

Reduction of Mass for Base Structure of a Spacecraft using CFRP

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ABSTRACT: The use of advanced materials and construction has become essential in the spacecraft for achieving low mass while satisfying the functional and structural requirements related to strength, stiffness, dimensional stability and agility. In the present paper, the linear static analysis is performed on the composite base structure which is a main load bearing member of the spacecraft using ANSYS 14.5 to compare the variation of the deformation and stresses on the structure by varying the material at the insert. The CFRP (Carbon Fibre Reinforced Plastic) material is used for the base structure and the Titanium insert of the structure is being replaced by the CFRP until some height. The deformation and the stresses obtained from the analysis shows that using the combination of Ti and CFRP gives the less deformation than using complete single material.

KEYWORDS: Base structure, ANSYS, CFRP, Titanium, deformation, stress.

I. INTRODUCTION

A **spacecraft** is a vehicle or a machine designed to fly in outer space. The Spacecraft Structure is the physical platform that supports and integrates subsystems and payload as such it is of fundamental importance for any spacecraft. The spacecraft is subjected to mechanical loads during launch and thermal loads during on orbit operations. A typical spacecraft contains a main load bearing base structure, which is a primary structure as well as supports all primary payloads and connects the satellite with the launch vehicle. Several improvements were implemented in these structures in recent times achieving significant mass reduction [1]. But the base structure of the interface ring remained metallic in all the cases. Such metallic base structures are normally integrally machined parts and contribute to a significant part of spacecraft structural mass [1]. Such structures are made of aluminium alloy often poses the severe problems of dimensional accuracy and stability. Recently there have been attempts on the use of light weight materials like composites for the construction of spacecraft structural systems [2]. The structure under study is a composite base structure of a Bepi Colombo spacecraft. It is a conical shell structure whose cross sectional view is shown in Fig1. This base structure is made of CFRP (Carbon Fibre Reinforced Plastic), Titanium at the insert and aluminium alloy at the base. Traditionally aeroplanes have been made of metal like aluminium. Now a days fibre composites have replaced the traditional metals. Use of CFRP makes the aircraft lighter with added benefits less maintainence, super fatigue resistance and high fuel efficiency. These composite material;s can provide high stiffness to weight ratio than metals[4]. A major challenge for space missions is that all materials degrade over time and are subject to wear, especially under extreme environments and external solitations. Impaact events are inevitable during the lifetime of a space composite structure, and once they are damaged they are hardly repairable. Self healing materials are conceived as having the potential to heal and restore their mechanical properties when damaged, thus enhancing the lifetime of materials and structures. Carbon fibre Reinforced Polymers are the self healing materials which have the flexural strengths [3]. In this paper the metallic base structure is replaced with the CFRP material and is simulated using linear static analysis at different Ti insert heights. The cross sectional view of the base structure is shown in the figure1 below.

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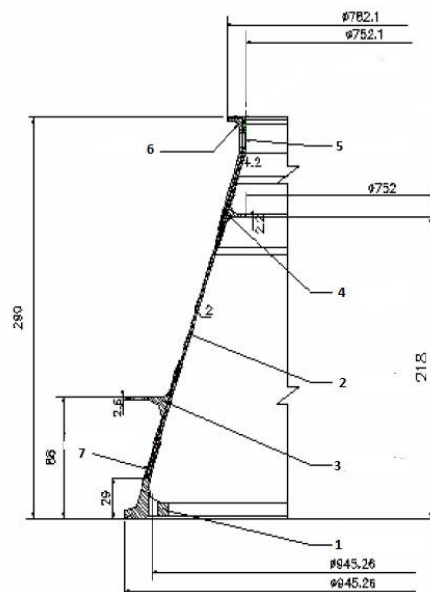


Fig 1 Cross sectional view of Base structure

II. RELATED WORK

The reduction of mass for any structure is a biggest task for the structural engineers. Weight reduction and improved damage tolerance characteristics were the prime drivers to develop new family of materials for the aerospace/aeronautical industry. There are many methods to reduce the mass of any structure. In them replacing the material of the structure with light weight material is mostly preferred. Here we have considered replacing of the material with the light weight material which is a fibre reinforced plastic material. The fibre reinforced plastics is a composite material which is made of complete fibre, light in weight and strong in nature. CFRP is the most famous material used in aerospace industry since its properties matches with the properties of the alloys used in the construction of the aerospace structures. So the CFRP is considered to replace the metallic alloys in the structure.

III. FINITE ELEMENT MODELLING AND ANALYSIS

A. MODELLING

The structure is modelled in ANSYS 14.5 using the key points and volumes are being generated. The areas created using the key points are shown in figure2 given below.

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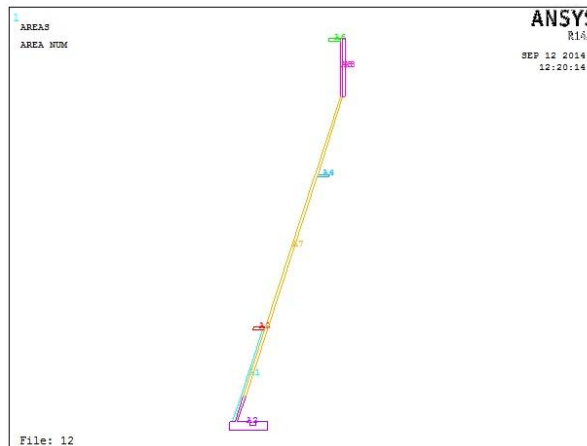


Fig 2: Areas created using the key points

B. Element Selection

Composite material models can be modelled in ANSYS using the specialized elements called layered elements. After building the model using these elements, any structural analysis like static, non linear static, Eigen buckling, modal analysis, dynamic analysis etc., can be performed. For modelling the base structure the SOLSH 190 element is used which is a combination of Solid and shell elements. After the completion of the modelling the material is selected and the layups are given for each volume separately. The material selection and the lay up for the composite structure are shown in the tables 1 and 2 given below.

Part number	Name of the part	Material selected
1	Base of structure	Aluminium alloy 7010 T73651
2	CFRP Main structure	CFRP M55J/914
3	Outer lip	CFRP M55J/914
4	Inner lip	CFRP M55J/914
5	Titanium insert	Ti alloy TI-6AL-4V
6	Top lip	CFRP M55J/914
7	Bottom stiffener	CFRP M55J/914

Table1: Parts of base structure with material used

Name of the section	Part number	Section number	Lay up
CFRP Main Structure	2	1	[#0 ₂ /0 ₂ /+45/-45/0 ₄] _s
Outer Lip	3	2	[#0 ₂ /90 ₂ /0 ₂ /+45/-45/0 ₂ /90/0 ₂] _s
Inner Lip	4	3	[#0 ₂ /0/90/0/+45/-45/0 ₄] _s
Top Lip	6	4	[#0 ₂ /0/90 _s /#0] _s
Stiffener	7	5	[#0 ₂ /90 ₃ /+45/-45/90/0/90/0] _s

Table 2: Lay ups for the CFRP structure

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C. Boundary Conditions

The elements are checked for free edges, distortion level and shell normal consistency to ensure reliable results after the analysis. The spacecraft mass is considered as 600kg and is applied at the top surface of the base structure by fixing the bottom surface. The interface ring is held from the bottom by a clamp band which interfaces the ring with launch vehicle payload adapter. So the interface ring that is the bottom surface of the structure is fixed. The boundary conditions applied on the base structure is shown in the figure 4 below.

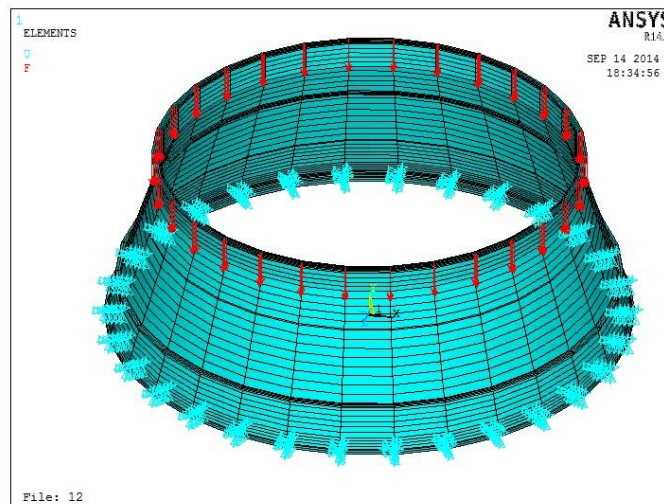


Fig 4 Applied boundary conditions on the base structure

D. Analysis

The linear static analysis is performed on the base structure by varying the material with height. The insert of the structure whose height is 48mm and made of Ti alloy is considered. The insert material is varied with height the deformation and stresses are calculated for each. By performing the linear static analysis on the base structure varying material with height, it is observed that as the thickness increases the deformation decreases. For each thickness the deformation is observed to be varying drastically with the difference in material with heights. The total deformation of the structure for the thickness of 8mm is shown in fig 5.

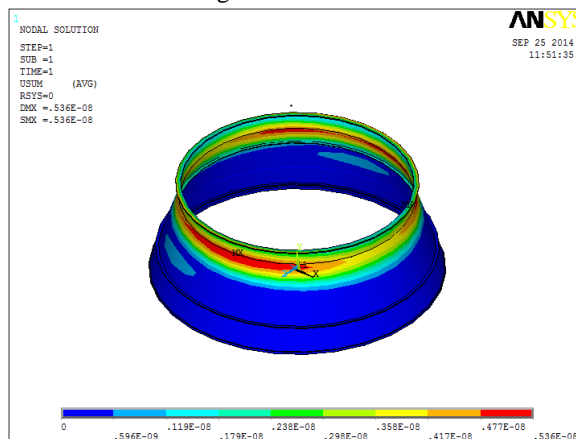


Fig 5: Total deformation of the structure for 6mm thickness and CFRP material till 278mm

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IV. RESULTS AND DISCUSSIONS

The results obtained from the linear static analysis performed on the base structure are compared with each case for different thicknesses. The deformation and the stress are compared for each.

A. Deformation

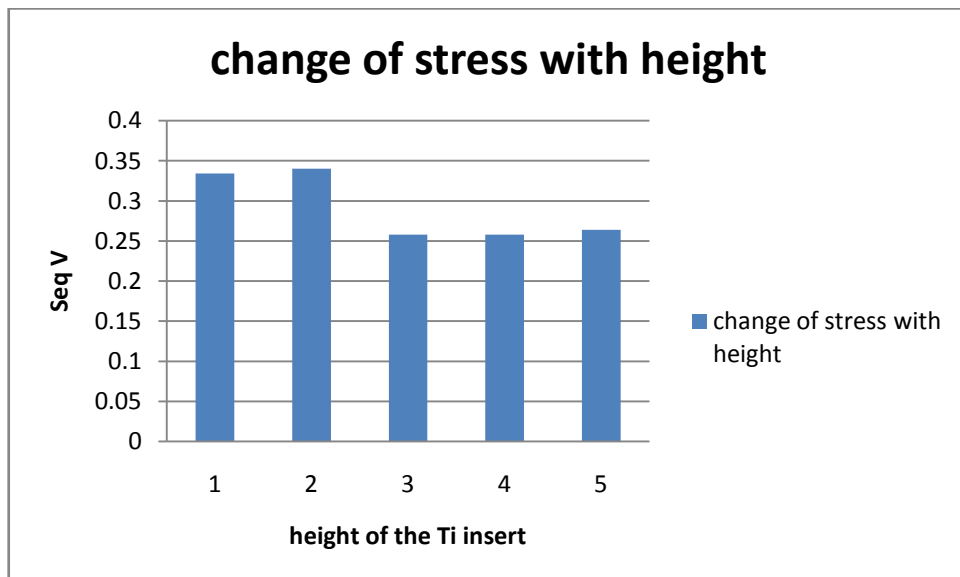
By comparing the values of deformation in the tabular column shown in table3 indicates that the deformation for the structure with material combination of Ti and CFRP is less than that of the deformation for the structure with individual materials.

Thickness	Total Titanium (1)	Total CFRP (2)	CFRP till 278mm (3)	CFRP till 266mm (4)	CFRP till 254mm (5)
6	0.334	0.34	0.258	0.258	0.264

Table 3: Total deformation varying with the different material for each thickness value

B. Stress

The Von Mises stress is often used to determine whether an isotropic and ductile metal will yield when subjected to a complex loading condition. This is accomplished by calculating the von Mises stress and comparing it to the material's yield stress, which constitutes the Von Mises Yield criterion. The graph 1 below shows the Von Mises stress acting on the base structure. By observing the graph, we can say that the stress acting on the structure 8mm thickness and insert material as combination of Ti and CFRP is less than that of all the other structures.



Graph 1: Variation of Von Mises stress with material

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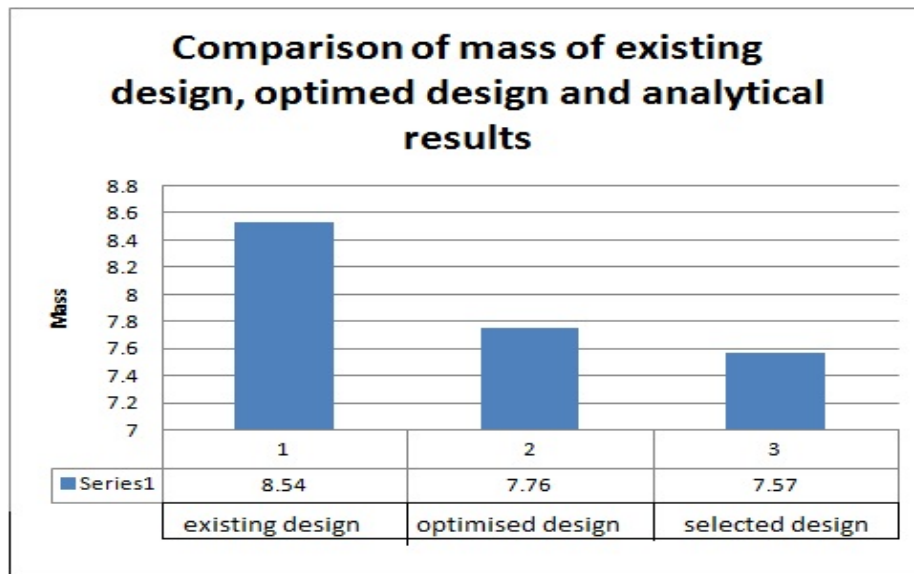
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C. Mass

The mass of the base structure can be reduced to reduce the mass of the complete spacecraft. By replacing the complete base structure with CFRP the mass is reduced by 5% for the base structure. By decreasing the mass, the performance can be increased for the spacecraft. But the insert cannot be replaced with the composite material, so only the insert is remained as metal. The material is changed at the insert at different heights which varies the stresses acting on it. The change of mass of the base structure with change in material is shown in the table 4 and the graph 2 shows the graphical representation of change in mass of the base structure.

Existing design	Optimized Design	CFRP including Ti insert and aluminum base	CFRP till 254mm	CFRP till 266mm	CFRP till 278mm	CFRP with only aluminum base
8.54 Kg	7.76 Kg	7.57 Kg	7.60 Kg	7.53 Kg	7.39 Kg	7.02 Kg

Table4: Estimated mass for each material change in the insert



Graph2: Reduction of mass with change in material

V. CONCLUSION

The base structure is a main load bearing member which always remains metallic even in the advancements in use of composites. In order to replace the metallic part, CFRP material is used for the base structure. The static analysis is performed on the base structure by applying the CFRP material to the main structure. Then analysis is done by varying the height of the titanium insert to check the best suitable material for better performance of the structure. From the analysis it is found that by using combination of CFRP and Ti material for the insert of the base structure showing less deformation and high strength than using a complete CFRP or complete Ti. Therefore we can conclude that the metallic

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part can be replaced by the composites and instead of using the complete composite or complete metallic, combination can be used which is reducing mass of the base structure.

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