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Development, Testing and Characterization of Multi-Layer Functionally Graded Nano Material (FGNM) Laminates

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Abstract
This investigation intends for the structural utility based development of a multi-layered sandwich structure of Functionally Graded Nano Materials (FGNM) by Compressive Moulding technique. Design and development of laminate includes standard sonification, moulding layer by layer and with conventional method of curing with a little improvement based on laminate requirement. The material and mechanical properties investigations for the observation of different characteristics by conducting various tests and the analysis after characterisation of each layer with microstructural study of interface by scanning electron microscope (SEM) have been performed.

Keywords: Functionally Graded Multi-Layered Laminate; FGNM; Nano alumina; Compressive Moulding Technique.

1. Introduction

Evolution of human style of living gradually joins science & technological applications. Nature also has gifted some topics of engineering interest. A multi layered pattern is found in honeycomb, wood and bamboo structure which sustain impact loading as well as impart strength. This formation of functional layering has invoked human thinking to work on such a structural material which could be strong as well as has variable properties in gradient. The Functionally graded material belongs to the class of advance composite materials, in which two or more materials are combined in continuously graded form layer by layer with different composition of material which is pre defined or selected for the application. For example, a material required with high thermal resistance capacity at one side and high strength and toughness at another side. This combination in a single material does not exist in nature which has both the required properties in a single material. A material with good thermal resistance having brittleness can face the temperature resistance but, it cannot face the high mechanical loading as ceramics. On the other side, the material with good toughness, strength and ductility, can face the mechanical loading very gently but, in case of temperature it is not acceptable as metals. In this condition the requirement is of such type of composite material which have metal at one side and ceramics on the other side for fulfilling the strength as well as toughness requirement. So, in this case a material is to be developed which transform from ceramic at one side and metal on the other side, in continuously graded form and hence known as functionally graded material. The main purpose of grading in functionally graded materials is to avoid the stress concentration factor [1]. In the recent years, study and development of functionally graded materials is the prime attraction of researcher's because of the composition and structure, both changes gradually over the volume, ensue from corresponding changes in the properties of materials as per the purpose or application of the material where it is going to be used [2].

A sandwich structure consists of two narrow, rigid, and strong face sheets connected by a thick, light and low-modulus core applying adhesive joints to achieve a competent lightweight structure. In most of the cases the faces carry the loading, on and the other in-plane and
bending [3]. A sandwich structure progress in the same path as an I-beam with comparison that the core of a sandwich structure is of another material and is spread out as an unbroken medium for the face sheets. The main impact of a sandwich structure is its particularly steep flexural stiffness to weight ratio compared with other architectures. As a repercussion, sandwich construction results in curtailed lateral deformations, higher buckling resistance and higher natural frequencies than other structures. In fact, for a given requirement of mechanical and environmental loads, sandwich/laminate construction usually results in a lower structural weight than do other composition. Sandwich structures have few drawbacks as manufacturing methods, quality control and joining difficulties [4].

Although, the concept of FGMs, and our ability to fabricate them, appears to be an advanced engineering invention, however the concept is not new. These sorts of materials have been occurring in nature as bones have functional grading; even our skin is also graded to provide certain toughness, tactile and elastic qualities as a function of skin depth and location on the body. The concept of FGM is basically bio-inspired and some naturally occurring FGMs and some human engineered ones are illustrated in Figure 1 and 2 respectively.

Figure -1: Functional Grading in Honeycomb structure
(a) Original, (b) Wooden

The FGM concept originated in Japan in 1984 during the space plane project, in the form of a proposed thermal barrier material capable of withstanding a surface temperature of 2000 K and a temperature gradient of 1000 K across a cross section <10 mm. Since 1984, FGM thin films have been comprehensively researched, and are almost a commercial reality and the term of functionally graded materials (FGMs), were coined for these gradient composites and materials for more accurate description and properties in 1986 [5]. Later on much research has been done on this novel material.

Figure -2: Functional Grading in Laminate/sandwich form [6]

2. Methodology

The selection of material possessing definite mechanical properties [7] hence overcoming this challenge plays an important role for the development of functionally graded material. Basically it depends on the properties required and the environment where this material is going to be used.

In current investigations, we have taken materials ‘A & ‘B’ as following:
‘A’ has been taken as Pure Aluminium in Nano powder form.
‘B’ has been taken as Alumina (Al\textsubscript{2}O\textsubscript{3}).

There exist several processing techniques for fabrication of this material [8] but the existing scenario and workability on Nano powered Al and Al\textsubscript{2}O\textsubscript{3} provoked us to use compression moulding route which is shown in figure 3 in the form of photographs of Multilayered-Sandwich/Laminate, which are developed at CSIR-AMPRI, Bhopal. The aluminum nano powder and aluminum oxide were taken in different weight % composition in different layers and mixed with epoxy and hardener, also by weight %.

3. Results and Discussions:

3.1 Tensile Tests

These multilayered- laminate materials were tested for tensile strength in terms of ultimate tensile strength (MPa) and percentage elongation. The tests on 3 layer and 5 layer sandwich structures have been performed and the results obtained are as follows:

(A) 3 Layered Sandwich-
(i) For Sample-1(Thickness=2.2 mm)  
Ultimate Tensile Strength=20 MPa  
Elongation up to Proportional Limit= 0.35 mm (3.5%)
(ii) For Sample-2 (Thickness=1.9 mm)  
Ultimate Tensile Strength=19MPa
Elongation up to Proportional Limit= 0.53 mm (5.3%)

(B) 5 Layered Sandwich
(i) For Sample-1 (Thickness=5mm)
Ultimate Tensile Strength=35MPa
Elongation up to Proportional Limit=0.26mm (2.6%)
(ii) For Sample-2 (Thickness=5mm)
Ultimate Tensile Strength=25MPa
Elongation up to Proportional Limit=0.19 mm (1.9%)

Table 1. Tensile Test Data arranged for samples of 3 layered laminate are as under.

| Property                     | Sample 1 | Sample 2 |
|------------------------------|----------|----------|
| Ultimate Tensile Strength (MPa) | 20       | 19       |
| Elongation up to Proportional Limit in mm (%) | 0.35 (3.5%) | 0.53 (5.3%) |

Table 2. Tensile Test Data arranged for samples of 5 layered laminate are as under.

| Property                     | Sample 1 | Sample 2 |
|------------------------------|----------|----------|
| Ultimate Tensile Strength (MPa) | 35       | 25       |
| Elongation up to Proportional Limit in mm (%) | 0.26 (2.6%) | 0.19 (1.9%) |

3.2 Hardness Test

Hardness tests have been conducted by Brinell hardness testing machine. The results of the hardness test show that the hardness (BHN) increases as the number of layers are increased.

![Photographs (a) & (b) in two positions showing Brinell Hardness Impression of FGNM laminate Test Sample]

Table 3: The readings of the Brinell Hardness Number (BHN) arranged for samples of 3 and 5 layered sandwich structures

| S. No. | Sample of 3 layer sandwich structure (BHN) | Sample of 5 layer sandwich structure (BHN) |
|--------|-------------------------------------------|-------------------------------------------|
| 1.     | 77.4                                      | 76.3                                      |
| 2.     | 66.4                                      | 69.4                                      |
| 3.     | 74.4                                      | 75.2                                      |
| 4.     | 78.4                                      | 79.4                                      |
| Average Hardness (BHN) | 74.15 | 75.08 |

3.3 Compressive Strength Test

The laminate kept under compression setup has given following values.

Table 4. Compressive test data arranged for samples of 5 layered laminate are as under.

| Property                     | Sample 1 | Sample 2 |
|------------------------------|----------|----------|
| Ultimate Compressive Strength c (MPa) | 54.88    | 55.27    |
| Elongation up to Proportional Limit in mm/ mm | 0.06     | 0.06     |

3.4 Micro structural Analysis

One layer of test sample is made of aluminium (100 wt. %) and other layer of Alumina (Al2O3) having 100 wt. %, and the SEM image of the same is shown in figure 4 (a) and (b). It represents the fine surface of pure aluminium and Alumina and the surface characteristics obtained at 100× magnification and 100µm micron marker by SEM. The micrographs show smooth surface of aluminium and also have very smooth surface of Al2O3 with some parabolic grooves distributed along the surface.
4. Conclusions:

In the present work the multilayer functionally graded sandwich structures were successfully fabricated using Compression Moulding Route, which utilises a process consisting of moulds (punch & die cavity). The material in powder form was laid in to the die cavity simply without any other process except curing under a hydraulic press. This process has a very high yield as there is almost no material wastage in mixing (exact weight % were measured) or no need of post processing like machining. The results of the tensile test, hardness test and SEM analysis are depicted in tests data, and the conclusions drawn from these test data are summarized below:

- The present investigation implies that the Compression Moulding route without thermal application is successful in development of FGNM laminates as in this system the distinctive line between two laminate (layers) is seen in microstructural analysis but there is no sign of any hair crack along joint also while conducting tensile & compression test the breaking line is not the joining line of layer/laminates.

- The ultimate tensile strength of 5 layered composite is more as compared to 3 layered sandwich and elongation was almost half, which matches with the theoretical data available and a data set of special properties such as Ultimate Tensile Strength v/s strain were found, hence the development of FGNM sandwich is successful.

- The compressive Strength value found in this investigation is very encouraging as this laminate is fabricated without application of heat or any rigorous instrumentation.

- Further, several different materials like Magnesium and Bronze may be tried to test improvements in strength and other mechanical properties.

- The developed FGNM sandwich have high potential for several industrial applications e.g. rotating components made by centrifugal moulding etc.

References

[1]. Roylance, D., Mechanics of Materials, 2nd Edition, Wiley & Sons, Newyork, 1996.

[2]. Rajeev Dwivedi and Radovan Kovacevic, “An expert system for generation of machine inputs for laser-based multi-directional metal deposition”, International Journal of Machine Tools and Manufacture 2006, Vol. 46, Issue: 14, pp. 1811-1822.

[3]. Apetre, N.A., Sankar, B.V. and Ambur, D.R., “Low velocity impact of Sandwich beams with functionally graded core”, International Journal of Solids and Structures, 2006, Vol. 43 pp. 2479-2496.

[4]. Victor Birman, Larry W. Byrd, “Modeling and Analysis of Functionally Graded Materials and
Structures”, Applied Mechanics Reviews- ASME-September 2007, Vol. 60, pp. 195-216.

[5]. Mortensen, A. and Suresh, S., “Fundamentals of Functionally Graded Materials”, 10M Communications Ltd., 1998, London.

[6]. Antje Schunck, Andreas Kronz, Cornelius Fischer and Gottfried Hans Buchhorn, “Release of zirconia nanoparticles at the metal stem–bone cement interface in implant loosening of total hip replacement”, Acta Biomaterialia, Vol. 31, February 2016, pp. 412-424.

[7]. Shaista Ayesha COM, Binoy Varghese, Anjali Baby, “A review on functionally graded materials”, International Journal of Engineering & Science (IJES), 2014, Vol.3, Issue 6, pp. 90-101.

[8]. Reddy, J. N., “Analysis of Functionally Graded Plates”, International Journal for Numerical Methods in Engineering, 2000, Vol. 47, pp. 663-684.