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A Systematic Review on the Functionally Graded Materials and Its Manufacturing

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Abstract – *Functionally Graded Material (FGM) are comes to a category of advanced material which have variation in properties according to the variations in the dimension. For this porous metals are used as functional materials, which are developed significantly modern years. Initially FGMs are designed for the thermal barrier materials for the applications in the aerospace structural and fusion reactors. This feature allows FGM to possess best material properties in required quantities only where it's needed. However, there are numerous approaches available for the manufacturing of FGMs like: additive based metal deposition technologies. In the present article effect of deviation of material properties through the thickness, load case, boundary conditions, side-to thickness ratio on the behaviour of FGM plates are presented and discussed.*

Key Words**:** *Pressure vessel, functionally graded material, ANSYS 18.1, finite element method.*

1. INTRODUCTION

An application may require a material that's hard also ductile, there's no such material existing in nature. To solve this problem, combination of 1 metal with other metals or non-metals is employed. This combination of materials within the molten state is termed alloying (recently mentioned as conventional alloying) that provides a property that's different from the parent materials. Functionally graded material, removes the pointed interfaces existing in composite material which is where failure is initiated [1]. For FGM cemented tungsten carbide (WC-Co) is most commonly used industrial tool material, due to its higher combination of high modulus, hardness, wear resistance, and moderate fracture toughness [1, 2,5].

But, the abrasion resistance and fracture toughness of WC-Co are inversely associated with one another. The mechanical properties of WC-Co are primarily bowed into Co content and WC grain size. [1, 2]. It replaces this sharp interface with a gradient interface which produces smooth transition from one material to the subsequent [6, 7]. One special features of FGM is that the ability to shape a material for specific application.

1.1 CLASSIFICATION

There are different sorts of fabricationprocesses for producing FGM. Functionally gradedmaterials are oftendividedinto two broad groups namely: (a) thin and (b) bulk FGM.

In thin FGM which are having thin sections contains thin surface coating, whereas for bulk FGM are volume of materials which require more labour intensive processes. Thin section coating FGM are formed by Physical and Chemical vapour deposition (CVD), by Plasma Spraying and by the Self-propagating High temperature Synthesis (SHS) etc. [11]. FGM who are Bulk are formed by means of powder metallurgy technique, by using centrifugal casting method, solid freeform technology etc. [10]. Two altered criteria's have been used in order to classify the functionally graded materials. One is on the basis of structure of the material and the other is based on size of functionally graded materials. functionally graded materials can be further divided into two major groups based on structure of materials (a) Continuously structured and (b) discontinuously structured FGM. For the continuous FGM, gradient are present in continuous from one material to the other material. Though, for the discontinuous FGM, material gradient is provided in layered fashion. Based on size of materials, FGM's are classified into two major types: Thin FGM and bulk FGM. FGM who are thin having comparatively thin sections like surface coating, while the bulk FGM's are complete volume of materials. Manufacturing processes like (i) physical Vapor Deposition (PVD), (ii) Chemical Vapor Deposition (CVD) and (iii) Self propagating High temperature Synthesis (SHS) method reused to manufacture thin FGM. Whereas, bulk FGM's are manufactured by the application of powder metallurgy, centrifugal casting method and solid freeform manufacturing techniques

2. HISTORICAL BACKGROUND

The primary thought of compositional and underlying angle in material microstructure was first proposed for composites and polymeric materials in1972.iBever in 1972 concentrated on different slope composites, examined in overall imaterial properties and concentrated on uses of the reviewed composites.

Shen in 1972 detailed that the degree of polymeric material could be actuated by the variety of the substance idea of the monomers, the atomic constitution of the polymers and in this way theisupra sub-atomic design or morphology of the

polymersi[9]. The genuine properties, as mechanical, compound and biomedical properties and having wide applications, including fuel tank and damping materials were thought of. Nonetheless, the planning, arranging, manufacture and assessment of this inclination structure was not analyzed.

Until 1985, the use of persevering surface control was acquainted with further foster the hold strength and breaking point the warm tension in the fired coatings and joints which created for a recyclable rocket engine (Nino et.al., 1986). Further wide thoughts are applied to report new properties and components of materials were organized by steady handling of the microstructure, also the planning of such materials introduced. The term of for all intents and purposes assessed materials was made for these slant composites and materials for more exact depiction and language in the year of1986.In 1987, the famous investigation plan of FGMs, focal examinations on the assistance of Thermal tension by Tailoring Graded Structures" was initiated inside the hotness check for a space plane in Japan. The capacities of driving forward through a surface temperature of 17000ºCiand a tendency ofi10000ºCacross simply a 10imm portion were refined by FGMs as a warm limit. Inferable from their indisputable assessed material properties, FGMs pulled in uncommon proportions of expert interest, FGMs are possibly comprehensively pertinent innumerous fields. In countto the recently referenced warm limits, coatings and associations into the flight, FGMs have moreover been created for other novel applications. In the field of biomaterials, biomedical implants like fake bones and dentalim plants are commendable models. Tampieri et al. ini2011 have made the porosity surveyed hydroxyapatite (HAP)ceramics, which is extraordinary and fastbone being developed anyway it moreover perseveres through early physiological strain as an implant to displace ordinary bone.

Various specialists upheld and uncovered that FGMs could give the install a suitable robustness to bear the physiological stacking and that the audited porosity development could deal with the mechanical property of the exchange to improve the materials response to outside stacking (ally and Bolton, 1997, Pompe et.al. 2003, Wang et.al. 2012).

3. PROCESSING TECHNIQUES OF FUNCTIONALLY GRADED MATERIALS (FGM)

Slight practically evaluated materials aretypically utilizes as surface coatings and there are a wide scope of surface depositionprocesses to pick fromdepending onthe administration prerequisite from the cycle.

3.1 Vapour Deposition Technique

There are various sorts of fume affidavit methods, they included: Sputter testimony, Chemical Vapor Deposition (CVD) and Physical Vapor Deposition(PVD). These fume affidavit techniques are utilized to store practically evaluated surface coatings and they give phenomenal microstructure, yet they must be utilized for keeping slender surface covering. They are energy serious and produce toxic gases as their results [13].

Different techniques usedin delivering practically evaluated covering include: plasma splashing, electrodeposition, electrophoretic, Ion Beam Assisted Deposition (IBAD), Self-Propagating High-temperature Synthesis (SHS), and so on [10].

3.2 Powder Metallurgy (PM)

Powder metallurgy (PM) strategy is utilized to deliver practically evaluated material[14, 15] through three essential advances specifically: gauging and blending of powder as per the pre-planned spatial dispersion as directed by the useful necessity, stacking and slamming of the premixed-powders, lastly sintering [16]. PM procedure gives rise toa stepwise construction. In the event that nonstop design is wanted, then, at that point, diffusive strategy is utilized.

3.3 Centrifugal Method

Divergent technique is like outward projecting where the power of gravity is utilized through turning of the shape to frame mass practically reviewed material[17]. The reviewed material is delivered in this manner in view of the distinction in material densities and the turning of the shape. There are other comparative cycles like outward technique in the writing (for example gravity technique, and so on) Althoughcontinuous evaluating can be accomplished utilizing radiating strategy however just round and hollow shapes can be framed. Extra missing of radial strategy is that here is breaking point to which kind of angle canbe produced[18] in light of the fact that the inclination is framed through regular interaction (diffusive power and thickness contrast). To tackle these issues, scientists are utilizing elective assembling technique known as strong freestyle.

3.4 SolidFreeform (SFF) Fabrication Method

Strong free structure (SFF) is an added substance manufacturingprocess that bargains many benefits that include: higher speedof creation, less energyintensive, greatest material usage, capacity to deliver complex shapes and plan opportunity as parts are delivered straightforwardly from CAD (for example AutoCAD) information [19]. SFF incorporates 5 essential advances [20]: age of CAD information from the product like AutoCAD, Solid edgeetc, conversionof the CAD information to STL document, cutting of the STLinto two dimensionalcross-segment profiles, working of the part layer by layer, and in conclusion evacuation and wrapping up.

3.5 Laser metal statement (LMD)

Laser designed net molding (LENS) and direct metal statement (DMD) are fundamental cycles dependent on DED innovation which utilizes laser pillar as power source and unrefined substance as powder. Focal point process was initially evolved by Sandia public research centers in 1997 and afterward authorized to Optomec (USA), while DMD process was together developedby POM gathering and University of Michigan [8, 9]. In these interaction, high power laser shaft is utilized to make a liquid pool on base material and afterward powder material is infused into the liquid pool by utilizing spouts. Conveyed powder at laser beamspot is assimilated into the liquefy pool and makes store. The worktable can move in x - y course to acquire wanted cross sectionof cut modeland then resulting layers can be saved by increasing testimony head in z bearing to finish the item. Affidavit of layers is rehashed until the ideal three layered parts has been additively framed. Metal powder is conveyed through spouts and disseminated around the boundary of statement head either by gravity, or by utilizing

inactive transporter gas. The whole cycle is directed under controlled argon air where oxygen levels are kept up with under 10 ppm. DED strategy of metal A M is the most appropriate innovation to deliver FGMs. A wide range of FGMs including nonstop/broken organized and slim/mass sort can be effectively made by utilizing LMD. Pre alloyed powders can be utilized to create irregular sort FGM. Though essential powders can be conveyed in exact sums to the dissolve zone utilizing separate feeders to produce different combinations and composite materials in consistently evaluated style.

3.6. Electron shaft direct assembling

Electron Beam Direct Deposition (EBDM) is one more innovation dependent on coordinated energy deposition which utilizes electron shaft as power source and natural substance as wire. This innovation was created by Sciaky (Chicago , USA) and furthermore known as Electron pillar added substance manufacturing (EBAM). This cycle can deliver medium to huge estimated close to net molded parts inside vacuum chamber straightforwardly from computerized model. In the wake of assembling, part requires completing tasks like hotness treatment and machining. Greatest size of part to be made by EBAM is confined by vacuums chamber size of the machine. Financially accessible welding wires are utilized as the statement material. The standard electron shaft framework is a Sciaky 60 kW/ 60kVwelder. The electron pillar is by electronic means, and the result power is adaptable over a verywide range. This empowers an extremely wide scope of testimony rates to be accomplished utilizing a similar framework. Normal statement paces of EBAM frameworks are from 3 to 9 Kgs/hrs dependingon the material utilized and part intricacy. Moreover, the EBAM framework has shut loopcontrol framework in which dissolve pool size is ceaselessly observed and boundaries are changed in accordance with keep the size steady. This guarantees steady part calculation, uniform microstructure, and mechanical assets.

3.7. FGMs by Arc affidavit advances

Wide scopes of bend based added substance producing processes are accessible where curve is utilized as power source and material is utilized as powder or wire. Plasma moved curve and plasma bend welding are free structure A M processes which utilizes plasma circular segment as power source and natural substance as powder and wire separately. Molded metal affidavit (SMD) is another A M technique which utilizes tungsten inactive gas (TIG) or Metal latent gas (MIG) welding with material as wires with the expectation of complimentary structure manufactures. Since the vast majority of such frameworks are wire feed type, these are otherwise called Wire helped added substance fabricating (WAAM) frameworks. Enormous number of framework arrangements can be accomplished by coordinating ordinary welding situation with robots, controllers or gantries for robotization. These cycles with legitimate inactive gas safeguarding can possibly deliver close netshaped medium to enormous measured parts at much lower cost when contrasted with laser and electron shaft based cycles. Hardly any welding based A M frameworks has been created which can store practically slope materials. For this situation, two filler wires are controlled independently and provided to the curve (TIG or MIG) for testimony. A few investigations have been completed to show adequacy of curve based AM setups to deliver FGMs. Sajan Kapilet. al[13] effectively manufactured Al-Si compound having angle in warm conductivity. It was created by utilizing Hybrid layered assembling machine (HLM) which joins 3 hub CNC and gas metalarc welding (GMAW) testimony framework. S. Surya kumar et al. [14] exhibited two unique ways of manufacturing practically angle materials by utilizing weld affidavit. FGMs can be delivered by fluctuating interaction boundaries or byusing twofold wire feder which canbe directed and controlled independently.

4. APPLICATION AREA

FGMs have wide range of applications where the operating conditions are, including spacecraft heat shields, heat exchanger tubes, biomedical implants, flywheels, and plasma facings for fusion reactors, etc. Various combinations of the ordinarily incompatible functions can be implemented to create new materials for aerospace, chemical plants, nuclear energy reactors, etc. For example, a discrete layer of ceramic material is bonded to a metallic structure in a conventional thermal barrier coating for high temperature applications.

5. RECENT DEVELOPMENTS AND CHALLENGES OF FGMS

For most FGMs, the material properties change along the thickness direction [32]. However, in modern applications FG materials with materiial properties in thickness and axial direction may be required [33]. Recently, a gradient material with different properties in two directions has also been developed and extensively studied [34, 35]. This smart material is called a bidirectional functionally graded (BDFGM) material. AM technology based on laser metal deposition is most suitable for producing such BDFGM [11].

6. CONCLUSIONS

1. Though substantial technology advancement has been made in the field of FGMs, few critical issues still need to bead dressed. A proper data base of FGMs in terms of parameters and testing is still not available.
2. Conventional testing and measurement method may not suitable to evaluate performance of modern FGMs, so developments of advanced testing methods are required [36].
3. Most of the processing techniques of FGMs are very costly, so low cost processing technique which can mass produce large sized, complex shape FGMs is still remain as a challenge.
4. The selection of proper material suitable for intended application is the immediate and direct challenge for future technology development in FGM research field.

REFERENCES

[1] Alloy, available at Wikipedia on http://en.wikipedia.org/wiki/Alloy, Accessed on 1st February 2012.

[2] S. S. Wang "Fracture mechanics for delamination problems in composite materials," Journal of Composite Materials, (1983), vol. 17(3), pp. 210- 223.

[3] M. Niino, T. Hirai and R. Watanabe, "The functionally gradient materials," J Jap Soc Compos Mat, vol.13, pp. 257-264.

[4] Report on "Fundamental study on relaxation of thermal stress for hightemperaturematerialby tailoring thegraded structure", Department of Science and TechnologyAgency, (1992).

[5] S. S. Wang "Fracturemechanics for delaminationproblems in compositematerials," Journalof Composite Materials, (1983), vol. 17(3), pp. 210-223.

[6] M. Niino, T. Hirai and R. Watanabe, "The functionally gradient materials," J Jap Soc Compos Mat, vol.13, pp. 257-264.

[7] Report on "Fundamental study on relaxation of thermal stress for hightemperaturematerialby tailoring thegraded structure", Department of Science and TechnologyAgency, (1992).

[8] P. Shanmugavel, G. B. Bhaskar, M. Chandrasekaran, P. S. Mani and S. P. Srinivasan, "An overview of fracture analysis in functionally gradedmaterials,"European Journal of Scientific Research, vol.68 No.3 (2012), pp. 412-439.

[9] Turkish Republic the Ministry of Public Works and Settlement, Turkish Earthquake Design Code TEC-2007, Ankara, Turkey, 2007.

[10] R. Knoppers, J. W. Gunnink, J. Van den Hout, and W. Van Vliet, "The reality of functionally graded material products," TNO Science and Industry, The Netherlands, pp 38-43.

[11] M. Ivosevic R. Knight, S. R. Kalidindi, G. R. Palmese and J. K. Sutter, "Solid particle erosionresistance of therma ly sprayedfunctionally graded coatings for polymer matrix composites," Surface Coat Tech, 2005.

[12] Kapil S, Kulkarni P, Karunakaran K, Joshi P 2014 Developmentand Characterizationof Functionally Graded Materials Using Hybrid Layered Manufacturing 5th International& 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014).

[13] Suryakumar S, Somashekara M 2013 Manufacture of functionally gradient materials usingweld-depositionSolid Free. Fabr. Symp. (2013) 1-36.

[14] M. M. Nemat-Alla1, M. H. Ata, M. R. Bayoumi, and W. Khair-Eldeen, "Powder metallurgical fabrication and microstructural investigations of Aluminium/Steel functionally graded material," Materials Sciences and Applications, vol. 2, (2011), pp. 1708-1718.

[15] F. Watari, A. Yokoyama, H. Matsuno, R. Miyao, M. Uo, T. Kawasaki, M. Omori, and T. Hirai, "Fabrication of functionally graded implant and its biocompatibility," functionally graded materials in the 21st century: a workshop on trends and forecasts. Boston, Kluwer Academic, (2001), pp. 187–190.

[16] J. Zhu, Z. Lai, Z. Yin, J. Jeon, and S. Lee, "Fabrication of ZrO2–NiCr functionally graded material by powder metallurgy," Materials Chem,

[17] Y. Watanabe, Y. Inaguma, H. Sato, and E. A. Miura-Fujiwara, "Novel fabrication method for functionally graded materials under centrifugal force: the centrifugal mixed-Powder method," Materials, Vol. 2, No. 4, (December, 2009), pp.2510-2525.

[18] B. Kieback, A. Neubrand, and H. Riedel "Processing techniques for functionally graded materials," Materials Science and Engineering, (2003), pp. 81–105.

[19] X. Lin and T. M. Yue "Phaseformationand microstructure evolution in laser rapid forming of graded SS316L/Rene88DT alloy," Mater Sci Engng, vol. A402, (2005), pp.294-306.

[20] M. A. Boboulos, CAD-CAM & Rapid Prototyping Application Evaluation, PhD & Ventus publishing Aps, accessed online on 1st March 2012, available at www.bookBoom.com.

[21] Liu, L. S., Zhang, Q.-J., and Zhai, P.-C., 2003, "The Optimization Design on Metal/Ceramic, FGM Armor With Neural Net and Conjugate Gradient Method," Functiona ly Graded Materials, VII Proceedings of the Seventh International Symposiumon Functionally GradedMaterials _FGM2000_, Materials Science Forum Vols. 423–425.

[22] Pan W, Gong J, Zhang L, and Chen L, eds., Trans Tech Publications Ltd., Uetikon-Zuerich, Switzerland, pp. 791–802.

[23] Chin ESC 1999 Army focused research team on functionally graded armor composites Mater Sci. Engg. A259: 155-161.

[24] Lee W, Stinton D 1996 Concept of Functionally Graded Materials for Advanced Thermal Barrier Coating Applications Journal of the American Ceramic Society, 79,12 (3003), 12.

[25] Das D, Saini A, Pathak M, Kumar S 2012 Application of functionally graded materials as thermalinsulator in high temperature engineeringcomponents IJREAS Volume 2, Issue 2

[26] Quin, X., and Dutta, D. 2004 Feature-Based Design for Heterogeneous Objects Comput.-Aided Des. 36, pp. 1263–1278.

[27] Birman V, Byrd L Modelingand Analysis of Functionaly Graded Materials and Structures".

[28] Zlatanović M 2003 Combined plasma surface treatmentsfor wear and corrosionprotection 8th International Tribology Conference, 8. - 10. Oktober 2003. Belgrade, Serbia 25.

[29] Epler L 2012 New DuplexSurface Treatment Dramaticaly Improves Die Life, Part Quality & Cost Saving Die Cast Engineer Magazine, September 2012.

[30] Li F, Takagi K, Ono M, Pan W, Watanabe R, Almajid A, and Taya M 2003 Fabrication and Evaluation of Porous Piezoelectric Ceramics and Porosity Graded Piezoelectric Actuators J. Am. Ceram. Soc., 86, pp. 1094– 1098.

[31] Takeuch K, Kawazoe M, and Kanayama K. 2003 Design of Functionally Graded Wood-Based Board for Floor Heating System With Higher Energy Efficiency Functionally

Graded Materials VII Proceedings of the Seventh International Symposiumon Functionally GradedMaterials (FGM2000), Materials Science Forum Vols. 423–425.

[32] Hao D, Wei C 2016 Dynamic characteristics analysis of bi-directional functionally graded Timoshenko beams Composite structures (Sciencedirect), 141, (2016), 253-263.

[33] Simsek M 2015 Bi-directionalfunctionally gradedmaterials (BDFGMs) for free and forced vibration of Timoshenko beams with various boundary conditions Composite structures (Sciencedirect), 133, (2015),968-978.

[34] Qian LF, Batra RC 2005 Design of bidirectional functionally gradedplatefor optimalnaturalfrequencies. J Sound Vib 2005; 280:415–24.

[35] Enab T Performance improvement of total knee replacement jointthrough bidirectionalfunctionally graded material International Journal of Mechanical & Mechatronics Engineering IJMME-IJENS Vol:14No:02.

[36] Udupa G, Rao S, Gangadharan K 2014 Functionally graded composite materials: An overview", International conference on advances in manufacturing and material engineering, AMME 2014.