Feasibility Study on the conversion of Aluminium Flat Rectangular Plate to Glass Composite

1Neethi B.
1Consultant Structural Engineer
1Ram Associates

Abstract - **A case study on the design and optimisation has been done to assess the feasibility of converting Aluminium to Composite in order to achieve weight reduction meeting the performance requirement with due consideration to cost and ease of manufacturability. The performance of existing Aluminium plate when subjected to a uniform pressure load and cantilever boundary condition was set as the benchmark for the design study. To achieve best performance with minimum cost, a fibre – matrix combination of Glass and Polyester resin was defined for the study. This case study was divided into 2 phases. The objective of the first phase was to evaluate the feasibility of matching stiffness of Aluminium plate by a Glass plate and draw a comparison of the weights. The objective of the second phase was to optimise the thickness distribution across the Aluminium and Glass plates. Based on the relative ease of manufacturing, a comparison is drawn between the Aluminium and Glass plates and an optimum solution is presented.**

keywords - **Cantilever boundary condition, Composite, Finite Element Analysis, Uniform pressure load, MSC Nastran, SOL 101, SOL 200**

I. INTRODUCTION

In today's world one is constantly looking out for materials with optimal characteristic satisfying the functional requirements. The optimal characteristics can be in terms of weight, cost, deflection, frequency etc. In order to meet these characteristics certain criteria should be kept in mind like the material, availability, cost, manufacturing possibilities etc. Metals offer high stiffness but possess restrictions on application due to their inefficiency in tailoring properties in the required direction. Hence, in the real case material is being overused in metallic structures resulting in an increase in weight. In order to overcome these difficulties and at the same time to meet the required characteristics, metallic structure are getting replaced by composites.

Composites are orthotropic materials obtained by the physical and chemical combination of two or more materials with different characteristics. The resulting material possesses better properties than the materials used alone. The major constituents of composites are reinforcement and matrix which can be selected as per requirement for a particular working condition [1]. The prime characteristic that make composite attractive is its high strength to weight ratio as well as it allow the designers to tailor the properties to desired requirements maintaining the weight [2].

Finite Element Analysis is essentially a widely used computational technique based on finite element method used to obtain approximate solutions for boundary value problems in engineering. The analysis is done by creating a mesh of points in the shape of the object that contains the information about the material and the object at each point of analysis. The advancement in finite element analysis software systems like MSC Nastran greatly simplified the task of analysing even complex structures. MSC Nastran is a general purpose finite element analysis computer program which addresses a wide range of engineering problems both static and dynamic. The design optimisation capability of MSC Nastran greatly simplified the task of obtaining an optimal design. Each type of analysis in MSC Nastran is called a solution sequence and once a solution sequence is chosen the particular set of commands sends instructions to perform the specified solution sequence [3],[4],[5].

A structural optimisation problem deals with identifying an optimal or best solution achieving a desired objective by varying the structural parameters, while satisfying specified design requirements. So a design optimisation problem will have a design objective which has to be either minimised or maximised, a design variable which can be varied and a specified set of design constraints. Optimisation works based on the relationship between the design variable and a property of the model. This relationship can be defined using a property variable relation. The outputs required can be defined using design responses. The design optimisation technique can be applied for structural design improvements, generation of feasible designs from infeasible designs, configuration evaluations, and model matching to produce similar structural responses etc.

The main objective of this paper is to study the feasibility of converting an Aluminium plate into Composite for weight reduction without compromising on the stiffness. Purely linear static analysis was conducted during the study as the results are viewed only for displacement. For achieving best performance with minimum cost, a fiber - matrix combination of glass - polyester resin was considered as the raw material for composite. The study was divided into two phases. The first phase is concerned with modelling two cantilever plates of same stiffness, one made of Aluminium and other made of composite. Initially, the design and analysis of the Aluminium plate of dimension 0.4mx0.3mx0.015m under a uniform pressure load of 4x105N/m2 was carried out using Linear Static Solution sequence of MSC Nastran [3], [4], [5]. Then the plate was converted into composite and modified the thickness to meet the stiffness of Aluminium. The objective of the second phase was to optimise the plates for weight reduction without compromising the stiffness using Design Sensitivity and Optimisation capability of MSC Nastran and to select the optimum design considering the ease of manufacturability.

II. PHASE 1

Design and Analysis

Initially, a flat rectangular plate of dimension 0.4mx0.3mx0.015m made of aluminium was modelled with a cantilever boundary condition. The plate was subjected to a uniform pressure load of 4x10-5 N/m2. The plate was then analysed for displacement and the result obtained is shown in Table 2.

The same plate was then analysed using glass polyester composite made of bidirectional glass fabric with [0/90] orientation for the same boundary condition and load case to meet the stiffness of aluminium plate. Figure 1 shows the trend of variation of displacement vs. thicknesses for composite plate.

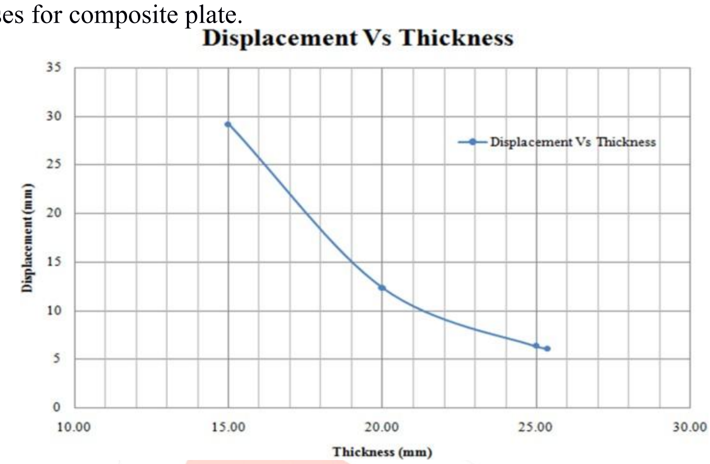

Fig 1- Graph showing variation of displacement with thickness

Finally, stiffness of aluminium was achieved by a plate of 0.02536m thickness. The result obtained is shown in Table 2.

Table 1 shows the material properties of Aluminium and Glass - polyester composite. For detailed properties of the laminate refer Appendix.

Based on the above two analyses, it can be concluded that in order to meet the metallic stiffness of aluminium, glass plate have to be thickened by providing additional layers. An increase in material of 0.313kg (6.4%) will be required by glass in order to meet the stiffness of aluminium.

III. PHASE 2

Optimisation

In the present study, we are looking for optimisation of weight for the same geometry and for a given deflection. So the design objective is to minimise weight. The design variable is the thicknesses of zones which can be varied within a range of 2mm to 30mm. The design constraint is a maximum displacement of 6mm.

For optimisation, the plates were divided into 12 equal zones. Dimensions of both the plates were the same used during static analysis. These models were then subjected to optimisation using MSC Nastran.

The results of optimisation for both aluminium and glass are given in Table 3

TABLE 1 MATERIAL PROPERTIES

Material	Young's modulus (GPa)	Poisson's ratio	Density (kg/m3)
Aluminium	70	0.35	2700
Composite	15	0.25	1700

The results of analysis obtained for both the models are shown in Table 2. Figure 2 shows the displacement pattern of both the models.

TABLE 2 RESULTS OF ANALYSIS

Material	Thickness (mm)	Deflection (mm)	Weight (kg)
Aluminium	15	6.038	4.86
Composite	25.36	6.035	5.173

TABLE 3 OPTIMISED WEIGHT COMPARISON OF ALUMINIUM AND COMPOSITE

	Aluminium	Glass
Input weight (kg)	4.86	5.173
Output weight (kg)	2.74	3.43
% weight reduction	43.6	33.7

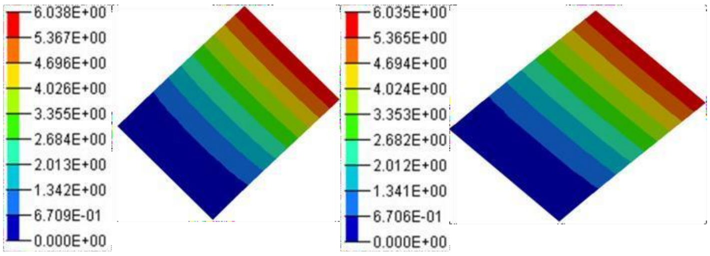

Fig 2- Displacement pattern for a) Aluminium plate b) Composite plate

A mass versus design cycle graph for aluminium and glass was plotted which is shown in Fig 3

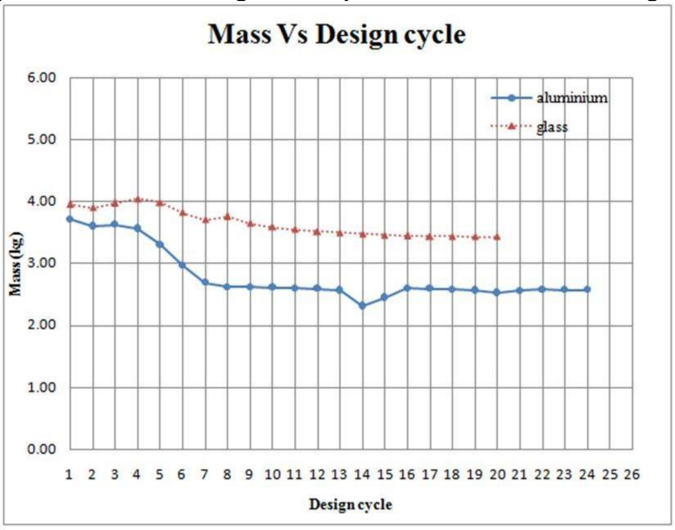

Fig 3 - Graph showing Mass Vs Design cycle for Aluminium and Composite optimisation

The optimised thicknesses are then assigned to the corresponding zones of both the models. These models are then analysed statically to validate the results of optimisation. The optimised thickness distribution for both the models are shown in fig 4 and fig 5 shows their corresponding static analysis results

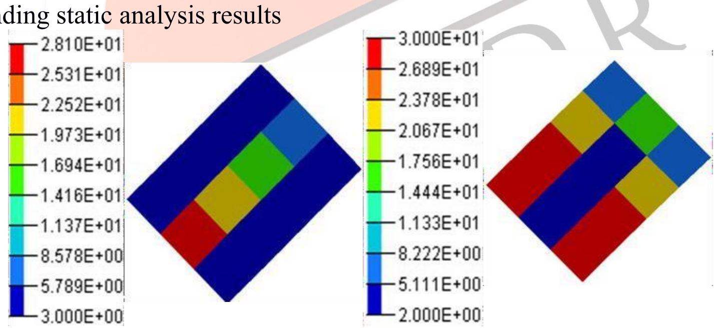

Fig 4 - Thickness distribution for a) Aluminium b)Composite

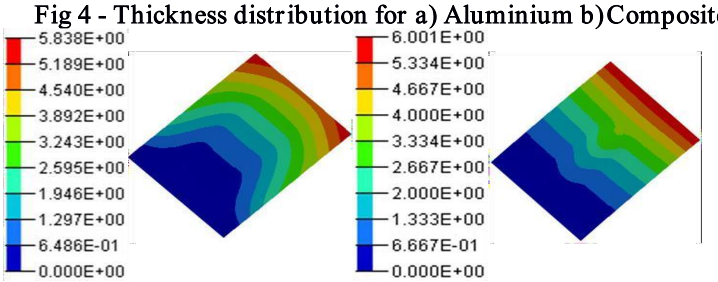

Fig 5 - Displacement pattern for a) Aluminium b)Composite

IV. CONCLUSION

The following conclusions were drawn based on the study.

- For a given uniform thickness, Aluminium offers better stiffness compared to glass-polyester composite material.
- For attaining same stiffness of aluminium, glass-polyester composite will require an increase in material of 6.4%, for uniform thickness.

- After optimisation 43.6% reduction in weight was observed for aluminium and 33.7% reduction in weight was found with glass polyester composite.
- The optimised solution for aluminium plate indicates that a plate of varying thickness profile will meet the requirement. However, such a design solution possesses practical difficulties since it involves precision machining. Whereas in composites, a varying thickness along the length can be easily achieved by staggering layers during lay-up and hence is a more holistic solution.
- The stiffness obtained by an aluminium plate of uniform thickness can be achieved by an optimised composite plate of lesser weight. 29.4% weight reduction can be achieved.
- For other loading conditions, better benefits can be achieved due to the ability to tailor properties of composites.

V. APPENDIX

Laminate Test Results

Item	Item	Specification
Raw materials	Fabric	Woven Roving Mat, 360gsm
	Orientation	Bidirectional, [0/90]
	Resin	Polyester
process	Process	Wet lay-up, oven cured under vacuum
Test Specimen	Size of the specimen	0.0254mx0.0254mx.0043m
	No. of layers	13
	% of resin	31.7
	Density, ρ (kg/m^3)	1700
	Young's Modulus, E (GPa)	15
	Poisson's ratio, ν	0.25

VI. REFERENCES

[1] Robert M Jones, *Mechanics of Composite Materials*, Philadephia, Pensylvania, pp. 2-203, 1998
[2] Dattatraya Parle, Ravi Udali, Anirudha Ambulgekar CHV Veerabhadram, "An Integrated Optimization Approach for Laminated Composite Panels Using FEA and EXCEL-VBA".
[3] MSC Nastran Design sensitivity and optimisation user's guide, MSC Software 2012.
[4] MSC Nastran Reference manual, MSC Software 2012.
[5] MSC Nastran Quick Reference Guide, MSC Software 2012.
[6] Ken Blakely, *Application of Design Optimisation using MSC Nastran, MacNeal*-Schwendler Corporation, Los Angeles, CA 90041, pp. 1227-1230.
[7] Prof.R.Arravind, Dr.M.Saravanan, R.Mohamed Rijuvan, "Study and Analysis of Composite Flat Plate", Vol. 4, issue 5, ISSN 2229-5518, May 2013.
[8] JOSE E. HERENCIA, Paul M. Weaver and Michael I. Friswell, "Optimisation of Anisotropic Plates that Vary in Thicknesses and Properties"Unpublished.
[9] Ming Zhou, Raphael Fleury, Martin Kemp, "Optimization of Composite: Recent Advances and Application", copyright Altair Engineering, Inc. 2011 available at www.altairproductdesign.com.
[10] A. Attaran, D.L. Majid, S. Basri, A.S. Mohd Rafie, "Structural Optimization of an Aeroelastically Tailoring Composite Flat Plate Made of Woven Fibreglass/Epoxy", No 22, pp:75-88, December 2006.
[11] David Roylance, "Finite Element Analysis", Unpublished, February 2001.