International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016 [ICSSCCET 2016]

ISBN	978-81-929866-6-1		VOL	02
Website	icssccet.org		eMail	icssccet@asdf.res.in
Received	25 – February – 2016		Accepted	10 - March – 2016
Article ID	ICSSCCET105		eAID	ICSSCCET.2016.105

A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition

Saiyathibrahim A[1], Subramanian R[2], Dhanapal P[3]

[1,2]Department of Metallurgical Engineering, P.S.G College of Technology, Coimbatore, India

[3]Department of Mechanical Engineering, Karpagam Institute of Technology, Coimbatore, India

Abstract: *The tailored gradual variation of microstructural features may be obtained through non-uniform distributions of the reinforcement phase(s) with different properties, sizes and shapes, as well as by interchanging the role of reinforcement and matrix materials in a continuous manner. Wide ranges of processing methods are considered on the production of FGMs. Microstructural evaluation, wear mechanisms, porosity, stress distributions, etc. of various metal-metal, metal-ceramic and ceramic-ceramic FGMs are discussed to expose an overall view for carrying future research. Improving the performance of processing techniques and extensive studies on material characterization on components produced will go a long way in bringing down the manufacturing cost of FGM and increase productivity in this regard.*

Keywords: *Functionally graded materials, Self propagating high temperature synthesis (SHS), elctrophoretic deposition, characteristics of FGM.*

1. INTRODUCTION

FGMs exhibit gradual transition in the microstructure and/or the composition in a definite direction, the presence of which leads to variation in functional performance within the part through microstructural manipulation. FGMs possess a characteristic of tailoring of graded composition and micro structure according to the distribution of properties needed to achieve desired function which distinguishes it from the conventional materials. As we all know composite materials and cermets have been employed as a solution for the various engineering problems for the number of years. Though the development of new materials (FGMs) is due to mismatch occurs while applying them as a coating on the surface of the base material to withstand desired condition which leads to change in the properties like elastic modulli, thermal expansion and hardness. The gradual transition allows the creation of superior and multiple properties without any weak interface.

This idea is emulated from nature to solve engineering problem the same way artificial neural network is used to emulate human brain. The pioneering properties and functions cannot be achieved by traditional materials with homogeneity. FGM's multifunctional behavior and performance create scope for applications require advanced materials namely aerospace, automotive, biomedical, defenses, electronics, power engineering, etc. A FGM is used to join two different materials without stress concentration at their interface. A Sharp interface as in the composite material leads to the initiation of failure. FGMs replace this sharp interface with a gradient interface which produces smooth transition from one material to the next. Gradation in properties from one portion to another portion can be determined by material constituent composition.

Cite this article as: Saiyathibrahim A, Subramanian R, Dhanapal P. "A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition". *International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016*: 521-526. Print.

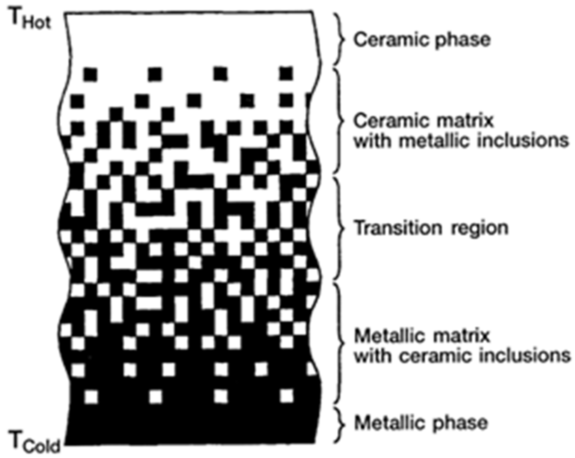

Fig.1. Structural view of continuously graded FGM

According to the material composition function specified, the volume fraction of one material constituent will be changed from 100% on one side to zero on another side, and that of another constituent will be changed the other way around as shown in Fig.1. The FGM helps to reduce stress, prevent peeling of the coated layer, prevent microcrack propagation, etc. For a component having a material region made of an FGM, its fabrication technology must be able to add different materials with certain volume fractions simultaneously for every pixel according to the specified composition function.

Various fabrication methods are available for the preparation of bulk FGMs and graded thin films. The processing methods are commonly classified into four ways like powder technology methods (dry powder processing, slip vesting, tape casting, infiltration process or electrochemical gradation, powder injection molding and self-propagating high temperature synthesis, etc.), deposition methods (chemical vapour deposition, physical vapour deposition, electrophoretic deposition, slurry deposition, pulsed laser deposition, plasma spraying, etc.), in-situ processing methods(laser cladding, spray forming, sedimentation and solidification, centrifugal casting, etc.) and rapid prototyping processes (multiphase jet solidification, 3D-printing, laser printing, laser sintering, etc.)[1].

In this paper processing techniques of FGMs are presented with their experimental investigation of various materials. Some research works on functionally graded materials in recent times are presented and the future research needs are proposed. This work clearly demonstrates various possibilities available in FGM research and useful to gain background knowledge. Also some applications of functionally graded materials are presented here.

2. Processing Techniques of FGM

In this chapter a summary of the different technologies and process for the production of FGM is provided. This includes promising processes such as SHS, elctrophoretic deposition.

2.1 Self Propagating High Temperature Synthesis (SHS)

SHS is a powder processing method. SHS also referred to as combustion synthesis is a process that is based on the ability of highly exothermic reactions to be self-sustaining and as such energetically efficient. The SHS reactants are normally in the form of powders that are pressed into pellets and ignited either at one local point (propagating mode) or by heating the entire pellet to the ignition temperature (simultaneous combustion mode). Following ignition, the generated heat of the reaction is manifested in the maximum or combustion temperature that may exceed 3000K. The advantage of using SHS is that the process is normally completed within a few seconds compared to many hours that are normal for conventional processes. The main limitation of SHS is the high level of porosity (typically 30 – 50%) that may result in the final products. In cases where it is desired to produce dense components using the SHS reaction, a simultaneous compaction process can be applied. At the combustion temperatures, SHS products can be either plastic and therefore easily deformable (or) viscous and highly fluid. SHS is increasingly used owing to the lower cost and better availability of starting materials, simple processing equipment and lower energy consumption resulting from less heat input and shorter processing times and higher product purity because of less reaction during the processing [2].

The steps involved in SHS are reactant powders preparation, cold compaction and occur either as a wave propagating across the specimen from a single ignition source or as volumetric combustion where the reaction is ignited at multiple sites throughout the specimen as a result of uniform heating of the entire specimen. The combustion wave velocity and stability control the level of porosity and uniformity of the product phase. The combustion wave can be controlled by the heating rate, reactant particle size, shape and distribution, specimen green density and diameter, conductive cooling, the addition of pre-treated diluents and externally applied pressure. SHS composites are formed either by mechanically adding the reinforcement to the reactant powder mixtures, when the product consists of two or more materials formed from the reactants. In the former, chemical interaction may occur between the reactants and the reinforcement, whereas the latter would produce a composite with matrix and reinforcement in a state of thermodynamic equilibrium [3]. The SHS processing are shown in Fig.2. A laser irradiates from the surface of a green compact. When the reaction temperature of nickel and aluminium is got, the laser is turned OFF. Then the following reaction depends on chemical heat, which is produced by the reaction between nickel and aluminium.

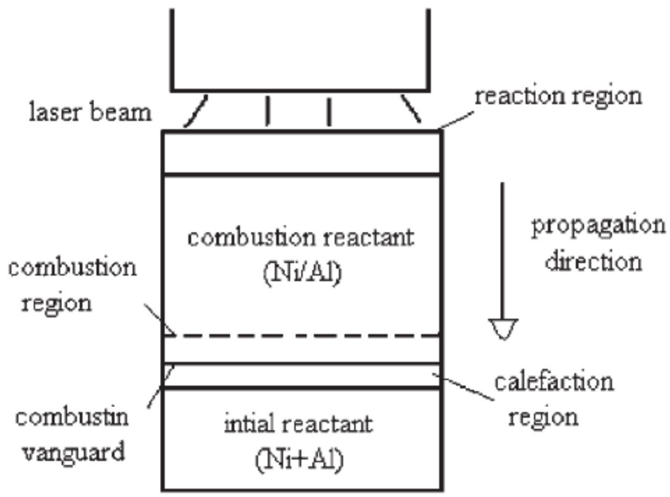

Fig.2. Schematic representation of SHS

Ni-Al system functionally gradient materials are successfully fabricated by the SHS. Compared with the conventional sintering, the laser sintering makes the specimens have the better properties. Because of high power density, ignition and reaction time are shortened, and the highest temperature which reaction can reach is improved. So the method of FGMs by laser self-propagating high-temperature synthesis can simplify production procedures and get pure production. The distribution of nickel and aluminium is smooth in laser-sintered FGMs. Top and bottom layers are nickel and aluminium respectively. We change the amount of gradient layers. When FGMs have seven layers and more, they have more holes. But if they have three and four layers, the FGMs are not integrated. So the FGMs with five or six layers are perfect [4]. Also the results showed that the synthesis density will be enhanced with the increasement of green density.

To compare the density of the sintered samples, densification parameter (ϕ) is introduced.

(1)

Where, ρ_s is synthesized density in g/cm^3, ρ_g is green compact density in g/cm^3 and ρ_t is theoretical density in g/cm^3.

And the densification parameter decreases with the increasement of green density. It is easy to understand that the lower green density has higher densification parameter, but the synthesis density still is very low. However, the liquid phase difficultly flows in the samples of high green density. Fras et al. proposed a new technique which contains SHS route with common casting technology called SHSM (self-propagating high temperature synthesis in mould). A characteristic feature of this technique is that the process of the formation of a gradient structure takes place in parallel with shaping of the fabricated material into a final product. The fabricated materials of the cast iron/NbC and Ni_3Al/NbC type are characterised by a non-homogeneous distribution of the carbide phase in matrix. The content of the reinforcing phase depends on the distance from the casting surface. The phase is generated in an SHS reaction, initiated by contact achieved between its substrates and the liquid metal at a temperature of about 1550°C, i.e. at the mould pouring temperature. The conclusion drawn from the study is that the size of carbides formed in the SHSB process depends on the duration of the synthesis [5].

2.2 Electrophoretic Deposition

Electrophoretic deposition is a colloidal process in which due to the application of a DC electric field particles are deposited from a stable suspension onto a shaped electrode that has an opposite charge. EPD consists of a two-step process. In the first step, particles

Cite this article as: Saiyathibrahim A, Subramanian R, Dhanapal P. "A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition". *International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016*: 521-526. Print.

having acquired an electric charge in the liquid in which they are suspended are forced to move towards one of the electrodes by applying an electric field to the suspension (electrophoresis). In the second step (deposition), the particles collect at one the electrodes and form a coherent deposit on it. The deposit replicates on the shape imposed by the electrode. The only shape limitation is the feasibility of removing the deposit from the electrode after deposition [1]. The disadvantage of this technique is the wide range of specific electrophoresis parameters (voltage, electrode surface, electrode separation distance, solids loading), as well as suspension specific parameters such as effective power charge, elctrophoretic mobility, specific resistivity of liquid and specific resistivity of the deposit. The rate of deposition is high and can be controlled by controlling the applied potential. The final green body obtained from the EPD process is to be dried and sintered for practical applications [6]. Askari et al. conducted their experiment for the fabrication of Al_2O_3/SiC/ZrO_2 functionally graded material. The wide flexibility of the EPD technique was applied to prepare a functionally graded form of Al_2O_3, SiC, and ZrO_2, in which the amount of SiC and ZrO_2 changed through the cross-section of the composite in order to control and allow different mechanical properties in the layers. The final bulk composition is presented schematically in Fig.3.

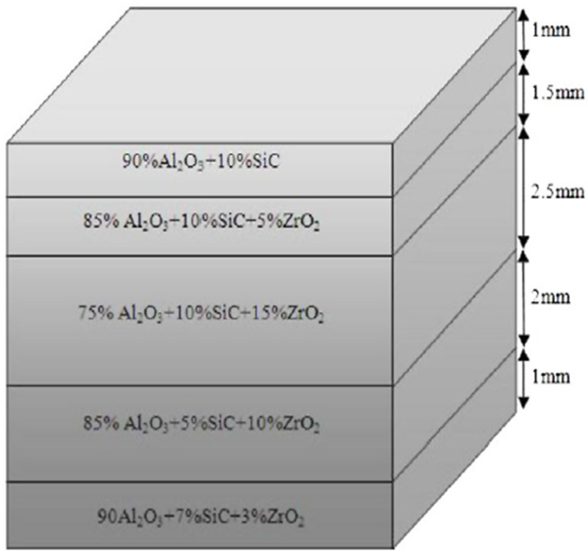

Fig.3. Schematic view of the geometry of a desired Al_2O_3/SiC/ZrO_2 functionally graded material.

Presintering and hot isostatic pressing were carried out to reduce porosity and to densify the deposit. As a result, the sample post the HIP process was much denser than it was after sintering. As a result of the application of high pressure and temperature during the HIP process, the porosity decreased. By comparing the density percentage after sintering with that after HIP, which was 70% and 97% respectively, it is clear that the differences in the porosity reduction were significant, at 30% and 3%. Porosity can affect the mechanical and physical properties of the FGM bulk in terms of hardness, fracture toughness, grain size, and shrinkage [7]. Anne et al. analysed the strength and residual surface stresses in Al_2O_3/ZrO_2 discs processed in which sintered materials were hot isotropically pressed to eliminate residual porosity and concomitantly to increase the strength. The density of the FGM components slightly increased upon HIPing, whereas the pure alumina discs were found to be fully densified after sintering. Also they concluded that the increased density and the thermal HIP cycle have no significant influence on the residual stresses in the FGM discs. The measured surface compressive stress of the as sintered FGM disc was hardly influenced by HIPing, but drastically increased upon surface material removal by grinding [8].

kaya produced tubular Al_2O_3–Y-TZP/Al_2O_3 functionally graded composites incorporating a tough central layer with graded composition (Al_2O_3–Y-TZP) and a hard outer surface layer of pure alumina were produced from nano-size sols using EPD in an attempt to generate a continuous property variation across the final component and to improve the microstructural features in terms of grain size, hardness and fracture toughness. Two different colloidal sols used were pure alumina and alumina plus Y-TZP as shown in Fig.4. Results of the investigation showed that as the volume fraction of TZP phase within the Al_2O_3–Y-TZP/Al_2O_3 functionally graded composite decreases, the hardness value increases whilst the fracture toughness decreases. So it is clear that the volume fraction of TZP grains having influence in hardness, fracture toughness and alumina grain size within the graded layer [21]. Put et al. conducted their investigation on functionally graded ceramic – ceramic (Ce-TZP - Al_2O_3) and ceramic – metal (WC-Co) composites by elctrophoretic deposition technique. Here two different types of FGMs were produced: (i) Ce–TZP/Al_2O_3 FGMs with a gradient in Al_2O_3 content and (ii) WC/Co FGMs with a gradient in Co content. Green WC/Co FGM bodies were cold isostatically pressed and subsequently presureless sintered for 1 h at 1290°C.Incase of later FGM, sintering at 1600°C for 1h alone carried out. In both FGMs experimentally obtained gradients were found to be in good agreement with the compositional profile [9].

Cite this article as: Saiyathibrahim A, Subramanian R, Dhanapal P. "A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition". *International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016*: 521-526. Print.

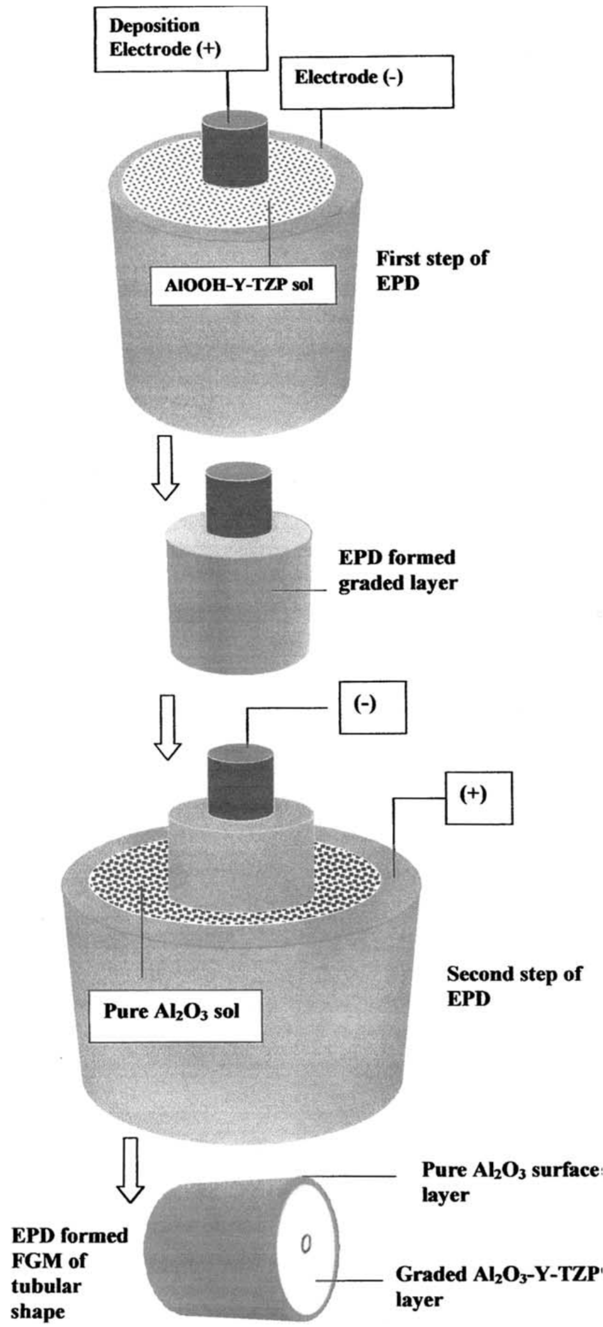

Fig.4. Processing of Al_2O_3–Y-TZP/Al_2O_3 FGM of tubular shape using double step EPD

In order to predict the width and composition change of the gradient for a given material, the powder-specific EPD characteristics such as the electrophoretic mobility, the effective powder charge, the conductivity of the liquid medium and the specific resistance of the deposit have to be determined for each of the powder grades from EPD experiments on the individual homogeneous suspensions [10]. Y-TZP/Ce-TZP and Al2O3/Ce-TZP functionally graded composites were processed with pressureless sintering in air. The resulting composites show a continuous variation in composition and microstructure. The Vickers hardness was found to increase continuously from the Ce-TZP side to the other side, whereas the indentation fracture toughness decreases along the same direction [11].

3. Conclusion

With the consideration of industrial needs new FGM families and their processing methods are to be developed especially with respect to real applications. In the field of FGM gradation forming is the critical step. To overcome this computer assisted modelling should be

Cite this article as: Saiyathibrahim A, Subramanian R, Dhanapal P. "A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition". *International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016*: 521-526. Print.

developed to improve forecasts for the proper gradient formation. Calculations related to the properties and combinations of the desire FGM should be done prior to the production. After the production of FGM, characterization is to be carried out by new testing methods in a non destructive way. Up scaling of laboratory route into industrial scale is necessary. In this regard a lot of works still needed to adopt the existing processing routes to industrial viable production routes. Industries are based on cost effective processes for the production either it may be mass or low volume. So technologies which transfer the FGM from laboratory to industry are to be invited. Also reproducibility in geometry, gradation and property of a FGM is very much important this has to be attained.

References

1. Astrid Rota, Technology and controlled tailoring of FGM.
2. Patila, K.C., Aruna, S.T., Mimani, T., Combustion synthesis: an update, Current Opinion in Solid State and Materials Science 6 (2002) pp.507–512.
3. Mukasyan, A.S., and White, J. D. E., Combustion Joining of Refractory Materials, International Journal of Self-Propagating High-Temperature Synthesis, 2007, Vol. 16, No. 3, pp. 154–168.
4. Lei, C., Jiandong, H., Zuoxing, G., Qihong, L., Zhijiang, W., Ni-Al Functionally Graded Materials by Laser Self-Propagating High-Temperature Synthesis, Materials Transactions, Vol. 45, No. 9 (2004) pp. 2791 to 2793.
5. Fra, E., Olejnik, E., Janas, A., Kolbus, A., FGMs generated method SHSM, Archives of Foundry Engineering Volume 9, Issue 2/2009, pp.123-128.
6. Kaya, C., Al_2O_3–Y-TZP/Al_2O_3 functionally graded composites of tubular shape from nano-sols using double-step electrophoretic deposition, Journal of the European Ceramic Society 23 (2003) pp.1655–1660.
7. Askari, E., Mehrali, M., Metselaar, I.H.S.C., Kadri, N.A., Rahman, Md.M., Fabrication and mechanical properties of Al_2O_3/SiC/ZrO_2 functionally graded material by electrophoretic deposition, Journal of the mechanical behaviour of biomedical materials 12 (2012) pp.144-150.
8. Anne, G., Mijic, S.H., Richter, H., Van der Biest, O., Vleugels, J., Strength and residual stresses of functionally graded Al_2O_3/ZrO_2 discs prepared by electrophoretic deposition, Scripta Materialia 54 (2006) pp.2053–2056.
9. Put, S., Vleugels, J., Anne, G., Van der Biest, O., Functionally graded ceramic and ceramic-metal composites shaped by electrophoretic deposition, Colloids and Surfaces A: Physicochem. Eng. Aspects 222 (2003) pp.223-232.
10. Put, S. Vleugels, J., Van Der Biest, O., Gradient profile prediction in functionally graded materials processed by electrophoretic deposition, Acta Materialia 51 (2003) pp. 6303–6317.
11. Zhao, C., Vleugels, J., Vandeperre, L., Basu B., Van Der Biest, O., Graded Tribological Materials Formed by Electrophoresis, Materials Science Forum, Vol. 308-311 (1999) pp.95-100.

Cite this article as: Saiyathibrahim A, Subramanian R, Dhanapal P. "A Review on the Functionally Graded Materials Produced by Self Propagating High Temperature Synthesis (SHS) and Elctrophoretic Deposition". *International Conference on Systems, Science, Control, Communication, Engineering and Technology 2016*: 521-526. Print.