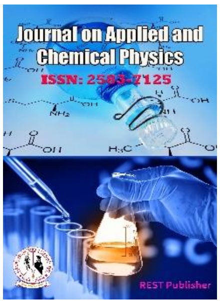
Journal on Applied and Chemical Physics
Vol: 2(1), March 2023
REST Publisher; ISSN: 2583-7125 (Online)
Website: https://restpublisher.com/journals/jacp/
DOI: https://doi.org/10.46632/jacp/2/1/3



Detection of Composites and Sandwich Structures for Aeronautic Application

***[1]K. Aravindh, [1]D. S. Robinson Smart, [2]Chandrasekar Raja, [2]M. Ramachandran**
[1]*Karunya Institute of Technology and Sciences, Coimbatore, Tamilnadu, India.*
[2]*REST Labs, Kaveripattinam, Krishnagiri, TamilNadu, India.*
*Corresponding Author Email: aravindhk20@karunya.edu.in

Abstract. *"An overview of sandwich structures in aviation applications is provided in this article. It emphasizes the complexity of designing these structures and addresses the main issues that designers face while working with them. Beginning with early instances from the 1930s and focusing on their significant development during World War II, the article examines the evolution of sandwich structures. It explores their wide range of uses in both civil and military spheres. The article also investigates the impact of polymer materials and sheet technology on the mechanical characteristics of composite sandwich constructions. The essay covers three different types of sandwich structures that were created using manual lay-up, press technique, and autoclave application manufacturing processes. These sandwich specimens underwent impact load tests to determine their failure properties. The structural analysis focused on sandwich panels produced in a similar manner, with an adhesive layer between the cores. The goal of the study was to generate research findings about the effects of stress during sandwich panel fabrication on several mechanical properties of structured sandwich composites, including flexural strength, impact strength, and compressive strength.*

1. INTRODUCTION

Maximizing weight savings while retaining structural integrity is the major goal of aircraft design. Due to this need, thin surfaces must necessarily be strengthened to sustain various forms of loads, such as tension, compression, torsion, and bending. This problem was addressed in traditional airframe structural design by adding longitudinal stiffeners, stringers, and ribs or frames to stabilize the structure. However, in composite design, this method is not the most elegant one. In fact, frequently, a more effective way to stabilize a surface against deformation forces is by using two skins with an intermediary layer to create resistance between them. Sandwich structures are a universal principle in nature that predates the emergence of humans. Elder tree branches make a superb illustration of a foam core sandwich structure. A similar sandwich-like structure with a foam-like core can be seen in the bones found in the skeletal systems of both animals and humans. These natural sandwich structures face numerous challenging load conditions. For instance, the bones of the feet must tolerate repeated compression and bending loads. As evidenced by the skeletons of birds, nature imposes strict requirements on main components to be lightweight. These examples highlight the concept of structural optimization, which involves using the least amount of material while still achieving optimum effectiveness. Sandwich structures are notable for their high strength-to-weight ratio, relative light weight, and degree of rigidity. The outer surfaces of a sandwich panel are constructed to withstand bending forces (including compression and flexural stress), while the core is designed to handle changing loads resulting from diverse circumstances. Essentially, the functioning of an I-beam at a macroscopic level can be successfully compared to the operation of a sandwich panel. Sandwich composite materials are categorized as anisotropic materials, meaning their strength characteristics shield the applied loads. By leveraging an understanding of this anisotropy, it becomes feasible to fabricate composite materials that demonstrate specific properties along desired directions, based on specific requirements. The development of these materials is contingent upon the associated requirements dictated by a particular composition. Furthermore, these requirements are directly tied to the utilization of a particular framework. The essential requirements include stiffness, strength, specific volume, thermal insulation, sound resistance, energy absorption capacity, and hydrostatic weight.

2. COMPOSITES SANDWICH STRUCTURES

Sandwich structures are increasingly being employed in a range of industries, including bridge construction, wind energy systems, train carriages, satellites, aircraft, and various types of cars. The use of sandwich constructions is growing due to their numerous benefits, such as lightweight design, the emergence of novel materials, and the demand for excellent performance. Despite advancements in other construction techniques, sandwich constructions are still in high demand as they provide a lightweight solution. There are many similarities between the equations developed for thin-walled composite structures and those explaining the behavior of sandwich-like structures. Sophisticated theoretical models may be necessary only when working with highly flexible core materials [1]. Sandwich constructions have been in use for at least fifty years. By sandwiching a low-density core between two rigid skins, it is possible to create a structure with excellent stiffness and strength-to-weight ratio. Additionally, sandwich structures offer advantages such as sound absorption and thermal insulation. Sandwich structures have established themselves in various industries, including aerospace, automotive, marine, and rail transportation. Currently, most sandwiches employ thermos composite skins with fiber reinforcement, which are adherently joined to the core components [2]. The design objective of the sand machine was to predict and handle barely apparent visual damage (PVID), also known as barely apparent damage, in sandwich constructions using a two-dimensional (2-D) shell modeling approach. By utilizing this tool, sandwich material finite element (FE) models can be created, the data can be post-processed, and BVID can be solved and compared to experimental results. The program's ability to simulate damage caused by impact loading determines its suitability for advanced composites engineering and evaluation applications [3]. The strength of sandwich structures with body-centered cubic lattice cellular cores has been assessed using three-point bending tests. Two ideal designs for functionally graded cores are proposed based on adjusting the spatial arrangement of lattice cells and the diameter of lattice beams. The optimized cores demonstrate significantly higher strength and stiffness compared to the standard benchmark core. Given the large number of design factors available for optimization, it is natural that the spatially standardized lattice core exhibits the greatest improvement in strength and stiffness. Dragoni considered the best design for aluminum tetrahedral cores, which can be used for corrugated cores, pyramidal cores, and other truss core types [4].

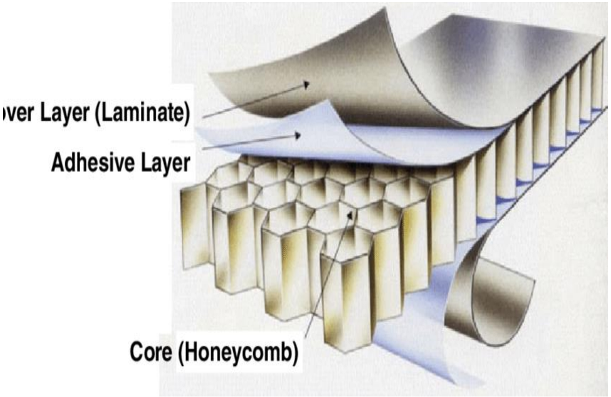


FIGURE 1. Composite sandwich structure

Supports are necessary in standard 3D printing because the skin is generated across spaces in the core for sandwich constructions with materials that resemble honeycombs. The core form, however, become an enclosed space when sandwich structures are merged, making it impossible to later remove the support. As a result, it is advised against using supports when creating the upper skin. This study looked into the use of a continuous carbon fibre 3D printer to create support less sandwich structures with a core shape that could be changed. Form analysis and three-point bending tests have been used in this work to evaluate the properties of those sandwich structures [5]. Composite sandwich constructions have drawn a lot of interest as a technique to maximise the possibilities of contemporary composite materials. These sandwich structures are often referred to as composite sandwich structures because they include a lightweight core and two composite face panels. The face sheets primarily handle plane and bending loads, whereas the core helps to maintain the spacing amongst the face sheets and carry transverse stresses. Composite sandwich structures are anticipated to be employed for principal structures in aerospace applications since they are extremely lightweight and naturally versatile [6]. A major category of lightweight materials that is frequently utilised in engineering applications, such as marine, automotive, and aerospace structures, are foam core sandwich constructions. In order to achieve high rigidity while minimising weight, Min et al. developed a stainless-steel fan utilising a metallic foam core. By proposing a comprehensive analysis method for foam insulated concrete sandwich constructions, Bai and Davidson made a theoretical contribution to the creation of composite foam core sandwich panels. The addition of core-face reinforcement via sewing, resulting in what are referred to as stitched foam core structures, is another breakthrough in foam core sandwich constructions. The stitching process utilised in monolithic composite materials served as the model for this idea [7].

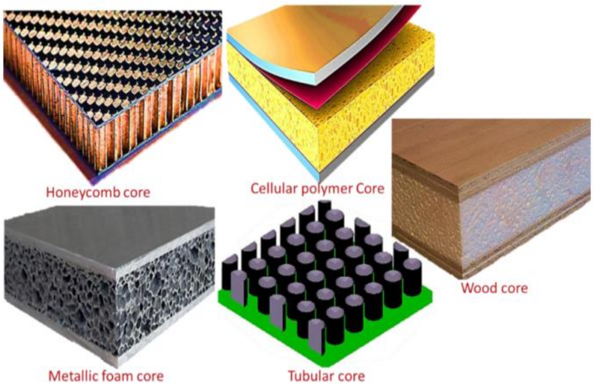


FIGURE 2. Sandwich composite structure

3. SANDWICH PANEL

Sandwich structures' impact resistance and energy absorption qualities have drawn interest for prospective uses in the design of vehicle and aviation structures. A prototype car's chassis, made up of two rigid polyurethane foam cores and shells constructed of either glass fiber-reinforced polyester or epoxy resin, was used by Raschbichler for testing. In crash tests, sandwich panels show a distinct advantage because they effectively absorb energy by limiting deformation to the impact location while preventing damage from spreading to other areas of the structure [8]. For the examination of sandwich panels, numerous well-known non-destructive techniques that are typically employed for metals have been applied. These techniques often rely on finding flaws in separate parts or sandwich panel assembly. Voids / voids in composite faces, splitting between the face and core, and deformation or erosion of the core are a few examples of flaws. Various authors have provided reviews of this topic. The most often employed methods for sandwich panels are thermography, X-ray radiography, and ultrasound [9]. Matsui explains the creation of the executive jet Honda-Jet's proof of concept model. Similar to Poland's research, sandwich panel fabrication demonstrated weight and cost benefits over traditional aluminium alloys. The sandwich panels are used in a number of locations on this aircraft, including the wing composite shroud, flap track fairing, wing-to-fuselage fairing, tail cone, tail boom, scoop, horizontal empennage fairing, spoiler, wing stub upper skin, forward fuselage pressure bulkhead and landing gear bay upper covers [10]. The comparatively low damage resistance of structural sandwich components, caused by the thin exterior composite skins, is a significant disadvantage. Whenever composite skin laminates get hit by a projectile, a number of fracture processes with corresponding energy-absorbing properties may take place. Despite the fact that the three main causes of harm in sandwich structures—matrix cracking, disbonding, and fibre failure—may initially appear to be distinct, their interactions with other factors, such as fibre type, lay-up, distribution, geometry, adhesive bonding between the matrix and the fibres, and environmental factors, lead to complex failure modes. The sandwich panel's core may be harmed and penetrated if the sandwich panel's outer skin breaks. The sandwich panel may bend and react to relatively low-velocity projectiles without being harmed because the elastic strain energy in the panel absorbed the projectile's energy. At high impact velocities, the localised contact stress—this may be the bending strength of the laminate, the compressive strength of the core, or the shear strength of the interface—reaches a critical threshold and surpasses the local strength. To increase durability and damage tolerance, structural evaluation of damage and deformations ought to be a part of the design process [11].

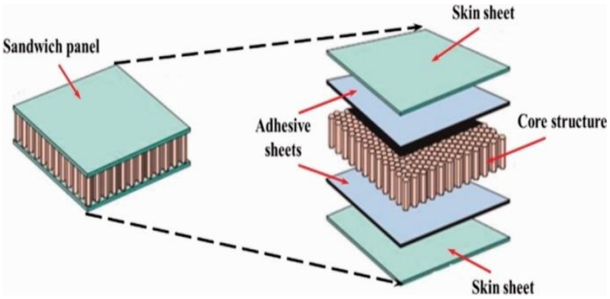


FIGURE 3. Sandwich panel

4. HONEYCOMB

The term "honeycomb" describes a thin structure that is made up of many interconnected cells. Thermoplastics like aluminium, Nomex, or propylene are a few examples of the materials utilised to make honeycomb constructions. As was previously mentioned, the exceptional mechanical performance of hexagonal honeycomb structures makes them suitable for usage as sandwich core structures. In the work of Côté et al., the addition of bonded skins had a more noticeable effect on the compressive response of the core with a relative density of 0.20 than cores having relative densities of 0.03 and 0.10. The authors compared the constructions of steel hexagonal honeycomb and aluminium square honeycomb. In comparison to the square honeycomb, the hexagonal honeycomb fared better under peak loads, had lower peak stresses, and had more rapid softening [12]. Numerous researchers have acknowledged the advantages of employing Lamb waves to detect various faults in metallic plates, pressure tubes, and composite laminates. Since it doesn't seem a complete theoretical model that completely describes Lamb wave propagation for these composite materials, traditional research has had trouble addressing honeycomb sandwich composites. As a result, a lot of basic study has focused on the characteristics of the propagation of surface-excited Lamb waves. For example, Hosseini and Gabbert used the traditional finite element method to simulate wave propagation while homogenising the underlying medium to generate a simpler model. We can better understand Lamb waves propagating in honeycomb sandwich structures as a whole by looking into specific aspects. Pitte et al. Analytical, computational, and experimental research on the Lamb wave propagation mechanism in honeycomb sandwiches were done with a focus on the influence of the material and geometric parameters on the Lamb wave dispersion curve. In this area, Tian and his colleagues also made significant achievements. Using experimental wave number analysis, the author explained the fundamental ideas of Lamb waves in a honeycomb sandwich structure. It is stated that the wave number alters as the frequency increases. The issue of wave scattering and reflection inside the core medium hasn't received much attention, though, particularly when guided waves are travelling through complex geometrical sandwich structures as the frequency of stimulation increases [13].

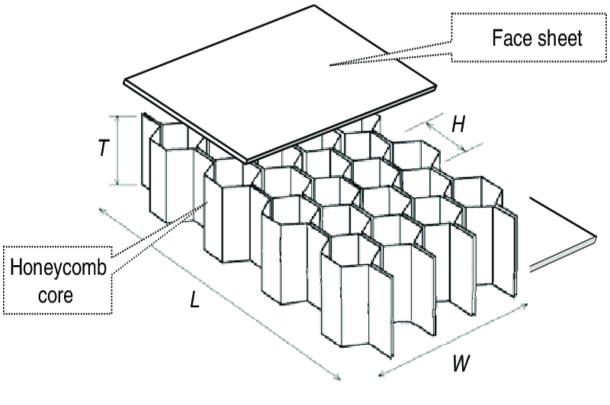


FIGURE 4. Honeycomb structure of sandwich

Due to its remarkable impact resistance and great energy absorption capacity, Nomex honeycomb has been studied as a critical material and has undergone major improvements. Herup and Palazotto's studies on sandwich plates made of graphite, epoxy, and Nomex honeycomb with different face sheet thicknesses revealed that larger face sheets are more effective at distributing transverse stress throughout the core. Hard projectiles induce deep damage that closely resembles the projectile shape, while soft projectiles only result in shallow core crushing. Sun et al. studied the response of honeycomb sandwich structures, particularly in the hollow region, to low-velocity impacts. They concentrated on how face-sheet flexibility affected things. In addition, Justo et al. investigated the function of impact energy absorption by honeycomb cores. The use of Nomex is indicated to increase the overall effectiveness of composite laminates because it promotes less unstable fracture propagation and lessens damage in the impact region. The performance of sandwich panels with a Nomex honeycomb core in tests involving either compression after impact (CAI) and low-velocity impact (LVI) was examined by Glioli et al. The findings demonstrated that the damaged core material is not contributing to the residual strength post-impact since the face sheet bears almost all of the compressive force. But it's important to keep in mind that the research above only looked at flat sandwich composite panels. Compression after impact (CAI) conduct, the evolution of damage in tubular composite sandwich structures, and the dynamic impact reaction and failure mechanisms of tubular composite frameworks with a Nomex honeycomb core have not received much attention from researchers. Due to the dearth of research in these disciplines, there has become a lack of understanding regarding the grasp of these unique qualities [14]. The PMI Foam Reinforced Kagome Honeycomb Composite Sandwich Systems (PKCSS), a distinctive structure, is made by incorporating PMI foams inside the Kagome honeycomb structure's base cells. Compression and bending tests that are carried out in compliance with the standards of the American Society for Testing and Materials (ASTM) are used to evaluate the PKCSS's compression, bending, and energy absorption characteristics. Then, these attributes are further examined using the finite element method (FEM). A comparison between the PKCSS and a sandwich structure produced using PMI foam and Kagome honeycomb of comparable size is made in order to offer a thorough evaluation and validate the performance of the PKCSS [15]. The stress intensity in the honeycomb cells doubles at a repair temperatures of 177°C (350°F). Therefore, it is advised to use composite prepregs or laminate patches and carry out a hot blanket curing process for repairs on damaged and moisture-affected composite honeycomb sandwich constructions. The honeycomb cell contains the same quantity of water at 121 C (=250 F). These two temperatures are recognised as the typical temperatures used for the first structural curing and the repair processes of the majority of composite structures. It is important to maintain ideal repair circumstances while using a reasonably high curing temperature to stop further water vapour damage from occurring close to the sandwich panel's damaged area. A force or relative stress that is given to a repair area during honeycomb structure repair that is wider than the connecting area [16].

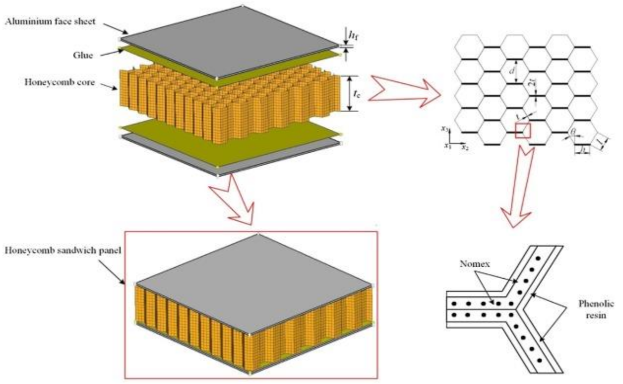


FIGURE 5. Honeycomb Sandwich panel

5. THERMOPLASTIC COMPOSITE SANDWICHES

Sandwich constructions could benefit from the incorporation of thermoplastic and thermoplastic composite (TPC) components because they could be produced more quickly and with greater mechanical, environmental, and damage tolerance. Fusion bonding, which relies on the interdispersion of the polymers of the parts and can be finished in a few minutes, is an effective bonding technique for thermoplastic materials. Grunwald et al. provide a summary of a number of TPC sandwich production methods [17]. The physical connection of molecules to thermoplastic polymers is reversible and is capable of being broken by the application of heat, solvents, or mechanical forces. The polymer becomes more malleable and opens up the option of thermoforming or fusion. The polymer becomes a solid when it cools or when the solvent is eliminated. When contrasted with thermos-based structures, this property provides an automated process chain with lower production costs. The usage of thermoplastic polymers also increases damage tolerance and recycling. As a result, the goal is to create sandwich constructions made of thermoplastic composites (TPC) with both the skin and core [18].

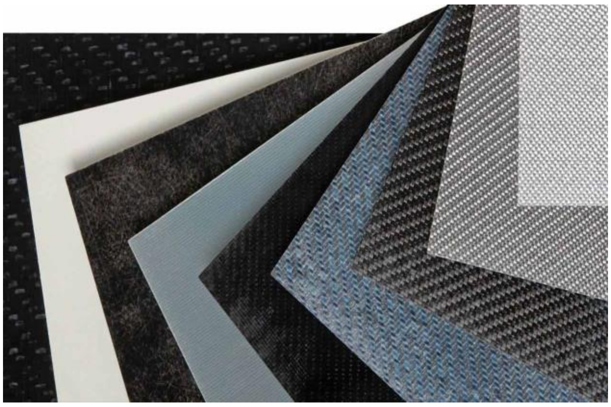


FIGURE 6. Thermoplastic Composites

The fundamental distinction between thermosetting and typical thermosetting is that the formation of thermoplastic compounds solely involves a physical phase transition, but the formation of thermosetting compounds involves a chemical process. Because of its repeatability, ductility, and deformation recovery, thermoplastic composites (TPC) have gained a lot of interest recently. When creating TPC sandwich structures, these properties offer additional options for bonding the face sheet and core. Research has been done on TPC sandwich designs with different core topologies. Composite sandwich structures were made using pyramid trusses made of self-reinforced poly (ethylene terephthalate) (SrPET) and corrugated cores, and Schneider et al. examined these structures for compressive response. The load-bearing and energy-absorbing abilities of sandwich structures were found to benefit from the thermoplastic material's ductility and thermal-meltability [19]. Compared to current thermoset-based sandwich structures, the use of fiber-reinforced thermoplastic polymer faces combined with a core made of the same thermoplastic polymer offers significant advantages. Thermoplastic matrix composites exhibit excellent fracture toughness, excellent impact tolerance, high chemical stability, unlimited raw material shelf life, and a clean and safe working environment. Also, using the same thermoplastic polymer throughout the sandwich allows for a strong face-to-face interface through fusion bonding, facilitating recyclability and offering attractive process efficiency opportunities. Studies with beakers and Afrikan polyetherimide (PEI)-based sandwich structures have demonstrated that the thermoplastic aspect of the sandwich allows the fabrication of shaped parts from flat panels by thermoforming techniques such as folding and edge-forming. One of the most attractive features of thermoplastic sandwiches with a single polymer applied to the faces and core is the possibility of rapid, low-cost mass production. All-thermoplastic sandwiches allow rapid production of a complex part by forming and joining in a one-step process [20]. A mechano-acoustic coupled study is being investigated to investigate the relationship between distinct micro-damage mechanisms seen in different polymer matrix composite (PMC) sandwich material and the overall macroscopic mechanical behaviour shown in three-point bending (TPB) tests. The AE approach was used in our group's earlier research to examine the mechanical behaviour and structural integrity of PMC materials. In this work, the ability of several PMC sandwich constructions to absorb energy during TPB testing is analysed and compared along with their bending stiffness, strength, and capacity. The beginning and propagation of distinct microscopic failures are coupled to the AE activity measurement in order to characterise the evolution of the suggested mechanical-acoustic link and damage processes. Various thermoplastic tube topologies are compared to conventional Nomex or aluminium honeycomb cores [21].

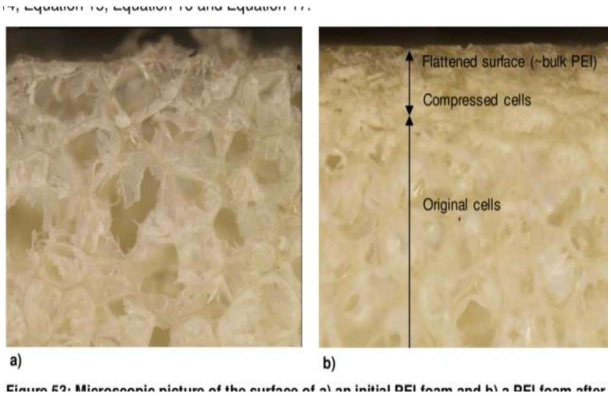


FIGURE 7. Microscopic view of Thermoplastic Material

6. NON-DESTRUCTIVE TESTING

The experimental research detailed in this paper was conducted as a part of the global research project "ALCAS," which is headed by Airbus and focuses on models ubiquitous to the aircraft industry. A number of destructive and non-destructive procedures are utilised to assess the damage caused by examined drop-weight impact tests on the samples. The remaining strength of the sandwich specimens was assessed using the compressive after impact (CAI) strength [22]. The NDE community has been actively involved in non-destructive inspection and assessment of thin carbon-fiber composites utilised by the aerospace industry for many years, and several monographs are currently produced on the topic. However, other from acknowledging the much greater inspection problem in the literature that has been published for all standard NDT, little effort has been dedicated to the test of thick period composites. These structures' methods [23]. In addition, composites may become internally flawed either during production or use. Impacts are a common cause of service failures. Low energy impacts, such as those caused by a car accident, can also significantly reduce the mechanical qualities and fatigue resistance of composite constructions. Due to rarely apparent impact damage (BVID), laminated composites' exceptional mechanical qualities are at a cost of their through-thickness characteristics. Despite affecting the structure's upper surface, BVIDs frequently cause cracking in the matrix and a complicated web of shapes on the interior or rear surface. Such harm poses a risk because it cannot be seen from the outside and is frequently difficult to spot during visual examinations. Porosity, voids (or adhesion reach area), & inclusion are some internal failure mechanisms that can cause a composite structure to fail in additional to impact-induced damage [24]. To improve detection capacities and inspection quality, automated and C-scan techniques have been increasingly popular in non-destructive testing (NDT) in recent years. In order to increase the precision of NDT inspections, C-scan imaging, which offers a two-dimensional data presentation, has shown to be especially helpful. It allows for the detection of even the smallest modifications to the properties of the structure being studied (Roche and Rice, 2016). C-scans are widely utilised in conjunction with acoustic-ultrasonic dry coupling techniques like PC for static immersion ultrasonic inspections of solid composite constructions. The quality of NDT examinations could be significantly improved by including C-scans into these techniques, especially for sandwich constructions and bonded joints [25].

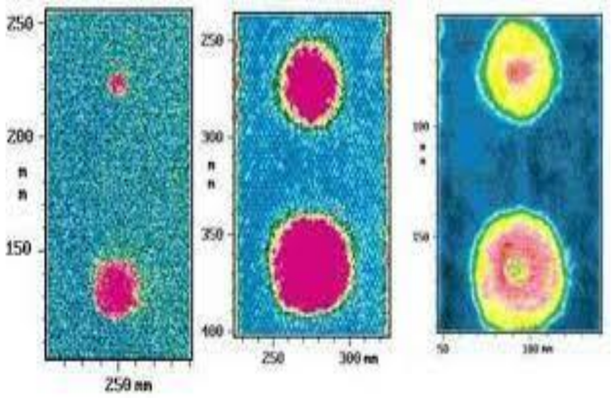


FIGURE 8. Ultrasonic view of Non-Destructive Testing

The most common non-destructive evaluation (NDE) method for finding faults in composite materials, such as foreign substance inclusions, disbonded regions, and resin bonded interfaces, is ultrasonic inspection. Applications for this method are constantly being expanded. In a transmission ultrasonography (TTU) test, an absence or reduction of the transmission pulse indicates potential difficulties, whereas an echo during a pulse-echo test indicates the existence of a problem [26]. Numerous techniques can be used to identify these flaws. However, at the moment, the only NDT method that leads to certification is ultrasonic testing. Ultrasonic testing requires substantial equipment (like a pool) and can be done in a touch or non-contact manner. It makes it possible to quickly and accurately identify numerous flaws, including delamination and disbonding. However, this moves forward somewhat slowly. Optical techniques have gradually developed over the past 20 years and are currently employed for non-destructive testing. Both the infrared thermograph and more contemporary techniques like speckle shearing interferometry are frequently employed [27].

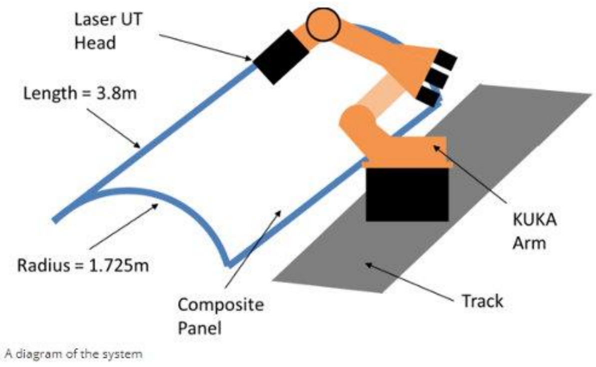


FIGURE 9: Simple setup of Non-Destructive Testing on a composite

7. CONCLUSION

Sandwich structures are increasingly being employed in a range of industries, including as bridge construction, wind energy systems, train carriages, satellites, aircraft, and various kinds of cars. Sandwich constructions are increasingly being used, which can be linked to their many benefits, like lightweight design, the advent of novel materials, and the need for excellent performance. Sandwich constructions are still in high demand because they can provide a lightweight solution. Sandwich structures' impact resistance and energy absorption qualities have drawn interest for prospective uses in the design of vehicle and aviation structures. A prototype car's chassis, made up of two rigid polyurethane foam cores and shells constructed of either glass fiber-reinforced polyester or epoxy resin, was used by Raschbichler for testing. In crash tests, sandwich panels show a distinct advantage because they effectively absorb energy by limiting deformation to the impact location while preventing damage from spreading to other areas of the structure. The term "honeycomb" describes a thin structure that is made up of many interconnected cells. Thermoplastics like aluminium, Nomex, or propylene are a few examples of the materials utilised to make honeycomb constructions. As was previously mentioned, the exceptional mechanical performance of hexagonal honeycomb structures makes them suitable for usage as sandwich core structures. Sandwich constructions could benefit from the incorporation of thermoplastic and thermoplastic composite (TPC) components because they could be produced more quickly and with greater mechanical, environmental, and damage tolerance. Fusion bonding, which relies on the interdispersion of the polymers of the parts and can be finished in a few minutes, is an effective bonding technique for thermoplastic materials. In addition, composites may become internally flawed either during production or use. Impacts are a common cause of service failures. Low energy impacts, such as those caused by a car accident, can also significantly reduce the mechanical qualities and fatigue resistance of composite constructions. Due to rarely apparent impact damage (BVID), laminated composites' exceptional mechanical qualities are at a cost of their through-thickness characteristics. Despite affecting the structure's upper surface.

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