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Stress analysis of U-type layered sandwich beams

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Abstract:

In this paper, the U-type symmetric sandwich beams with three layers are analyzed. Variations in the ratio of Young's modulus between the skin and core, as well as the curvature radius (R/H), parameters are considered for the U-type beams. The study investigates the influence of various core materials on the U-type beams. The stress analysis is conducted through numerical simulations utilizing the Finite Element Method software ANSYS.

Keywords: U type beam, Sandwich, ANSYS

Introduction

Sandwich beams are a type of composite structure that consists of a core material sandwiched between two outer layers, often referred to as face sheets. The core material can be lightweight and less stiff, while the face sheets provide strength and rigidity. This design allows sandwich beams to offer a combination of high strength-to-weight ratio, improved bending stiffness, and damping properties. The analysis and design of sandwich beams involve considering various factors to ensure their structural integrity and optimal performance.

The analysis of sandwich beams holds significant importance in various engineering and design contexts due to several key reasons. In depth analysis helps in determining the most efficient configuration for sandwich beams in terms of material selection, dimensions, and layer thicknesses.

This leads to achieving the desired performance while minimizing weight and material usage.

Sandwich beams offer a high strength-to-weight ratio due to their composite structure. Effective analysis ensures that the core material provides the required stiffness while minimizing overall weight, which is crucial in industries such as aerospace and automotive. Different applications require different performance characteristics. Through analysis, engineers can tailor the design to meet specific requirements, such as stiffness, load-carrying capacity, and damping properties. Analysing

sandwich beams helps identify potential stress concentrations, deformation patterns, and failure modes. This information is vital for ensuring the structural integrity and safety of the final design. Accurate analysis enables the prediction of natural frequencies and mode shapes of sandwich beams. This information is essential for applications where vibration control is critical, such as in aerospace structures and architectural elements. Sandwich beams are susceptible to buckling due to their thin face sheets and lightweight core. Analysis allows engineers to assess buckling behaviour and design to prevent premature failure. By analysing different materials for face sheets and core, engineers can determine which combination will yield the best performance for a specific application, considering factors like strength, stiffness, and durability. Efficient analysis helps in optimizing the use of materials and manufacturing processes, leading to cost-effective designs without compromising on performance. Advanced analysis techniques enable the exploration of novel sandwich beam designs, pushing the boundaries of what is possible in terms of performance and efficiency. The lightweight and energy-efficient nature of sandwich beams can contribute to more environmentally friendly designs, reducing energy consumption and emissions in transportation and other industries. The analysis of sandwich beams requires knowledge from various fields, such as structural engineering, materials science, mechanics, and manufacturing. This promotes interdisciplinary collaboration and knowledge exchange. Efficient analysis ensures that the designed sandwich beams will meet or exceed the specified performance requirements, enhancing the overall quality and reliability of the final product. In essence, the analysis of sandwich beams allows engineers to make informed decisions during the design phase, leading to more efficient, safe, and innovative structural solutions across a wide range of industries and applications.

Finite element analysis (FEA) has emerged as a powerful tool for simulating and predicting the behaviour of laminated composite sandwiched beams. With applications spanning aerospace, automotive, and civil engineering, FEA has significantly contributed to the understanding and optimization of these structures. This literature review provides an overview of the research conducted on the finite element analysis of laminated composite sandwiched beams, highlighting key insights and advancements in the field. **5 Finite element analysis (FEA) has played a pivotal role in advancing the understanding and design optimization of laminated composite sandwich beams.** This literature

survey presents a comprehensive overview of research conducted on the application of FEA to laminated sandwich beams, highlighting significant findings and contributions in this domain. Kant's review article [1] provides a comprehensive overview of various analysis and design methodologies for sandwich panels. The paper critically assesses different approaches and highlights recent advancements in the field. Shen and Han [2] investigate static and free vibration behaviors of sandwich beams with functionally graded material faces. The finite element method is employed to analyze these complex structures with varying material properties. Wang and Wang [3] study the response of sandwich panels with composite faces and a paper core subjected to impact loading. Finite element analysis is used to examine the structural behavior and damage patterns under dynamic loading conditions. Aydogdu and Seker [4] focus on the dynamic behavior of functionally graded sandwich beams using **1 the finite element method**. The study investigates the impact of material gradation **on the natural frequencies** and mode shapes of these beams. Triantafyllou and Bergan [5] delve into the vibration and damping characteristics of sandwich beams. The finite element method is employed to analyze the vibration response and evaluate the damping behavior of these structures. **8** Mead and Markus [6] investigate **the forced vibration of a damped sandwich beam** composed of three layers. The study utilizes the finite element method to analyze the dynamic response of the structure. Mir and Cardew-Hall [7] explore the behavior of sandwich beams with composite face-sheets under combined bending and impact loading conditions. The paper employs finite element analysis to predict the structural response and failure mechanisms. Carrera and Petrolo [8] propose a higher-order finite element model to analyze sandwich structures. The study focuses on accurately capturing the intricate **6 behavior of sandwich panels**, considering various complexities and material properties. Goudarzi and Zenkert [9] investigate the impact of core shear compliance on the stress distribution within sandwich beams. **1 The finite element method is** utilized to analyze stress concentrations and validate design approaches. Carrera [10] presents simplified finite element models **for the buckling and free vibration analysis of composite** sandwich beams. The study aims to provide efficient yet accurate tools for predicting the structural behavior of these beams. Reddy and Phan [11] investigate the influence of core shear compliance on stress distribution in sandwich beams using finite element analysis. The study emphasizes the importance of accurately modeling core shear

deformation to capture realistic stress patterns. Librescu [12] investigates the vibration and buckling behavior of symmetric sandwich and orthotropic plates. The study provides insights into the modal characteristics and stability of these structures. Varelis and Tsamasphyros [13] focus on the finite element analysis of sandwich beams with functionally graded cores. The study explores the effects of material gradation on the **6 mechanical behavior of** these structures. Gurdal and Vegter [14] undertake the **design and optimization of composite sandwich** beams for achieving maximum fundamental frequency. The study contributes to enhancing the dynamic performance of these structures. The paper [15] provides insights into the dynamic response and damping characteristics of these structures. Shu and Li [16] analyze the **9 response of sandwich panels with honeycomb** cores **under low-velocity impact** using finite element analysis. The study addresses the impact behavior and damage prediction in such structures. Ochoa and Jensen [17] **2 investigate the damping characteristics of** sandwich beams with flexible cores. The study sheds light on the damping mechanisms and their impact **on the dynamic behavior of the** structures. Bressan and Carrera [18] propose a **1 finite element model** to analyze functionally graded sandwich beams. The study explores **the effect of material** gradation on the structural response and provides insights into designing such structures. Wünsch and Bischoff [19] present a finite element approach for analyzing three-dimensional sandwich panels. The study contributes to understanding **3 the structural behavior and response** of these complex systems. Chu and Bisch [20] investigate the vibration and stability of simply supported orthotropic sandwich plates subjected to sinusoidal in-plane loading. The paper offers insights into the dynamic and stability behavior of these plates. Viola and Hinton [21] conduct finite element analysis of sandwich beams using refined theories. The study aims to accurately capture the intricate behavior of sandwich beams and validate against experimental data. Liew and Kitipornchai [22] present a study on the **12 buckling analysis of** sandwich beams using the spline **finite strip method**. The paper introduces a numerical technique for analyzing buckling behavior, which is important for understanding the stability **3 of these structures**. Shen and Han [23] **2 investigate the dynamic behavior of functionally graded** sandwich beams incorporating viscoelastic damping layers. The study analyzes the impact of damping **3 on the dynamic response**, enhancing the understanding of **vibration control in** sandwich structures.

Batsell and Bert [24] delve into the finite element analysis of elastic sandwich beams. The paper contributes to the understanding of stress distribution and deformation patterns in these structures, providing insights into their mechanical behavior. Shen and Han [25] propose a unified higher-order finite element model for analyzing the static and free vibration behavior of sandwich beams. The study enhances the accuracy of analysis while considering the complexities of sandwich structures. This article investigates the analysis of U-type symmetric sandwich beams consisting of three layers. The study delves into the impact of diverse core materials on the behaviour of U-type beams. The stress analysis is executed using numerical simulations employing the Finite Element Method software ANSYS [26].

Numerical Results

In this example, U-type symmetric sandwich beam (00/core/00) is analyzed as shown in Fig. 1. Symmetry's advantage finds application in analysis, leading to the modeling of just half the beam, as illustrated in Fig. 1. This approach reduces complexity without compromising accuracy. By capitalizing on symmetrical properties, resource and computational efficiencies are gained. The utilization of this technique is a common practice in engineering and physics. Through this method, insights into the behavior of the entire structure can be gleaned from the study of its symmetrical portion. The presented figure visually represents this modeling approach. It's a strategic simplification that aids in understanding the beam's behavior while minimizing the computational burden.

(a) (b)

Figure 1 Geometry of U-type sandwich beam

Here, the U-type sandwich beam is defined with constant parameters: $H = 2\text{mm}$ (width) and $L = 20\text{mm}$. The internal radius (R_{int}) varies within the range of 5 to 0.125, and the R/H ratio varies from 3 to 0.5625. The beam's thickness is set at 1mm, which holds significance in the study due to its role in approaching a singularity as the ratio decreases. The core possesses a thickness of $0.8 H$, while the two laminated faces each have a thickness of $0.1 H$, where the overall beam width is H (2mm). Refer to Table 1 for a presentation of the internal radius and R/H ratio.

Table 1 Internal radius and R/H ratio.

R_{int}

R/H

5

3

3

2

2

1.5

1

1

0.50

0.75

0.125

0.5625

The material characteristics for both the face sheets and the core are outlined: For the face sheets, they consist of unidirectional glass/epoxy T300-934. The values for the elastic moduli are $E_{11} = 131 \text{ GPa}$, $E_{22} = E_{33} = 10.34 \text{ GPa}$, $\nu_{12} = \nu_{13} = 0.49$, $\nu_{23} = 0.22$ and $G_{12} = G_{23} = 6.895 \text{ GPa}$, $G_{13} = 6.205 \text{ GPa}$. Regarding the core, the Poisson's ratio remains constant at $\nu = 0.4$. However, the elastic modulus (E) assumes the subsequent values: 3400 MPa for epoxy, 340 MPa for foam, 140 MPa for medium foam, and 70 MPa for soft foam.

The applied lateral force is $F = 1 \text{ N}$ (the thickness of the beam is equal to 1 mm). By symmetry, only one half of the beam has been modeled. Displacements and stresses of different core material of a symmetric U-type sandwich beam as shown in Tables 2 to 6 for, displacements in x-direction, displacements in y-direction, inplane normal stresses in x-direction (σ_x), inplane normal stresses in y-direction (σ_y), transverse shear stresses in xy- direction (τ_{xy}).

Contour plots of U-type sandwich beam as shown in Fig. 2. Comparison of inplane normal stresses in x-direction (), inplane normal Stresses in y-direction (), transverse shear stresses in xy direction (), displacements in x-direction and displacements in y-direction w.r.t. R/H ratio for different core material as shown in Fig. 3.

Table 2 Inplane normal stresses in x-direction ()

R/H ↓

Inplane Normal Stresses in x-direction () MPa

Core Material →

Epoxy

Foam

Medium Foam

Soft Foam

3

111.691

123.491

129.402

98.629

2

106.794

118.585

98.0234

126.926

1.5

98.8718

87.7567

92.0247

93.6486

1

141.096

166.148

168.573

169.452

0.75

148.617

157.852

161.848

163.345

0.5625

139.252

139.685

137.321

136.291

Table 3 Inplane normal stresses in y-direction ()

R/H ↓

Inplane Normal Stresses in y-direction () MPa

Core Material →

Epoxy

Foam

Medium Foam

Soft Foam

3

45.327

113.074

119.829

77.319

2
48.049
110.656
77.6999
119.689
1.5
112.865
105.964
112.13
114.499
1
78.632
77.0147
83.4869
86.0882
0.75
148.435
136.547
139.331
140.362
0.5625
212.03
238.229
242.558
244.162

Table 4 Transverse shear stresses in xy- direction ()

R/H ↓

Transverse Shear Stresses in xy- direction () MPa

Core Material →

Epoxy

Foam

Medium Foam

Soft Foam

3

31.606

67.633

69.140

48.379

2

29.994

47.7096

48.986

50.3732

1.5

46.7822

36.4399

38.0299

38.6471

1

67.5484

62.2918

62.541

62.6128

0.75

117.477

127.664

139.282

129.852

0.5625

109.151

144.821

148.873

150.393

Table 5 Displacements in x-directions

R/H ↓

Displacements in x-direction (mm)

Core Material →

Epoxy

Foam

Medium Foam

Soft Foam

3

0.9765

1.9147

2.057

2.186

2

0.7423

1.4536

1.6207

1.6068

1.5

0.6074

1.2175

1.3073

1.3421

1

0.4727

0.9372

1.0052

1.0316

0.75

0.4153

0.6068

0.8631

0.8849

0.5625

0.3866

0.7545

0.8076

0.8282

Table 6 Displacements in y-directions

R/H ↓

Displacements in y-direction (mm)

Core Material →

Epoxy

Foam

Medium Foam

Soft Foam

3

0.727e-8

1.9297

2.072

2.198

2

0.0176

0.0226

0.0399

0.0246

1.5

0.0192

0.0361

0.0384

0.393

1

0.0259

0.0604

0.0651

0.0669

0.75

0.0282

0.0581

0.0625

0.0642

0.5625

0.0213

0.0401

0.0428

0.0439

The ANSYS results [11](#) are shown in following figures for stresses and deflections in U-type sandwich beam under unit load applied at free end.

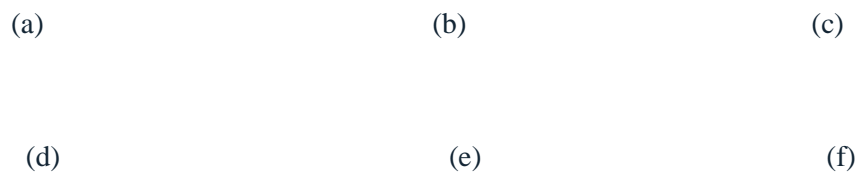


Figure 2 (a) Modeling, (b) displacements in x-direction, (c) displacements in y-direction, (d) inplane normal stresses in x-direction (), (e) inplane normal stresses in y-direction (), (f) transverse shear stresses in xy- direction () contour plots of U-type sandwich beam in ANSYS.

2 Figure 3 Comparison of (a) inplane normal stresses in x-direction (), inplane normal Stresses in y-direction (), transverse shear stresses in xy- direction (), displacements in x-direction and displacements in y-direction w.r.t. R/H ratio for different core material

Conclusion

1. At the radial position of $R/h = 1.0$, there is an abrupt increase in the inplane normal stress in x direction (), followed by a rapid decrease at $R/h = 1.5$. Notably, among the materials, namely Foam, Medium Foam, and Soft Foam, the highest values are observed at $R/h = 1.0$. In contrast, the epoxy core exhibits a comparatively lower value at this radial position. The in-plane normal stress in the y-direction () decreases at the radial position of $R/h = 1.0$, with the epoxy core yielding lower values.
2. At the R/h ratio of 3.0, the displacement in the x-direction reaches its peak, and the soft foam core exhibits the highest displacement, succeeded by the medium foam, foam, and epoxy in descending

order.

3. Transverse shear stresses reach their peak at $R/h = 1.0$ and experience a significant decrease at $R/h = 3.0$.

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