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Assessment of Impact Resistance in Composite Sandwich Structures: An Experimental and Numerical Approach

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Abstract: This paper presents an evaluation of the impact resistance of composite sandwich structures with regard to the type, design, and characteristics of impact in three parts. Structure consisting of lightweight core and reinforced face layers are widely used in all fields where high strength to weight ratios is desirable. It has established that carbon and glass fiber face sheets make quite different properties in impact absorption and structural resilience as foam or honeycomb cores. Both experimental and numerical formulations offer valuable results with few limitations toward the analysis of damage mechanisms within composite materials. A few suggestions for future work are related to further investigations of the constituent materials, improvements in numerical simulations, and the creation of purpose-oriented design recommendations for broader utilization of these structures in critical-end use applications.
Keywords: Composite sandwich structures, impact resistance, face sheet materials, core materials, structural configuration, damage mechanisms, experimental methods, numerical simulations, energy absorption, failure modes.

I. INTRODUCTION

A. Background

Composite sandwich structures comprised of a lightweight core material bonded between two faces made of composite materials exhibit excellent strength to weight ratios. This particular configuration is well appreciated in industries that require high strength to weight ratio and superior mechanical and impact properties such as aerospace, automobile and construction industries that emphasize more on safety and high performance. These sandwich composites usually involve the use of core materials, for instance honey comb structures, or foam which is adhered to outer layers of more rigid materials such as fiber-reinforced polymers (FRPs). These elastomeric materials improve the structural stiffness, impact energy, and damage tolerance for these applications since load-carrying capability and energy dissipation are vital following impacts [1], [2].

These materials are especially essential for the aerospace industry, due to its need to cut overall weight for better fuel efficiency without compromising on strength and durability under different stress levels [3]. In automotive applications, the application of composite sandwich structures has been realized due to the manufacturers of automotive vehicles seeking to produce lighter automobiles that consume lesser fuel and are safer. For instance, glass fiber reinforced polymer (GFRP) is used in vehicle panels for enhanced durability, resilience or crash energy absorption [4], [5]. In construction, sandwich structures are used in roofing and, cladding systems because of their thermal insulation and resistance to various factors in the environment [6].

B. Problem Statement

In fact, although composite sandwich structures offer increased applicability and astounding material efficiency, the structures are confronting demanding problems such as impact issues. Such structures are subjected to low velocity and high velocity impacts including those that occur in car accidents, debris strikes and unintended drop on conveyors which may cause internal damage without any external manifestations. In this case there is concealed danger as the existing weaknesses may reduce the load bearing capability of structure, in the event of further loading, bringing about catastrophic collapse. It is therefore crucial to understand the response of sandwich structures under impact conditions and the corresponding failure mechanisms [7].

The fact that the composite sandwich structures have a poor resistance to the internal damages is the main reason why the behavior of the structures under impact loading should be studied in detail in order to prevent the damages growing gradually and to predict failure in the future.

Scientists are paying more and more attention to such damages and exploring the methods to forecast and identify these damages; moreover, improving the materials and structures in order to reduce them. Nonetheless, quantifying the behavior of impact effectively entails many investigation procedures such as experimentation and computational extrapolations, as well as focusing on certain primary aspects that include particularity of material, geometry of core, and environmental aspects [8].

C. Objective and Scope

The primary objectives of this study are as follows:

1) To assess the impact resistance of composite sandwich structures through experimental testing and numerical simulations.
2) To investigate the effects of various core and face sheet materials on the impact resistance of composite sandwich structures.
3) To analyze different failure modes observed under impact loading conditions, such as core shear, face sheet cracking, and delamination.
4) To evaluate the accuracy of numerical models in predicting the experimental outcomes for impact behavior in composite sandwich structures.
5) To identify optimal material and design configurations that enhance impact resistance in applications such as aerospace, automotive, and construction.

Specific areas of the study include composite structures including honeycomb and reentrant topologies in conjunction with face sheets made from carbon and glass fiber reinforced polymers. Furthermore, the study will compare the performance of these structures under low velocity, as well as high velocity impacts and will seek to record as many failure modes as possible including; core shear, face sheet crack and delamination. Nevertheless, the following limits are inherent in this research: Material availability limits this study to a few selected core and face sheet types and is relevant to certain impact circumstances that are typical for industries of interest [9], [10].

D. Research Questions

To guide this investigation into the impact resistance of composite sandwich structures, the following research questions have been formulated:

1) How do different core and face sheet materials affect the impact resistance of composite sandwich structures?

This question aims to uncover the influence of various material combinations on the overall performance of sandwich structures. Different materials possess unique mechanical properties, and understanding these differences is essential for designing structures with optimal impact resistance.

2) What are the failure modes observed under different impact loading conditions?

Identifying failure modes is crucial to enhancing the durability of sandwich structures. By analyzing the types of damage incurred under various impact scenarios, such as low-velocity and high-velocity impacts, this study aims to highlight areas where design improvements are necessary. Typical failure modes include core compression, core shear, and face sheet delamination, each of which affects the structure's residual strength differently.

3) How accurately can numerical models predict the experimental outcomes for impact behavior in composite sandwich structures?

Numerical simulations, when validated against experimental data, can be powerful tools for predicting the behavior of composite structures under impact. This question will explore the correlation between numerical predictions and actual experimental outcomes, evaluating the effectiveness of current modeling techniques. By achieving accurate predictions, numerical simulations can play a vital role in designing materials without the need for exhaustive physical testing.

By addressing these questions, this research seeks to enhance the current understanding of impact behavior in composite sandwich structures. The findings are expected to contribute to the development of more resilient composite materials, with implications for safer and more efficient designs in aerospace, automotive, and construction applications.

II. LITERATURE REVIEW

A. Overview of Impact Resistance in Composite Sandwich Structures

Composite materials are widely utilized in several industries because they possess excellent mechanical characteristics, durability and weightlessness.

Comprising two or more constituents which possess different physical and/or chemical characteristics these materials exhibit superior performance attributes like high strength to weight ratios, toughness and resistance to environmental stresses.

As a result, composites find usage in fields that require the superior performance of the material in high stress applications such as aerospace, automobile industries, construction, defense, etc. where cyclic loading and toughness of the material are very important [1], [2].

However, within the framework of 3D printing, improvements in the discrete manufacturing technology have broadened the use of composite structures, with regard to the design freedom of complex shapes and improvements to the applied mechanical performance. Current research on 3D printed composites identify print orientation as a crucial parameter which determines the performance of structures. It was shown in the previous work by Fisher et al. [1] that the direction of layers identified in 3DP density consequences in mechanical response of the printed construction to impact loading, which proves that proper layer orientation can reduce damage and increase the lifespan of extent of printed composite.

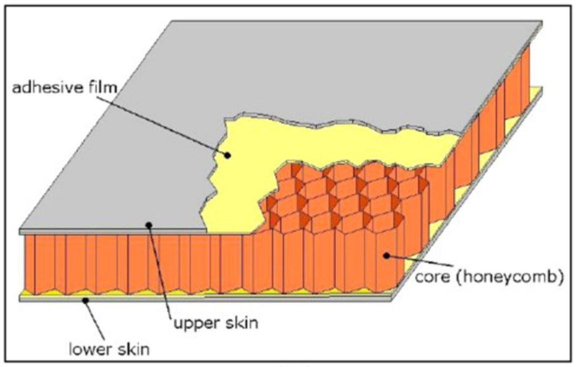

Figure 1: Composite sandwich structure in aeronautic applications [3]

The present study of the low-velocity impact behavior of composite structures is also important to know for future works to other similar researches on composite structures especially sandwich panel, a widely-used high-impact structure, has also been studied in the recent years [2], [3]. Such panels, with honeycomb, or re-entrant core, for instance, boast of impressive energy absorption characteristics well suited to applications with repetitive load and impact forces. For instance, Indreș et al. [2] have identified the peculiarities of the behavior of 3D printed sandwich panels with honeycomb core, arguing that the combination of such types of cores makes such structure highly resistant to impact forces, which attests to the possibility of further improving the core designs in composite structures.

One additional area of interest is cork-based composites that provide the multi-impact response. Cork has emerged in the most recent composites literature as a natural, renewable material that can naturally provide shock absorption. Antunes et al. [3] examined cork agglomerates with experimental and numerical investigations demonstrating that the material possesses high values of resilience and energy dissipation concurrent with impact situations requiring repeated load bearing. By examining cork's composite materials, essential information regarding sustainable and impact resistant materiality can be gleaned, becoming pivotal as the engineering world initiates its turn toward eco-friendly solutions.

Besides the composites with cork, authors also have concerned with how static and dynamic characteristics of the sandwich structures with aluminum core depend upon its configuration. The influence of core design on the stability and response of al aluminum honey comb sandwich structures in different loading conditions was investigated by Hamza et al. [4]. In this work, the authors demonstrate how core configurations contribute to stress distribution and impact energy absorption, and therefore are crucial to a broad range of applications where structure integrity is paramount, especially in defense technology [4].

The dynamic response of fiber–metal laminate (FML) composites stands out as yet another potential area of investigation in composite science. Compared to FMLs, AFMs stack metal and fiber layers; the structure exhibits greater ductility, strength that can be useful in fields experiencing high load conditions such as those caused by blast impact. A study done by Yang et al [5] showed that FML sandwich beams perform well under uniform blast loading and helped in the understanding of design parameters for blast resistant structures and development of protective composite materials [5].

Availability of structural health monitoring (SHM) has also appeared as an equally important component in composite material use especially where reliability is very important. Therefore, by incorporating nanotechnology it is possible to augment SHM where the health of composites and damage can be contemporarily detected.

Carbamate glass fibers coated with carbon nanotube have been used by Zhao et al. [6] as sensing layers to inspect on the state of glass fiber reinforced polymers whereby the damages resulting from low velocity impacts were discerned.

This work can be regarded as an important step in identifying the application of SHM in the composite structures for the effective and efficient maintenance of the composite materials in order to increase its life cycle and reliability [6].

In the area of ballistic protection different features have been studied, for instance, the use of shear-thickening fluids (STFs) that have some different properties under high load conditions. Alexe et al., [7] explored STFs as "liquid body armors," due to their application in ballistic energy dissipation. Through non-Newtonian routing these fluids possess the function to increase viscosity once shocked, thus to absorb and release energy. This property makes the product especially useful in protective shielding such as body armors and gear to be used in harsh conditions [7].

Another layered material that has the possibility of improving the mechanical attributes of composite composites is CFRP. Until now, the reinforcement of composites by incorporation of carbon nanofibers has been used in improving the mechanical characteristics of the composites. Santos et al [8] described physical and mechanical properties and enhancement of epoxy-based composites through carbon nanofiber, and observed that this kind of modification resulted in better tensile strength and modulus apart from fracture toughness. This research provides a clear validation of carbon nanofibers in areas that require highly durable and lightweight materials, for instance in automobile and aircraft engineering [8]. At the same time, the studies of impact conditions for CFRP composites including the analysis of how distinct damage modes are developed are conducted. Experimental and simulation work to analyze CFRP reinforcements were carried out by Bounjoum et al. [9] and the most apparent damages such as delamination and matrix cracks were noted. These understandings allow for the development of CFRP fits with increased tolerance of certain forms of loading to provide a vast range of practical uses where longevity and durability are paramount [9].

Another significant factor, which affects overall composite efficiency is environmental influences, which were examined by Osa-uwagboe et al. [12] and their research on composites' performance in seaborne environment. Their studies shed light on how condition of environment degrades or affects the composite material with respect to parameters such as strength and service interval among others. This work, along with the ability to utilize machine learning for a forecast of the overall composites' performance under conditions of environmental impacts, can be considered a progressive approach to create highly durable materials for using in the marine industry [12].

When it comes to using composites in response to present-day consumer demand for the application of environmentally friendly composites, bio composites are gaining significance. Cork as described by Dymek et al. [14], is used in formulation of bio-composites of cork and polyurethane that can offer great impact performance and elasticity under loading. In light of increasing use of composites derived from natural resource, possibly this sort of studies underscores the viability of bio composites in offsetting or enhancing environmental impacts in as much as they meet the need for performance standards [14].

The thermal conductivity and the thermal expansion coefficients of composites, which are very important for application where temperature variations are expected, are also being studied. Further, Anwajler et al. [16] examined the effectiveness of thermal composite material of 3D printed and pointed out that geometry has a key influence on thermal resistance. These findings apply to the construction industry in the development of energy efficient building materials that can endure unfavorable macro environment [16].

Structurally integrated lightweight and high durability structures, particularly in transport applications, are on an upward trajectory, enabled by improvements in material science and dynamic structural design. Cascino et al [18] provided a Concept Design of operation Car Body of Railway Vehicle with composite material and dynamic structural optimization in which the authors emphasized the weight saving imperative for energy and performance [18].

Altogether, material investigated during these past few years investigating composites depict the usage of material in many applications that demand strength, toughness, and hardness [11]. Having a clear appreciation of how impact is handled, how structures are monitored, and how well the composites are protected from the environment, it is possible to create enhanced materials suited to certain uses. With the continuous development of composite technology, further work such as the development of different reinforcement methods, post-impact behavior and structural health monitoring will surely expand the use of composite materials in more demanding sectors.

B. Experimental Methods and Findings

The assessment methods of the influence factors affecting the performance of composite sandwich structures are divided into several experimental methods, and the drop weight impact test and high-speed impact test are more commonly used.

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Drop weight tests involve subjecting a sample of the composite to a weight dropped from a specific height while high velocity impacts use projectiles that emulate real life situations such as those experienced in industrial settings. The outcomes of these methods of investigation show that the performance of composite sandwich [17].

Under impact loading is closely related to the energy absorption characteristics, damage initiation, and failure modes. Several failure modes are commonly observed in composite laminates: core shear, face sheet cracking and delamination, of which the last one, that is, it can happen in ‘‘the internal layers” of the laminates and is thus not visible from the outside.

There is Energy absorption which is a measure of how much the structure is able to withstand an impact. Foam cored sandwich structures, for example, are commonly associated with high energy absorption capacities owing to the compressive response of the core which provides energy absorption prior to failure [19]. Research has shown that damage initiation is normally localized to the area of impact on the face sheet with spread of energy to the core and other parts of face sheet. Also, this study shows that failure modes depend on core as well as face sheet material properties and impact velocity. In drop-weight tests, high-impact energy levels appear to cause more severe delamination, while low-velocity impacts reveal different damage mechanisms: indentation or core buckling.

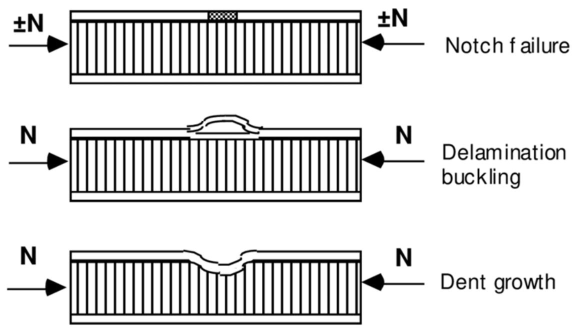

Figure 2: Face sheet failure modes caused by impact damage [19]

C. Numerical Approaches (Theoretical)

Numerical simulations especially Finite Element Analysis (FEA) are employed to predict impact behaviour of composite sandwich structures, and the researcher can predict failure under different conditions without actual testing [20]. Software used for such analyses includes ABAQUS, LS-DYNA and ANSYS since they enable great material modeling and impact process modeling. The modeling of these materials requires the identification of its properties and their calibration against experimental data to ensure a high level of modeling accuracy [21]. Furthermore, the validation of such models is often accomplished by reproducing such features as the initiation of failure and energy absorption that are produced in experiments.

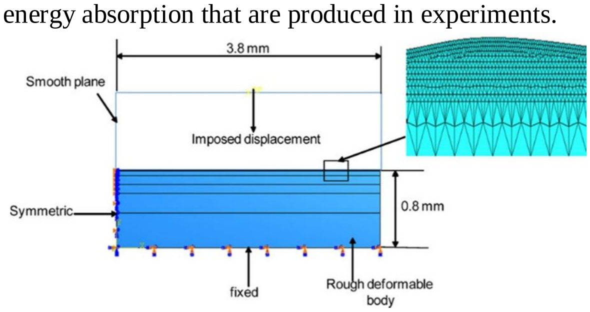

Figure 3: Boundary conditions, dimensions and mesh used in numerical simulation [21]

These papers prove that there are still some difficulties present, although numerical simulations could accurately predict the influence behaviors of composite sandwich structures in actual applied environments. Some of the challenges that researchers have observed include; challenges in modelling delamination and core crushing. Impact force induced delamination is difficult to model because it necessitates accurate, nonlinear material property data that represent step-wise failure. Moreover, pressure applied to the cores during the core crushing can differ from structure and density, so it can be another challenging aspect of the simulations that appear usually demanding experimental identification.

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D. Comparison of Experimental and Numerical Results

Several works analyze the observed experimental results with theoretical computations to evaluate how accurate these models are in emulating actual effects.

In general, the results show numerical models can be used to estimate some impact behaviors including initial damage points and overall energy absorption characteristics. However, limitations exist. Numerical models, however, fail to produce relatively complex failure modes such as internal damages in the form of delamination and core buckling [22]. According to some sources, simulations generally provide under or over estimates of the damage that may be due to such factors as the use of elementary material models like linear elasticity despite complex impact damage features.

Accordingly, the authors have pointed out that despite the increased realism offered by such techniques as cohesive zone modeling and progressive damage models, experimental and numerical results are still significantly apart, especially in multifaceted, high-energy impacts. For example, it has been found composites materials are anisotropic in nature, in other words they do not behave similarly to metals during impact movement modeling. Secondly, the development of numerical models relies heavily on the quality of experimental data used for calibration and validation and thus demand for experimental research even with improvement in the numerical models.

III. ANALYSIS OF KEY FACTORS INFLUENCING IMPACT RESISTANCE

A. Material Selection

Material selection is a critical factor influencing the impact resistance of composite sandwich structures. Studies have shown that face sheet materials, such as carbon fiber and glass fiber, significantly affect the stiffness and energy absorption capacity, while core materials, including foam and honeycomb, influence the structure’s overall weight and resistance to core crushing.

Table 1: Summary of findings from key studies, highlighting the benefits and drawbacks of various face sheets and core materials

Material Type	Properties	Advantages	Disadvantages
Carbon Fiber Face Sheets	High stiffness, strength	Superior impact resistance, lightweight	Higher cost
Glass Fiber Face Sheets	Moderate stiffness, strength	Cost-effective, good energy absorption	Lower stiffness than carbon fiber
Foam Core	Lightweight, crushable	Good energy absorption	Lower shear strength, limited durability
Honeycomb Core	High strength-to-weight ratio	Excellent resistance to core crushing	Complex to manufacture, costly

B. Structural Configuration

The structural configuration, including core thickness, density, and the number of face sheet layers, plays a crucial role in impact resistance.

Studies have shown that increasing core thickness generally enhances the impact energy absorption, while density adjustments help tailor the balance between weight and resistance.

Table 2: Summarizes findings on structural configurations.

Configuration	Impact on Resistance	Observations
Increased Core Thickness	Enhances energy absorption	Thicker cores reduce face sheet bending

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Higher Core Density	Improves shear resistance	Denser cores increase weight
Additional Face Sheet Layers	Increases overall stiffness	More layers improve impact absorption but add weight

C. Impact Conditions

Impact conditions, including the impactor's velocity, angle, and mass, greatly influence damage patterns and failure modes. Higher impact velocities, for example, can lead to delamination and core crushing, while oblique angles tend to produce asymmetric damage patterns.

Table 3: A synthesis of impact conditions based on current research

Impact Condition	Effect on Damage	Failure Modes Observed
High Impact Velocity	Increases damage severity	Delamination, fiber breakage
Oblique Impact Angle	Produces asymmetric damage	Localized core crushing, face sheet bending
Increased Impactor Mass	Amplifies energy absorption requirements	Core cracking, face sheet penetration

This analysis underscores how each factor—material choice, structural configuration, and impact conditions—interacts to influence the overall performance of composite sandwich structures under impact, as observed across studies. These insights help establish the foundational understanding for optimizing these structures for impact resistance.

IV. SYNTHESIS AND DISCUSSION

A. Summary of Main Findings

Composite sandwich structures, composed of face sheets (such as carbon or glass fiber) and core materials (like foam or honeycomb), exhibit impact resistance influenced by material selection, structural configuration, and impact conditions. Below are the synthesized findings from the literature.

1) Face Sheet Materials: Carbon fiber is noted for high stiffness and strength, making it ideal for applications needing robust impact resistance, despite its high cost. Glass fiber, while less expensive, provides moderate impact resistance and energy absorption, suiting applications with lower impact demands.

2) Core Materials: Foam cores provide high energy absorption but are weaker under shear stress, making them susceptible to crushing. Honeycomb cores, although costlier, offer excellent strength-to-weight ratios and better resistance to crushing.

Table 4: Consolidates the key characteristics of these materials.

Material Type	Component	Stiffness	Strength	Energy Absorption	Cost	Common Uses
Carbon Fiber	Face Sheet	High	High	Moderate	High	Aerospace, high-end automotive structures

Glass Fiber	Face Sheet	Moderate	Moderate	High	Moderate	General-purpose industrial applications
Foam	Core	Low	Low	High	Low	Low-cost structures needing energy absorption
Honeycomb	Core	Moderate	High	Moderate	High	Aerospace, lightweight high-strength structures

3) Structural Configuration: Increasing core thickness typically enhances energy absorption and reduces bending stresses in the face sheets, contributing to better impact resistance. Higher core density provides better shear strength but may increase overall weight, which is a critical factor in aerospace and automotive applications. Adding extra face sheet layers increases stiffness and impact resistance, but it also increases the weight and material cost.

Configuration	Effect on Resistance	Observations
Increased Core Thickness	Enhanced energy absorption	Reduces bending, better supports face sheets
Higher Core Density	Improved shear resistance	Adds weight, affects fuel efficiency in vehicles
Additional Face Sheet Layers	Higher stiffness	Increases weight, offers greater impact absorption

4) Impact Conditions: The nature of the impact (velocity, angle, and mass of the impactor) greatly influences the failure modes in these structures. High-velocity impacts tend to cause severe delamination and fiber breakage, while oblique impacts often lead to asymmetric damage patterns, affecting structural integrity.

Impact Condition	Effect on Damage	Failure Modes Observed
High Impact Velocity	Severe delamination, fiber breakage	Intense damage, often localized near impact area
Oblique Impact Angle	Asymmetric damage patterns	Localized core crushing, face sheet bending

Increased Impactor Mass	Greater energy absorption demand	Core cracking, face sheet penetration

B. Strengths and Limitations of Approaches

1) Experimental Approaches

Experimental methods provide direct insights into damage modes and real-world material responses under impact, such as fiber breakage, core crushing, and delamination. However, they can be costly and time-consuming, especially with high-end materials like carbon fiber, which may limit the frequency and variety of tests.

Experimental Method	Advantages	Limitations
Drop-weight Impact	Realistic impact simulation	Equipment and material costs; labor-intensive
High-speed Impact	Precise observation of failure modes	High material costs; requires sophisticated equipment

2) Numerical Approaches

Numerical methods like finite element analysis (FEA) allow flexible, hypothetical testing of impact scenarios without physical testing constraints. However, simulating complex damage mechanisms, such as delamination and core crushing, remains challenging, and models often require validation through experimental data to ensure accuracy.

Numerical Method	Advantages	Limitations
Finite Element Analysis (FEA)	Flexibility in scenario testing; adaptable	Difficulty in simulating delamination accurately; requires validation

C. Implications for Future Design

1) Material Prioritization: For high-impact applications, designers should prioritize carbon fiber for its stiffness and resilience, especially in sectors like aerospace and high-performance automotive manufacturing. For more budget-sensitive projects, glass fiber is a viable alternative.
2) Structural Optimization: To enhance impact resistance without compromising weight, core thickness and density can be strategically adjusted. Thicker, denser cores may be optimal for applications requiring energy absorption, while layered face sheets can be added selectively for critical areas.
3) Impact-Specific Configurations: Engineers can tailor designs based on expected impact conditions, employing thicker and denser cores in high-velocity impact scenarios, while retaining lightweight configurations for lower-impact settings.

In summary, composite sandwich structures' impact resistance can be optimized by considering material properties, structural configurations, and specific impact scenarios. Leveraging a combination of experimental and numerical approaches allows for greater adaptability in design and more effective prediction of structural behavior, catering to the diverse requirements across industries.

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V. CONCLUSION

A. Summary of Main Conclusions

This review has thus looked at the ability to ameliorate the composite sandwich structures' ability to withstand impact forces, with focus on materials and structure layouts. Sandwich structures formed by face sheets and a lightweight core material have high carrying capacities to density ratios and are employed in many industries such as aerospace, automotive and construction. Concerning impact behavior, the selection of the materials especially the face sheets (carbon fiber glass fiber) and, the core (foam or honeycomb) is critical to the structure. For example, the carbon fiber face sheets offer high stiffness and strength and tops away relatively poor compressional resistance, thus, it is ideal for highly resilient purposes but more costly. Porous fiberglass is less expensive, but has average impact strength so is good for broad use.

The use of the core materials is to maximize energy absorption while at the same time minimizing crushing loads. Foam cores are very light weight, possess high energy absorption but fail under shearing force or loads. While honeycomb cores are stronger and can less readily be crushed, they are much more expensive compared to the sandwich panel. Furthermore, other characteristics of these materials, including core density, and face sheet layering as well as thickness can be modified to enhance the level of impact resistance. Increased core thickness and density provide better energy absorption with extra layers of face sheets providing added stiffness at the cost of increased mass. Overall, these findings suggest that better understanding of heterogeneous core fundamental properties and their mechanical behavior will allow for the development of improved composite sandwich structures for various impact applications.

Furthermore, the circumstances which such impacts take place are also very important for example speed of the impacting object and angle as well as the mass of the impactor. Higher velocity damages cause delamination damages and fiber breakage and where impact angle is not normal to the plane of the composite structure this causes asymmetric damages to the structure. Such failure modes can be directly observed in experimental studies since they offer real behavior under impact. But they can be costly in terms of utilization of equipment and also in terms of materials involved in the construction of the equipment. Hypothesis testing and scenario analysis are also provided using numerical methods such as FEA, which is a shaded technique supplying an alternative option. While numerical approaches are not ideal in simulating detailed damage phenomena such as delamination and core crushing, they are useful for the first design evaluations and in situations where experimental tests cannot be performed.

B. Recommendations for Future Research

Since this review is based on secondary research the following are potential areas of improvement understanding and technology development in composite sandwich structures. Several key areas for future research are recommended below:

1) Search for Other Material

The review was further restricted to conventional matrices like carbon fiber, glass fiber, foam, and honeycomb for composite sandwich structure. Nevertheless, certain new materials like hybrid fibers, bio-based core and superior polymer matrix revealed evidence of impact resistance enhancement but with relatively low environmental impact and cost. For instance, hybrid fiber composites are possible, which will combine some properties of the carbon and glass fibers, including higher performance and reduced expense. Furthermore, the bio-based cores and the use of sustainable materials presented an environmentally utilitarian approach that may not necessarily affect structural integrity of cores. More exploration is possible: future research could look at these new materials and examine their effectiveness in experimental high impact applications.

2) Enhanced Numerical Models

Finite element analysis is well employed for simulation of impact on composite sandwich structures however Modeling of these structural engineering systems including delamination, fiber breakage, and core crushing is still a formidable task. Improvement in the numerical models is another aspect and the current ones are not capable of providing such structural insights into the complex consequences of such damages. It was seen that element techniques like cohesive zone modeling (CZM) and extended finite element methods (XFEM) have the capability of modeling of delamination more effectively whereas progressive damage modeling might bring improvements in predicting the core crushing failure and face sheet failure. However, the advancement of these models is still required as far as required variables are established to provide better simulation fidelity.

3) Comparative Assessment of Impact based on Experimental Validation

The majority of works are concerned with a small set of impact conditions, in which the most essential parameters – velocities and angles – are usually fixed.

Increasing the number of testing parameters, such as impact angle, impact velocity and geometry of impactor, could generate additional data for better calibration of the models. This would also provide useful information on the response of the composite sandwich structures under various practical service conditions especially at areas of aerospace and automotive application where impact condition is not fixed. Other such studies could improve the level of risk associated with simulation-based design as experimental observations are compared with numerical results of the study.

4) The Techniques of Optimizing Multi-layered Configurations for Specific Uses

While it is possible to enhance this property by laminating face sheets and modifying the core characteristics, these alterations invariably result in increased weight, which is disadvantageous in some uses. Future work could also identify layering patterns that enhance the strengthening of certain regions at risk of impact without adding to the structure's mass. For example, possibilities for the localized strengthening of components in areas that may sustain higher stress impacts could be explored for use in optimizing the reinforcement, and therefore minimizing the use of mass and material, while increasing required strength.

5) Research on Fatigue Resistance with Respect to Repeated Loads

However, the majority of studies reveal data on single-load bearing, but in practice materials are exposed to influence in cycles, and it leads to decrease bearing capacity. Research on the fatigue properties of composite sandwich structures concerning considerable repeated impacts might result to cyclic durability and the progressive effect of the damage. Research could examine how minimal energy impacts and cyclic stress add up to progressive micro-damage and failure that would inform engineers on how best to design their structures to last longer.

6) Application of Smart Material/Smart Sensors for Damage Identification

One of the main issues when working with composite sandwich structures is an ability of identifying internal damage, like core crushing or delamination, and as it was mentioned before, these damages cannot be seen from the outside. The possible use of smart materials and embedded sensors may create real-time monitoring systems for the detection of fly-away-head impact damage. Research could be directed towards the viability of placing fiber Bragg gratings or piezoelectric sensors in the composite to monitor internal stress levels, strain and possible damage occurring. This would not only increase safety but also decrease ongoing costs because analysis for predictive maintenance model is possible.

7) Category-Wise Design Guidelines Depending Upon Requirement of Impact Resistance

Industrial applications differ by segments including aerospace, auto, and construction and each of these has their peculiar need regarding the impact resistance. The future research could focus on defining specific guidelines for the same, with the application expected impact conditions taken into account, material costs, and structural requirements. For example, the choice of materials for aerospace application may involve high lightweight and high stiffness materials, while for automotive structures, high energy absorbing material may be desirable. Creation of guidelines of this application specific need would enable the engineers to arrive at correct design decision for efficient utilization of material.

Thus, composite sandwich structures help to constitute one of the important trends in the modern engineering where materials are required for their specific impact-resistance and low density. Accordingly, this review has underscored the key factors defining the performance of these structures with regards to impact; these include the choice of material to be used in the structure, the structural configuration as well as impact conditions. In this respect, a good deal of work has already been done; however, there is enormous potential for growing the database through further studies of new materials, improvement of numerical models, checking simulation results across any situation, and the creation of novel design concepts. This will mean that the future of the use of composite sandwich structures will see further enhancement of safety, performance and inclusiveness of sustainability features across the various applications that the structures can be employed in.

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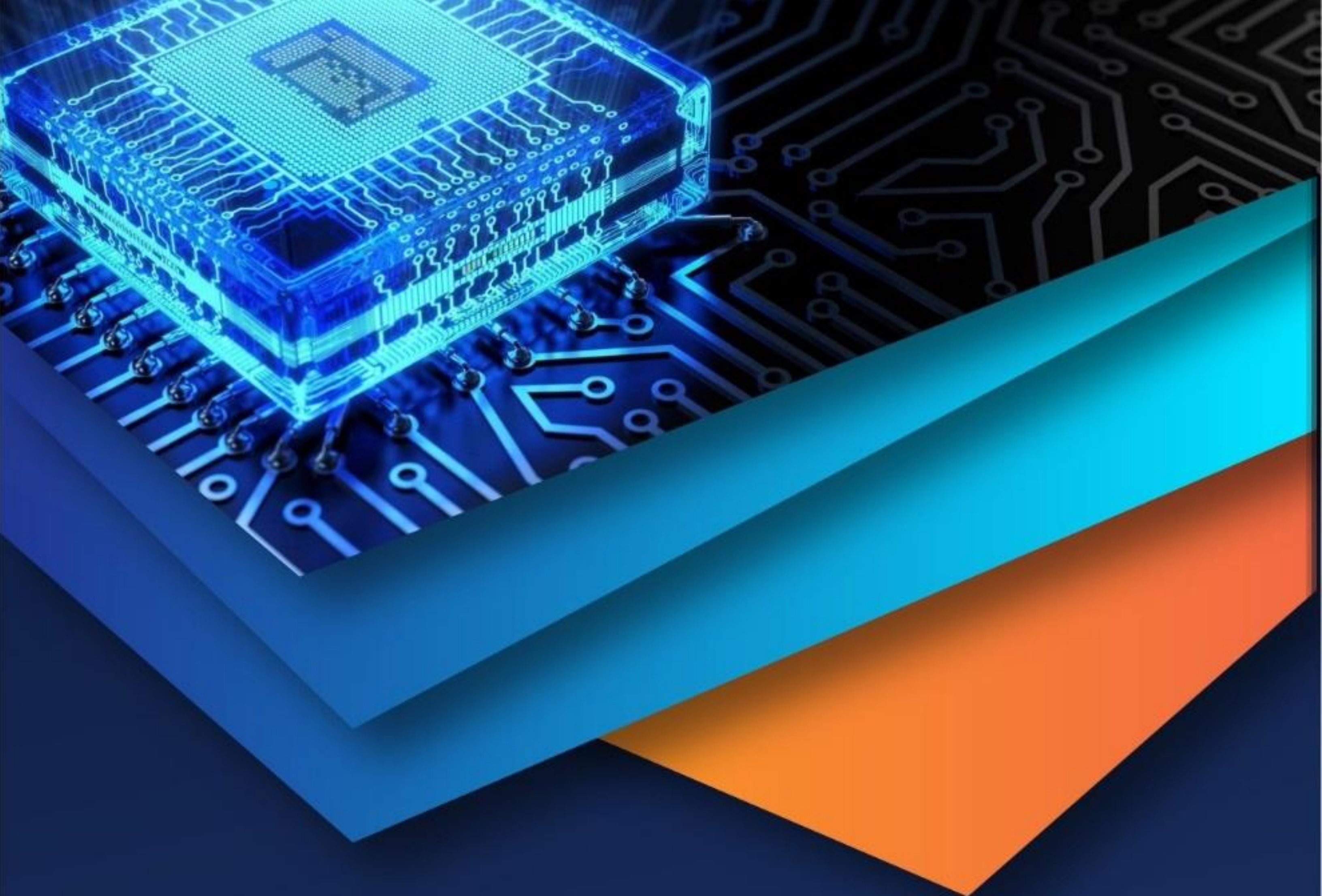

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