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Faculty of Science and Technology
Laboratory of Structures, Properties and Interatomic Interactions LASPI2A

Organize:

The First International Conference on Materials Sciences and Applications (Hybrid) ICMSA2023

February 7th-9th, 2023, Khenchela, Algeria

Deadlines

Interested authors should note the following deadline :

- **Submission beginning** November. 25, 2022
- **Submission Deadline** January. 15, 2023
- **Notification of Acceptance** January. 25, 2023
- **Conference Date** February. 07-09, 2023

Call for Paper

The first edition of (ICMSA2023) provides an update on the latest advances in technology and applications of synthesized nanostructures and nanomaterials. Includes challenges encountered and solutions adopted in the fields of materials sciences and applications.

The first International Conference on Materials Sciences and Applications (Hybrid) (ICMSA2023)" aims to bring together leading academic scientists, researchers, and research scholars to exchange and share their experiences and research results on all aspects of Materials Synthesis, Characterization, Protection, and Applications. It also provides a premier interdisciplinary platform for researchers, practitioners, and educators to present and discuss the most recent innovations, trends, and concerns as well as practical challenges encountered and solutions adopted in the fields of Materials.

TOPICS

1. Thin Films.
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5. Polymer and Composite Materials
6. Ceramics
7. Functional Materials
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Publication

Paper submitted to ICMSA2023 must be original and not simultaneously submitted to another journal or conference, will be reviewed by technical committees of the conference. Selected papers will be published in the following indexed journal

1. Materials Science Forum.Scientific. Net. ISSN: 1662-9752
2. Journal of Algerian Journal of Environmental Science and Technology, p-ISSN: 2437-1114, Journal Home page: https://www.aljest.org .
3. Fundamental and Applied Sciences J Fundam Appl Sci (ISSN 1112-9867) https://www.univ-eloued.dz/en/index.php/en/.
4. Algerian Journal of Renewable Energy and Sustainable Development AJRESD (ISSN: 2710-849X). https://ajresd.univ-adrar.dz/index.php.
5. Other indexed Journals.

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01	Numerical modeling of a composite functionally graded material beam using the finite element method	Khenchela, ALGERIA 1 St International Conférence on Materials Sciences and Applications (ICMSA2023)	08-09	02	2023	/	/	/	/	**Web site :** https://www.univ-khenchela.dz/events/the-first-international-conference-on-materials-sciences-and-applications-hybrid-icmsa2023/ Université de Khenchelaجامعة عباس **Email:** ICMSA_23@univ-khenchela.dz

☞ **Page officielle de l'événement sur le site de l'Université Abbes Laghrour de Khenchela**

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📌 **Informations visibles sur cette page :**

- Titre de l'événement : **The first international conference on materials sciences and applications (hybrid) ICMSA2023**. Université de Khenchela
- Dates : **8 – 9 février 2023** – l'événement est **terminé**. Université de Khenchela
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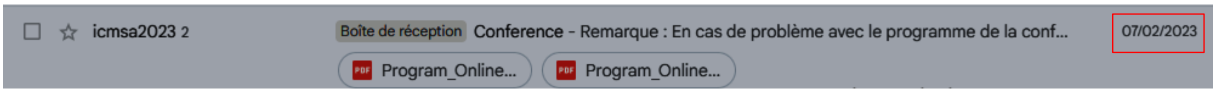
☞ **Programme de la conférence ICMSA23 (communications orales en ligne), reçu par courrier électronique en date du 07 février 2023.**



✅ **Participation à la conférence ICMSA2023 (voir fichier ci-dessous programme page 09)**

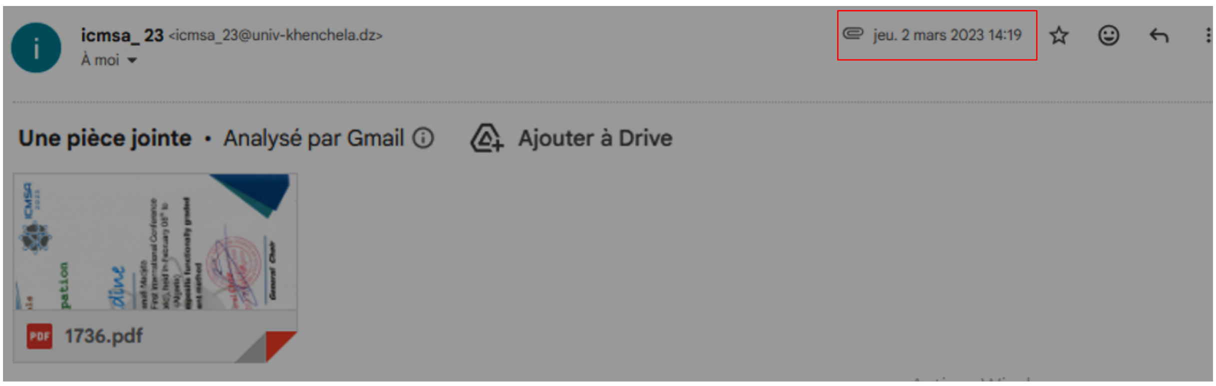
J'ai participé à la conférence internationale ICMSA2023 par une **communication orale en ligne**, programmée dans la **ROOM 2**, le **08 février 2023**, de **15h15 à 15h30** (First Day).

Titre de la communication: *Numerical modeling of a composite functionally graded material beam using the finite element method*.

Lien de la session : https://meet.google.com/iqq-gmzv-xcw

Auteur / Intervenant : ASSAS TAQIYEDDINE.

☞ **L'attestation de participation a été envoyée par e-mail le jeudi 02 mars 2023.**



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1st International Conference on Materials Sciences and Applications

(ICMSA2023)

Conference Program

ICMSA23

Online Oral

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1st International Conference on Materials Sciences and Applications (Hybrid)

(ICMSA' 2023)

08th and 09th February 2023, Khenchela

Online Oral - Online Poster

First Day 08th February 2023	
09 :30 – 10 :30	**Online Plenary Conference - Auditorium** **Pr. Belgacem HABA** **Title: The evolution of the semiconductor chip manufacturing and the new paradigm shift** **Plenary Chairs:** **Pr. Djelloul Abdelkader. U. Khenchelan, Algeria.** **Pr. Boumaaza Abdecharif. U. Khenchela, Algeria.** **Pr. Messai Amel. U. Khenchela, Algeria.** **Auditorium : https://meet.google.com/hpq-nfhv-epi**
10 :00 – 13 :45	**Online Oral 1** ROOM 1 : https://meet.google.com/ige-cbyb-yjj ROOM 2 : https://meet.google.com/iqq-gmzv-xcw **Online Poster 1** ROOM 3 https://meet.google.com/amb-yqvo-fps ROOM 4 : https://meet.google.com/edq-dcaq-yih ROOM 5 : **https://meet.google.com/shk-cmtn-yxf**
13 :45-15 :00	**Lunch**
15 :00 – 18 :00	**Online Oral 2** ROOM 1 : https://meet.google.com/ige-cbyb-yjj ROOM 2 : https://meet.google.com/iqq-gmzv-xcw **Online Poster 2** ROOM 3 https://meet.google.com/amb-yqvo-fps ROOM 4 : https://meet.google.com/edq-dcaq-yih ROOM 5 : **https://meet.google.com/shk-cmtn-yxf**
18:00	**Closing Room : 1, 2, 3 ,4 and 5**

1st International Conference on Materials Sciences and Applications (Hybrid)

(ICMSA' 2023)

08th and 09th February 2023, Khenchela

Second Day 09th February 2023	
08 :30 – 13 :00	**Online Oral 3** ROOM 1 : https://meet.google.com/ige-cbyb-yjj ROOM 2 : https://meet.google.com/iqq-gmzv-xcw **Online Poster 3** ROOM 3 https://meet.google.com/amb-yqvo-fps ROOM 4 : https://meet.google.com/edq-dcaq-yih ROOM 5 : **https://meet.google.com/shk-cmtn-yxf**
13 :00-14 :00	**Lunch**
14 :30 – 18 :00	**Online Oral 4** ROOM 1 : https://meet.google.com/ige-cbyb-yjj ROOM 2 : https://meet.google.com/iqq-gmzv-xcw **Online Poster 4** ROOM 3 https://meet.google.com/amb-yqvo-fps ROOM 4 : https://meet.google.com/edq-dcaq-yih ROOM 5 : **https://meet.google.com/shk-cmtn-yxf**
18:00	**Closing Room : 1, 2, 3 ,4 and 5** **Closing ICMSA' 2023**

1st International Conference on Materials Sciences and Applications (Hybrid)

(ICMSA' 2023)

ROOM 1 Online Oral

First Day 08th February 2023 https://meet.google.com/ige-cbyb-yjj	
10 :00 – 10 :15	**Anfal Djouadi** Biomedical application of Zinc oxide nanoparticle mediated by Algerian spinach (Spinacia oleracea) extract: In vitro study of biological capacities
10 :15 – 10 :30	**Rawiya Dridi** Synthesis, structural study and hirshfeld surface of a coordination polymer based on glutaric acid and strontium metal
10 :30 – 10 :45	**Brahim REMILA** Valorization of vegetable plants as a filler for poly(3-hydroxybutyrate-co-3-hydroxyvalerate) based biocomposites: Effect of alkaline and silane treatments
10 :45 – 11 :00	**BENTAHAR Mohammed** Application of the SFEM method for the analysis of a crack in a UHMWPE material in 2D
11 :00 – 11 :15	**Houssam Eddine BENOUIA** Etude expérimentale d'un nouveau matériau composite pour la construction de bâtiments
11 :15 – 11 :30	**Mohamed El Amine KHIARI** Application of Hashin damage criterion in the Analysis of composite reduction pipe
11 :30 – 11 :45	**Yahia Bekkar** In Silico Evaluation of Antidiabetic Activity and ADMET Prediction of ferrocene derivatives
11 :45 – 12 :00	**Mohamed M'hamed Ezzine** Rotational-vibrational energies of some diatomic molecules for the deformed hyperbolic barrier potential (DHBP) using the Feynman path integrals formalism
12 :00 – 12 :15	**Chennai Yassmine** In silico Investigation of several series of heterocyclic molecules for drug discovery
12 :15 – 12 :30	**Abir Berkouk** Strength at break and Elongation at break Study of Composites of Unsaturated Polyesters (UP) - Date Palm Leaf Fiber (DPLF)
12 :30 – 12 :45	**Abir Berkouk** Thermal and Mechanical Properties of Date Palm Leaf Fiber Reinforced Polyvinyl Chloride Composites
12 :45 – 13:00	**Adel Boulebnane** Ténacité en choc de matériau composite fibre de palmier dattier/époxy
13 :00 – 13 :15	**Ahlem Hattali** New mathematic models for intraparticle diffusion in alginate composite beads
13 :15 – 13 :30	**Hana Boucheta** Adsorption of methylene blue dye from aqueous solution using activated chitosan
13 :30 – 13 :45	**Berber Messaoud** Effet of Cr2AlC MAX particles on mechanical and tribological properties of epoxy resin
13 :45 -15 :00	**Lunch**
15 :00 -15 :15	**Hadjou Bélaid Zakia** Characterization of Polysulfone and Polyethylene glycol Membranes
15 :15 -15 :30	**TAIBI Hadi** Effet de la configuration géométrique de la fibre sur les propriétés effectives d'un composite unidirectionnel

15 :00 -15 :15	**Ounis Amina** the mechanism of transformation of a material based on Aurivillius
15 :15 -15 :30	**ASSAS TAQIYEDDINE** Numerical modeling of a composite functionally graded material beam using the finite element method
15 :30 -15 :45	**Rahma benyahia** Monitoring of the abatement of organic matter and suspended matter in aqueous solutions polluted by violet methyl and treated by an innovative oxidation process «the Galvano-Fenton process»
15 :45 -16 :00	**Sayah Rezgui** Optical properties and Judd Ofelt analysis of europium doped lead sodium antimonate glasses
16 :00 -16 :15	**MARMI Saida** Microstructure and Corrosion Behavior of Electrodeposited Ni-Cr-ZrO2 Coatings
16 :15 -16 :30	**MARMI Hayat** Wear and hardness evaluation of electrodeposited Ni-ZrO2 nanocomposite coated copper
16 :30 -16 :45	**Djedjiga BOUKHLEF** Corrosion Protection of a Pivot installed at URERMS, Adrar
16 :45 -17 :00	**Mesbah Abdelhak** Développement d'un Nouvel Elément Finis pour Analyse le Comportement de Vibration Libre et de Flambage des Poutres FGM
17 :00 -17 :15	**Dadda Karima** (Co2Mn)100-xNix powders tested in heterogeneous Fenton-like process
17 :15 -17 :30	**Salah Eddine DAHO** First-Principles Calculations on Structural and Electronic Properties of SrTe compound using FP-LMTO method
17 :30 -17 :45	**HARA Hamza** Structural characterization of Alumina Synthesized by sol gel methods.
17 :45 -18 :00	**Hesna SAIDIA** Hybridizing Nanomaterials–Synthesis and Practical Application for the Heterogeneous Photo-Fenton Degradation of dye in water
18 :00	**Closing Room 2**

First International Conference on Materials Science and Applications

ICMSA 2023

Certificate of Participation

This Certification of participation is presented to

Assas Taqiyeddine

Co-authors: Bourezane Messaoud, Chenafi Madjda

Was presented as an **Online oral presentation** at the First International Conference on Materials Science and Applications ICMSA'23 (Hybrid), held in February 08th to 09th, 2023 at Khenchela University (Algeria)

Title of the presentation: **Numerical modelling of a composite functionally graded material beam using the finite element method**

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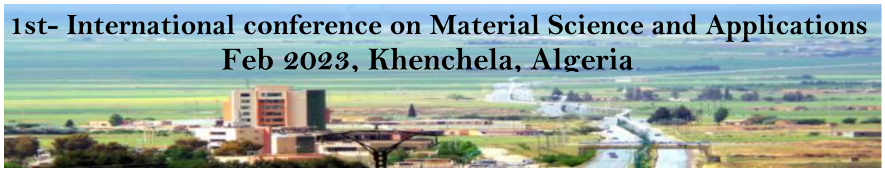

Numerical modelling of a composite functionally graded material beam using the finite element method

Assas Taqiyeddine [a,*], Bourezane Messaoud [b], Chenafi Madjda [c]

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ABSTRACT

The functional gradient or functionally graded material (FGM) is a new variety of composite materials having a gradual and continuous variation of the volume fractions of each constituent (in general, metal and ceramic) across the thickness, inducing changes as a result of the global thermo-mechanical properties of the structural element it constitutes. The change in the properties of the materials for our study takes according to a power law. The paper offers a new flat shell finite element. It results from the combination of a membrane and bending elements, both based on the strain-based formulation. The shell element result of this combination is robust, competitive and efficient. The finite element method is used here to study extensively the static analysis. A cantilever beam subjected to a concentrated force P at the free end for different length-to-thickness ratio has been chosen here for the analysis. For each example, Poisson's ratio of the P-FGM beam is assumed to be varied continuously throughout the thickness direction according to the power law, and other time it is held constant. The interpolation functions of strain, displacements and stresses fields are developed from equilibrium conditions. In this study, the influences of the volume fraction index, length-to-thickness ratio and the Poisson's ratio on the mid plane deflections, stresses distribution and strain energy along the thickness of FGM beam are examined.

Index Terms- FGM, finite element method, FEM, Power-law, beam.

I. INTRODUCTION

In the development of new materials, attainment of homogeneity of the material characteristics is often attempted. The efforts in pursuit of uniformity in chemical composition, structure and texture have resulted in the continuing progress of material science and technology. In recent years, however, as the environments in which materials are used become more demanding, there are frequently cases in which the conventional homogeneous materials cannot withstand severe environments. For example, in aerospace applications such as turbines and combustion chambers, there is no approved homogeneous material that can withstand the prevailing temperatures (up to 1800◦C in combustion chambers) at a usable stress level. To meet the increasing requirement for industrial materials, studies have also been conducted to design inhomogeneous composites, such as coated and joined materials. These inhomogeneous composites are characterized by having different characteristics on separate surfaces or parts, and therefore have two or more different functions within the given material. Unfortunately, however, these materials possess sharp boundaries, the existence of which often results in various undesirable behavior caused by the discontinuities in the physical and chemical characteristics at the boundary. The boundary separation in a coated material due to thermal stress is one typical example of such disadvantages.

In the 1980s, in an effort to develop thermal stress-resistant materials for aerospace applications, a new concept of materials was proposed to deal with the boundary problem [1]-[2]. That is, a ceramic coating on metal or a ceramic/metal joined material with continuous texture was developed in order to increase the adhesion strength and minimize the thermal stress near the ceramic/metal boundary. This new type of material is termed as "functionally graded materials" (FGMs).

[*]**Correspondence Author** – Author name, email address, alternate email address (if any), contact number.

Although the conceptual idea of gradient structure was initially advanced for composites and polymeric materials in the early 1970s [3]-[4], there was no systematic experimental investigation of the design, fabrication and evaluation of the graded structure until the 1980s. In a general definition, an FGM is a composite consisting of two or more phases, structures or textures, which vary gradually in a certain direction [5]. As the result of variation in composition and/or structure, the functions also vary along with the graded direction within the material. For example, a ceramic/metal FGM consists of pure ceramic at the hotter end and pure metal at the cooler end, so that the different parts within a material are endowed with better resistance of ceramics to high temperatures and the better mechanical and heat-transfer properties of metal according to the different environments.
In the present work, a finite element model is developed to analyse the response of isotropic and FGM beams. In FGM beam the variation of material properties is along the beam thickness and assumed to follow the power-law. Therefore, the aim of the present work is, 'the formulation of thick flat shell finite element based on the 'deformation approach' whose reason is to avoid these difficulties on the one hand, and the construction of thick flat finite shell element which is simple and competent for the analysis of complex structures. The shear correction factor is used to improve the obtained results. A MATLAB code is constructed to compute to predict the static responses for both types of beams and for different length to thickness ratio. A cantilever beam subjected to a concentrated force P at the free end for different length-to-thickness ratio has been chosen here for the analysis. For each example, Poisson's ratio of the P-FGM beam is assumed to be varied continuously throughout the thickness direction according to the volume fraction of the constituents once, and other time it is held constant. The influences of the volume fraction index and the Poisson's ratio on the mid plane deflections, stresses distribution and strain energy along the thickness of FGM beam are examined.

II. Materials and Method

II.1 Material properties of FGM beam and finite element formulation

a) Effective material properties of metal ceramic functionally graded beams

Figure 1 shows a FGM beam composed of ceramic and metal of length L, width b and thickness h. Material properties vary continuously in the z direction. Topmost surface consists of only ceramic and bottom surface has only metal. In between volume fraction of ceramic Vc and metal Vm are obtained by power law distribution in conjunction with simple law of constituent mixture as follows:

$$V_c=\left(\frac{Z}{h}+\frac{1}{2}\right)^p \tag{1-a}$$

$$V_m=1-V_c \tag{1-b}$$

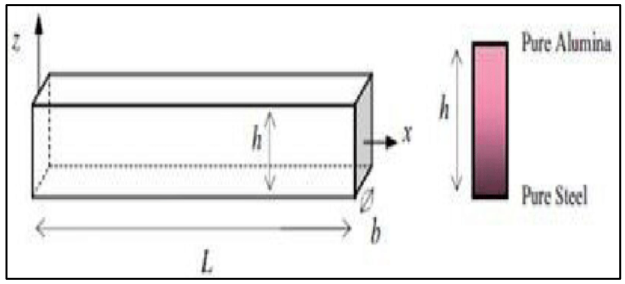


Fig. 1 Geometry of FGM beam and the possible variation of ceramic and metal through thickness

Where, z = distance from mid-surface and p = power law index, the non-negative variable parameter which dictates the material variation profile through the thickness of the beam a positive real number. For p = 0 volume fraction of ceramic becomes one and homogeneous beam consisting only ceramic is obtained, when value of p is increased, content of metal in FGM increases.
The effective material properties M_{Peff} corresponding to the model of Voigt (Shen, 2009) are evaluated using the relation:

$$M_{Peff}=MP_m V_m(z)+ MP_c V_c(z) \tag{2}$$

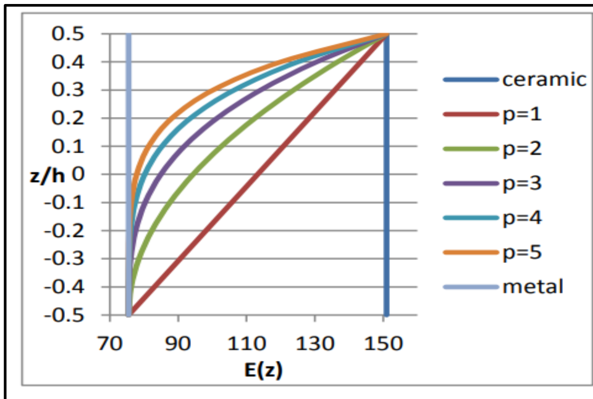
where MP_m and MP_c stands for material properties of metals and ceramics respectively. Thus, the modulus of elasticity E_{eff}, Poisson's ratio ν_{eff}, and shear modulus G_{eff}, of FGMs can be given by a simple power law distribution (Simsek, 2009):

$$E_{eff}=(E_c-E_m)\left(\frac{Z}{h}+\frac{1}{2}\right)^p+E_m \tag{3-a}$$

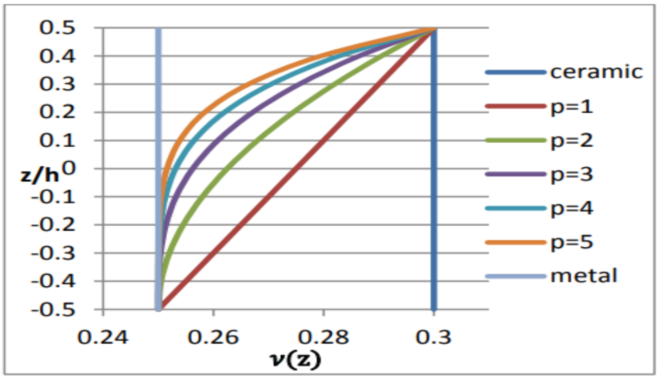
$$\nu_{eff}=(\nu_c-\nu_m)\left(\frac{Z}{h}+\frac{1}{2}\right)^p+\nu_m \tag{3-b}$$

$$G_{eff}=(G_c-G_m)\left(\frac{Z}{h}+\frac{1}{2}\right)^p+G_m \tag{3-c}$$

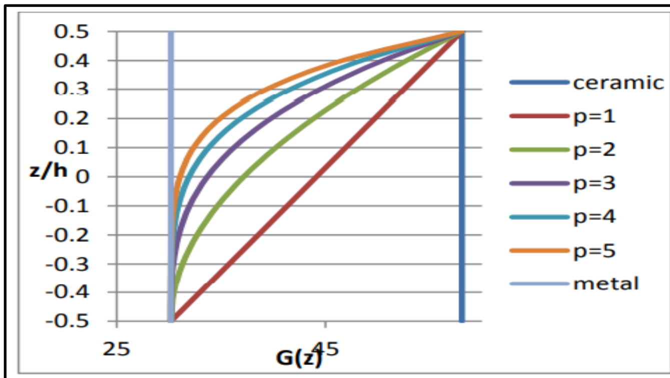
Using the above relation, it is possible to obtain an insight into the variation of the material properties across the thickness of the beam for different power law indexes. (Fig. 2a, 2b, 2c) illustrate the variation of young's modulus and Poisson's ratio and shear modulus of an FGM beam [8]



(a)



(b)



(c)

Fig. 2 Variation of Poisson's ratio, young's modulus and Shear modulus of an FGM beam along the thickness for various power law indexes, (a) Young's modulus E(z) (b) Poisson's ratio ν(z) (c) Shear modulus G(z) (see online version for colours)

b) Finite element formulation

- **Description of the SBRES formulated shell element**

The SBRES (Strain Based Rectangular Shell Element) element has four nodes and six degrees of freedom per node: the three displacements U, V, W along the global axes (X, Y, Z) and the three rotations θx, θy, θz around the axes global (X, Y, Z). The SBRES is obtained by superimposing the element of membrane and that of plate in bending /CT.

- The membrane part is represented by the rectangular finite element named SBREDR (Strain Based Rectangular Element with Drilling Rotation) [6] with three degrees of freedom (U, V, θz) at each of the four corner nodes (the two translations and the in-plane rotation) and the displacement functions of the developed element satisfy the exact representation of the rigid body modes.
- The bending part is represented by the rectangular finite element for the linear analysis of plate bending with transverse shear based on the Reissner/Mindlin plate theory effect named SBRP (Strain Based Rectangular Plate) [7] with three degrees of freedom at each of the four corner nodes (w, θx, θy) and the displacement functions of the developed element satisfy the exact representation of the rigid body modes.

The combination of the two elements SBREDR and SBRP made it possible to formulate the shell element with plane facet SBRES for the modeling of the structures (beam and shell)

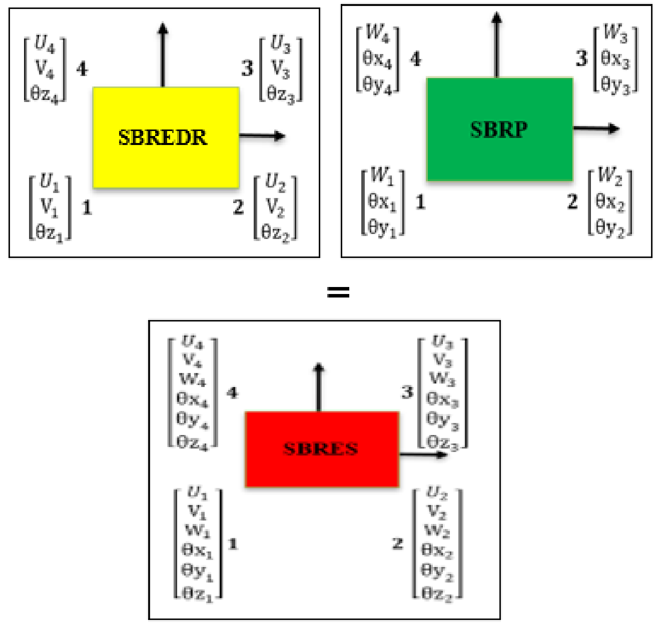


Fig. 3 formulated shell element SBRES

- **The stiffness matrix of element membrane** $[\boldsymbol{K_{SBREDR}}^{e}]$

The displacement functions of the SBREDR [6] element is:

$$
\begin{aligned}
U &= a_1 - a_3 y + a_4 x + a_5 y + a_6 xy + a_8\left(y^2/2 + x^2/2\right) \\
&\quad + a_9 y^2 + a_{10}\left(xy^2 + y^2\right) + a_{11} x^2 y^3 \\
V &= a_2 + a_3 x + a_5 x + a_6 x^2/2 + a_7 y + a_8 xy + a_9 y^2 \\
&\quad - a_{10}\left(x^2 y + x^2\right) - a_{11} x^3 y^2 + a_{12} x^2 \\
\theta &= a_3 - a_9 y - 2a_{10}\left(xy + (x+y)\right) - 3a_{11} x^2 y^2 + a_{12} x
\end{aligned} \tag{4}
$$

The displacement functions of the developed element (SBREDR) [6] satisfy the exact representation of the rigid body modes of movement, satisfy the compatibility within the element and contain constant independent strain terms. The 12 nodal degrees of freedom of the element are expressed in terms of the $\alpha_1, \alpha_2 \ldots\ldots, \alpha_{12}$ constants by the transformation matrix [C].

$\{\delta^e\}$=[C] $\{\alpha_i\}$

The column vectors $\{\delta^e\}$ and $\{A\}$are:

$\{\delta^e\}=\{U_1\ V_1\ \theta z_1\ U_2\ V_2\ \theta z_2\ U_3\ V_3\ \theta z_3\ U_4\ V_4\ \theta z_4\}^T$

$\{\alpha_i\}^T=\{\alpha_1 \alpha_2\ \alpha_3\ \alpha_4\ \alpha_5\ \alpha_6\ \alpha_7\ \alpha_8\ \alpha_9\ \alpha_{10}\ \alpha_{11}\ \alpha_{12}\}^T$

Following the well-known procedure for displacement type finite elements [6], the stiffness matrix $[\boldsymbol{K}_{\mathrm{SBREDR}}{}^{e}]$ for the rectangular element is given by:

$[\boldsymbol{K_{SBREDR}}^{e}]=([C]^{-1})^T\ (\iint([Q]^T[D]\ [Q])ds)\ [C]^{-1}$ (5-a)

$[\boldsymbol{K_{SBREDR}}^{e}] = ([C]^{-1})^T\ [K_0][C]^{-1}$ (5-b)

(For a matrix [C] and [Q] see appendix in reference [6])

For an orthotropic material (FGM), the stress–strain relationship theory is given by

$$\begin{Bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{Bmatrix} = \frac{E(z)}{1-\nu^2}\begin{bmatrix}1 & \nu & 0\\ \nu & 1 & 0\\ 0 & 0 & \frac{1-\nu}{2}\end{bmatrix}\begin{Bmatrix}\varepsilon_x\\ \varepsilon_y\\ \gamma_{xy}\end{Bmatrix}$$

The rigidity matrix [D] is defined as

$$[D]=D_a\begin{bmatrix}1 & \upsilon & 0\\ \upsilon & 1 & 0\\ 0 & 0 & \frac{1-\upsilon}{2}\end{bmatrix} \quad (6)$$

With $D_a = \frac{1}{1-\upsilon^2}\int_{-\frac{h}{2}}^{\frac{h}{2}} E(z)dz$ (6-a)

$D_a = (\frac{h}{1-\upsilon^2})\left(E_m + \frac{(E_c-E_m)}{p+1}\right)$ (6-b)

where h is the thickness of the beam, E_m , E_c the modulus of elasticity of metals and ceramics, D_a is the axial stiffness and p = power law index.

- **The stiffness matrix of the plate element [$K_{SBRP}{}^{e}$]**

The displacement functions of the SBRP [7] element is:

$W=\alpha_1 - \alpha_2 x - \alpha_3 y - \alpha_4 \frac{x^2}{2} - \alpha_5 \frac{x^2y}{2} - \alpha_6 \frac{y^2}{2} - \alpha_7 \frac{xy^2}{2} - \alpha_8 \frac{xy}{2} + \alpha_9 \frac{x}{2} + \alpha_{10}\frac{xy}{2} + \alpha_{11}\frac{y}{2} + \alpha_{12}\frac{xy}{2}$

$\beta_x=\alpha_2 + \alpha_4\, x + \alpha_5\, xy - \alpha_7\frac{y^2}{2} + \alpha_8\frac{y}{2} + \frac{\alpha_9}{2} + \alpha_{10}\frac{y}{2} - \alpha_{12}\frac{xy}{2}$

$\beta_y = \alpha_3 - \alpha_5\frac{x^2}{2} + \alpha_6\, y + \alpha_7\, xy + \alpha_8\frac{x}{2} - \alpha_{10}\frac{x}{2} + \frac{\alpha_{11}}{2} + \alpha_{12}\frac{x}{2}$

We write the displacement field in the matrix form as follows:

$$\begin{Bmatrix}W\\ \beta_x\\ \beta_y\end{Bmatrix} = [f(x,y)]\{\alpha_i\} \quad (7)$$

With

$\{q^e\}=\{W_1\, \beta_{x_1}\, \beta_{y_1}\, W_2\, \beta_{x_2}\, \beta_{y_2}\, W_3\, \beta_{x_3}\, \beta_{y_3}\, W_4\, \beta_{x_4}\, \beta_{y_4}\}^T$

$\{\alpha_i\}^T=\{\alpha_1 \alpha_2\, \alpha_3\, \alpha_4\, \alpha_5\, \alpha_6\, \alpha_7\, \alpha_8\, \alpha_9\, \alpha_{10}\, \alpha_{11}\, \alpha_{12}\}^T$

The nodal displacements vector, at the elementary level, corresponding to the nodes j(j=1….4),is obtained by applying the relation $[f(x,y)]$ after recognizing the nodal coordinates (x_i, y_i):

$$\{q^e\}=\begin{bmatrix}f(x_1,y_1)\\ f(x_2,y_2)\\ f(x_3,y_3)\\ f(x_4,y_4)\end{bmatrix}\{\alpha_i\} \quad (8)$$

$[A]=\begin{bmatrix}f(x_1,y_1)\\ f(x_2,y_2)\\ f(x_3,y_3)\\ f(x_4,y_4)\end{bmatrix}$ is the nodal coordinate's matrix

Since relation (8), we gather the value of parameters 'α_i'the following system:

$$\{\alpha_i\} = [A]^{-1}\{q^e\} \quad (9)$$

By replacing the parameters, which have the relationship given by (9), in the equation system (7), we obtain the following relationship:

$$\begin{Bmatrix}W\\ \beta_x\\ \beta_y\end{Bmatrix} = [f(x,y)][A]^{-1}\{q^e\} \quad (10)$$

Which represents the interpolation functions matrix N_i.

the stiffness matrix $[\boldsymbol{K_{SBRP}}^{e}]$ for the plat element is given by the expression:

$(\delta W_{int}) = \int \delta\{\varepsilon\}^T [\sigma]dV$ (11)

Knowing that:

$\{\varepsilon\}=[N]\{q^e\} = [Q_{SBRP}][A]^{-1}\{q^e\}$ (12)

and:

$\{\sigma\}= [D_{SBRP}]\{\varepsilon\}$ (13)

Moreover, substituting in the expression (11){ε} and{σ} by values given respectively in equation (12) and (13) produces:

$[\boldsymbol{K_{SBRP}}^{e}] = ([A]^{-1})^T(\iint([Q_{SBRP}]^T[D_{SBRP}][Q_{SBRP}])ds)\, [A]^{-1})$

$[K_{SBRP}{}^{e}] = ([A]^{-1})^T\, [K_0][A]^{-1}$ (14)

For a matrix ($[Q_{SBRP}]$ and $[D_{SBRP}]$ see appendix in reference [7])

For an orthotropic material (FGM) the stress-strain relationship equation of Reissner/Mindlin theory are given:

$$\begin{bmatrix}M_x\\ M_y\\ M_{xy}\\ T_x\\ T_y\end{bmatrix}=\begin{bmatrix}d_{11} & d_{12} & 0 & 0 & 0\\ d_{12} & d_{22} & 0 & 0 & 0\\ 0 & 0 & d_{33} & 0 & 0\\ 0 & 0 & 0 & d_{44} & 0\\ 0 & 0 & 0 & 0 & d_{55}\end{bmatrix}\begin{bmatrix}k_x\\ k_y\\ k_{xy}\\ \gamma_{xz}\\ \gamma_{yz}\end{bmatrix}$$

Where $M_x, M_y, M_{xy}, T_x, T_y$ represent the bending and twisting moments and the transverse shear forces per unit length, respectively.

The rigidity matrix *[D_{SBRP}]* contains d_{ij} terms, which are defined as:

$$[D_{SBRP}] = D_b\begin{bmatrix}1 & \upsilon & 0 & 0 & 0\\ \upsilon & 1 & 0 & 0 & 0\\ 0 & 0 & \frac{1-\upsilon}{2} & 0 & 0\\ 0 & 0 & 0 & \frac{6k(1-\upsilon)}{h^2} & 0\\ 0 & 0 & 0 & 0 & \frac{6k(1-\upsilon)}{h^2}\end{bmatrix}$$

With $D_b = \frac{1}{1-\upsilon^2}\int_{-\frac{h}{2}}^{\frac{h}{2}} z^2E(z)dz$ (15-a)

$D_b=(\frac{h^2}{12(1-\upsilon^2)})\left(3(E_c - E_m)(\frac{p^2+p+2}{(p+3)(p+2)(p+1)})\right)$ (15-b)

and h is the plate thickness, D_b is the bending stiffness. The symbol k represents the shear factor which is usually taken as k=5/6 except where noted

- **The stiffness matrix of the shell coupling "SBREDR - SBRP" [$K_{SBREDR/SBRP}{}^{e}$]**

$[\boldsymbol{K_{SBREDR/SBRP}}^{e}]$=

$([C]^{-1})^T \iint([Q_{SBRIEIR}]^T[\boldsymbol{D_{SBREDR/SBRP}}][Q_{SBRP}])ds)\, [A]^{-1}$

For:

$$[\boldsymbol{D_{SBREDR/SBRP}}] = D_{ab}\begin{bmatrix}1 & \upsilon & 0 & 0 & 0\\ \upsilon & 1 & 0 & 0 & 0\\ 0 & 0 & \frac{1-\upsilon}{2} & 0 & 0\\ 0 & 0 & 0 & \frac{6k(1-\upsilon)}{h^2} & 0\\ 0 & 0 & 0 & 0 & \frac{6k(1-\upsilon)}{h^2}\end{bmatrix}$$

With:

$$D_{ab} = \frac{1}{1-\upsilon^2}\int_{-\frac{h}{2}}^{\frac{h}{2}} z\, E(z)dz = \left(\frac{h^2}{2(1-\upsilon^2)}\right)\left(3(E_c - E_m)\left(\frac{p}{(p+2)(p+1)}\right)\right)$$

- **The shell element SBRES**

The shell element the present element is a flat plane thick shell element, obtained by superimposing the SBREDR. membrane finite element [6] with the SBRP thick plate finite element [7] For the orthotropic material (FGM) case, we obtain his elementary stiffness matrix by adding the stiffness matrix of the membrane element to that of the bending element with coupling effect. We outline the approach with his principles as follows:

- We approximate the real geometry with flat planes, so we neglect the curvatures on the element. This avoids the membrane locking
- Use of a membrane element coupled to that of a plate-bending element
- The shell element may have any orientation in the global coordinate system XYZ.
- We establish the passage of the local coordinates to the global coordinates through the rotation matrix [Ro] as follows: $K_{e\ glob}$=$[R]^T K_{e\ local}$[R]

We rearrange the local rigidity terms (24,24) before assembly in the local

III. RESULTS

III.1 Static analysis

Two examples are considered in this section for different length-to-thickness:

Example 1: L/h = 100.

In this section, the results are discussed for the FGM cantilever beam discretised in 50 elements (L = 1.2 m, h = 0.012 m, b = 0.1 m) subjected to a concentrated force P at the free end (P = 1,000 N). The beam is composed of alumina (Al_2O_3) (Ec =151 GPa) and steel (Em = 75.5 GPa). Firstly, the Poisson ratio is assumed to be varied through the thickness of the beam according to the power-law (νc = 0.3, νm = 0.25), then it is held constant (νc = νm = 0.3). The shear correction factor is taken as Ks = 5/6. Coding is done in f. In this study, the compressive and tensile stresses are shown by positive and negative signs respectively. Geometric characteristics and properties of the FGM beam are shown in Figure 4.

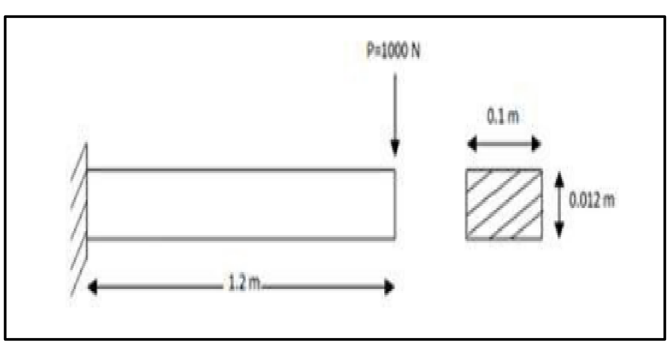


Fig. 4 Geometric characteristics and properties of the FGM beam (L/h = 100) [8]

The non-dimensional quantities used here are:

$\frac{E_c}{E_m}$ =2, $\frac{G_c}{G_m}$ =1.92 (when Poisson ratio is assumed to be varied)

$\frac{E_c}{E_m}$ =2, $\frac{G_c}{G_m}$ =2 (when Poisson ratio is constant)

Example 2: L/h = 15

The static analysis is done considering a FGM cantilever beam, subjected to a point load at the free end (P =1000 N). Discretised in 50 elements. The geometric characteristics and properties of the beam are (L = 1.2 m, h = 0.08 m, b = 0.1 m). The beam is composed of alumina (Ec = 151 GPa) and steel (Em = 75.5 GPa). Like the previous example, firstly, the Poisson ratio is assumed to be varied through the thickness of the beam according to the power-law (νc = 0.3, νm = 0.25), then it is held constant (νc = νm = 0.3). Geometric characteristics and properties of the FGM beam are shown in Figure 9. The non-dimensional quantities used here are:

$\frac{E_c}{E_m}$ =2, $\frac{G_c}{G_m}$ =1.92 (when Poisson ratio is assumed to be varied)

$\frac{E_c}{E_m}$ =2, $\frac{G_c}{G_m}$ =2 (when Poisson ratio is constant)

III.2 Numerical results and discussions

If Poisson's ratio of the P-FGM beam is assumed to be varied continuously throughout the thickness direction according to the volume fraction or it is held constant, we get the same results. Figure 5 and Figure 10 show the mid plane transverse deflections along the beam length for the two examples respectively. In transverse deflection we see that for full ceramic (p = 0) the deflection is less than the FGM composition and as the value of p increases, the deflections of the beam increase too. It is also to be noted that as the value of power-law exponent increases, the composition of the FG beam approaches to the composition of the full metal beam. Figures 6, 11 and Figures 7, 12 show the distribution of axial and shear stresses at x = 0.576 m (node 25) respectively for different values of p. As seen from Figure 6 and Figure 11 the axial stress distribution is linear for full ceramic or for full metal and also the values of tensile and compressive stresses are equal for isotropic beam (full ceramic or full metal). But for other values of p the axial stress distribution is not linear and also the values of compressive stresses are greater than tensile stresses. Also, the value of axial stress is zero at the mid-plane but it is clearly visible that the values of axial stresses are not zero at the mid-plane of the FGM beam for the other values of p; it indicates that the neutral plane of the beam moves towards the lower side of the beam for FG beam. This is due to the variation of the modulus of elasticity through the thickness of the FGM beam. Figure 7 and Figure 12 depicts the variation of the shear stress across the thickness of beam. With increasing power law index (p), the tip of shear stress decreases. By the way, it has not considerable effect on the distribution of shear stress.

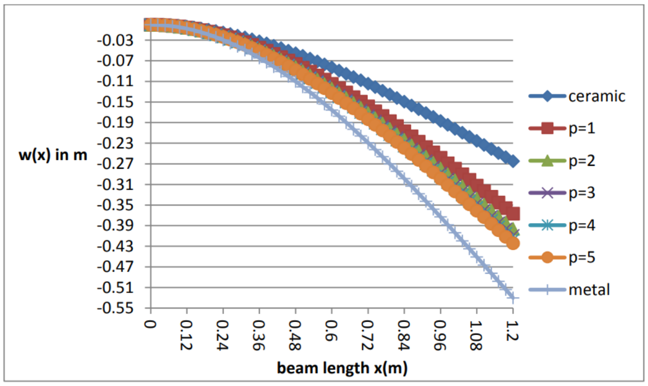


Fig. 5 Mid plane transverse deflection along the beam length (see online version for colors

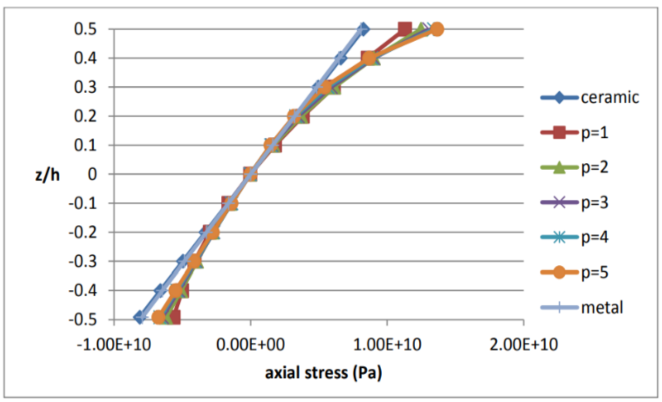


Fig.6 Depth wise axial stresses distribution for a concentrated force P at the free end in a beam with CF edges at x = 0.576 m (see online version for colors)

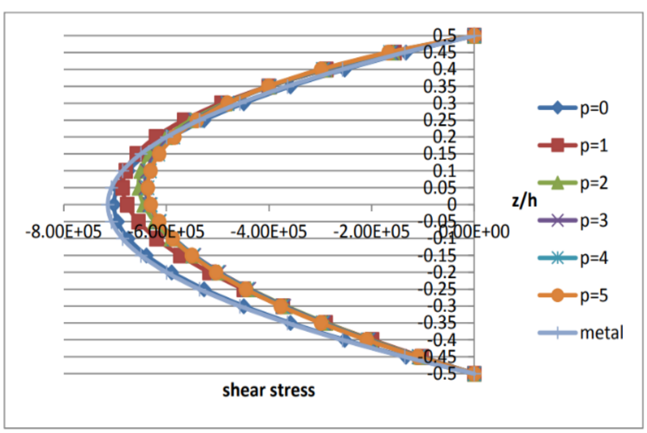


Fig.7 Depth wise shear stresses distribution for a concentrated force P at the free end in a beam with CF edges at x = 0.576 m (see online version for colors)

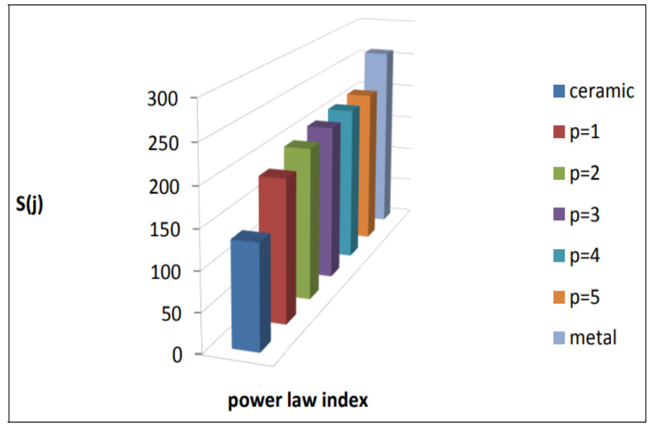


Fig.8 Strain energy for different value of power-law exponent (L/h = 100) (see online version for colors)

Example 2: L/h = 15

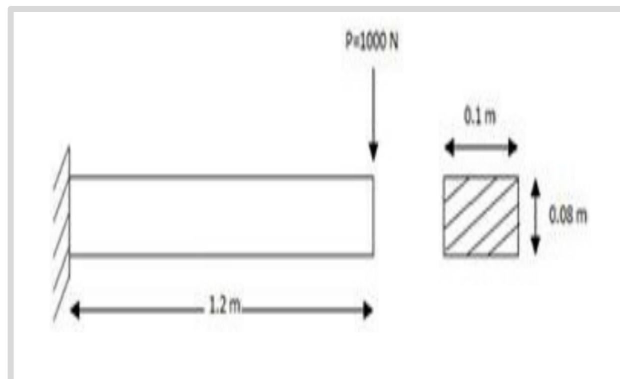


Fig. 9 Geometric characteristics and properties of the FGM beam (L/h = 15) [8]

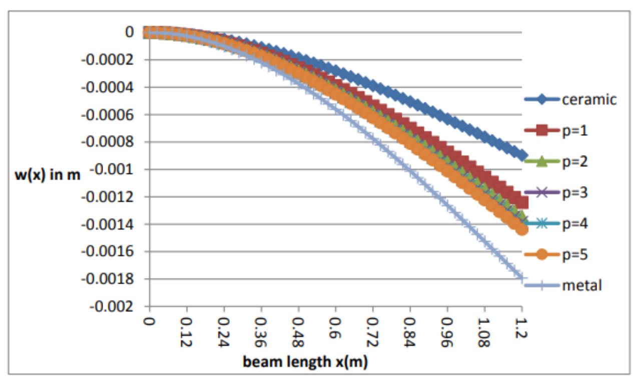


Fig. 10 Mid plane transverse deflection along the beam length (see online version for colors)

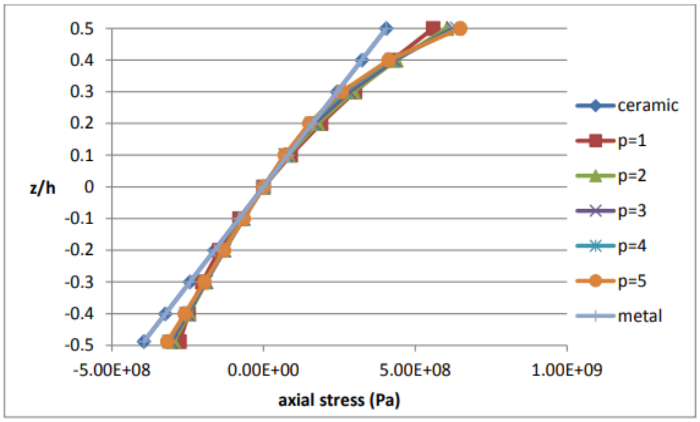


Fig. 11 Depthwise axial stresses distribution for a concentrated force P at the free end in a beam with CF edges at x = 0.576 m (see online version for colors)

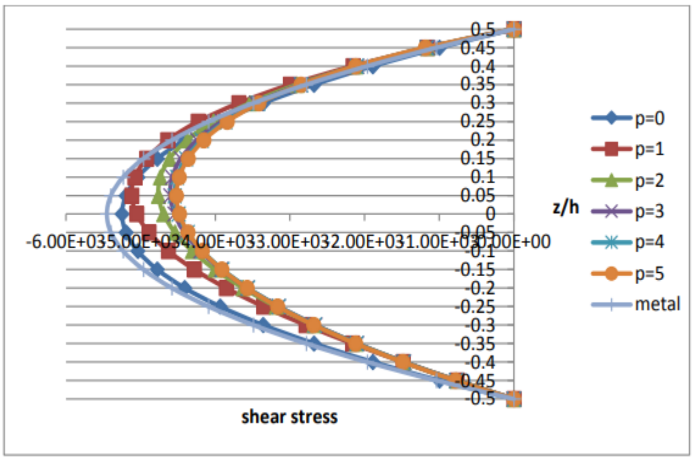


Fig.12 Depthwise shear stresses distribution for a concentrated force P at the free end in a beam with CF edges at x = 0.576 m (see online version for colors)

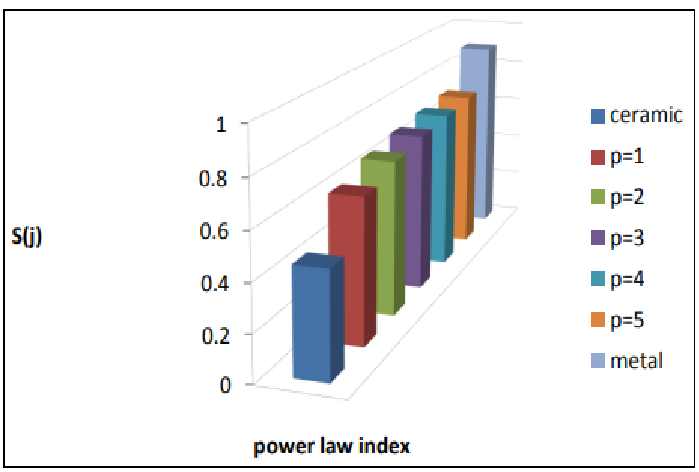


Fig.13 Strain energy for different value of power-law exponent (L/h = 15) (see online version for colors)

IV. CONCLUSION

The FEM (approximation) is used here formulation of a flat rectangular thick shell element with a true rotation based upon the strain approach has been successfully developed and presented in the present paper to study extensively the static displacement field components, axial stress and shear stress distribution for different length-to-thickness ratio in FGM beams and different value of Poisson's ratio (Once across the thickness of the P-FGM beam is assumed to be varied continuously throughout the thickness direction according to the volume fraction of the constituents, and other time it is held constant). It was observed that the deflections are more highly for metal rich beam when compared to ceramic rich beam and deflection increases as the power law index p increases. The axial stress distribution through the depth is linear for metal-ceramic FGMs when power law index value leads to a homogeneous beam (p = 0). For power law index other than homogeneous (p = 1, 2…5) composition the stress profile is not linear. The magnitude of maximum axial tensile stress and maximum axial compressive stress is dependent on the metal-ceramic combination. Distribution of transverse shear stress profile also depends on the metal-ceramic combination. It was observed too that there is not relationship between Poisson's ratio and deflections, stresses distribution and strain energy. It was noted also that the strain energy is higher for metal rich beam when compared to ceramic rich beam and her value increases as the power law index p increases. Investigations on the static analyses of the FGM beams revealed that the deflections, stresses and the location of the neutral surface are highly dependent on power law index, and they are not dependent on Poisson ratio. It can be said that in the design of structures, by choosing a suitable power law exponent, the material properties of the FG beam can be tailored to meet the desired goals of minimizing stresses and the displacements in a beam-type structure

V. References

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