Linear Buckling Analysis of Pressure Hull with Functionally Graded Material

Reshma R Pillai
Dept. of Civil Engineering, Sree Buddha College of Engineering, Pathanamthitta, Kerala, India

Dr. Nivin Philip,
Assistant professor, Dept. of Civil Engineering, Mar Athanasius College of Engineering, Ernakulum, Kerala, India

Aiswarya S
Assistant Professor,
Dept. of Civil Engineering, Sree Buddha College of Engineering. Pathanamthitta, Kerala, India

***Abstract* - Pressure hulls are the main load bearing structures of naval submarines that withstands the compressive hydrostatic pressure. In materials science Functionally Graded Material (FGM) may be characterized by the variation in composition and structure gradually over volume, resulting in corresponding changes in the properties of the material. In this thesis pressure hull is modelled with functionally graded materials and is analysed using ANSYS software. The linear buckling analysis is done to get the mode shapes of the chosen models.**

Keywords: Functionally Graded Materials, Linear Buckling, Pressure hull

1. INTRODUCTION

The pressure hull is the inner hull of a submarine; this holds the difference between outside and inside pressure. Huang and Chenb [4] in their work *studies the* powder metallurgy method used to make the functionally graded $Al2O_3$–ZrO_2 composite. Xin et al [5] in their work discusses the thermo elastic problem of the functionally graded thick walled tube subjected to axi-symmetric mechanical and thermal loads.

Hong and Lee [6] in their work present a spectral element model for a modified FGM axial bar model. Ramu and Mohanthy [9] in their work aims to carry out modal analysis of a FGM plate to determine its natural frequencies and mode shapes by using finite element method. Mahendra [2] et al in their work, the assembly of the pressure hull including navigation compartment shell; battery compartment shell which are connected with bolts is designed. Deepika and Kumar [4] in their work studied pressure hull subjected to huge dynamic loads and have analysed the pressure hull for vibrations and shock loads.

Little et al [1] studied the buckling of 12 thin-walled geometrically imperfect tubes were tested to destruction under uniform external hydrostatic pressure. Seung-Eock Kim and Chang-Sung Kim [7] in their work developed practical design equations and charts estimating the buckling strength of the cylindrical shell and tank subjected to axially compressive loads. N. Jaunkya et al. [8] in their work, a design strategy for optimal design of composite grid-stiffened cylinders subjected to global and local buckling constraints and strength constraints was developed. MacKay [3] in his work the state-of-the-art of pressure hull structural analysis and design was established.

In this thesis a pressure hull is modelled with Functionally Graded Materials and is analysed using ANSYS software. The linear buckling analysis is done and is compared with the results of analysis result of normal pressure hull to obtain its feasibility. The work emphasis on finding the applicability of functionally graded materials in submarine works and its buckling analysis using software.

2. FUNCTIONALLY GRADED MATERIAL

A functionally graded material (FGM) is a two-component composite characterised by a compositional gradient from one component to the other. In this thesis mainly two types of Functionally Graded Materials are used. Titanium-Aluminium FGM and Steel-Aluminium FGM. Firstly the Steel-Aluminium FGM, where the hull plates are composed of outer layer fully of Steel and the quantity of Aluminium is increased throughout the thickness. FGMs offer great promise in applications where the operating conditions are severe. For example, wear-resistant linings for handling large heavy abrasive ore particles, rocket heat shields, heat exchanger tubes, thermoelectric generators, heat-engine components, plasma facings for fusion reactors, and electrically insulating metal/ceramic joints.

3. MODELLING

A pressure hull is a structure whose primary load-bearing responsibility is to withstand the compressive forces associated with hydrostatic pressure. The most efficient geometries for resisting these compressive forces are circular thin-walled cross-sections. Hence for this thesis a cylindrical hull is considered and only the cylindrical portion with end fixed support conditions is considered. I stiffeners were provides for circular ring stiffening at 0.8m spacing. Fig 2 shows the cross section of the ring stiffener used.

The dimensions of the hull considered in this study are:
Total Length of Hull = 66 m
Length of ring stiffened cylindrical portion = 60 m
Internal Diameter of the hull = 6m
Design depth = 350m

After several trial and error modelling of pressure hulls, an optimum thickness was chosen. The Steel pressure hull have a thickness of 24mm in total and the Steel-Aluminium FGM model have a thickness of 24mm with 12 layers each of 2mm thickness. The Titanium hull with a thickness of 14.4 mm was taken and for the Titanium-Aluminium FGM a thickness of 14.4mm with 12 layers each of 1.2mm thickness is considered. The Steel used for hull is HY 100 grade Steel

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which has a yield strength of 690MPa and Grade 19 Titanium plates are used for Titanium models which has a yield strength of 1170MPa. Fig 3.2 shows the ring stiffened cylindrical portion of the pressure hull modelled in ANSYS. The Young‘s modulus and Poisson‘s ratio of the plates vary continuously only in the thickness direction (z-axis) i.e. E = E(z), ν = ν (z). However, the Young‘s modulus in the thickness direction of the FGM plates vary with power-law functions (P-FGM), exponential functions (E-FGM), or with sigmoid functions (S-FGM).A mixture of the two materials composes the through the thickness characteristics. The values are calculated and applied in the model. Fig 3 shows the typical model used for the study.

4. LINEAR BUCKLING ANALYSIS

The most basic form of buckling analysis in Finite Element Analysis (FEA) is linear buckling. This is directly related to the classic Euler type of calculation. A small displacement of a perturbed shape is assumed in each element that induces a stress dependent stiffening effect.

The full models considered for linear buckling analysis are as follows:

1. Steel pressure hull with fixed supports and I stiffeners at 0.8m spacing. (SFI)
2. Steel FGM pressure hull with fixed supports and I stiffeners at 0.8m spacing. (SFFI)
3. Titanium pressure hull with fixed supports and I stiffeners at 0.8m spacing. (TFI)
4. Titanium FGM pressure hull with fixed supports and I stiffeners at 0.8m spacing. (TFFI)

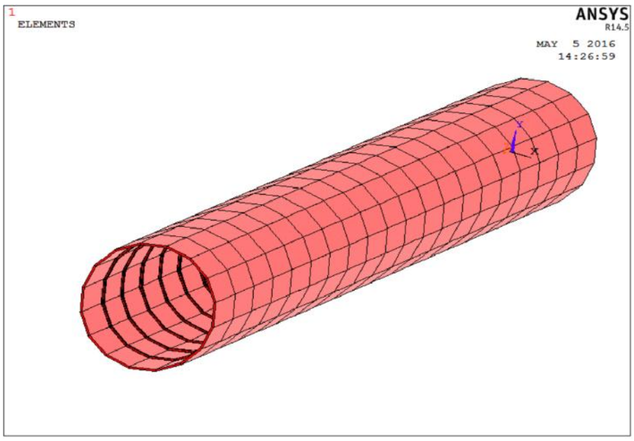

Fig 3: Basic Model in ANSYS

For linear buckling analysis to obtain the critical load factor of buckling, unit load is applied as uniform external pressure. The result of the analysis is a table of buckling load factor as given in Table 1 and Table 2 for each model followed by set of mode shapes, or eigenvectors. The buckling load factor gives the critical load value above which the model buckles.

Table 1: Buckling load factor

Mode No	Buckling load factor (MPa)			
	SFI	SFFI	TFI	TFFI
1	8.37	6.19	1.39	1.10
2	8.37	6.19	1.39	1.10
3	9.10	6.19	1.39	1.10
4	9.10	6.19	1.39	1.10
5	9.63	6.19	1.39	1.10
6	9.63	6.19	1.39	1.10

Table 2: Deformation factor

Mode No	Deformation factor (MPa)			
	SFI	SFFI	TFI	TFFI
1	1.338	0.176	0.166	0.166
2	1.001	0.176	0.166	0.166
3	1.167	0.176	0.166	0.166
4	1.029	0.176	0.166	0.166
5	0.177	0.176	0.166	0.166
6	0.177	0.176	0.166	0.166

Fig 4(a) to Fig4(f) shows the first six mode shapes of the model with Steel pressure hull with fixed supports and I stiffeners at 0.8m spacing. (SFI) Fig 5(a) to Fig5(f) shows the first six mode shapes of the model with Steel FGM pressure hull with fixed supports and I stiffeners at 0.8m spacing. (SFFI). Both the models of Titanium and its FGM gave the same mode shapes as that of model steel and its FGM.

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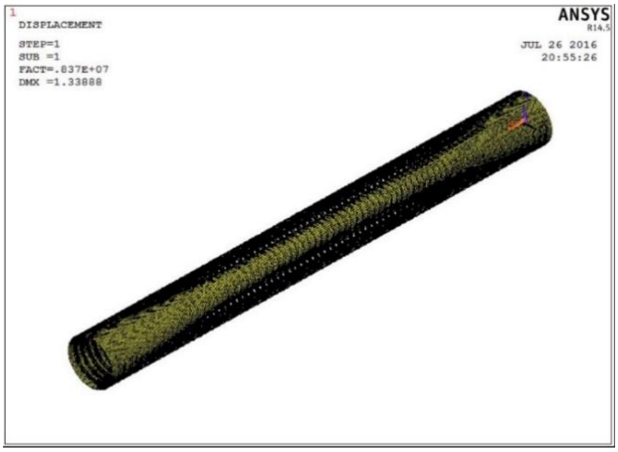

Fig 4(a): Steel hull (Mode 1)

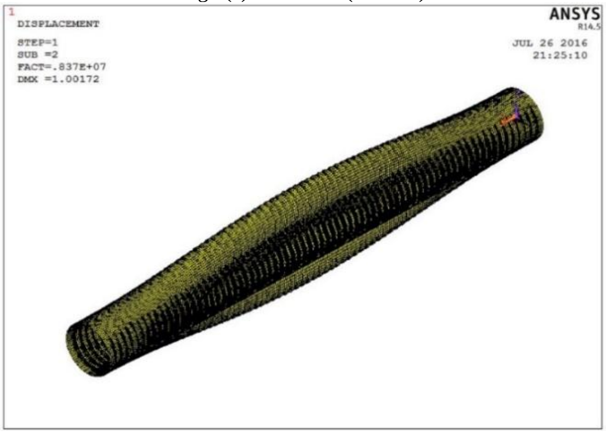

Fig 4(b): Steel hull (Mode 2)

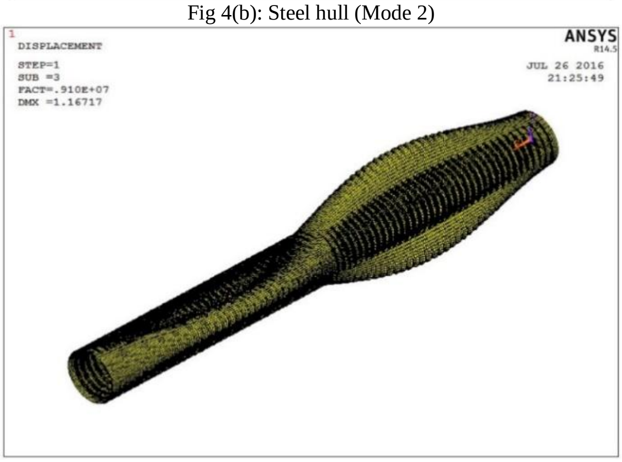

Fig 4(c): Steel hull (Mode 3)

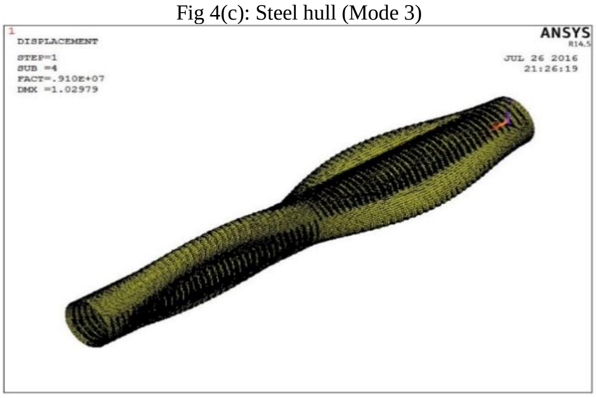

Fig 4(d): Steel hull (Mode 4)

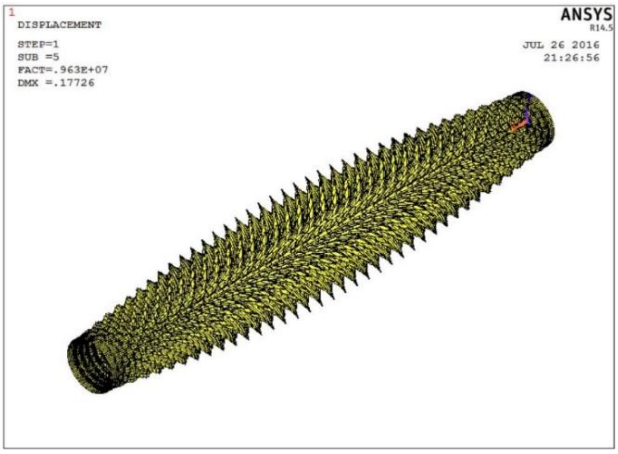

Fig 4(e): Steel hull (Mode 5)

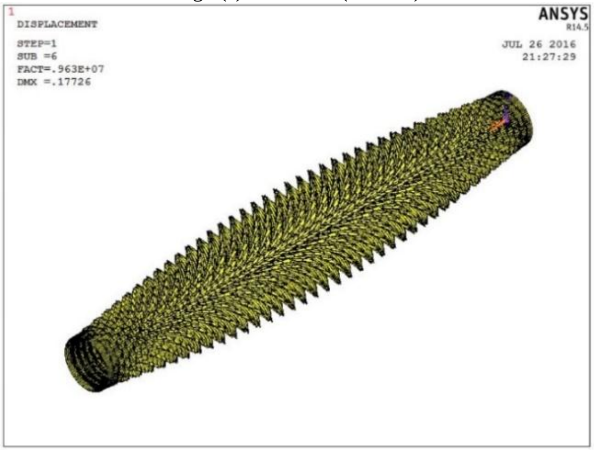

Fig 4(f): Steel hull (Mode 6)

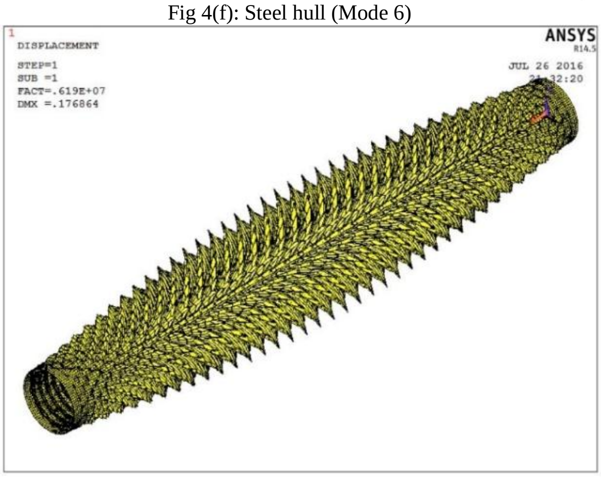

Fig 5 (a): Steel FGM hull (Mode 1)

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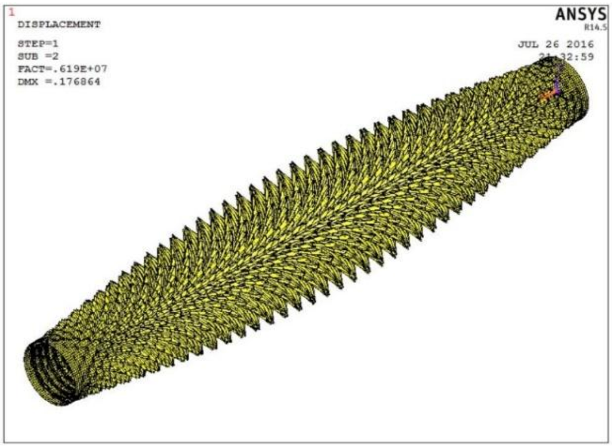

Fig 5(b): Steel FGM hull (Mode 2)

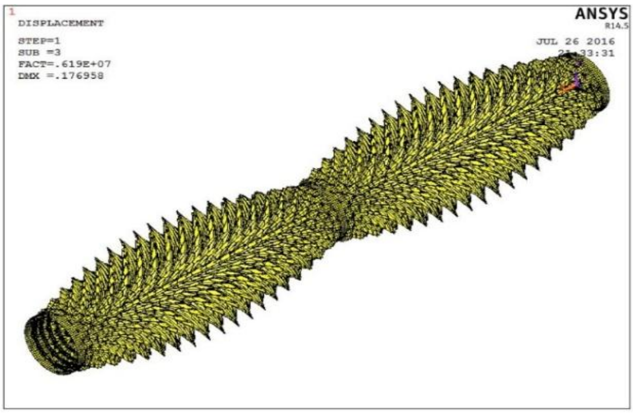

Fig 5(c): Steel FGM hull (Mode 3)

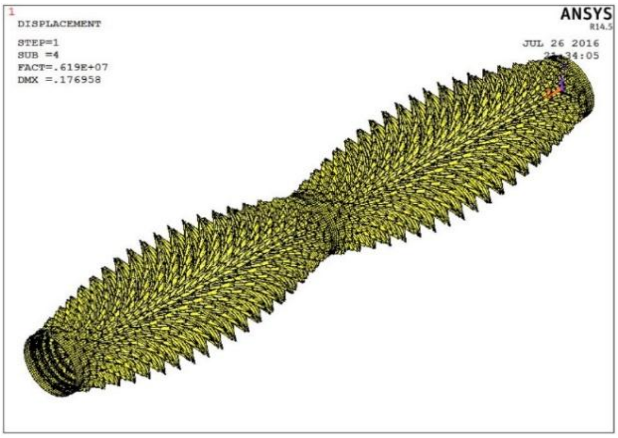

Fig 5(d): Steel FGM hull (Mode 4)

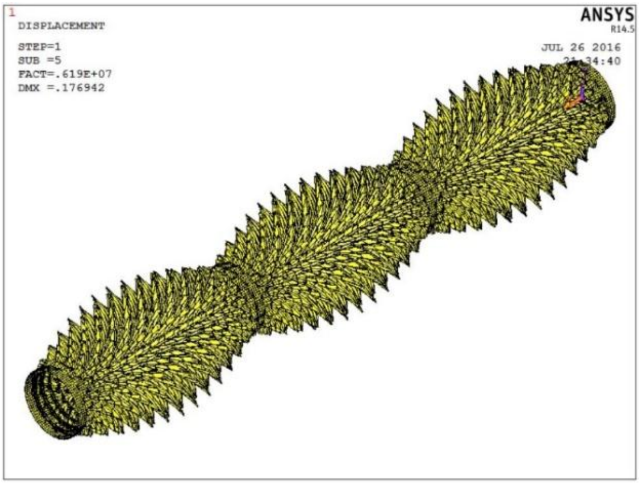

Fig 5(e): Steel FGM hull (Mode 5)

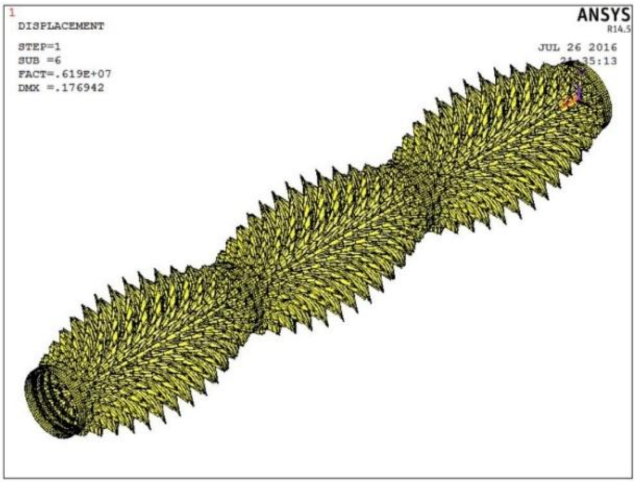

Fig 5(f): Steel FGM hull (Mode 6)

5. RESULTS AND DISCUSSIONS

The linear buckling analysis gave the critical buckling loads and first six mode shapes were considered. We can see that mode 1 and 2, 3 and 4, 5 and 6, are identical in most case. We can also see the failure modes are "Chinese lantern" modes, which may occur once, twice or thrice depending on how higher the mode number is.

The mode shape obtained shows that Steel have 26% higher buckling load capacity compared to Steel FGM. The Steel models shows inter layer buckling from its fifth mode while Steel FGM have inter layer buckling from the very first mode. The critical buckling load is much higher than the design load hence both Steel and its FGM models are safe under global buckling failure.

The mode shape obtained shows that Steel have 83% higher buckling load capacity compared to Titanium models and Titanium models have 21% higher buckling load capacity than Titanium FGM models. Both the Titanium and its FGM models shows inter layer buckling from its first mode itself. The critical buckling load is lower than the design load hence both Titanium and its FGM models are not safe under global buckling failure. This might be because of the reduced yield strength of the Titanium models and they also have lesser thickness of hull compared with Steel hulls.

The deformation values shown in the mode shapes cannot be considered as actual deformation values. Just like a normal modes analysis, all we can get is the shape of the buckled mode. The stresses calculated from the mode shape and often shown in a linear buckling analysis cannot be used as the displacements are arbitrary and therefore the strains and stresses are as well.

Buckling is a critical failure condition for many classes of structure. The linear buckling analysis give an estimate of the critical buckling load and the likely mode shape that will result at buckling. The information we get is very useful in design, but it is more of an indicator than a hard number.

6. CONCLUSIONS

- The linear buckling of the major models were done, steel and its FGM gives critical loads much higher than the design loads
- Titanium and its FGM gave lesser critical buckling values than the design loads which is due to the reduced hull thickness and lower value of elastic modulus.
- The linear buckling analysis give an estimate of the critical buckling load and the likely mode shape that will result at buckling.
- The information we get from linear buckling analysis is very useful in design, but it is more of an indicator than a hard number.
- The stresses and displacements in the nonlinear case are meaningful.

7. FUTURE SCOPE

- The study shows that FGM could be efficiently used for pressure hulls, hence the major future study is the experimental verification of the work.
- The yield strength of the FGM plates should be experimentally verified.
- Dynamic analysis of the pressure hull with functionally graded materials can also be considered in future for more accurate results.
- The study can be extended to Nonlinear buckling analysis of the models.
- The study can also be done with different FGM materials (eg .ceramics)

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