# DESIGN OPTIMIZATION OF SANDWICH CORE

MOHAMMAD TAUHIDUZZAMAN

Master's Program in Computational Science



APPROVED:

Pavana Prabhakar, Ph.D., Chair

Vinod Kumar, Ph.D.

Natasha Sharma, Ph.D.

Charles Ambler, Ph.D.
Dean of the Graduate School

# Dedication

**Dedicated to my parents.**

**Mohammad Khaleduzzaman** and **Farida Yesmin**

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by

MOHAMMAD TAUHIDUZZAMAN, B. Sc. ME

THESIS

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Abstract

Ultralight sandwich structures comprising of low-density core with stiff facings have attracted significant research interest for their considerable weight saving applications. The aircraft industries are focusing on decreasing the structural mass to lower the manufacturing and operating costs. Design analysis of the sandwich cores using finite element analysis has been developed as a promising concept to feature sandwich structures with maximum strength, stiffness, and reduced weight. To obtain multifunctional behavior of sandwich panels, a profound investigation of geometrical and mechanical properties in the transverse plane is required because it is very susceptible to any kind loadings. Structural optimization is one of the key factors for designing lightweight structures, where the main concern is not merely to ensure an intricate design, but also to identify the limiting factors and resolve the issues by generating optimum values of the main parameters.

This thesis presents the design optimization of multifunctional sandwich panels in two chapters. The first chapter reports the shape optimization approach of four different core topologies considering three-dimensional isotropic patterns that are optimally designed for minimum weights. Additive manufacturing technology is a suitable and amenable method for the construction of sandwich structures because it ensures strong bonding between the facings and core to reduce the slipping. Fused deposition modeling method is employed to build the 3D printed structures. Short beam shear tests were carried out on the initially non-optimized structures to generate the structural response. Peak loads and deformations were recorded to compare the flexural properties. To obtain the new design of the sandwich cores with optimum stiffness and reduced weight shape optimization task is performed by ABAQUS. Stress and weight are the design variables to carry out the optimization method. Shape optimization process deals with the coordinates of surface nodes; eventually, it creates a new design of the cores that demonstrates versatile performance. Finally, based on the output of the optimization procedure new STL files are imported in the additive manufacturing machine to produce the optimized structure. Optimized panels are

subjected to short beam shear test again to investigate their performance that has changed by employing shape optimization. Comparison using the mechanical properties are subsequently performed for the optimized and non-optimized panels to demonstrate the overall responses numerically. Results show that optimized structures are significantly lighter that perform decently from the strength standpoint with diverse characteristics such as ductility and brittleness.

Algorithms, like a genetic algorithm, mimics natural process can be employed in the structural optimization technique. In this paper, both finite element analysis and genetic algorithm are employed to obtain the optimum result of the cross- sectional area for truss structures. The area is the main variable for this optimization technique that can be expressed by the array of binary numbers to carry out genetic algorithm operation and subsequently stress analysis is performed using the material properties. Since minimization of the weight is the objective function, so decreasing the cross-sectional areas subjected to a higher stress of the truss members and allowable stress operates as a stopping criterion for this iterative process. Finally, stress analysis and genetic algorithm create a possible solution set for areas and weight of the unit cell for the truss structure is determined. FEA is conducted by combining FEA (using ABAQUS) and genetic algorithm that is implemented in MATLAB.

The findings shown in this thesis have established appropriate weight saving technique for sandwich structures. The work provided a solid foundation for structural optimization that utilizes finite element package and a robust tool genetic algorithm which is not found in the commercial software packages.

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# Chapter 1: Introduction

## 1.1 Cellular materials

The emergence of sandwich composites introduced a considerable progress for the aerospace and different engineering industries due to their multifunctional features. Sandwich panels consist of a lightweight core material that exhibits high flexural stiffness, is covered by two facesheets which are stiff skins. Sandwich construction is based on the concept of cellular materials. The word cell derives from the latin word cella which means enclosed space [1]. Cellular materials consist of solid struts or plates which are interconnected in a certain pattern to construct the edges and faces of a structure. Well known cellular materials are highly porous such as wood, coral, bone, and bee honeycombs. Even though porosity reduces the strength and stiffness, its light interior core with regularly spaced pores and hard outside layer form a structure that can resist bending loads efficiently [2]. The performance of these natural structures has spurred the designers to create an artificial structure, known as a sandwich structure, that mimics the design of cellular solids. Design integrate multi-functional behavior in a single material such as stiffness, strength, damping, insulation and many more. The geometric interactions and properties of the constituent materials of sandwich composites have attracted interests and provided a great opportunity for diverse implementations. Diverse characteristics of cellular materials offer different engineering applications in aviation, automotive, construction and packaging industries. Dweib et al. presented a work using VARTM technology to manufacture sandwich panels for structural applications[3]. Wang et al. utilized shock tube experiments to represent the dynamic behavior of sandwich panels [4]. Damping properties of sandwich cantilever beams were investigated by Yim and his co-authors where they mentioned viscoelastic core thickness has a great effect in reducing damping factor [5]. A general concept of conventional material is the more energy it absorbs, the heavier it will be. But sandwich structure consumes less material and yields more energy that made them environmentally friendly. Apart from this, freedom of design, extreme cost savings, non-

corrosiveness, sound insulation characteristics encouraging the designers to investigate in detail that outperform previous accomplishment.

### 1.2 FEA importance for design

Finite element analysis is the idealization of the physical system by employing a finite number of elements that subjected to given loads or boundary conditions. Performing finite element analysis for three-dimensional sandwich panels offer the designers to control several aspects such as model the geometries, boundary conditions, loadings and material properties [6]. Typically, three steps are followed to perform FEA: (i) initial geometry is created and required material properties and boundary conditions are applied (ii) analysis steps generate results by solving the associated equations (iii) at last results are interpreted in the post-processing stage. One distinct nature of sandwich composite panel is it combines the positive properties of individual materials that, if well designed, cause the material to behave smartly. Design of sandwich structure is an iterative process that feature a sandwich structure with advanced mechanical properties such as maximum flexural strength and stiffness with minimum weight and cost. To predict the behavior of sandwich composites under a definite loading conditions such as transverse load, shear load structural analysis is performed. Analyzing the responses, designer can identify the regions which are very prone to failure, strength and stiffness along a definite direction. Additionally, several software packages are introducing commercial FEA programs with optimization process integrated into it. This thesis explores the methods to minimize the total weight of sandwich composites for multiple core geometry Incorporation of finite element modeling with experimental validation has been proved an excellent approach for acquiring high strength to weight ratio and further investigation reveals that multiple objectives can be optimized by employing genetic algorithm [7], [8], [9], and [10]. Hutchinson and Xue presented work that discusses the optimization of the sandwich plates under impulsive loading. They utilized square honeycombs to obtain the optimal distribution of the mass between faces and core. Finite element modeling was performed to demonstrate the structural response [11]. Wadley et al. studied the fabrication and