laser spot size, laser power and scanning speed are the most significant parameters for laser deposited materials. a brief description of the above mentioned parameters are given below.

Laser spot size: This determines the beam diameter of the laser and also influences the concentration of the laser beam (large spot size tend to produce lower intensity beams and vice versa). Additionally, the width of deposited tracks is also influenced by the laser spot size.

Laser power: Laser power has a significant effect on melt pool dynamics, quality and evolving properties of a deposition. Mahamood et al. [27] presented the analysis of their studied on the mechanical property and microstructure of laser consolidated Ti6Al4V/TiC composite. The composite was processed by varing the laser power between 0.8 and 3.0kW. Laser power was observed to influence the microhardness, grain structure and dilution of the fabricated component. Shukla et al [28] observed a similar trend in their experiment, they found that higher laser power caused an increase in microhardness. However, Bayode et al. [29] found in their study that laser power had an inverse relationship with microhardness in laser consolidated AISI 316L powder. The surface finish of Ti6Al4V powder processed by LMD was investigated by Mahamood and Akinlabi [30]. They observed a reduction in surface roughness the laser power increased.

Scanning speed: describes how fast a laser beam travels along a predetermined path. The scan speed affects the laser- material interaction time and the cooling rate during solidification. The scanning speed should neither be too fast or too slow. Depending on the laser power, shallow melt pools are formed at a very high scanning speed due to insufficient energy input. While, a deeper melt pool is created at extremely low scan speeds. Akinlabi et al. [31] investigated the influence of scan speed on material efficiency. The results revealed that powder efficiency decreased as the travel speed increased. The lowest speed (0.01m/sec) produced the highest powder efficiency, while the lowest efficiency (24.82%) was obtained at 0.005m/sec scanning speed. Similarly, Mahamood et al. [32] investigated the influence of scan speed on deposition efficiency and clad height of the laser processed Ti6Al4V alloy. All parameters were fixed except for scan speed which was uniformly increased from 0.005 to 0.095 m/sec. No clear relationship was found between scanning speed and powder efficiency. However, optimum material efficiency occurred when the speed was set at 0.045m/sec and.

Powder flow rate: This refers to the amount of powder discharged from the nozzle per unit time. Powder flowability is dependent on several factors such as particle morphology and particle size distribution. Generally, powder flow rate influences dimensional accuracy and material efficiency of LMD processed parts [28], [33], [34]. Powder flow rate has also been reported to influence porosity, microhardness and microstructure of LMD processed

Ti6Al4V/Cu composites [35]. Surface roughness of deposition tend to increase as powder flow rate increases, because the exposure time to laser irradiation of the powder particles is small at high powder flow rate but more when the flow rate is low [34].

Laser spot size, laser power and scan speed have a strong influence on each other and together. These variable regulates the amount of energy supplied per unit area during laser metal deposition. The relationship between these three quantities determine the energy supplied per unit area or laser energy density (LED). LED is defined by the following relationship [36]:

$$Laserenergydensity\left(\frac{J}{mm^2}\right) = \frac{P}{VxD} \quad (1)$$

P is laser power (W), V is scanning speed (mm/s) and D is the laser spot size (mm). LED is also a vital factor in laser metal deposition and its effects are well reported in the literature. For example, Mahamood et al. [37] in their study found that energy density and surface roughness had an inverse relationship. However, microhardness of the samples varied linearly with laser energy density.

1.7 Laser Deposited Functionally Graded Material

There are very limited studies on metal-metal FGM in the literature compared to metal-ceramic FGMs. The focus of most of these studies were to verify the feasibility processing FGM using LMD, identifying optimal processing conditions and also investigating their evolving properties. Wu et al. [16] investigated the microstructural evolution and mechanical properties of AISI 316/Inconel 718 FGM fabricated laser rapid manufacturing. The aim of their research was to determine the feasibility of consolidating both metal powders and also report on the evolving properties of the fabricated component. Two different type of FGM were produced by varying their compositions and build direction. Different solidification modes were observed in both FGMs, cellular to dendritic morphologies were observed at different regions of the FGMs. The microhardness of the FGMs were also measured at different sections of the samples. An initial reduction in microhardness was observed between layers 1-4 of the traditional FGM, however as the inconel718 content increased to about 40%, the hardness value started to increase. On the other hand, the microhardness value of FGM 2 showed an increase along the graded direction in both the longitudinal and transverse directions.

Sahasrabudhe et al. [38] investigated the microhardness and microstructure of stainless steel and titanium bimetal structure fabricated by LENS. Two different types of FGMs were fabricated in this study, one was fabricated by simply varying the compositions of 316L and Ti64 powders. While the other was almost identical to the first FGM except an intermediate layer which was made up of NiCr was added. The FGM produced without the NiCr layer was characterized by cracks and delaminated as the volume fraction of Ti64 increased. While the specimen with NiCr interlayer had no cracks but porosity was observed in certain areas of the structure. The authors reported that the delamination and cracks could be attributed to the formation of brittle intermetallic phases such as Cr_2Ti, Fe_2Ti and FeTi in the microstructure.

Lin et al. [17] investigated the evolving properties of compositionally graded AISI 316L/Rene88DT. The structure was characterized mostly by dendritic growth except for region of the deposit having a 100% Rene88DT super alloy content. Lin et al [39] conducted another experiment using laser deposition to manufacture compositionally graded Titanium and Rene88DT composite. The structure was characterized by epitaxial growth and columnar/equiaxed transition in the microstructure.

Noecker et al. [40] conducted a study on LMD of functional graded copper and steel bi-metal. The aim was to enhance the thermal conductivity of steel moulds through the introduction of Cu to the component. Their attempt at compositionally grading Cu to tool steel was hindered by solidification cracking. They observed a relationship between solidification cracking and Cu concentration in the built part. They categorized cracking susceptibility into three; low, medium and high susceptibility.

Carroll et al. [41] studied the feasibility of producing AISI 304L /Inconel 625 FGM by DED. They investigated the evolving properties of the FGM and also did thermodynamic computational modelling of the fabricated component. The results of the authors' attempt to fabricate and characterize a compositionally graded 316L/17-4PH bi-metal composite synthesized by LMD is presented in the next subsection.

2 EXPERIMENTAL

This section describes the equipment and materials used in this study to fabricate the compositionally graded bi-metal and also presents the methodology used in evaluating the mechanical and microstructural properties of the laser processed component.

2.1 Materials

Two different varieties of stainless steel (SS) alloys; 17-4PH and AISI 316L stainless steel powders were used in this study. The 17-4PH powder is a martensitic and was manufactured by gas atomization process, while the 316L alloy is austenitic and water atomized. According to manufacturer's label, the 17-4PH and 316L powders have particle sizes of 45-90 µm and 44 µm respectively. While AISI 316 is an austenitic stainless steel and non-magnetic. The stainless steel alloy composition provided by the suppliers is presented in Table 1.

Table 1: Elemental composition of the powders

Element	17-4PH (wt.%)	316L (wt.%)
Iron	73.7	67.5
Nickel	4.4	13.0
Manganese	0.9	-
Chromium	16.4	17.0
Copper	4.0	-
Carbon	0.01	-
Silicon	0.7	-
Niobium	0.32	-
Molybdenum	-	2.5

The substrate used was AISI 316 stainless steel plate having a dimension of 100 × 100 × 10 mm and was supplied by Metal Centre (Pty) South Africa. Before laser deposition, the substrate was sand blasted and then cleaned with acetone and water. This was done for two reasons, firstly to rid the substrate surface of any pollutant and lastly, to increase laser absorptivity of the plate surface.

2.2 Experimental Setup

The FGM was fabricated using the LMD machine at the Council for Scientific and Industrial Research (CSIR), laser laboratory. The LMD system consist of the following key components; laser source, powder feeder, laser head, and motion device. The laser used in this study was a 3.0 kW continuous wave Nd:YAG laser operating at a wave length of about 1.06 um. A GTV PF 2/2 powder feeder with two hoppers that are separately driven and independently controlled was used for material delivery. A laser deposition head comprising of a coaxial delivery nozzle and laser beam focusing lens assembly was mounted on a KUKA industrial robot for motion. Argon was used as both the carrier and cover gas. A picture of the LMD machine is displayed in Figure 3.

Figure 3: LMD system [42]

2.3 Processing

The FGM was fabricated by directing the laser beam on the substrate creating a molten pool into which the stainless steel powders were supplied. The melt pool increases in size as a result of added metal and solidifies to form a solid track or deposited layer. The deposition head is moved incrementally along the z-axis to deposit new layers until the build is completed. The powder ratio for both stainless steel powder was varied uniformly from 100% 17-4PH to 100% 316L stainless steel alloy by adjusting the flow rate of both powders to produce a 9 layered structure as shown in Figure 4. The processing parameter used to fabricate the FGM is presented in Table 2.

Figure 4: Image of the FGM

Table 2: Processing parameters

Sample	Powder flow rate (rev/min) (17-4PH)	Powder flow rate (rev/min) (316L)	Laser power (W)	Scanning speed (m/min)	Gas flow rate (l/min)	Beam diameter (mm)	Overlap percentage (%)
A1	2.0	0	2200	0.6	2.54	2	50
	1.6	0.4					
	1.2	0.8					
	0.8	1.2					
	0.4	1.6					
	0	2.0					

2.4 Specimen Characterization

The laser deposited material was sectioned perpendicular to the scanning direction and then metallographically prepared in accordance to the standard preparation for stainless steel [43]. Samples for microscopy studies were chemically etched using Kalling's No2 etchant (5g copper(II) chloride, 100 ml hydrochloric acid, 100 ml ethanol). The microstructure was investigated using a Tescan scanning electron microscope (SEM)). Elemental analysis of etched samples was also investigated using the Oxford Instrument Energy Dispersion Spectrometry (EDS) fitted in the SEM. The microhardness profile of the sample was measured using Metknon (MH-3) Vickers indenter. The test was carried out as prescribed by the ASTM standard [44]. The measurement was taken from the top surface to bottom of sample at an interval of 0.3 mm. The machine was set to run at load and dwell time of 500g and 30s respectively.

3 RESULTS AND DISCCUSION

3.1 Macrostructure

Figure 5 shows the cross section of the fabricated 316L/17-4PH stainless steel composite. As can be seen from the SEM micrograph, the specimen appears to be structurally sound with no evidence of micro-cracks or pores. Intersecting bowl-shaped features representing melt pool boundaries formed as a result of laser scan and overlap are noticeable. The maximum height of FGM was about 4.8 mm and the average melt pool depth across the substrate was 0.445mm. The low dilution observed could be attributed to the short interaction time of the laser beam on the substrate due to the high laser scan speed used during processing. Minimal dilution suggests that there is very little mixing between the deposited material and the substrate, hence, reduced contamination with the baseline material. Laser processed materials with minimal dilution are desirable compared to high dilution deposition [45], [46]. However, the deposit and substrate interface is the weakest point in the structure, so having a high dilution clad are considered beneficial in certain applications as it ensures a stronger metallurgical bond between the substrate and deposited layer.

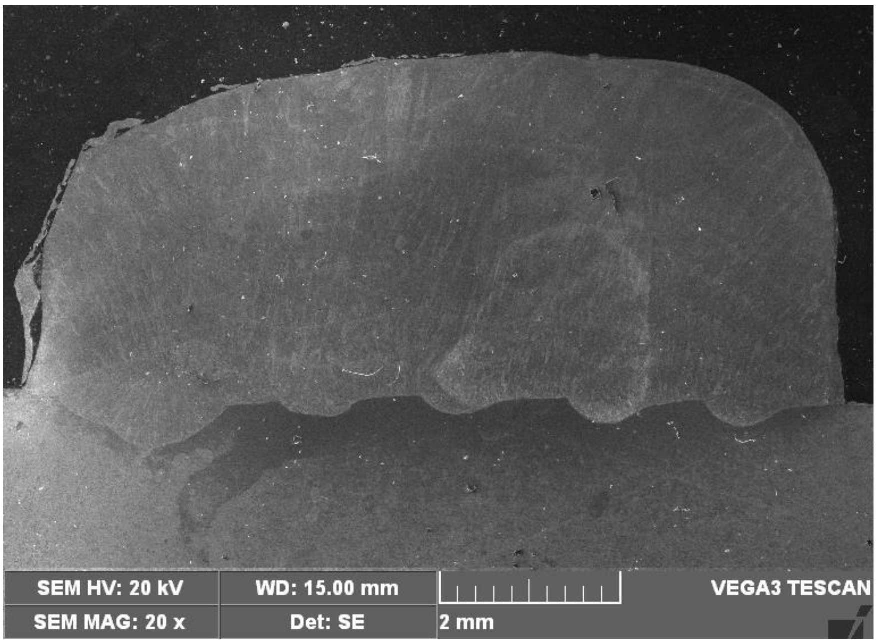


Figure *5*: Cross sectional SEM image of FGM produced at a laser power of 2200W and scan speed of 0.6m/min

3.2 Microstructure

Variation in microstructure was observed across the deposition as the compositions from one end of the component to the other. The microstructure changes gradually from a wholly martensitic microstructure at the bottom of the deposit to an austenitic microstructure at the top of the clad. The predominately martensitic microstructure at the bottom was expected since dilution was quite low resulting in very minimal mixing between austenitic substrate and martensitic 17-4PH powder. Figure 7 shows the SEM images taken at different positions on the functionally graded material. The AISI 316 stainless steel substrate has a purely austenitic microstructure with clearly defined grain boundary as seen in Figure 6f. No signs of grain crystallization and heat affected zone (HAZ) were observed in the vicinity of substrate-deposit interface (see Figure 6e). This may be because this grade of stainless steel are generally non-transformable [47]. The region above the interface is characterized by a dendritic grain structure which grew expitaxially from the substrate. The columnar dendrites observed above the interface are as a result of the high solute concentration of deposited 17-4PH powder and rapid cooling experienced in LMD. The columnar dendrites are vertically oriented which suggests directionally solidification. Figure 7 shows the EDX analysis of spots 1 and 2 depicted in Figure 6e. The EDX analysis was carried out to evaluate inter-diffusion of elements between the substrate and fusion zone. As can be seen in Figures 7a and 7b, no transfer of elements appears to have occurred between the substrate and cladded layer, since elements such as Cu and Mo which are found in 17-4PH powder and 316 substrates respectively did not diffuse across both regions.

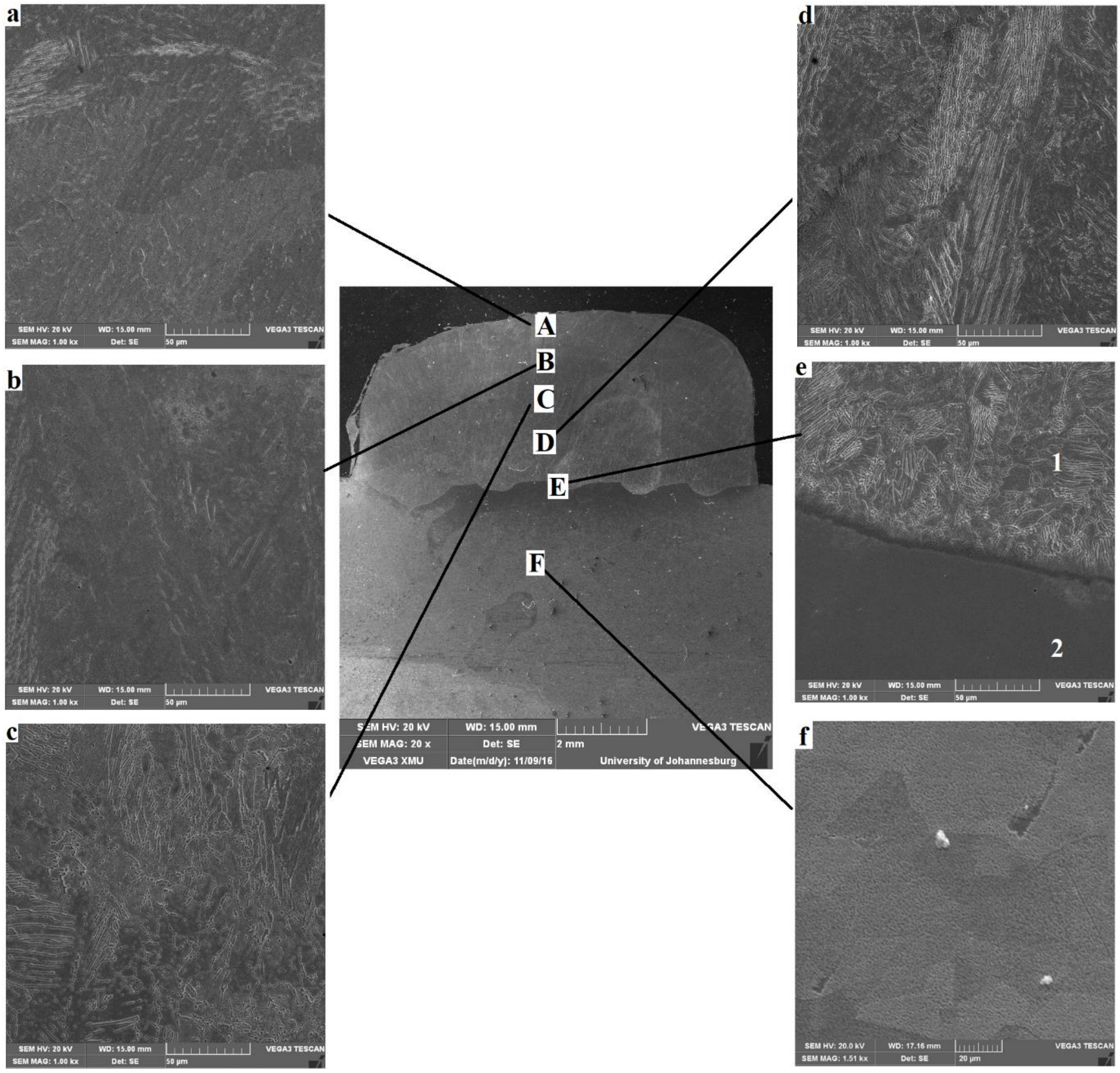
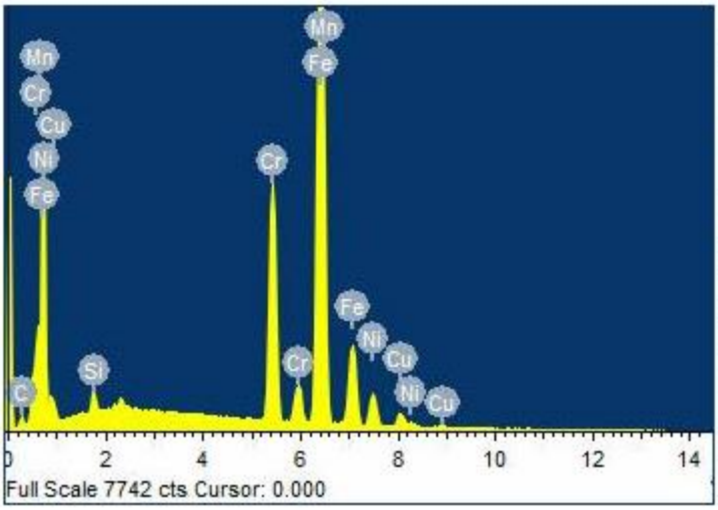
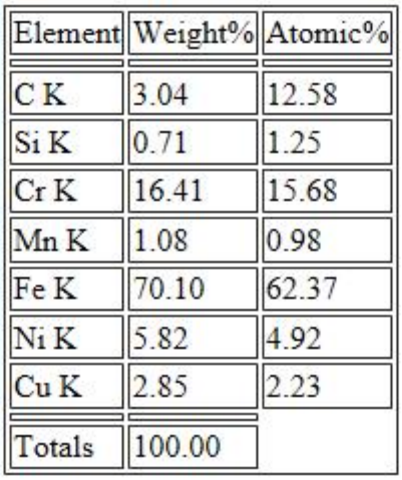


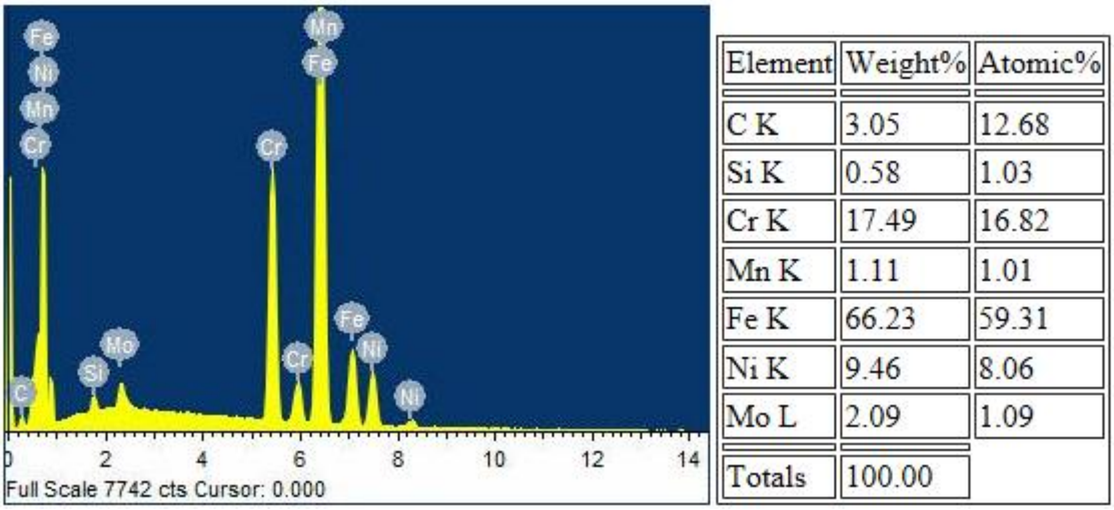
Figure 6: Microstructure at different regions of the FGM





Element	Weight%	Atomic%
C K	3.04	12.58
Si K	0.71	1.25
Cr K	16.41	15.68
Mn K	1.08	0.98
Fe K	70.10	62.37
Ni K	5.82	4.92
Cu K	2.85	2.23
Totals	100.00	

(a)



Element	Weight%	Atomic%
C K	3.05	12.68
Si K	0.58	1.03
Cr K	17.49	16.82
Mn K	1.11	1.01
Fe K	66.23	59.31
Ni K	9.46	8.06
Mo L	2.09	1.09
Totals	100.00	

(b)

Figure 7: EDX analysis of (a) spot 1, and (b) spot 2

The rest of the structure also appears to be predominantly dendritic except for the top layer. The transition region depicted by region D, C, and B respectively in Figure 6, is characterized by columnar grains with and without secondary dendrite arm. The grains also appear to have grown expitaxially from previous layers as oppose to re-nucleating across layers. Thermal gradient increases with height of the deposition and also the effect of heat accumulation becomes more substantial as more layer are added. These factors favour dendritic growth and grain refinement. The top of the FGM is characterized by fine nodular structure as shown in Figure 6a. The finer grains and nodular structure observed can be accredited to rapid cooling at the surface by the covering gas.

3.3 Microhardness profiling

The microhardness profile along the graded direction is shown in Figure 8. It can be inferred from the graph that the hardness decreased with increasing AISI 316L content. This was expected since austenite is a weaker phase compared to martensite. The region just above the interface comprising of about 100% 17-4PH had the highest hardness value of HV 347. As can be seen from the microhardness profile, there is very little variation in the hardness values between the top layer which is 100% AISI 316L (183 HV) and wrought 316 substrates (186 HV). The similarity in the microhardness value of the top layer and substrate is indicative of the non-hardenability of austenitic stainless steel.

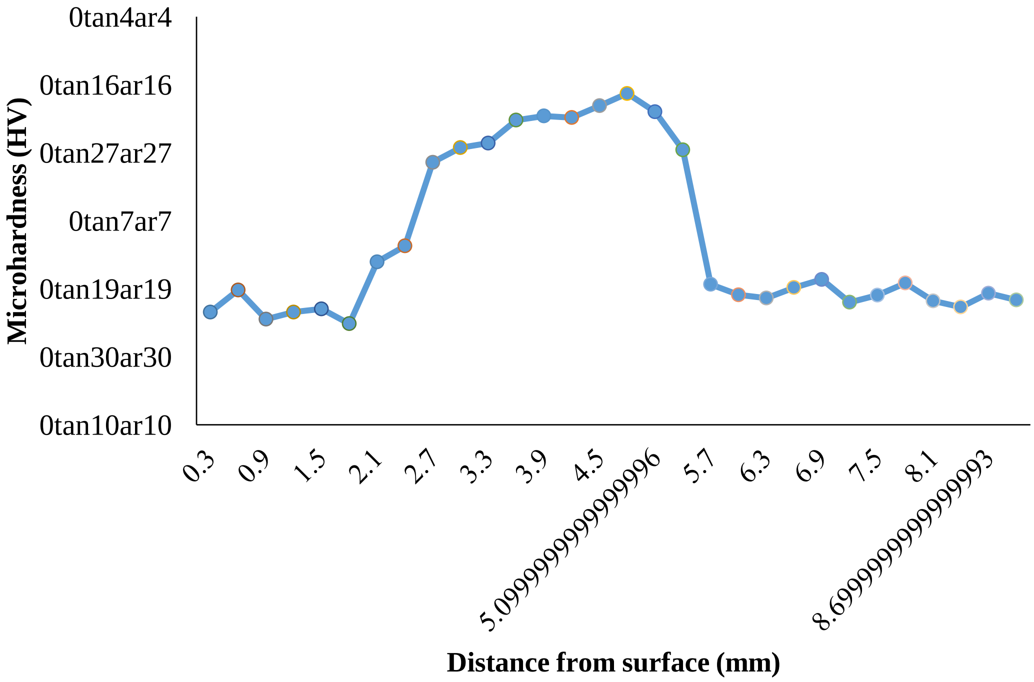


Figure *8*: Microhardness profile along the depth of the FGM produced at a laser power of 2200W and scan speed of 0.6m/min

4 Conclusions

Functionally graded materials are a class of advanced materials with exceptional properties and characteristics. The FGM concept allows for tailoring of properties for diverse applications. Compositionally graded AISI 316L and 17-4 PH stainless steel composite was successfully manufactured using laser metal deposition technique. The FGM was defect-free and showed no evidence of porosity. The microstructural analysis conducted revealed that the microstructure varied with depth. A similar trend was observed with microhardness of the structure. The hardness increases with depth, with the highest hardness value recorded at the bottom of the FGM with 100% 17-4PH content.

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Correspondence and email

FYI.

Sorry Prof, I forgot to CC you on this email.
---------- Forwarded message ----------
From: "Bayode Abey" <reachabeyy@gmail.com>
Date: Nov 9, 2017 11:22 AM
Subject: Re: Book Chapter

To: "K Kumar" <kkumar@bitmesra.ac.in>
Cc:
Dear Dr Kumar,

Please find attached as requested.

Regards
Abey

On Wed, Nov 8, 2017 at 4:02 PM, K Kumar <kkumar@bitmesra.ac.in> wrote:
Respected Sir,
By camera ready manuscript I meant the final one. Use any format you feel comfortable and submit the same. Please also provide me the figures separately in a zipped file.
I am extremely sorry for the inconvenience caused. Please excuse me.
Thanking you and awaiting your final manuscript.

On Wed, Nov 8, 2017 at 6:42 PM, Bayode Abey <reachabeyy@gmail.com> wrote:
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What referencing style is permitted?

Regards,
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On Wed, Nov 1, 2017 at 8:07 AM, K Kumar <kkumar@bitmesra.ac.in> wrote:
Respected Sir,
The Chapter is now ok and acceptable in the present form.
Kindly provide me with the final Camera Ready manuscript with figures. The figures are also required to be submitted separately in .tiff extension with minimum 300 dpi.
Awaiting your response

On Mon, Oct 30, 2017 at 3:48 PM, Bayode Abey <reachabeyy@gmail.com> wrote:
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On Sat, Oct 14, 2017 at 2:12 PM, K Kumar <kkumar@bitmesra.ac.in> wrote:
Respected Researcher,
Greetings of the day!
Thank you for submitting chapter titled "**Fabrication of stainless steel based FGM by laser metal deposition**" for our book ***HIERARCHICAL COMPOSITE MATERIALS***.

The review process is almost over but before we can proceed any further it has been noticed that your chapter has **12%** similarity from publication and /or internet material (Report Attached).
Kindly resubmit the chapter after reducing the same (**<10%**) (the acceptance norm of the publisher) by 30th October 2017.
Thanking you once again and awaiting your response
With Regards
DR. KAUSHIK KUMAR
Editor
HIERARCHICAL COMPOSITE MATERIALS

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