International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 4, Issue 6, June-2018

A NUMERICAL STUDY ON THERMAL BEHAVIOUR OF CYLINDRICAL SHELL MADE WITH FUNCTIONALLY GRADED MATERIALS

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ABSTRACT

This thesis presents an analytical study for structural behavior of a cylindrical shell which is composed of a functionally graded material (FGM). The cylindrical shell is assumed to have two-constituent material distributions through the thickness of the structure, and material properties of the cylindrical shell are assumed to vary according to a power-law distribution in terms of the volume fractions for constituent materials, the exact solution for the structural behavior for cylinder under structural and thermal loads is solved through simulation. The goal of this investigation is to study the structural behavior of FGM.

I. INTRODUCTION

Pure metals are of little use in engineering applications because of the demand of conflicting property requirement. For example, an application may require a material that is hard as well as ductile, there is no such material existing in nature. To solve this problem, combination (in molten state) of one metal with other metals or non-metals is used. This combination of materials in the molten state is termed alloying (recently referred to as conventional alloying) that gives a property that is different from the parent materials. Bronze, alloy of copper and tin, was the first alloy that appears in human history. Bronze really impacted the world at that time, it was a landmark in human achievement and it is tagged the 'Bronze Age' in about 4000 BC. From then, human has been analyzing with one shape of alloy or the other with the only cause of developing properties of material. Because of thermodynamic equilibrium limit there is border to which a material can be diffuse in a solution of another material. When more amount of the alloying material is required, then they can't utilize traditional alloying. Another restriction of standard alloying is when alloying two heterogeneous materials with wide independent melting temperatures it becomes restrictive to amalgamate these materials through this process. Powdered Metallurgy (PM) is another system of producing part that cannot be fabricated through the conventional alloying. Alloys are processed through some of the problems, powdered form and analogous with the conventional alloying are overcome. Notwithstanding the excellent characteristics of powdered metallurgy, there prevail some limitations which include poor strength and complex shapes features that can't be produced using PM. The parts are permeable and also have these limitations are of benefits to some applications but are harmful to alternatives. Another procedure of producing materials with amalgamation of properties is by integrating materials in solid state, which is mentioned to as composite material.

RECENT RESEARCH EFFORTS IN FUNCTIONALLY GRADED MATERIAL

Many experimentations been regulate on etiquette of FGM, and the literature is very high on this because of the wide areas of application of this novel material. Presentation of functionally graded material under localized transverse loading was examined by Kashtalyan and Woodward, on property evaluate study was conducted by Lu et al. A complete review on performance of functionally graded material was published in the year 2007 by ByrandBirman. An overview on fracture deportment of functionally graded material was conducted by Shanmugavel et al... More reviews on FGM available in the review study on research and development by Tilbrook et al. and Cherradi et al., they also conducted review study on crack propagation in functionally graded materials.

Materials of Graded Structure

The idea of functionally graded material was substantially advanced in the early in the year 1980’s in Japan, where this new material concept was proposed to increase adhesion and minimize the thermal stresses in metallic-ceramic composites developed for reusable rocket engines.Meanwhile, FGMs concepts have triggered world-wide research activity and are applied to metals, ceramics and organic composites to generate improved components with superior physical properties.

FUTURE RESEARCH DIRECTION

FGM is an excellent approach material that will revolutionize the produce world in the 21st century. There are a number of roadblocks for perceive this objective. Cost is a major problem with considerable part of the cost expended on fabrication method and powder processing. Solid freeform fabrication technique offers a greater advantage for manufacturing functionally graded material but there are still plenty of issues that need to be resolved with this optimistic technology. More research needs to be supervise on developing the performance of solid freeform processes through extensive characterization of functionally graded material in other to generate a comprehensive database and to develop a predictive model for proper process control. Further work should also be done to improve the process control through development of more powerful feedback control for overall functionally graded material fabrication process improvement.

II. LITERATURE REVIEW

The functionally graded materials are one of the revolutionary materials which got attention by researchers and various studies have shown the interest in this material. Various research had been conducted and different fabrication processes have been used for the analysis of different properties of functionally graded materials. The functionally graded materials are developed and analyzed using different methods in past and few of the studies are presented here for the sake of brevity.

The term “composite” broadly refers to a material system which is composed of a discrete constituent (the reinforcement) distributed in a continuous phase (the matrix), and which derives its distinguishing characteristics from the properties of its constituents, from the geometry and architecture of the constituents, and from the properties of the boundaries between different constituents Composite materials are usually classified on the basis of the physical or chemical nature of the matrix phase Functionally graded materials (FGMs) first emerged as a distinct technology in an era when improved performance for advanced military systems provided a primary motivation for materials development [13]

III. CATIA

CATIA which stands for Computer Aided Three Dimensional Interactive Application is CAD software owned and developed by Dassault Systems and marketed worldwide by IBM. It is the world’s leading CAD/CAM software for design and manufacturing. CATIA supports multiple stages of product development through conceptualization, design, engineering and manufacturing.

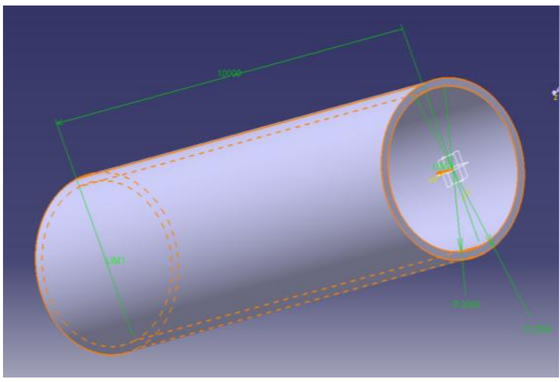


Fig. 5.1.1 Model with dimensions

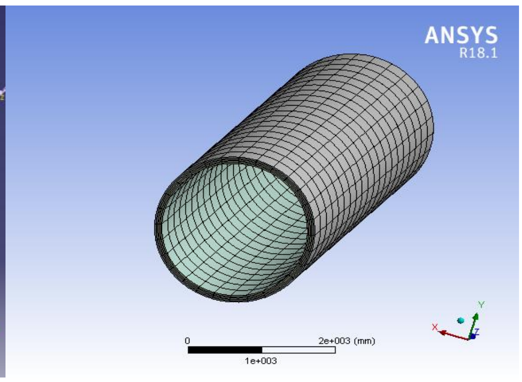


Fig. 5.1.5 meshed model of cylindrical shell

IV. PROBLEM DESCRIPTION

FGM material properties with volume fractions and cylindrical shell design considerations:

The cylindrical shell is composed of "metal" and "ceramic" materials and the material constituents of the shell varies from the outer surface to the inner surface, i.e. the outer surface (z = −h/2) of the cylindrical shell is metal-rich and the inner surface (z = h/2) is ceramic-rich. In such a way, material properties Pand piezoelectric coefficients p (z) of the FGM cylindrical shell are assumed to vary through the thickness of the shell. Here, FGM's material properties Pare related not only to material properties of the material constituent, but also to their volume fractions V_1 and V_2, therefore.

$$P\,(z) = P_1V_1 + P_2V_2 = P_2 + (P_1 - P_2)\,V_1$$

Where subscript 1 and 2 denotes, respectively, metal material and ceramic material.

Consider a FGM cylindrical shell subjected to mechanical load *q* and thermal load *T* (*z*). Its inner radius *a*, length *L* and thickness *h* are shown in Fig. 1. The Cartesian coordinate system (*x*, *y*, *z*) is set on the mid-plane (*z* = 0) of the FGM cylindrical shell, where *x* and *y* denotes the axial and circumferential directions of the mid-plane of the FGM cylindrical shell, respectively.

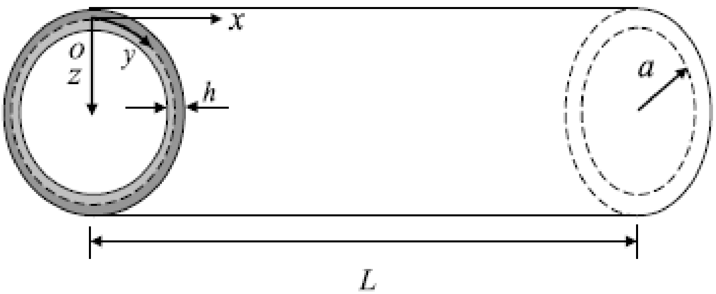


Fig.4.1 Picture of FGM cylindrical shell

Consider an FGM cylindrical shell with length *L* = 10 m, inner radius *a* = 2 m, the ratio of radius to thickness is 20. t= 0.1, L/id=10/4 (id =internal diameter), L/ed=10/4.2 (ed =external diameter) in all the following numerical calculations

V. MODEL CALCULATIONS

(Case 1) 5 layers V_1= (1, 0.75, 05, 025, 0)
(Case 2) 10 layers V_1 = (1, 0.89, 0.78, 0.67, 0.56, 0.45, 0.34, 0.23, 0.12, 0)

$$\mathbf{P\,(z) = P_2 + (P_1 - P_2)\,V_1}$$

P (z) =Properties of "z" layer
P_1 =properties of metal
P_2 =properties of ceramic
V_2 =volume fraction

Material properties of both metal and ceramic materials

Properties	Aluminium (metal)	Zirconium (ceramic)	mullite (ceramic)	Titanium carbide (ceramic)
Young's modulus (e)	70Gpa	151Gpa	151gpa,	460Gpa
Poisson's ratio (V)	0.3	0.3	0.26,	0.336
Thermal conductivity (K)	204 v/mk	2.9 v/mk	6 v/mk,	5.64 v/mk
Co-efficient of thermal expansion (α)	$23*10^{-6}$ /k	$10*10^{-6}$ /k	$5.4*10^{-6}$ /k,	$7.4*10^{-6}$ /k
Density (ρ)	$2.7*10^3$ kg/mm^2	$5.89*10^3$ kg/mm^2	2800 kg/mm^3	4930 kg/mm^3

The above material properties are substituted in **P (z) = P_2+ (P_1- P_2) V_1**to obtain the values given in the table below

Calculated values of various volume fractions of FGM

volume fractions	(case 1) aluminium - zirconium 5-Layers				
	(e) Gpa	**(V)**	**(K)** v/mk	**(α)**/k	**(ρ)** kg/mm^2
1	70	0.3	204	2.30E-05	2700
0.75	90.25	0.3	153.725	1.98E-05	3497.5
0.5	110.5	0.3	103.45	1.65E-05	4295
0.25	130.75	0.3	53.175	1.33E-05	5092.5
0	151	0.3	2.9	1.00E-05	5890
(case 2) aluminium - zirconium 10-Layers					
1	70	0.3	204	2.30E-05	2700
0.89	78.91	0.3	181.879	2.16E-05	3050.9
0.78	87.82	0.3	159.758	2.01E-05	3401.8
0.67	96.73	0.3	137.637	1.87E-05	3752.7
0.56	105.64	0.3	115.516	1.73E-05	4103.6
0.45	114.55	0.3	93.395	1.59E-05	4454.5
0.34	123.46	0.3	71.274	1.44E-05	4805.4
0.23	132.37	0.3	49.153	1.30E-06	5156.3
0.12	141.28	0.3	27.032	1.16E-06	5507.2
0	151	0.3	2.9	1.00E-05	5890

volume fractions	(case 1) aluminium - mullite 5-Layers				
	(e) Gpa	**(V)**	**(K)** v/mk	**(α)**/k	**(ρ)** kg/mm^2
1	70	0.3	204	2.30E-05	2700
0.75	90.25	0.29	154.5	1.86E-05	2725
0.5	110.5	0.28	105	1.42E-05	2750
0.25	130.75	0.27	55.5	9.80E-06	2775
0	151	0.26	6	5.40E-06	2800
(case 2) aluminium - mullite 10-Layers					
1	70	0.3	204	2.30E-05	2700
0.89	78.91	0.2956	182.22	2.11E-05	2711
0.78	87.82	0.2912	160.44	1.91E-05	2722
0.67	96.73	0.2868	138.66	1.72E-06	2733
0.56	105.64	0.2824	116.88	1.53E-05	2744
0.45	114.55	0.278	95.1	1.33E-05	2755
0.34	123.46	0.2736	73.32	1.14E-05	2766
0.23	132.37	0.2692	51.54	9.45E-06	2777
0.12	141.28	0.2648	29.76	7.51E-06	2788
0	151	0.26	6	5.40E-06	2800

volume fractions	(case 1) aluminium - titanium carbide 5-Layers				
	(e) Gpa	**(V)**	**(K)** v/mk	**(α)**/k	**(ρ)** kg/mm^2
1	70	0.3	204	2.30E-05	2700
0.75	167.5	0.309	154.41	1.91E-03	3257.5
0.5	265	0.318	104.82	1.52E-05	3815
0.25	362.5	0.327	55.23	1.13E-05	4372.5
0	460	0.336	5.64	7.40E-06	4930
(case 2) aluminium - titanium carbide 10-Layers					
1	70	0.3	204	2.30E-05	2700
0.89	112.9	0.30396	182.1804	2.13E-05	2945.3
0.78	155.8	0.30792	160.3608	1.96E-05	3190.6
0.67	198.7	0.31188	116.7216	1.79E-05	3435.9
0.56	241.6	0.31584	116.7216	1.61E-05	3681.2
0.45	284.5	0.3198	94.902	1.44E-05	3926.5
0.34	327.4	0.32376	73.0824	1.27E-05	4171
0.23	370.3	0.32772	51.2628	1.10E-05	4417.1
0.12	413.2	0.33168	29.4432	9.27E-06	4662.4
0	460	0.336	5.64	7.40E-06	4930

VI. ANALYSIS

The properties values of Density, Specific heat, Thermal conductivity, viscosity are calculated by using manual calculations .this values used for CFD analysis. The cfd analyses is done in ansys fluent on the shell and tube heat exchanger for four nano fluids and five volume fractions 0.5, 0.6, 0.7, 0.8, 0.9. at every volume fraction finite element analysis was generated five results ,these are Velocity magnitude, dynamic pressure, total heat transfer, mass flow rate. This simulation was conducted on FourNano fluids considered are Aluminum Oxide, copper oxide, Silicon Oxide and Titanium carbide. Taken major parameters was Density, Specific heat, Thermal conductivity, viscosity of the above four nano fluids .finally the simulated graphical result and graphs generated at each and every volume fraction

5.2 Case results of Aluminium/mullite with 5 layer cylindrical shell

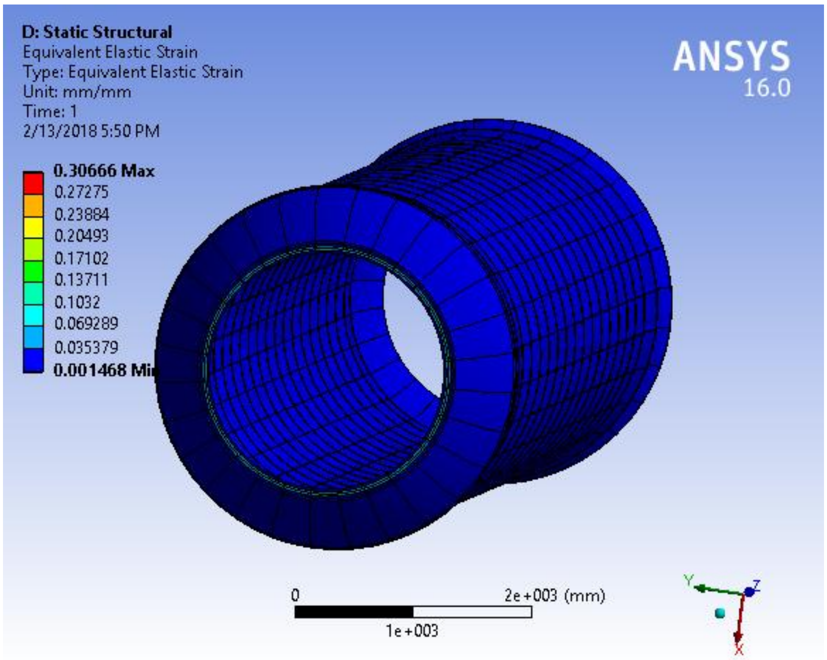


Fig: 5.2.1 Picture showing min/max values from equivalent strain of 5layer cylindrical shell

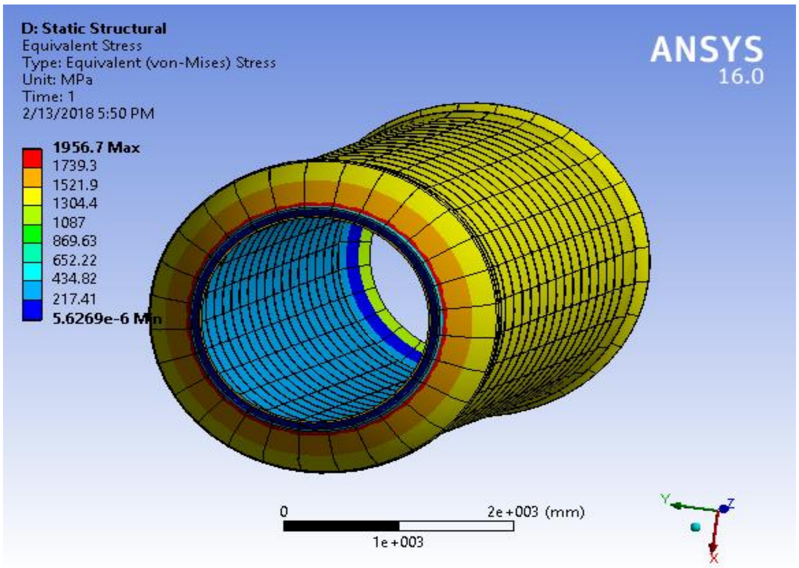


Fig: 5.2.2 Picture showing min/max values from equivalent stress of 5layer cylindrical shell

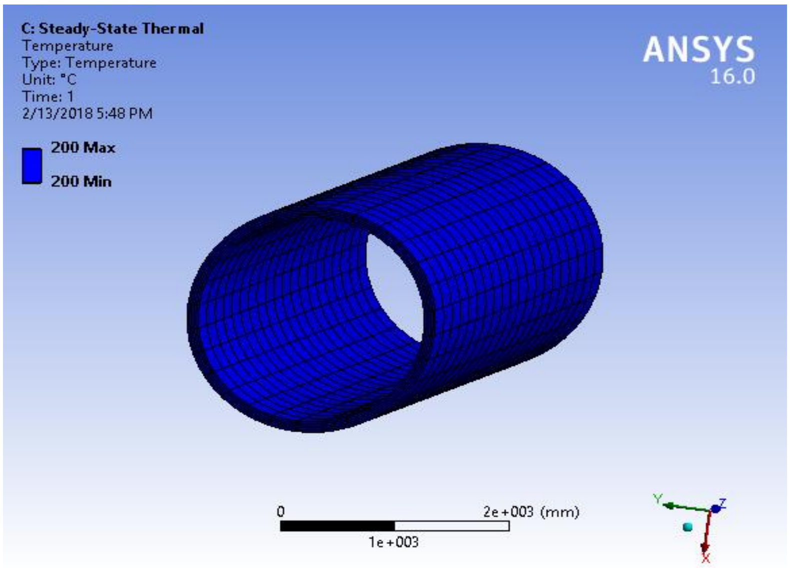


Fig: 5.2.3 Picture showing min/max values from temperature of 5layer cylindrical shell

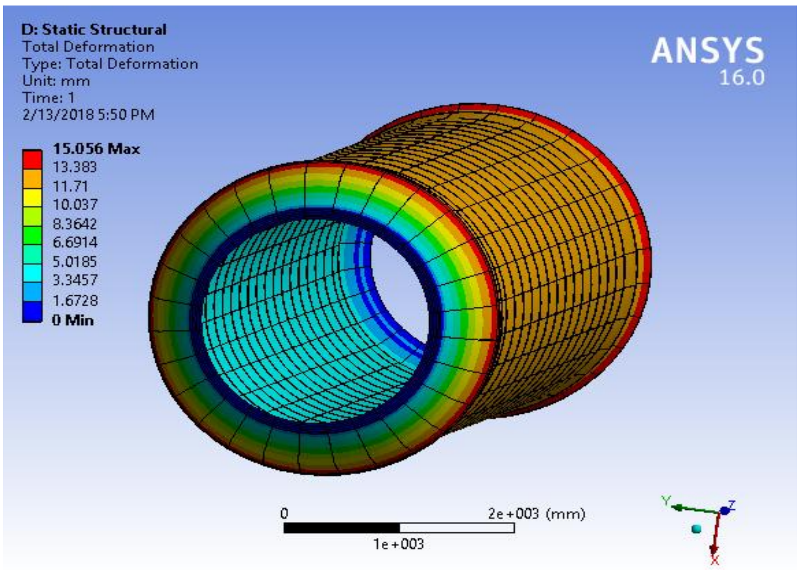


Fig: 5.2.4 Picture showing min/max values from total deformation of 5layer cylindrical shell

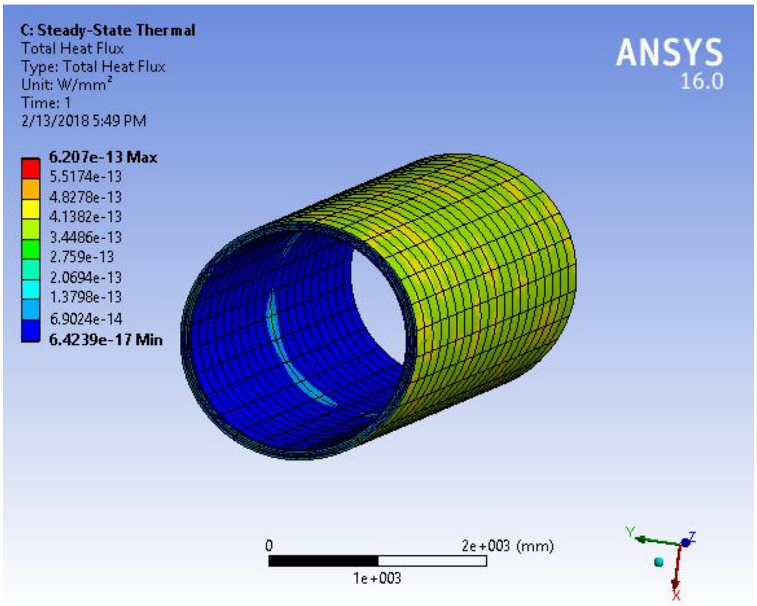


Fig: 5.2.5 Picture showing min/max values from total heat flux of 5layer cylindrical shell

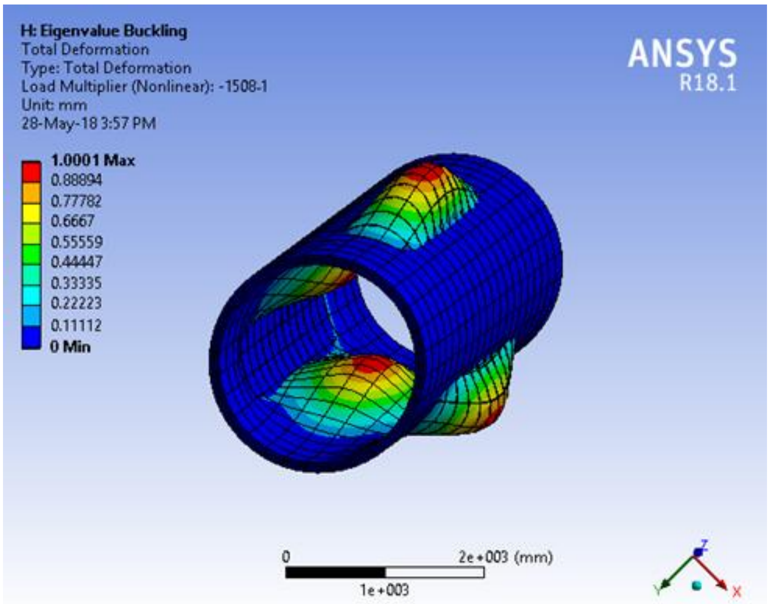
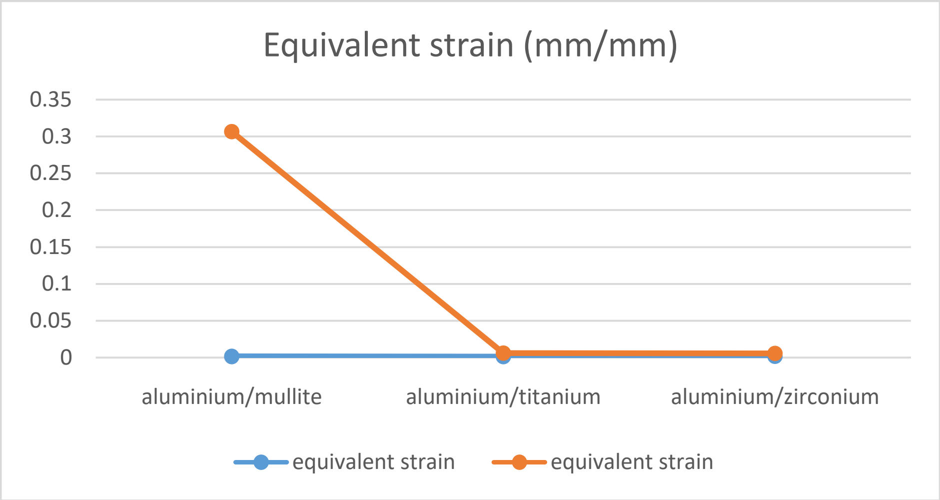


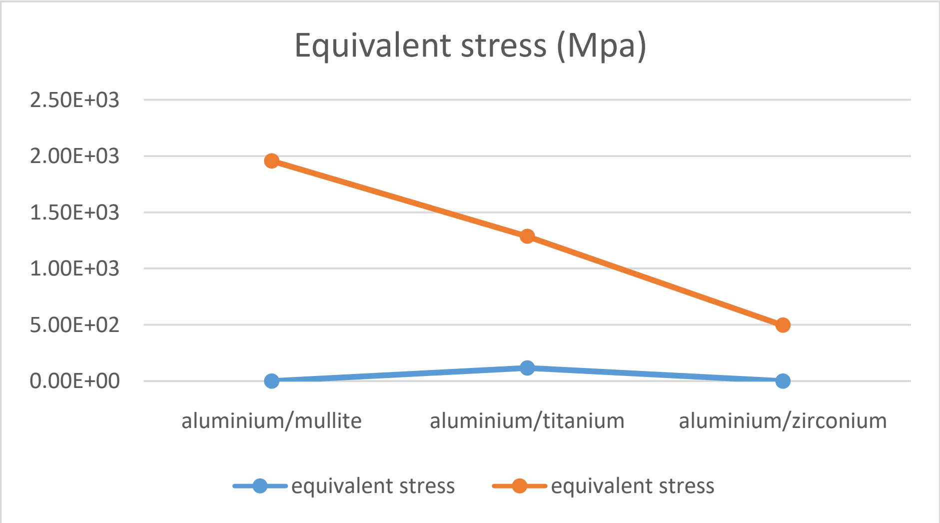
Fig: 5.2.6 Picture showing min/max values from buckling deformation of 5layer cylindrical shell

6.7 Table representingvalues for 5 layer cylindrical shell

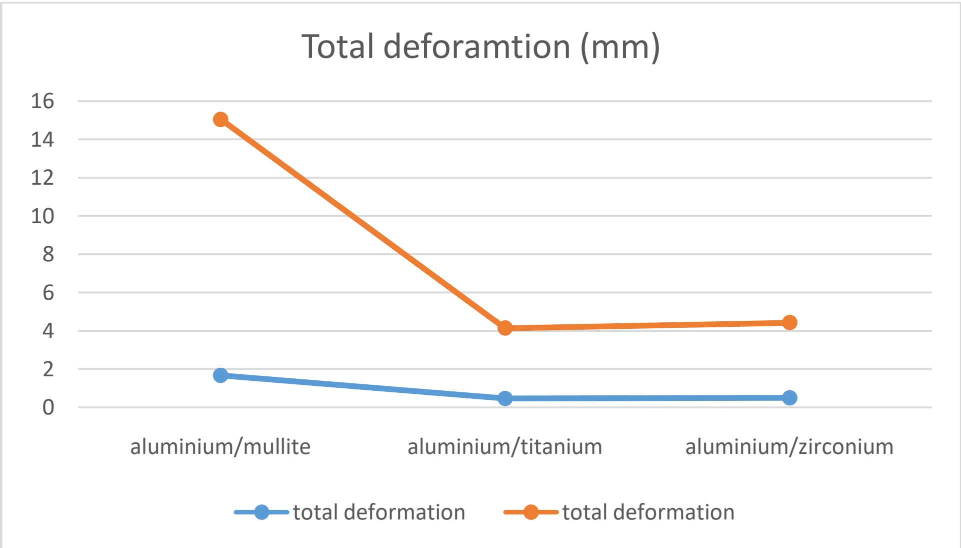
5-layers	equivalent strain (mm/mm)		equivalent stress (Mpa)		total deformation (mm)		Temperature (^{0}C)		total heat flux (W/mm^2)		buckling deformation (mm)		buckling factor
	min	max	min	max	min	max	min	max	min	max	min	max	
Aluminium-mullite	0.001468	0.30666	5.63E-06	1956.7	1.6728	15.056	200	200	6.42E-17	6.21E-13	0.11112	1.0001	-1.5081
Aluminium-titanium	1.27E-03	5.94E-03	117.17	1286	0.45995	4.1396	200	200	4.13E-17	4.95E-13	0.120806	1.0878	-3425.5
Aluminium-zirconium	0.001596	0.005502	3.00E-07	496.59	0.49165	4.4249	200	200	6.66E-17	1.01E-12	0.14846	1.3361	-487.87



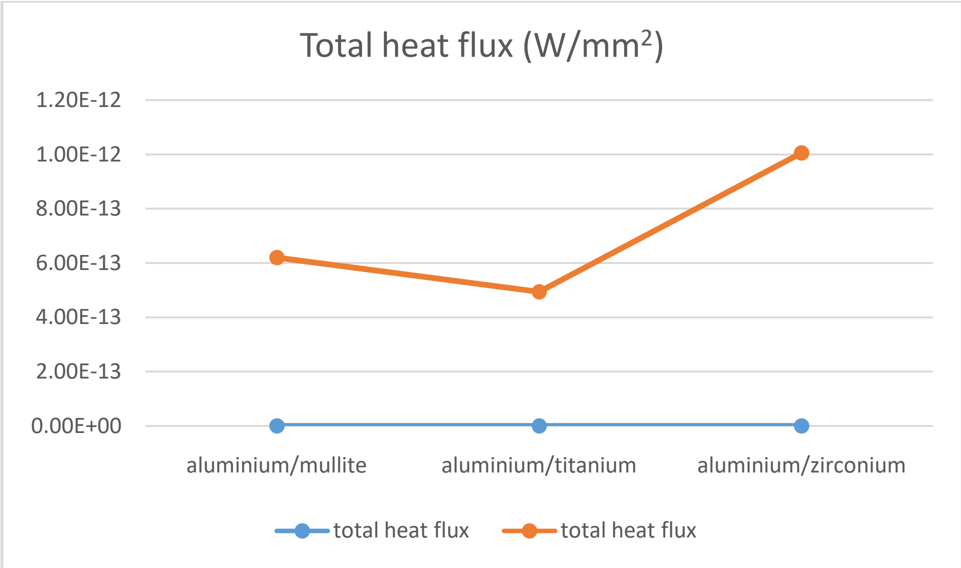
Graph.6.7.1 Graph showing equivalent strain for 5 layer cylindrical shell



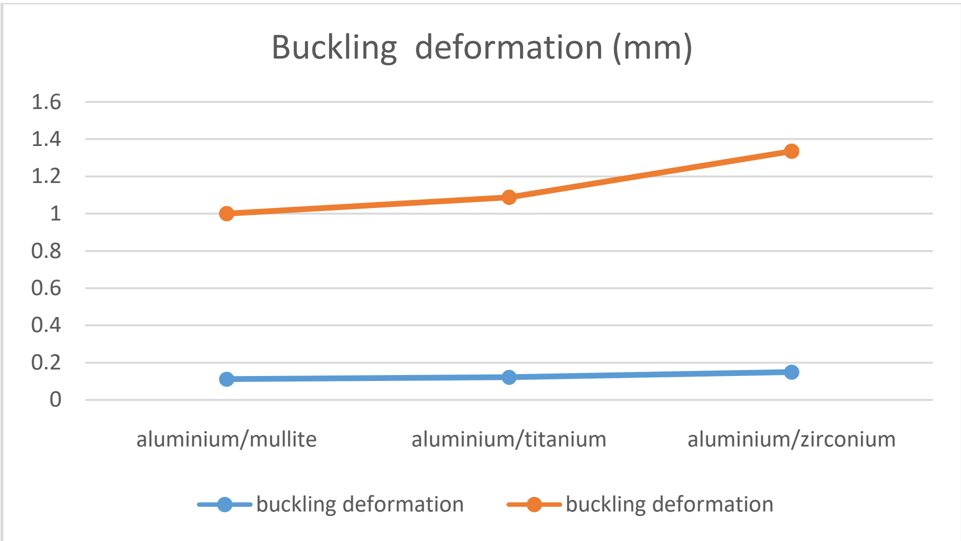
Graph.6.7.2 Graph showing equivalent stress for 5 layer cylindrical shell



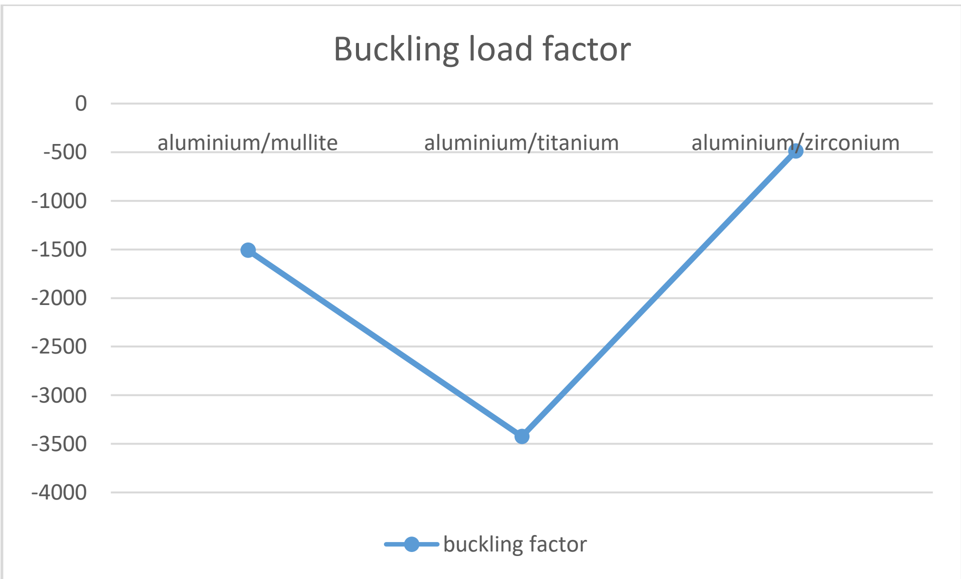
Graph.6.7.3 Graph showing total deformation for 5 layer cylindrical shell



Graph.6.7.4 Graph showing total heat flux for 5 layer cylindrical shell



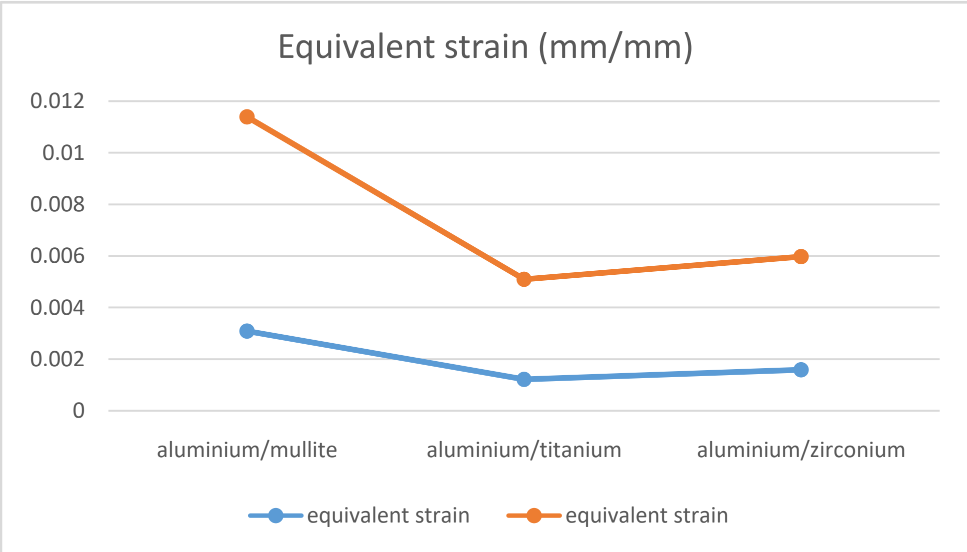
Graph.6.7.5 Graph showing buckling deformation for 5 layer cylindrical shell



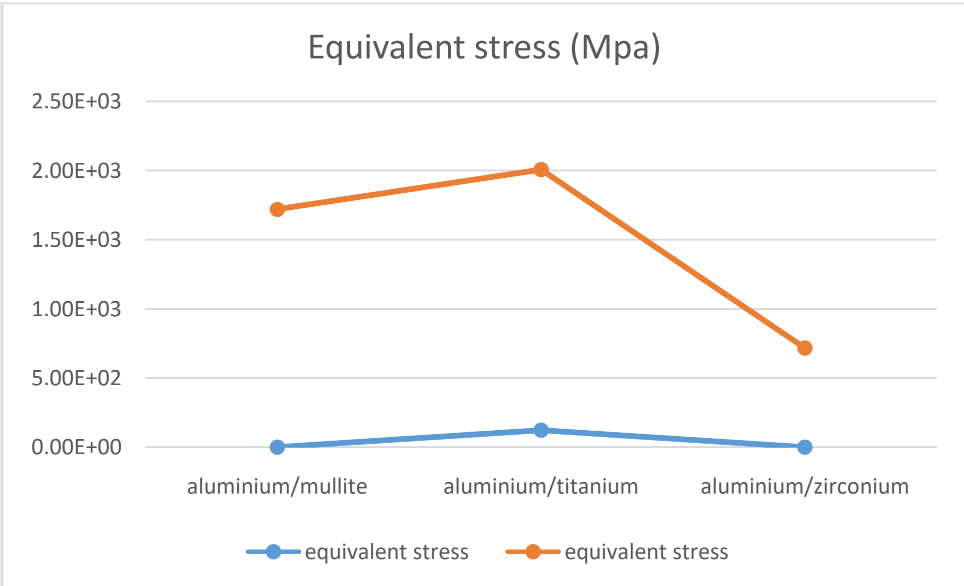
Graph.6.7.6 Graph showing buckling factor for 5 layer cylindrical shell

6.8 Table representing static structuralvalues for 10 layer cylindrical shell

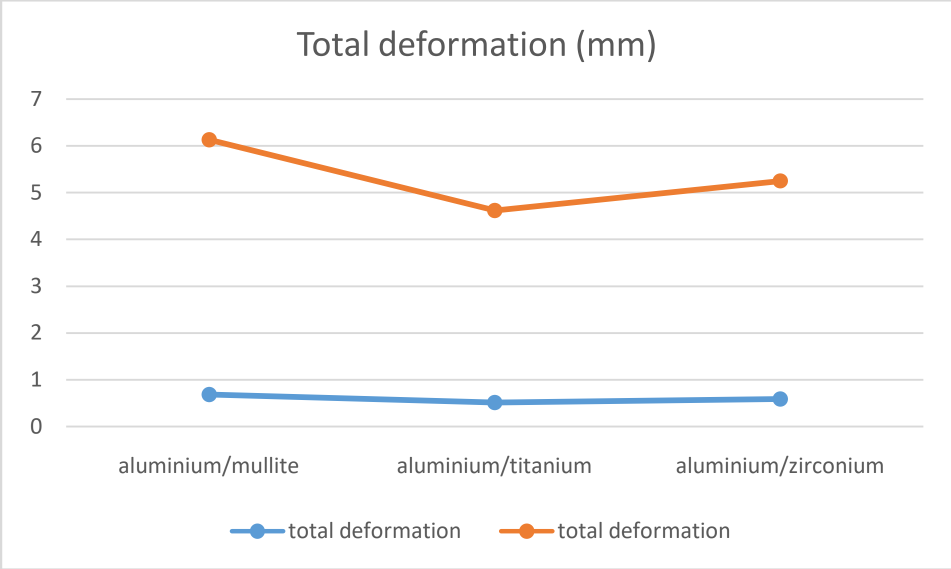
10-layers	equivalent strain(mm/mm)		equivalent stress(Mpa)		total deformation(mm)		Temperature(^{0}C)		total heat flux(W/mm^2)		buckling deformation(mm)		buckling factor
	min	max	min	max	min	max	min	max	min	max	min	max	
Aluminium-mullite	0.00309	0.011391	3.83E-07	1720	0.68153	6.1338	200	200	2.56E-16	3.62E-12	0.11111	1	-1007.9
Aluminium-titanium	0.001221	0.005101	122.45	2008	0.51296	4.6166	200	200	4.46E-16	3.84E-12	0.11111	1	-3330.6
Aluminium-zirconium	0.001595	0.005979	3.95E-07	717.03	0.5851	5.2516	200	200	3.31E-16	2.92E-12	0.11111	1	-1210.6



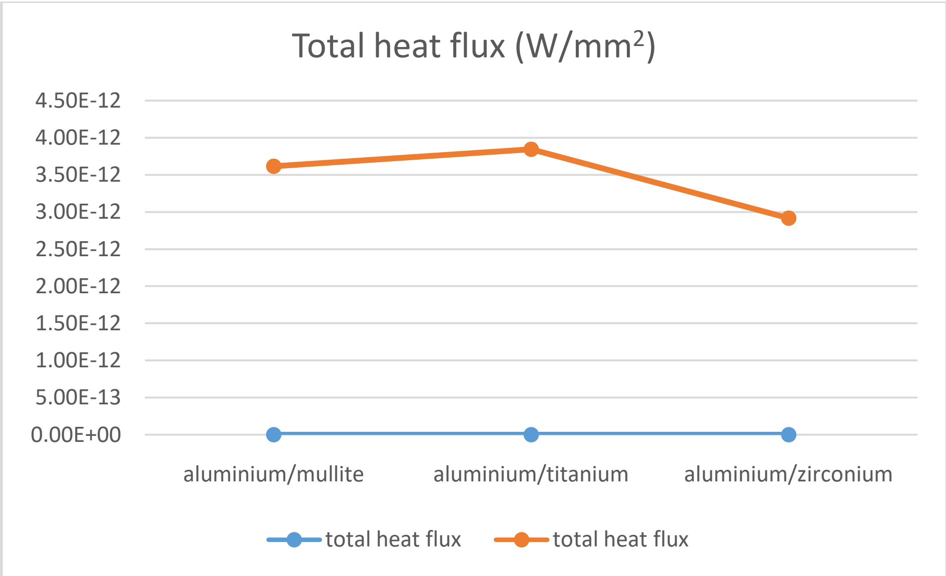
Graph.6.8.1 Graph showing equivalent strain for 5 layer cylindrical shell



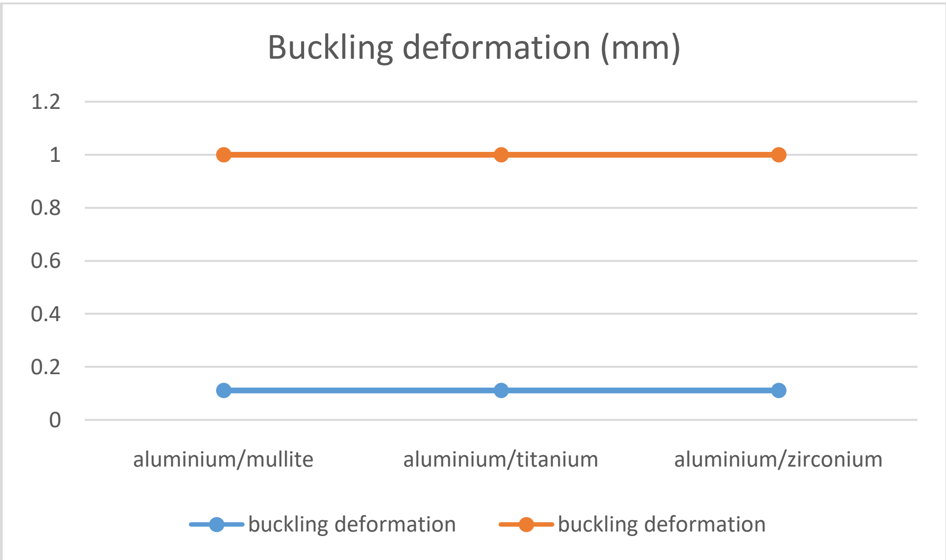
Graph.6.8.2 Graph showing equivalent stress for 5 layer cylindrical shell



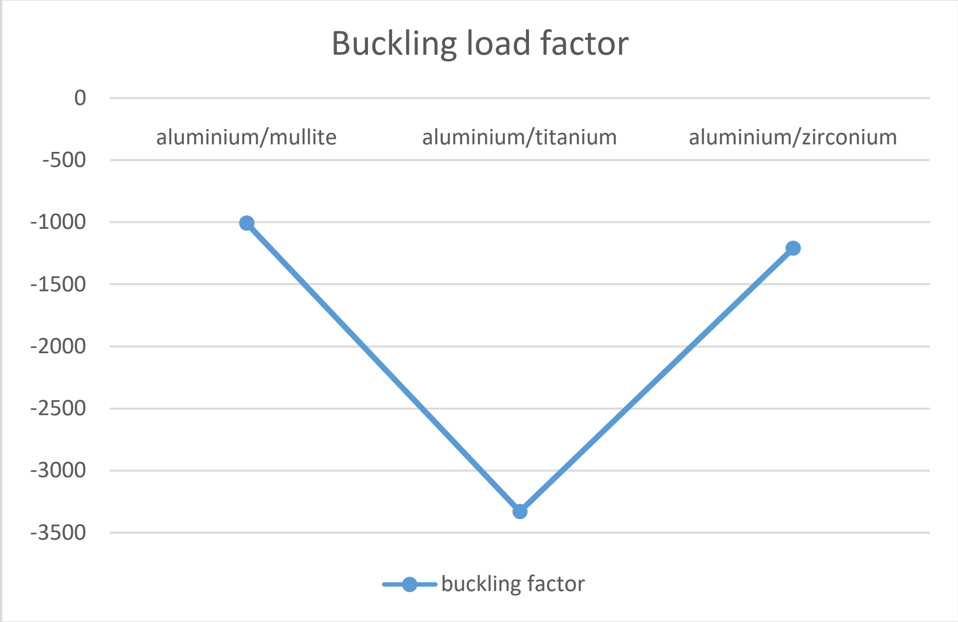
Graph.6.8.3 Graph showing total deformation for 5 layer cylindrical shell



Graph.6.8.4 Graph showing total heat flux for 5 layer cylindrical shell



Graph.6.8.5 Graph showing buckling deformation for 5 layer cylindrical shell



Graph.6.8.6 Graph showing buckling factor for 5 layer cylindrical shell

VI. CONCLUSIONS

In this thesis thermal, structural and buckling behaviour of cylindrical shell made up of functionally graded materials are studied using ansys simulation tool. Material properties for the study are calculated using available formulation from literature. Total three FGM's are included in this study namely aluminium-mullet, aluminium-titanium and aluminium-Zirconium. The following observations are made from the study.

1. Lowest fluxes are recorded in aluminum-titanium FGM as both are metals. Coming to other two combinations aluminum-zirconium has lowest heat flux than aluminium-mullite. Whereas all three materials have low flux.
2. In structural analysis highest deformation are in aluminum-mullet combination in both the models and lowest deformations are developed in aluminum-titanium.
3. Coming to stress, highest stress are recorded in aluminum-titanium for 10 layer model and in aluminum-mullet for 5 layers.
4. The buckling behavior is similar irrespective of the materials in terms of deformations.
5. Buckling load factor varies with respective of material and number of constituent layers.

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