Validation of High-Order Theories for Sandwich Beam Behavior Using Direct Image Correlation (DIC) Techniques

RESEARCH PLAN

A.

Rationale

As engineering technology advances, a demand for new, innovative materials have arisen to support and realize new concepts. Many of these technologies demand material properties that no natural substance possesses. Therefore, to achieve these goals, new material breakthroughs, mainly in the form of composite materials, must be explored. One type of composite material currently being intensely studied and developed for these purposes is the sandwich panel composite.

Sandwich composites are layered structures that consist of two thin, high-strength, and stiff face plates, typically fashioned from metal or carbon composites, attached to a thick core of light but low-strength material, usually a honeycomb structure or foam. Sandwich structures are characterized by their low density and light weight, high stiffness and strength, and high energy-absorption capability, especially in the case of high velocity impacts. (Yuan, et al.) Due to these unique properties, sandwich structures have become more widely used in aerospace, nautical, and civil applications where strength and light weight are of great importance. The increased use of sandwich structures in industry has necessitated the development of new sandwich theories that would be able to better model the real-life performance of sandwich composites.

The conventional theory used in analysis of sandwich composite panels is the Classical theory. This theory is based on the general Timoshenko beam theory with the Euler-Bernoulli assumptions that cross sections of the face sheets do not deform significantly under load and that there is no rotation of the cross section as a result of the load. This model does, however, not factor into consideration the compression of the sandwich beam core, modelling the compressible core of the sandwich structure if it were completely rigid. This model could reasonably accurately model the behavior of older metal honeycomb-cored sandwich panels, which were much less susceptible to in-plane deformation as a response to stress than newer foam and non-metallic honeycomb cores. (Forstig et al.) Therefore, the Classical model has serious limitations when it comes to modeling modern sandwich construction methods (Phan et al.). This study investigates various theories to determine which is best to fully model the real-world behavior of the compressible core. More specifically, this study seeks to use a model sandwich beam structure to investigate the accuracy of predictions by the EHSAPT, HSAPT, and Elasticity theories for sandwich structures.

B.

Research Question

How do different beam theories – Classical, First-Order Shear, Elasticity, HSAPT (High-Order Sandwich Panel Theory), and EHSAPT (Extended-HSAPT) – predict the normalized deflection response of a sandwich beam under loading stress?

Hypothesis

The Classical Theory will not be able to accurately predict the normalized deflection response of the sandwich beam under loading stress due to its assumption of rigidity in the entire structure, which causes it to be unable to properly model the compressible core of the sandwich beam. The First-Order Shear Theory will be a better model than the Classical Theory but suffers from limitations in modeling the response of stiff face sheets characteristic of sandwich beams. The Elasticity, HSAPT, and EHSAPT theories will be the best models of sandwich beam loading stress, as these higher order theories are able to more properly model the properties of compressible sandwich beam core and face sheets.

Engineering Goal and Expected Outcome

A model sandwich beam will be fabricated and loaded in a three-point loading press. The normalized deflection of the sandwich beam under loading stress will be derived and compared to predictions made by the five theories being investigated.

C.

Procedures:

The sandwich sample will be constructed of a core of glass-embedded foam and two face sheets of woven carbon fiber. Glass-embedded foam has the advantage of having randomly dispersed reflective particles within its structure that will allow Direct Image Correlation (DIC) techniques to be applied in the analysis of the sandwich panel under stress without the need to apply a speckle pattern using paint, which would likely affect the mechanical properties of the sandwich panel.

To bond the face sheets with the core, epoxy glue will be applied to the bottom face sheet and then evenly spread. The foam core will then be placed on top of the bottom plate. Epoxy will then be applied to the top face sheet and evenly spread. The top face sheet will then be stacked on top of the core. Weights will be placed evenly on top of the completed sandwich panel and then left for 24 hours in order to remove as many air gaps as possible, and to completely cure the epoxy binder before experimentation. After the 24-hour setting period, the sides of the sandwich composite structure will be removed using a band saw and then sanded to remove any epoxy residue that spilled over the side of the sandwich panel during the setting process.

The completed sandwich panel is to be placed in a three-point loading machine that will be operated by the mentor. Cylindrical bottom supports will be placed at each end of the sandwich composite structure. Cylindrical supports are preferred due the fact that a cylinder with its side tangent to the sandwich panel theoretically will contact the sandwich composite panel along one infinitesimally thin line, and therefore will minimize the influence of the bottom supports on the shear and bending response of the sandwich panel under stress.

Once placed in the loading machine, a downward force will be applied by lowering a load arm upon the sandwich panel. A load cell with force readings being fed to the control software of loading machine will be attached to the loading arm. At set intervals, loading will be stopped and an image will be taken until the proportionality limit, where the structure reaches the plastic state and undergoes irreversible structural changes, is reached. The proportionality limit will be determined to have been reached by monitoring the stress-strain graph output in the loading machine control software. After the proportionality limit is reached, data collection will be stopped, and the loading machine returned to its zero position.

Risk and Safety

Carbon fiber – dust may cause temporary respiratory and eye irritation – goggles, gloves, and masks will be worn when working with carbon fiber.

Glass-particle embedded foam – respiratory and eye irritation caused by dust may occur – goggles, gloves, and masks will be worn when working with foam.

Epoxy binder – contact with the resin part of the epoxy glue may cause skin and eye irritation – goggles, gloves, and masks will be worn when working with epoxy.

Bending press – may cause mechanical injury to appendages – will be operated by trained adult mentor.

Data Analysis

The loading machine control software exports a data set that correlates compression force to the displacement of deflection. The data set will then be correlated with the stress-strain curve created by the control software in order to find the domain of the elastic portion of the stress-strain curve. This data will used to derive the Young's Modulus and distributed load of the sandwich beam.

The calculation of Young's Modulus and distributed load will be necessary in order to calculate the variable of comparison between the theories under investigation – normalized deflection. The calculation of normalized deflection for the model sandwich beam allows comparison with the normalized deflection presented by the theoretical prediction of the theories under consideration. Graphs will then be created presenting the relationship between normalized deflection and the percentage distance along the beam to compare the performance of the five theories.

Direct Image Correlation (DIC) techniques will be used to compare the response of the sandwich beam between loading cases. DIC is a technique that allows correlation between two different loading cases based on a speckle pattern present on the cross-section of the sandwich beam being analyzed. As the sandwich beam deforms under stress, the speckle patterns will deform with the beam. Digital photos are taken at given intervals of displacement. A software solution will then be used to correlate between different images using the speckle pattern within the sandwich beam.

D.

References

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ADDENDUM

No changes were made to the research plan