A Review For Functionally Gradient Materials Processes And Useful Application

Nabaa S. Radhi

[a] Lecturer of Materials College engineering, University of Babylon-Hilla-Iraq.

E-mail: dr.nabbaa@gmail.com

Abstract. In the science of materials, the term Functionally Graded Materials (FGMs) which could be recognized by the gradual changes in structure and composition leading to variation in the characterization of materials. (FGMs) is considered one of the recent development of composite materials to enhance the strengths and reduce the weaknesses of these materials. (FGMs) were used for the first ti
me in Japan in 1984 via an airplane project because these materials could be used and designed for many roles and applications. The reasons that make (FGMs) are multi-function materials due to the variation in the chemical composition, microstructure and design features depending on the requirements. In this review, the functionally graded materials are studied on many different sides such as the application (the field of implementation) of this new technology and the reason of each use. Moreover, discuss the manufacturing processes for functionally graded materials and discuss the reason of choosing each process. On the other hands, discuss the limitation of the using Functionally graded materials were taking in the consideration.
Keywords: Functionally gradient materials (FGMs), Applications, limitations.

مراجعة لعمليات تصنيع المواد المتدرجةوظيفياً وتطبيقاتها المفيدة

د نبأ ستار راضي

جامعة بابل، كلية هندسة المواد

E-mail: dr.nabbaa@gmail.com

الخلاصة:

المواد المتدرجة وظيفيا (FGM) هي أجيال جديدة من المواد المركبة حيث يتم تغيير خصائصها خطيا وفقا للتغير في التركيب مما يؤدي الى تغيير خواص المادة الناتجة. تعتبر المواد المتدرجة وظيفياً الجيل الجديد من المواد المركبة مع تطورات لزيادة المقاومة والتخلص من عيوب هذه المواد. استخدمت المواد المتدرجة لاول مرة في اليابان في عام 1984 في الطائرات وبما ان هذه المواد تمتلك خواص تصميم مميزة اهلها للقيام بادوار وتطبيقات كثيرة. هذه الاسباب جعلت المواد المتدرجة متعددت الوظائف عند تغيير التركيب الكيميائي ، او البنية المجهرية او التصميم اعتمادا على متطلبات الاستخدام، تطرق المقال الى طرق تصنيع هذه المواد واسباب الاستخدام . اضافة الى ذلك ناقش المقال عمليات تصنيع المواد المتدرجة واسباب اختيار كل طريقة. من جانب اخر ناقش المحددات من استخدام المواد المتدرجة.

الكلمات الاساسية:المواد المتدرجة وظيفياً، التطبيقات، المحددات.

1. Introduction

Day after day, the materials development are continuous to enrich the properties of materials, limited uses for pure metals and the properties of pure metals cannot controlling to achieve the required properties be suitable for the new technologies. The materials developed from iron to pure metals to composite materials which widely in use today. The materials development return to the Bronze Age until now and it will continuously develop in the future. On the other hands, alloys are considered stronger than pure metals and multipurpose due to the ability to produce

the required properties. Bronze is the first alloy consists of copper and tin which developed in Bronze age about 4000 BC. After that many researches try to mix different metallic and non-metallic material to develop their strength, physical and chemical properties and producing multiple function materials ,[1]**.**

Functionally graded materials are one of the revolutionary technology that happened in the 21st century; they consist of the two-component composite, which properties depend on the compositional gradient of one or both of the components. Whereas, the conventional composites have A homogeneous composition; hence, the composition has the desirable properties of their component materials. The need for compromising the properties is eliminated because the important properties of FGM contain the pure structure for each component. Additionally, the properties of FGM components can be fully utilized; for instance, the refractoriness of ceramic can be mated with the toughness of metal, without any requirement to compromise in toughness of the metal side or the refractoriness of the ceramic side, [2]**.**

The mechanical characteristics like elastic modulus, Poisson's ratio, elastic modulus for shear, the density of materials and thermal expansion coefficient are differing smoothly and continuously in preferable FGMs directions. Due to these various properties, the functionally graded materials used as a biomedical material and there are many examples of natural functionally graded materials such as bones, teeth, skin and bamboo tree. And the first idea to produce functionally graded material (FGM) was developed in Japan in 1984 by researchers to increase thermal barriers between inside and outside temperature by using just 10 mm thickness. And the result of this research was standing the space plane the thermal barrier with on outside temperature of 2000 K and inside temperature of 1000K, [3]**.**

After discovering the Functionally Graded Materials (FGMs) in early 1980s in Japan, many researchers try to study the properties of this new technology, where they found and increasing in the adhesion and decreasing the thermal stresses in the composite materials (metallic-ceramic) and that help to reuse the rocket motor, [3]**.** On the other hands, FGM terms open the way for new researches around the world to investigate the performance of the materials (metals, ceramics, and organic composites) to improve compositions with superior physical characteristic, [4]. Based on the area of applying and the load conditions in order to specify varying approaches that could be used to produce the structure gradients.

Composite materials allow distinct combinations giving hard, wear resistant surface and softcore as per functional requirement of the application. Heterogeneity, anisotropy, symmetry, and hierarchy are the main properties of composite materials reaping particular interest for various applications. High strength to stiffness rate, give higher resistance to fatigue, wear and corrosion, high reliability and other properties are the benefits of composites over pure or alloyed metals. Although all these benefits, composite materials are exposed to the sharp transition of properties at the interface which can result in component failure (by delamination) at risky working conditions, [5]**.**

This disadvantage of traditional composites reduced by improved composites forms known as functionally graded materials (FGMs). In these materials, the sharp interface is replaced by a gradient interface and that led to the smooth transition of characteristics from one material to the other. These advanced materials with engineered gradients of composition, structure and specific characteristics in the preferred direction are superior to a homogeneous material composed of similar constituents, [6]**.**

2. Manufacturing Process For Functionally Graded Materials (FGMs)

The functionally graded materials are usually thin as a surface coating, so the surface deposition processes are wide variety processes to select from them based on the service requirements.

2.1. Vapour Deposition Technique

Vapour deposition method has many different types such as Chemical, Physical Vapour Deposition (CVD, PVD) respectively and sputter deposit. These different techniques are using to precipitation functionally graded coatings on the surface. This coating characterized by a thin coating layer and provide an excellent microstructure to the coated surface. But these techniques are required intensive energy and generate poisonous gases as a side effect, [7].

As well as there are other methods that used to precipitation functionally graded coatings on the surface of materials such as Self-Propagating High-temperature Synthesis (SHS), electrophoretic, plasma spraying, electrodeposition, Ion Beam Assisted Deposition (IBAD) and many other methods [8]. All the previous methods cannot be used to achieve bulk FGM due to the speed of these process are slow and required intensive energy. Thus; these methods are not economic for producing bulk FGM.

2.2. Powder Metallurgy (PM)

The first production method that producing a bulk functionally graded materials is Powder metallurgy (PM) the technique of producing Powder metallurgy are generally consist of three steps as following: firstly the materials should be weighted to mix the powder depending on the previous spatial design to distribute as a dictate for the requirements of the purpose, loading the premixing-powder that ramming and then sintering the mixture to become powder, [9]. (PM) method increase a structure stepwise which desired in the continuous structure.

2.3. Centrifugal Method

The second production method that producing a bulk functionally graded materials is Centrifugal technique is same as centrifugal casting where both of them are using the force of gravity during the rotation of the mould to produce bulk functionally graded material. The main reason for using this method to produce the graded materials is a return to the difference between the densities of material and the mould rotation. There is another method which is the similar process as a centrifugal method, but is known as gravity method. In spite of the centrifugal method could achieve the grading of materials continuously, but it has some issues such as the shape that produces is just cylinder. And the second issues that related to this method, it is a limitation on the product gradient type due to the gradient is produced by a natural process (centrifugal force and density difference). And many researchers try to solve these problems by using another manufacturing process called solid freeform, [10].

2.4. Solid Freeform (SFF) Fabrication Method

Solid freeform is an alternative manufacturing method that has many benefits such as the high production speed, low intensive energy required, optimum utilization of materials, producing a complicated shape with design breeze where the designs drawing on CAD (AutoCAD program) and take it directly. SFF consists of five essential steps: Drawing the design on CAD (AutoCAD program), convert CAD data to Standard Triangulation Language (STL) file, then convert (STL) file into 2D profiles, the building of the component layer by layer, and lastly removal and finishing. Solid freeform fabrication has many different types of methods technologies, laser process are mainly used to produce the functionally graded materials. This technology is consists of the laser cladding based method, Selective Laser Sintering (SLS), 3-D Printing (3-DP), and Selective Laser Melting (SLM). Cladding Laser system and melting

Laser Selective have the ability to produce denser components. Solid freeform considered more flexible manufacturing process compared with other processes, but the surface finishing is poor, [11].

3. Applications of Functionally Gradient Materials

There are many applications for functionally graded materials (FGMs) and below some of them:

3.1. Aerospace

(FGMs) are used in aerospace industries due to the ability of these materials to stand the high thermal gradient, the withstanding for extremely high thermal gradient make these materials suitable structures airplane body the components of the rocket motor and many other applications in the space, [12].

3.2. Medical

The human body contains many tissues that characterize as a natural functionally graded material such as teeth and bones and during the accidents, the human tissues suffering from damages and in the most conditions these damages are impossible to treat it so it needs an alternative parts to replace it. According to, [6], [13]-[15]. Functionally graded materials could use in the medical field to replace the damaged tissues such as teeth and bones by biomedical materials.

3.3. Defense

From the properties of the functionally graded materials is well known these materials have an excellent ability to prevent cracks from spreading. These characteristics help to apply these materials in defense especially to protect soldiers from a gun by producing armour plates and bullet-proof vests, [16].

3.4. Energy

According to **[(Müller, et.al., 2003) and (Niino, et.al., 2005)]** the functionally graded materials (FGMs) are using to generate energy because it used to produce solar power, devices energy conversion as well as it used as a thermal protection to protect the coating of the blades of turbine in gas turbine motor,[17],[18].

3.5. Optoelectronics

Functionally graded materials could use also in Optoelectronics field like low threshold current edge lasers (GRINSCH), storage media particularly magnetic discs (audio-video) and tuneable photodetectors due to the graded refractive index for these materials, [19]**.**

3.6. Construction field

Construction industry faces many challenges that related to materials performance, cost of materials and their environmental impact. Also the change of the functionality of the building structures that vary depending on the building location open the way to using functionally graded materials (FGMs) in the construction field, [20]. When using (FGMs) the structure and the composition of materials will be changed gradually over the volume, and that led to the various material characteristic, [21].

3.7. Other applications

In addition to that, there are many fields could use (FGMs) as a foundation materials such as coating of cutting tools, [22]. components of engines automobile, components of nuclear reactors, blades of turbine, exchangers of heat, sensors of fire, Tribology (advance materials), doors retardant and many other application. The appearance of all these applications which are springing up because of the cost of production and the possibility of controlling and improving the properties of FMGs, [5].

4. The problems of (FGMs)

One of the revolutions that happened in the 21st century and will change the manufacturing world is the Functionally graded materials (FGMs) which is an advanced material used widely. In spite of the (FGMs) using and applications become so famous, but there are many limitations for achieving the objective of changing the manufacturing world. The limitations are varied

depending on the field of applying, but most of them concentrated on the cost such as the cost that expanded on the methods of processing and fabrication of powder. For Example, Solid Freeform Fabrication (SFF) is one of the techniques that used to produce (FGMs), but it still has many issues that required an efficient solution. Also many researches should be conducted to improve the performance of (SFF) in order to create database that controlling on the properties of Functionally graded materials (FGMs). And finally, (FGMs) process are still manual, so it needs many improvements to make it full automation so as to improve the overall performance of the process, reduce the cost of (FGMs) and improve the reliability of the fabrication process.

5. Conclusions

To sum up, Functionally graded materials (FGMs) are considered one of the most important materials that could apply in the engineering field and another field, but the cost of (FGMs) producing is so expensive for this reason it has limited uses. This piece of the paper presents an overview on (FGMs), different manufacturing methods and focusing on solid freeform method due to the advantages of this method over other processes and because of the manufacturing flexibility it offers. As well as, it gives an overview of various application fields also presented how the application field can enhance and also extended by reducing the manufacturing cost via improving the most promising fabrication method (SFF).

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