Structural & 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.

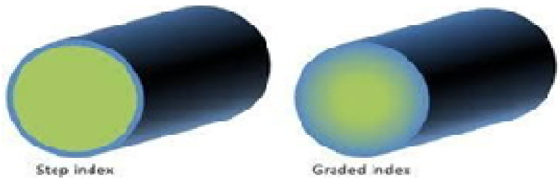
Keywords- structural behavior, FGM, cylindrical shell, simulation study.

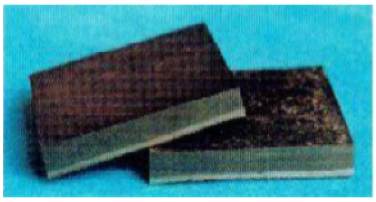
I. INTRODUCTION

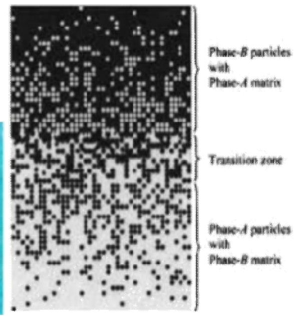
Pure metals are of little use in engineering applications because of the demand of conflicting property requirement. For example, an application may require a material that is hard as well as ductile, there is no such material existing in nature. To solve this problem, combination (in molten state) of 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 analysing 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

The importance of functionally graded materials, there are many research efforts at developing the fabrication processing, material processing, and properties of the FGM. This paper represents an overview of application areas of FGM and fabrication methods. Some research works on FGM in recent times are shown and the future study needs are preferred.





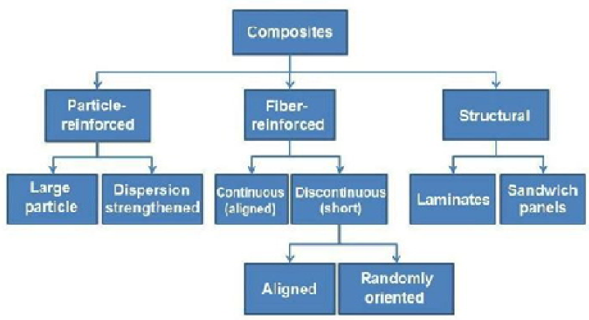


Classification of composites I (based on matrix material)

Metal Matrix Composites (MMC)
Ceramic Matrix Composites (CMC)
Polymer Matrix Composites (PMC)

Classification of composite materials II (based on reinforcing material structure)

Short-fiber reinforced composites
Long-fiber reinforced composites
Laminate Composites



II. PROCESSING TECHNIQUES OF FGM (FUNCTIONALLY GRADED MATERIALS)

Thin FGM are generally in the form of surface coatings, depending on the service requirement from the process there are a vast range of surface deposition processes to pick it from.

- Vapour Deposition Technique There are different types of vapour deposition techniques, they include:
- Powder Metallurgy (PM)
- Centrifugal Method
- Solid Freeform (SFF) Fabrication Method

Areas of application are:

- automobile engine components
- heat exchanger
- nuclear reactor components
- sensors
- cutting tool insert coating
- turbine blade
- Tribology
- Fire retardant doors, etc.

This list of applications is endless and many more applications is springing up as the processing technology, properties of FMG and cost of production developed.

III. AREAS OF APPLICATION OF FGM

The applications of FGM are explained below:

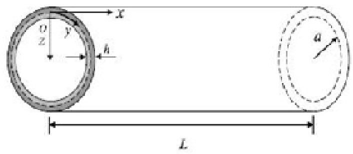
1. FGM in Aerospace: FGM can resist very high thermal gradient, this makes it satisfactory for use in space plane body and rocket engine component, structures, etc... If processing technique is developed, functionally graded material are promising and can be used in vast areas of aerospace.
2. FGM in Medicine: Living tissues like teeth and bones are characterized as FGM from nature, to substitute these tissues, a well matched material is required that will fulfil the cause of the original bio-tissue. The absolute candidate for this application is FGM. Functionally graded material has found wide range of entreaty in dental and orthopaedic solicitation for bone and teeth replacement.
FGM in Defence: It is the most important characteristics of FGM is the capability to hamper crack generation. This property makes it functional in defence application, as a PRM (penetration resistant materials) used for bullet-proof vests and armour plates.
4. FGM in Energy: Functionally graded material are worn in energy conversion devices. They also provide thermal barrier and are used as protective coating on turbine blades in gas turbine engine.
5. FGM in Optoelectronics: FGM also finds its application in optoelectronics as graded refractive index materials and in audio-video discs magnetic storage media.

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 P and piezoelectric coefficients p (z) of the FGM cylindrical shell are assumed to vary through the thickness of the shell. Here, FGM's material properties P are related not only to material properties of the material constituent, but also to their volume fractions V1 and V2, therefore.

$P(z) = P1V1 + P2V2 = P2 + (P1 - P2)V1$

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.



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, the following material constants for the FGM cylindrical shell

Properties	Symbol	Unit's
Young's modulus	E	Gpa
Poisson's ratio	V	
Thermal conductivity	K	W/mk
Co-efficient of thermal expansion	A	1/K
Density	P	kg/m^3

Material constants of FGM cylindrical shell

P (z) =Properties of "z" layer
P1 =properties of ceramic
P2 =properties of ceramic
V2 =volume fraction

$$P(z) = P2 + (P1 - P2)V1 = P1(V1) + P2(V2)$$

ALUMINIUM WITH ZIRCONIUM

Properties	Aluminium (metal)	Zirconium (ceramic)
Young's modulus (e)	70Gpa	151Gpa
Poisson's ratio (V)	0.3	0.3
Thermal conductivity (K)	204 W/mk	2.9 W/mk
Co-efficient of thermal expansion (α)	$23*10^{-6}$ /k	$10*10^{-6}$ /k
Density (ρ)	$2.7*10^3$ kg/m^3	$5.89*10^3$ kg/m^3

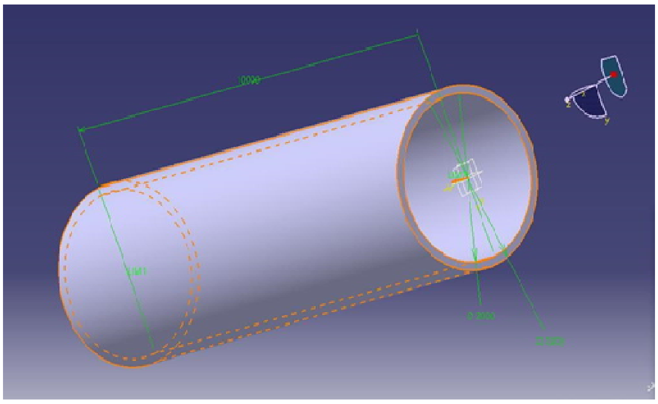
ALUMINIUM WITH MULLITE

Properties	Aluminium (metal)	mullite (ceramic)
Young's modulus (e)	70Gpa	151gpa,
Poisson's ratio (V)	0.3	0.26,
Thermal conductivity (K)	204 W/mk	6 W/mk,
Co-efficient of thermal expansion (α)	$23*10^{-6}$ /k	$5.4*10^{-6}$ /k,
Density (ρ)	$2.7*10^3$ kg/m^3	2800 kg/m^3

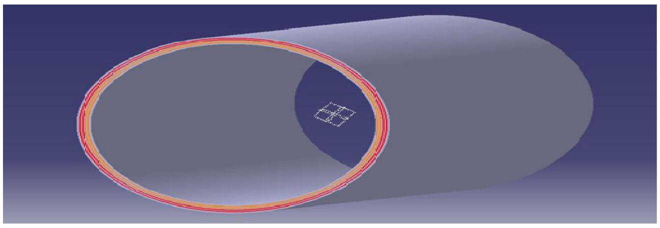
ALUMINIUM WITH TITANIUM CARBIDE

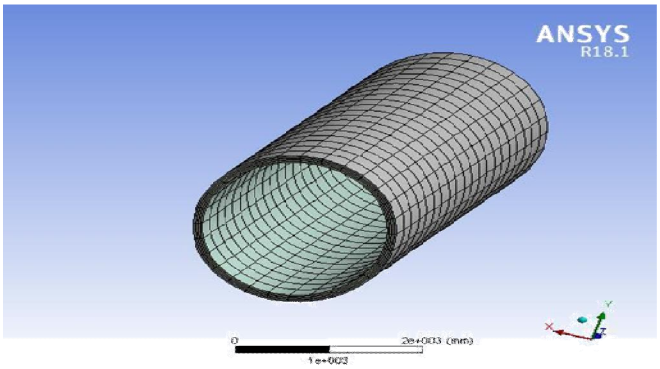
Properties	Aluminium (metal)	Titanium carbide (ceramic)
Young's modulus (e)	70Gpa	460Gpa
Poisson's ratio (V)	0.3	0.336
Thermal conductivity (K)	204 W/mk	5.64 W/mk
Co-efficient of thermal expansion (α)	$23*10^{-6}$ /k	$7.4*10^{-6}$ /k
Density (ρ)	$2.7*10^3$ kg/m^3	4930 kg/m^3

IV. DESIGN MODELS AND MESHED MODEL



CATIA model of a cylindrical shell

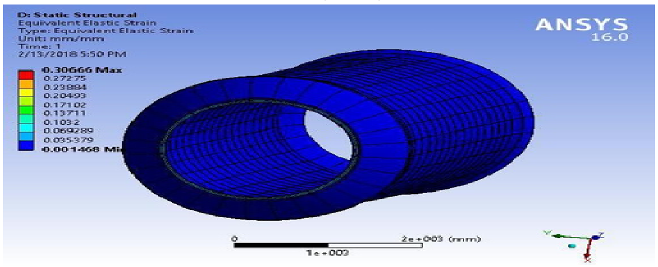




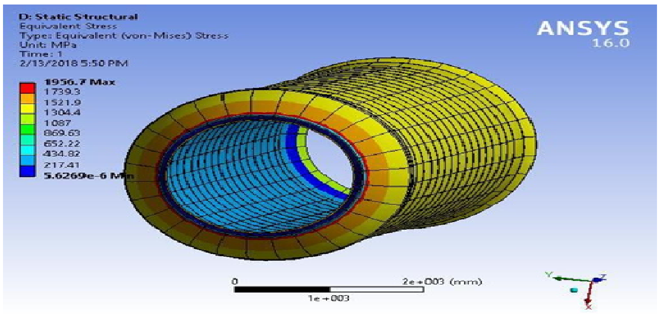
Mesh structure 10 layer cylindrical shell

RESULTS

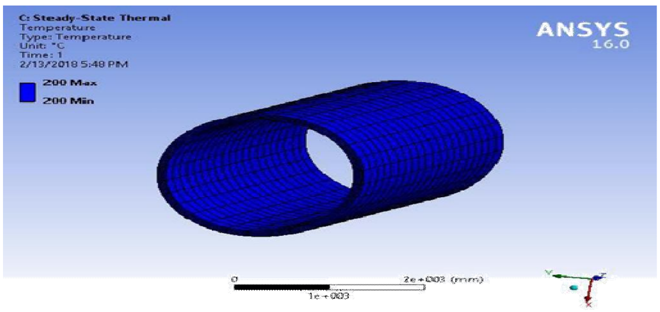
Aluminium/mullite with 5 layer cylindrical shell



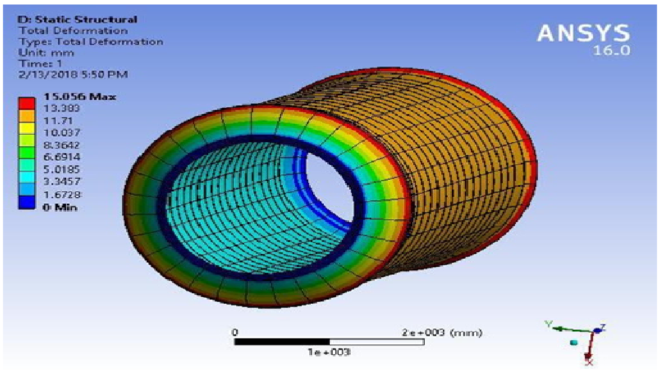
min/max values from equivalent strain of 5layer cylindrical shell



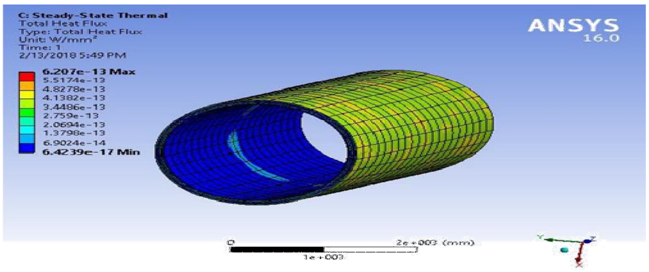
min/max values from equivalent stress of 5layer cylindrical shell



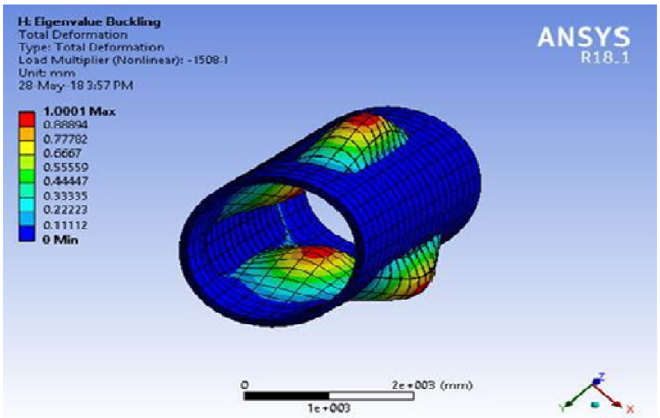
min/max values from temperature of 5layer



min/max values from total deformation of 5layer cylindrical shell

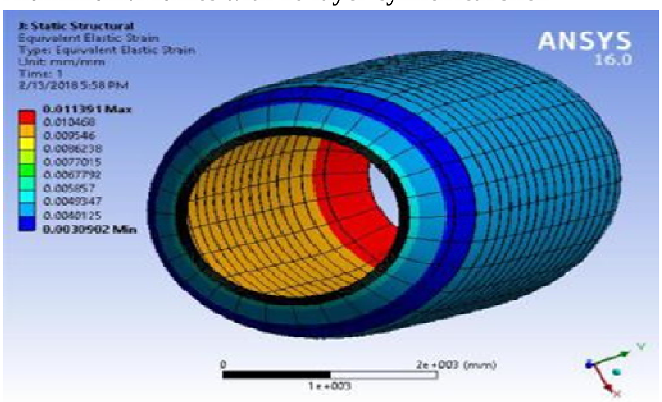


min/max values from total heat flux of 5layer cylindrical shell

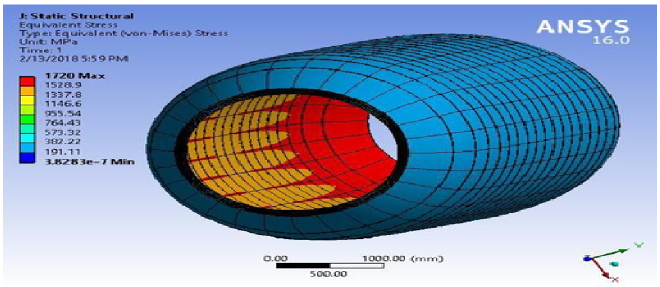


min/max values from buckling deformation of 5layer cylindrical shell

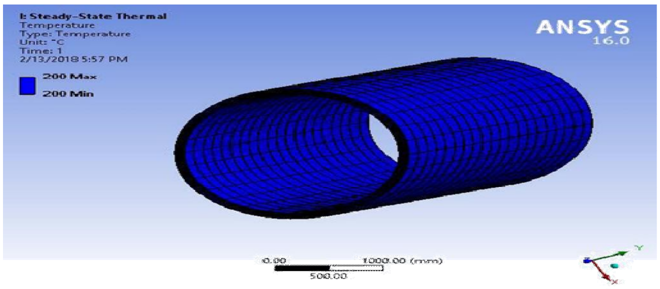
Aluminium/Mullite with 10 layer cylindrical shell



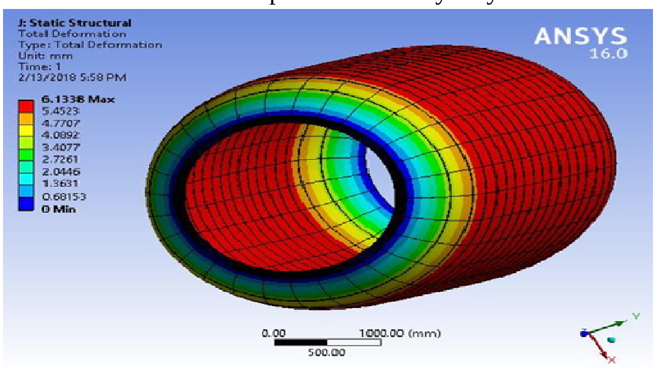
min/max values from equivalent strain of 10layer cylindrical shell



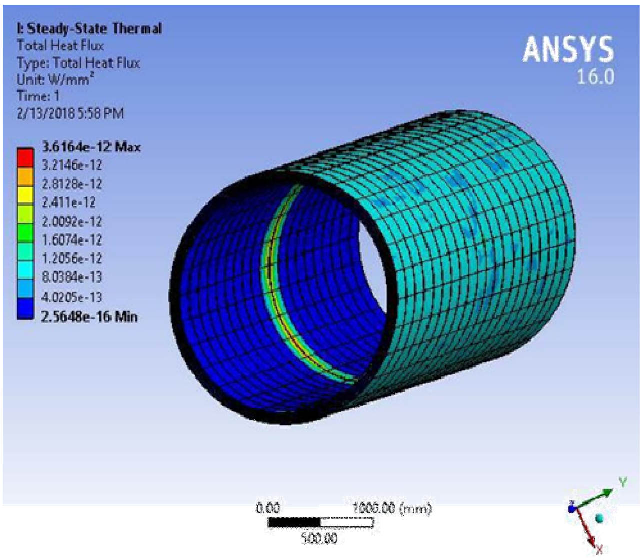
min/max values from equivalent stress of 10layer cylindrical shell



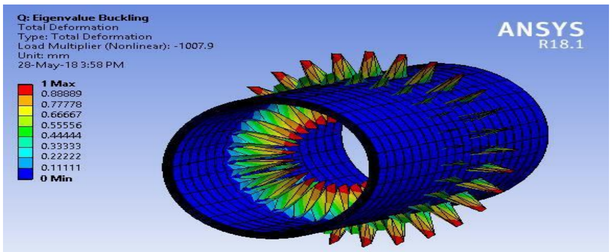
min/max values from temperature of 10layer cylindrical shell



min/max values from total deformation of 10layer cylindrical shell

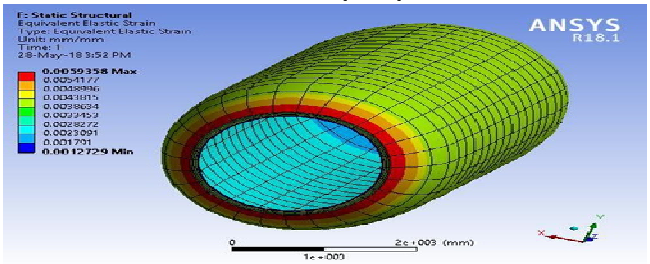


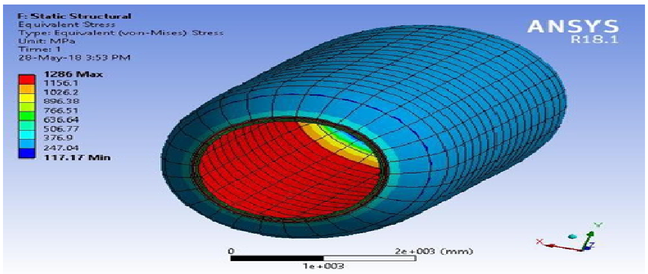
min/max values from total heat flux of 10layer cylindrical shell

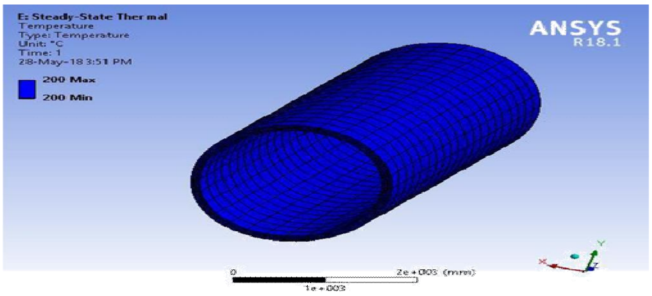


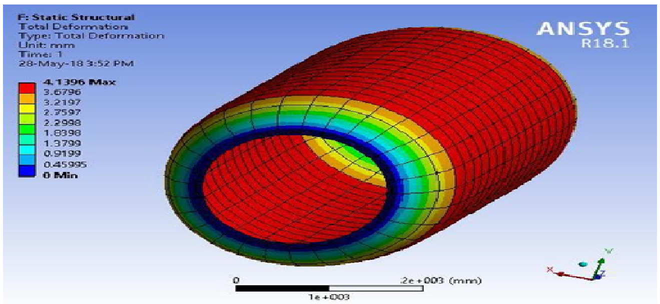
min/max values from buckling deformation of 10layer cylindrical shell

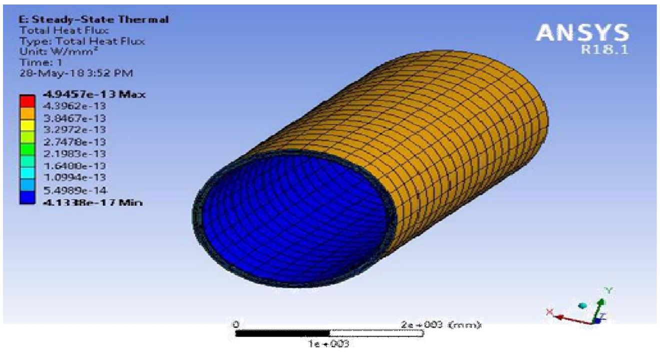
Aluminium/Titanium with 5 layer cylindrical shell

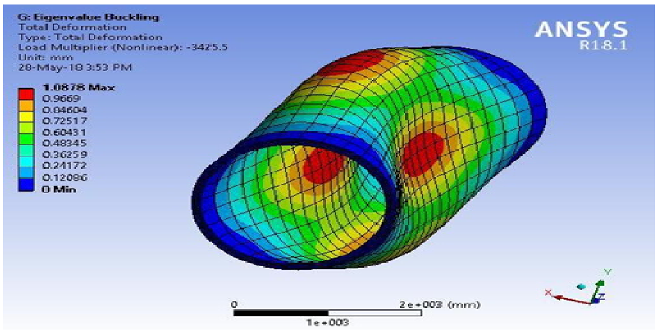






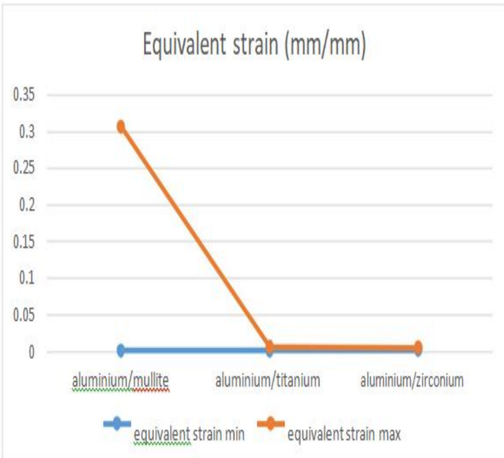




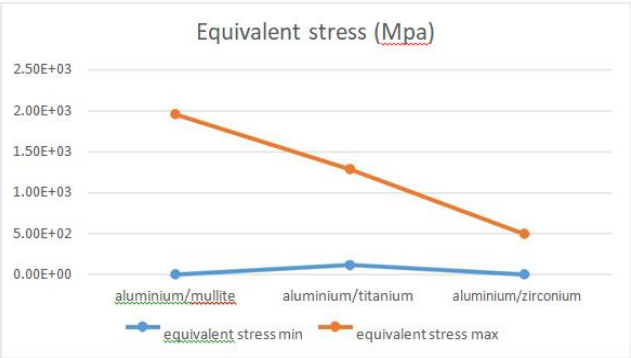


static structural values for 5 layer cylindrical shell

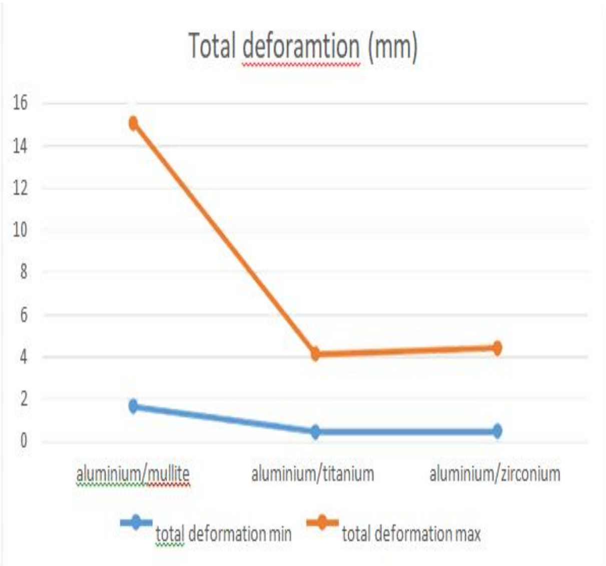
5-layers	Equivalent strain (mm/mm)		Equivalent stress (Mpa)		Total deformation (mm)	
	Min	Max	Min	Max	Min	Max
aluminium/mullite	0.001468	0.30666	5.63E-06	1956.7	1.6728	15.056
aluminium/titanium	1.27E-03	5.94E-03	117.17	1286	0.45995	4.1396
aluminium/zirconium	0.001596	0.005502	3.00E-07	496.59	0.49165	4.4249



Equivalent strain for 5 layer cylindrical shell

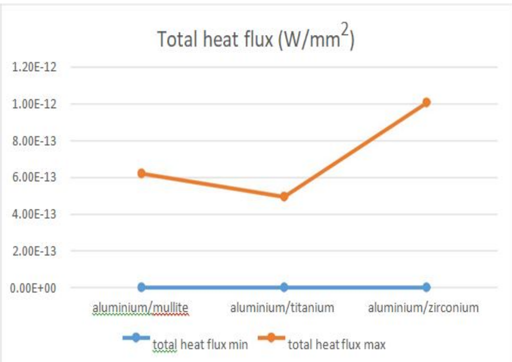


Equivalent stress for 5 layer cylindrical shell



Total deformation for 5 layer cylindrical shell

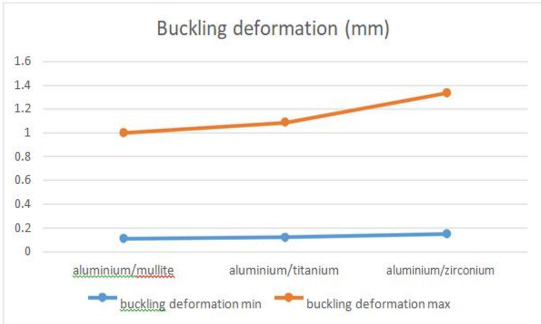
5-layers	Temperature (^0C)		Total heat flux (W/mm^2)	
	Min	Max	Min-	Max-
aluminium/mullite	200	200	6.42E-17	6.21E-13
aluminium/titanium	200	200	4.13E-17	4.95E-13
aluminium/zirconium	200	200	6.66E-17	1.01E-12



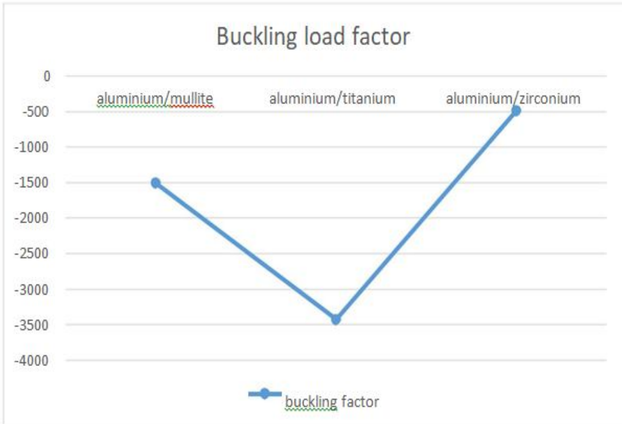
Total heat flux for 5 layer cylindrical shell

Buckling analysis values for 5 layer cylindrical shell

5-layers	Buckling deformation (mm)		Buckling load factor
	min	max	
aluminium/mullite	0.11112	1.0001	-1508.1
aluminium/titanium	0.120806	1.0878	-3425.5
aluminium/zirconium	0.14846	1.3361	-487.87

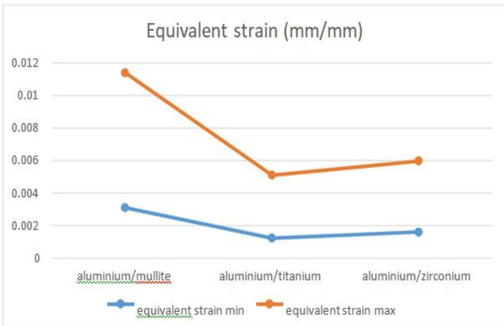


Buckling deformation for 5 layer cylindrical shel

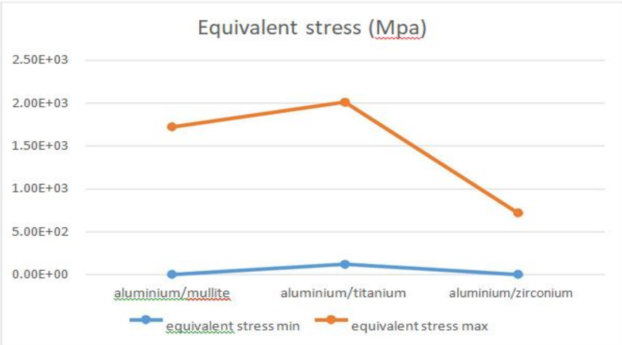


Buckling load factor for 5 layer cylindrical shell

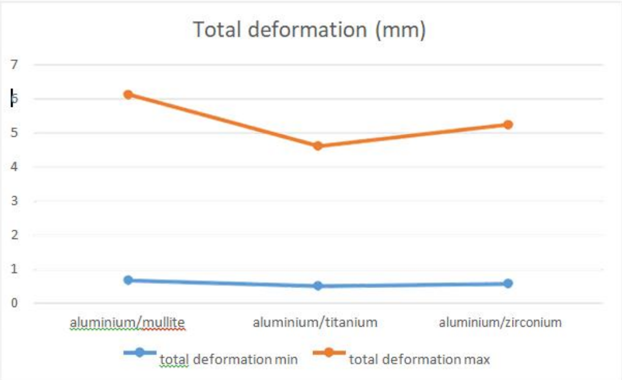
10-layers	Equivalent strain (mm/mm)		Equivalent stress (Mpa)		Total deformation (mm)	
	min	max	min	max	min	max
aluminium/mullite	0.00309	0.011391	3.83E-07	1720	0.68153	6.1338
aluminium/titanium	0.001221	0.005101	122.45	2008	0.51296	4.6166
aluminium/zirconium	0.001595	0.005979	3.95E-07	717.03	0.5851	5.2516



Equivalent strain for 10 layer cylindrical shell



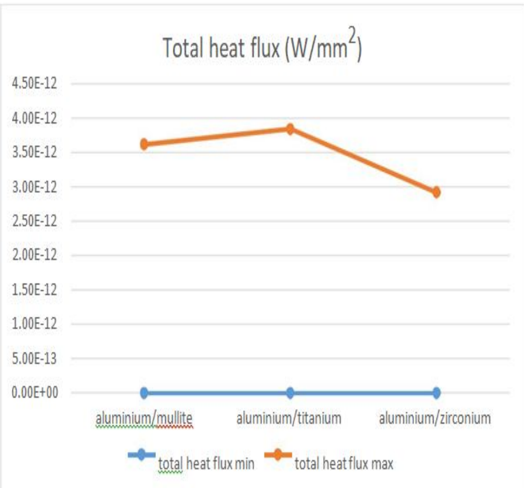
Equivalent stress for 10 layer cylindrical shell



Total deformation for 10 layer cylindrical shell

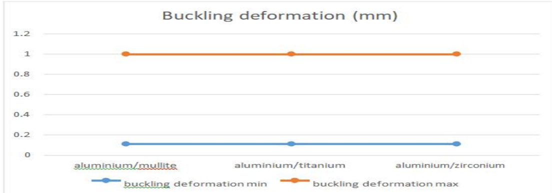
static structural values for 10 layer cylindrical shell

10-layers	Temperature (^{0}C)		Total heat flux (W/mm^2)	
	min	max	min	max
aluminium/mullite	200	200	2.56E-16	3.62E-12
aluminium/titanium	200	200	4.46E-16	3.84E-12
aluminium/zirconium	200	200	3.31E-16	2.92E-12

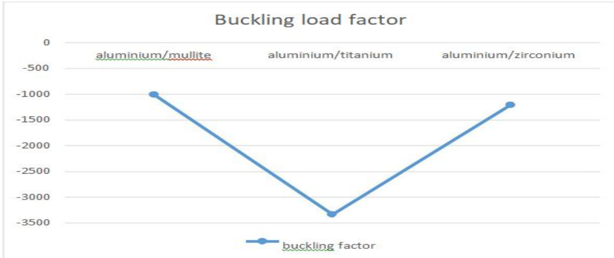


Total heat flux for 10 layer cylindrical shell

10-layers	Buckling deformation (mm)		Buckling load factor
	min	max	
aluminium/mullite	0.11111	1	-1007.9
aluminium/titanium	0.11111	1	-3330.6
aluminium/zirconium	0.11111	1	-1210.6



Buckling deformation for 10 layer cylindrical shell



Buckling load factor for 10 layer cylindrical shell

Values from thermal, pressure, structural and buckling values obtained by simulation

5-layers	equivalent strain		equivalent stress		total defomation		total heat flux		buckling defomation		buckling factor
	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	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	4.13E-17	4.95E-13	0.120806	1.0878	-3425.5
aluminium/zirconium	0.0015964	0.0055024	3.00E-07	496.59	0.49165	4.4249	6.66E-17	1.01E-12	0.14846	1.3361	-487.87

10-layers	equivalent strain		equivalent stress		total defomation		total heat flux		buckling defomation		buckling factor
	min	max	min	max	min	max	min	max	min	max	
aluminium/mullite	0.0030902	0.011391	3.83E-07	1720	0.68153	6.1338	2.56E-16	3.62E-12	0.11111	1	-1007.9
aluminium/titanium	0.0012209	0.0051007	122.45	2008	0.51296	4.6166	4.46E-16	3.84E-12	0.11111	1	-3330.6
aluminium/zirconium	0.0015952	0.0059786	3.95E-07	717.03	0.5851	5.2516	3.31E-16	2.92E-12	0.11111	1	-1210.6

V. 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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