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Joining Methods for Thin Sandwich Materials: A Review

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ABSTRACT

Joining thin sandwich materials with a total thickness of up to approximately 1.5 mm is a major technological and structural challenge because the joint must ensure reliable load transfer without causing unacceptable damage to the face sheets and core. Based on a literature review, this paper analyses the main joining approaches applied to this class of materials, namely adhesive bonding, mechanical joining, hybrid joints, and selected thermal and thermomechanical methods. These approaches are assessed in terms of technological feasibility, joint strength, and the risk of local damage. The results indicate that adhesive bonding is the most broadly applicable approach because it enables load transfer without perforation and without pronounced local deformation. Mechanical joining methods are suitable only selectively, as they increase the risk of delamination, local indentation, and stress concentration. Hybrid joints appear to be a promising solution in terms of reliability and resistance to peel loading, whereas thermal and specialized methods are particularly suitable for thermoplastic and metal-polymer systems. The selection of a joining technology should therefore be based not only on joint strength but also on the extent of disturbance to the original multilayer structure.

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I. INTRODUCTION

One of the dominant trends in contemporary mechanical engineering, transportation, and related technical fields is the reduction of structural weight while maintaining or improving mechanical performance. Accordingly, modern materials are expected to combine low density, sufficient strength, high stiffness, in-service reliability, and good manufacturability. In many applications, these requirements have driven the adoption of multilayer and hybrid material systems that enable the deliberate combination of the properties of individual constituents. Among these systems, sandwich materials occupy an important position.

Sandwich materials are multilayer structural systems typically consisting of two thin and relatively strong face sheets separated by a lightweight core. This configuration enables low areal density while retaining favorable mechanical properties, as the core increases the spacing between the face sheets and thereby enhances the bending stiffness of the overall structure [1, 2]. In the literature, these structures are regarded as a distinct class of lightweight material systems intended for applications in which high structural efficiency under strict weight constraints is a key requirement [1, 3].

The relevance of sandwich materials stems primarily from their high specific stiffness and favorable strength-to-weight ratio. The combination of stiff face sheets and a lightweight core make it possible to design components that provide higher bending stiffness than monolithic materials at the same areal density [1]. From a structural perspective, an additional advantage is the ability to tailor the properties of the core and face sheets to the required function of the component, for example in terms of energy absorption, vibration damping, or local structural stability [4]. In thin metal-polymer sandwich systems, their potential to replace conventional sheet metals while maintaining a favorable stiffness-to-weight ratio has also been demonstrated [2].

From an application perspective, sandwich materials are used primarily in the aerospace and automotive sectors, mechanical engineering, and electrical engineering. In the automotive industry, particular attention has been devoted to metal-polymer and three-layer aluminum/polymer systems developed to reduce vehicle mass and operating energy demand [5, 6].

Despite these advantages, joining sandwich materials remains technologically demanding. This is primarily due to their heterogeneous multilayer architecture, which combines materials with different strength, stiffness, formability, and often also different thermal sensitivities. Mechanical joining entails a risk of local indentation, core damage, delamination, and stress concentration in the vicinity of the joint [7]. For adhesive joints, surface preparation, joint geometry, adhesive properties, and service conditions must all be considered because they directly affect joint load-bearing capacity and durability [8, 9]. In hybrid thin-walled structures, the limitations of conventional joining methods become particularly apparent, especially the need for perforation, the presence of notch effects, and the sensitivity of some layers to heat input and local deformation [10, 11].

In adhesively bonded thin-walled structures, bending deformations and peel stress become more pronounced, which may adversely affect stress distribution within the joint [12]. In thin metal-polymer sandwich sheets, the small overall thickness also restricts joint formation without local damage to the face sheets or core and narrows the process window for forming-based mechanical joining [2, 6, 13].

The aim of this article is to review selected joining methods for thin sandwich materials and to evaluate them in terms of technological feasibility, joint strength, and the degree of damage induced in the joined material.

II. Thin Sandwich Materials and Joining-Specific Challenges

Thin sandwich materials are multilayer structural systems composed of two face sheets and a core placed between them. The face sheets carry most of the mechanical load, whereas the core maintains their spacing and thus contributes significantly to the bending stiffness of the overall assembly. This separation of the load-bearing layers by a lightweight core underlies the favorable balance between weight and mechanical performance in these materials [1, 2, 3].

From a material and structural perspective, sandwich materials include systems with foam, honeycomb, corrugated, or otherwise shaped cores, as well as metal/polymer/metal sheets [1, 4]. Of particular interest are reduced-thickness sandwich materials developed to retain the advantages of multilayer architecture even at low overall thickness while allowing subsequent forming and integration into lightweight structures [2, 5, 13]. An example of the layered structure of the Hybrix material is shown in Fig. 1.

Fig. 1 Layered structure of the Hybrix material [13]

This group also includes vibration-damping metal-polymer sheets, in which the polymer interlayer serves primarily for vibration and noise damping. A representative example of such a layered configuration is shown in Fig. 2 [14].

Reducing the overall thickness significantly affects both the mechanical response of sandwich materials and their manufacturability. Smaller spacing between the face sheets reduces resistance to local deformation, whereas thin face sheets are more susceptible to indentation, wrinkling, peeling, and local thinning. At the same time, the process window for manufacturing and joining operations becomes narrower because even relatively minor interventions in the joint region may significantly alter local stiffness or damage the core. In thin-walled joints, bending deformations and peel stress also become more pronounced, particularly in lap and adhesive-bonded configurations [2, 12, 13].

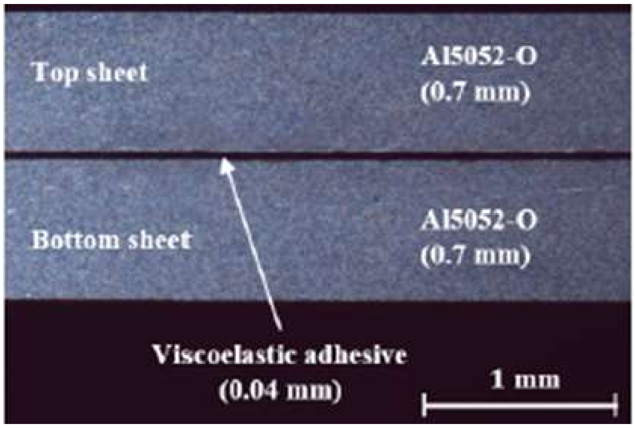

Fig. 2 Cross-section of a vibration-damping aluminum sandwich panel with a viscoelastic interlayer [14]

When thin sandwich materials are joined, the effects of heterogeneous architecture, small thickness, and the local discontinuity introduced by the joint accumulate. In the joint region, layers with different stiffness, strength, formability, and thermal stability interact, leading to non-uniform stress transfer and damage localization. Joint quality is therefore determined not only by the strength of the joining zone but also by the extent to which the original multilayer architecture of the material is disrupted [7, 8, 11].

One of the dominant failure mechanisms is delamination, i.e., separation of individual layers or failure of the interface between the face sheet and the core. Delamination may be initiated by processing defects, local normal and shear stresses, machining, joint geometry, or service loading [7, 12]. In thin sandwich structures, it is particularly critical because it leads to a loss of composite action between the layers and a reduction in both load-bearing capacity and stability in the vicinity of the joint. An example of delamination in the form of skin/core debonding in a balsa sandwich material is shown in Fig. 3.

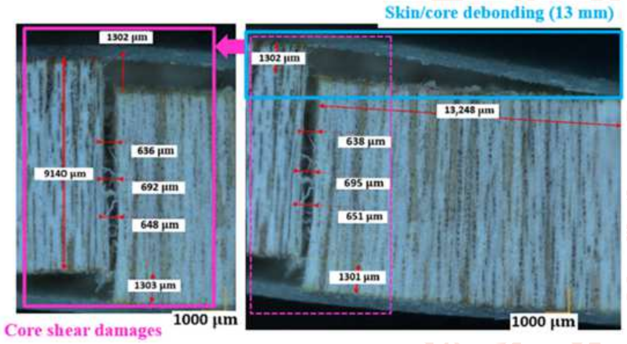

Fig. 3 Microscopic image of skin/core debonding as a form of delamination in a balsa-core sandwich material [15]

Another important mechanism is local indentation, i.e., severe local deformation at the point of load introduction. During mechanical joining or local forming, the face sheet may be indented, while the core may undergo densification, thinning, or damage. Owing to the small thickness of the face sheets, this mechanism is more pronounced than in thicker sandwich panels [7, 10]. A typical example of local indentation and layer thinning in Litecor material is shown in Fig. 4.

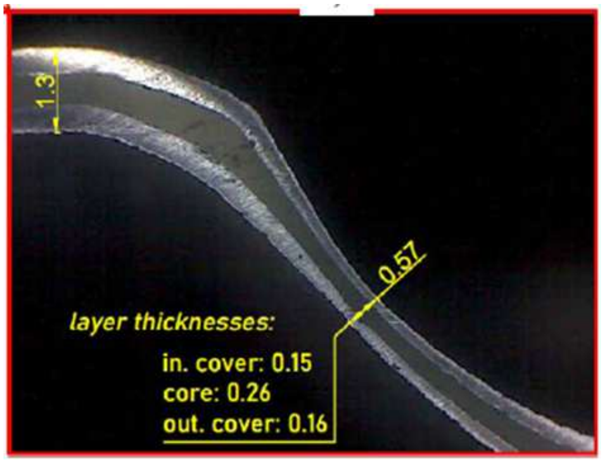

Fig. 4 Local indentation and layer thinning in thin Litecor sandwich material [16]

In adhesive and eccentrically loaded joints, peel stresses acting perpendicular to the joint plane also play an important role in promoting separation of the face sheet from the core or interlayer [8, 12]. Closely related is stress concentration at joint edges, in regions of geometric discontinuity, and at locations of local changes in stiffness or total thickness. In adhesive joints, critical stresses are typically concentrated at the ends of the overlap, whereas in mechanical joints they are amplified by holes, notches, and local plastic deformation [8, 10, 12].

In sandwich systems with a polymer core or an adhesive interlayer, thermal degradation must also be considered. Excessive heat input may alter the properties of the polymer component, weaken the interface, and generate defects, whereas insufficient temperature may prevent the formation of a high-quality joint [11, 14, 15]. The effect of excessive heat input on joint quality is illustrated in Fig. 5, which shows a cross-section through a joint in Litecor sandwich material with characteristic defects in the joint region.

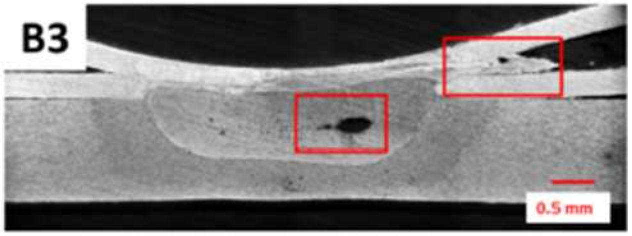

Fig. 5 Cross-section of a joint in Litecor sandwich material showing defects caused by excessive heat input [17]

Another consequence of joining is a local reduction in stiffness. The high bending stiffness of a sandwich structure depends on preserved face-sheet spacing and core integrity. If the core is locally damaged, densified, or replaced by a joining element in the joint area, local stiffness decreases and the deformation of the joined region deviates from that of the surrounding structure [1, 2, 7]. This leads to stress redistribution and may promote premature failure.

Thin sandwich materials therefore represent a particularly sensitive class of multilayer systems with respect to joining. Their structural advantages stem from low weight and efficient layer architecture, yet small thickness, core sensitivity, and susceptibility to local damage significantly limit the applicability of conventional joining approaches. The selection of an appropriate joining method must therefore consider not only the strength of the resulting joint, but also the extent to which the original sandwich structure is disturbed.

Review of Joining Methods for Thin Sandwich Materials

For thin sandwich materials with a total thickness of approximately 1.5 mm or less, the choice of joining technology is critical because the joint must ensure reliable load transfer without unacceptable damage to the face sheets and core. The main options considered are adhesive bonding, mechanical joining, hybrid joints, and selected thermal or thermomechanical methods. These approaches differ in their joint formation mechanisms, the requirements imposed on the material system, and the associated risk of local damage. Accordingly, they are best compared in terms of technological feasibility, material integrity, and overall joint performance rather than assessed in isolation [8, 11, 12].

Adhesive Bonding

Adhesive joints are formed by introducing an adhesive layer between the surfaces to be joined, with load transfer occurring primarily through shear within the adhesive and the interphase between the adhesive and the substrate. For thin sandwich materials, this is a highly advantageous principle because it does not require perforation or substantial plastic deformation of the layers. This is particularly important in thin-walled and composite structures, where perforation increases stress concentration and disrupts the continuity of the load-bearing layers [8, 9, 12].

The main advantages of adhesive bonding are more uniform stress distribution over a larger joint area, low added weight, good sealing properties, and preservation of the geometric integrity of the joined layers. In thin sandwich materials, adhesive bonding is also advantageous because it generally does not damage the core in the way mechanical methods based on perforation or local compression do [8, 12]. Its main drawbacks are high sensitivity to surface condition, adhesive selection, adhesive layer thickness, curing conditions, and service environment [8, 9]. In thin sandwich systems, the failure mechanisms most reported for adhesive joints include interfacial adhesive failure, cohesive failure within the adhesive, face-sheet peeling, delamination near the joint, and crack initiation at the overlap edges [12].

Mechanical Joining Methods

Mechanical joining methods include riveting, bolted joints, clinching, and various types of joining elements or local reinforcing inserts [10, 18]. Their common features are loading transfer by means of mechanical interlocking, contact pressure, or an independent joining element. The advantages of mechanical joints include immediate load-bearing capability without curing, the possibility of disassembly in bolted joints, and relatively straightforward quality control during manufacture [7, 18]. An example of a riveted joint in a thin sandwich material produced by self-piercing riveting is shown in Fig. 6.

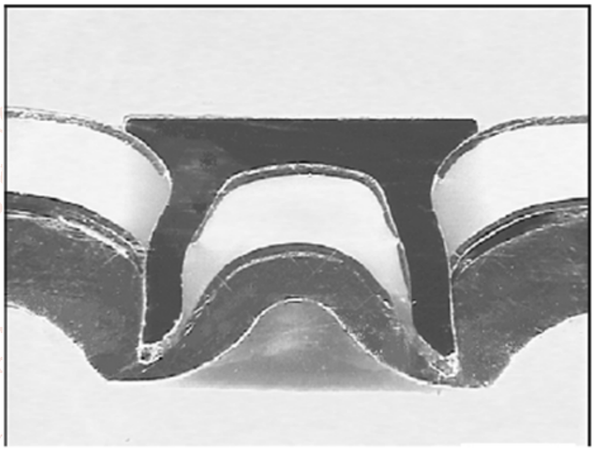

Fig. 6 Self-piercing-riveted joint between Hylite LSS material and aluminum [19]

At small thicknesses, however, mechanical joining faces substantial limitations. The main problem is perforation of the face sheets, local introduction of force into a small area, and the associated stress concentration. In sandwich materials, not only the face sheet but also the core may be damaged, as the latter is often more compliant and less resistant to local compression or indentation [7, 10, 18]. Mechanical joining in thin sandwich systems is therefore generally more susceptible than adhesive bonding to delamination, local indentation, and stiffness reduction in the vicinity of the joint.

Clinching occupies a special position among these methods. In clinching, two or more layers are locally plastically deformed to create a geometrical interlock without the use of an additional joining element. Its advantages include low process complexity and the absence of rivets or screws, but its applicability depends on sufficient formability of the joined materials and appropriate tool geometry [10]. In multilayer thin sandwich systems, clinching is suitable only under selected conditions, especially when the face sheets can accommodate local plastic deformation without pronounced delamination or core damage [6, 10]. Clinched joints between Litecor and HCT600X+Z materials are shown in Fig. 7 [20].

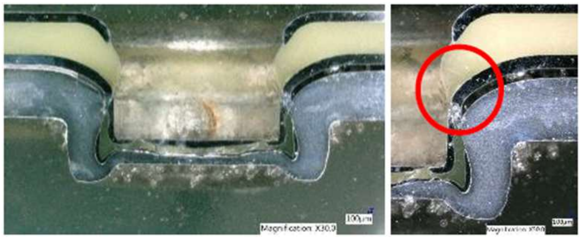

Fig. 7 Clinched joints between Litecor and HCT600X+Z materials [20]

Hybrid Joining Methods

Hybrid joining combines two or more techniques to achieve a joint with better properties than those provided by the individual methods alone. In thin sandwich materials, this most often involves combining adhesive bonding with a mechanical joint or combining an adhesive with a point-based or other local thermal joint [11, 21]. In such configurations, the adhesive layer provides more distributed load transfer and sealing, whereas the mechanical or local point element improves joint security, peel resistance, and often also immediate handling strength.

The main benefits of hybrid joints include higher load-bearing capacity under static and dynamic loading, more uniform stress distribution, greater resistance to peel loading, improved load sharing between the individual elements, and good sealing properties [21]. In thin sandwich materials, a local mechanical element may also limit crack propagation in the adhesive layer, which is important from the standpoint of safety and damage tolerance. The drawbacks of hybrid joining are higher process complexity, more demanding parameter optimization, and more difficult prediction of failure mechanisms [21].

Thermal and Advanced Joining Methods

This group includes ultrasonic joining, laser joining, resistance welding, and other methods applicable to systems containing a thermoplastic component or a thermally activated interlayer. These technologies offer short cycle times and high automation potential, but their applicability strongly depends on the sandwich-system architecture and on the thermal sensitivity of the individual layers [11].

Ultrasonic joining is particularly promising for thermoplastic composites and hybrid metal-thermoplastic systems. In this method, heat is generated directly at the interface by high-frequency mechanical vibrations, enabling rapid joint formation [22]. Joint quality, however, depends on surface characteristics, the ability to establish mechanical interlocking or chemical bonding, and the stability of the process conditions [22].

Laser joining is considered a promising method, particularly for hybrid polymer-metal structures, because it enables highly localized and precisely controlled heat input [23]. In thin sandwich systems with a polymer core or thermoplastic layer, it is advantageous only if the applied heat input does not cause core degradation, interfacial failure, or peeling of the face sheets [11, 23]. A cross-section of a laser-welded metal/polymer/metal sandwich panel is shown in Fig. 8 [24].

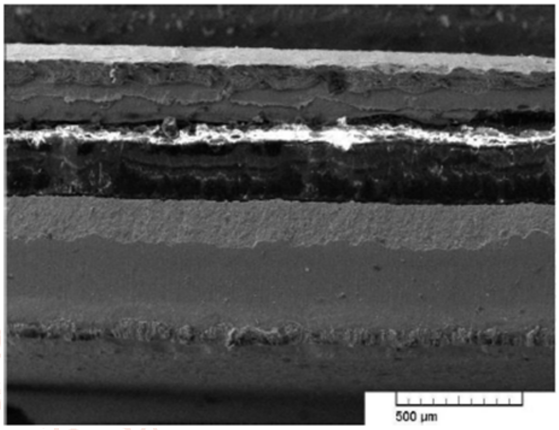

Fig. 8 Cross-section of a laser-welded metal/polymer/metal sandwich panel [24]

Resistance and other fusion-based joining methods are relevant mainly for thermoplastic composites, in which a joint can be formed by local heating followed by material consolidation. This group includes promising techniques such as ultrasonic, induction, and resistance welding [25]. Accordingly, these technologies are applicable only to sandwich systems containing a weldable thermoplastic component or a compatible interlayer. Spot welds produced by shunt current-assisted resistance spot welding are shown on Fig. 9 [17].

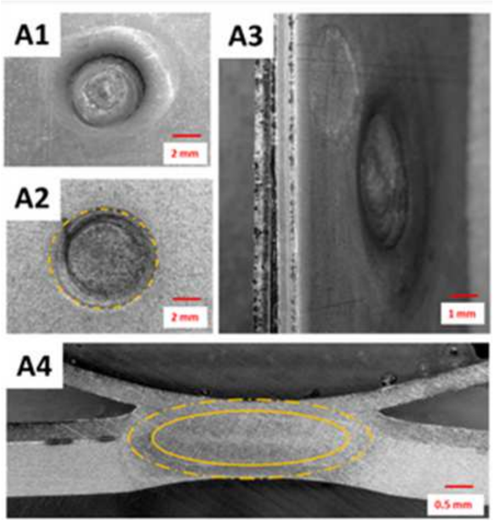

Fig. 9 Spot welds produced by shunt current-assisted resistance spot welding: (A1) top view, (A2) bottom view, (A3) side view, (A4) cross-section at low magnification [17]

No single joining method can therefore be regarded as universally optimal for thin sandwich materials. Adhesive bonding is advantageous because it preserves material integrity and promotes more distributed load transfer; mechanical joining offers immediate load-bearing capability and, in some cases, disassembly; hybrid joints improve reliability; and advanced thermal methods are particularly promising for thermoplastic systems. The selection of the joining technology must therefore be based on sandwich architecture, required joint performance, and the allowable degree of local damage.

Discussion

The analyzed studies indicate that joining thin sandwich materials with a thickness of approximately 1.5 mm or less is substantially more sensitive to the choice of technology than joining monolithic sheets or thicker sandwich panels. The governing factors are the multilayer architecture of the material, the small overall thickness, and the high susceptibility to local damage. For this class of materials, the primary evaluation criteria should therefore include not only maximum joint strength, but also the ability of a given technology to preserve the integrity of the face sheets, the core, and the local stiffness of the joined region [11, 12].

A comparison of the individual methods shows that adhesive bonding can generally be regarded as the most broadly applicable approach for very thin sandwich materials. Its main advantage is the absence of perforation and pronounced local material deformation, which reduces the risk of delamination, local indentation, and severe stress concentration [8, 9, 12]. At the same time, however, the reliability of adhesive joints depends strongly on surface preparation quality, adhesive selection, adhesive-layer thickness, and curing conditions [8, 9]. Adhesive bonding should therefore not be regarded as an intrinsically optimal solution, but rather as a technologically favorable method whose performance remains highly sensitive to process control.

The situation is different for mechanical joining. The advantages of these methods include immediate load-bearing capability, relatively straightforward integration into production, and, for some joint types, the possibility of disassembly. In thin sandwich materials, however, mechanical methods encounter limitations arising from local force introduction into a small area, which promotes delamination, local core compression, face-sheet peeling, and stress concentration in the joint vicinity [7, 10, 18]. Mechanical joining should therefore be regarded as selectively suitable rather than generally optimal for this class of materials.

Hybrid joining appears particularly promising because it combines the advantages of adhesive bonding with mechanical or local point reinforcement. Hybrid joints may provide higher reliability, better resistance to peel loading, and more favorable load distribution than the individual technologies applied separately [21]. In thin sandwich materials, this approach is particularly important because it may partially compensate for the weaknesses of the individual methods. Its drawbacks, however, remain with higher process complexity, more demanding optimization, and usually also higher cost.

Thermal and advanced joining methods represent a rapidly developing field, but their applicability is closely tied to the material compatibility of the joined system. Their greatest potential lies in thermoplastic and metal-polymer sandwich systems, where they enable rapid processing, good automation potential, and, in some cases, high repeatability [11, 22, 23, 24, 25]. Their main limitations remain the risk of thermal degradation of polymer layers, the formation of local defects, and limited universality with respect to material architecture.

An important finding emerging from the analyzed studies is that direct comparison of the individual methods is often hindered by differences in experimental conditions. Individual studies differ in face-sheet material, core type, total thickness, joint geometry, testing methodology, and failure-evaluation criteria. For this reason, the reported results cannot always be transferred directly into a single evaluation framework or used to derive a universally valid ranking of method suitability [9, 11, 12].

From a practical perspective, the methods can be summarized as follows. For general use in very thin sandwich materials, adhesive bonding appears to be the most suitable approach, especially where material damage must be minimized. For applications with increased demands for safety and load-bearing capacity, hybrid joining appears particularly promising. Mechanical methods are suitable mainly in specific cases in which operational or assembly-related requirements are decisive. Thermal and advanced methods have high potential, particularly in thermoplastic and hybrid systems, but their applicability must always be assessed individually with respect to material composition and the system's sensitivity to heat input [11, 12, 22, 23, 25].

Overall, the decisive factor in thin sandwich materials is not only the load-bearing capacity of the joint itself, but above all the ability to create a joint without excessive disruption of the multilayer structure. The most promising technologies are therefore those capable of ensuring reliable load transfer while limiting delamination, local indentation, thermal degradation, and stiffness reduction in the joint region.

CONCLUSION

Thin sandwich materials represent a promising class of multilayer structural systems that combine low weight with high specific stiffness and a favorable strength-to-weight ratio. Their relevance is increasing particularly in applications where weight reduction is required while maintaining the necessary mechanical performance. At the same time, however, small thickness, heterogeneous architecture, and core sensitivity significantly complicate their joining [1, 2, 11].

The results of the literature review show that the selection of joining technology for sandwich materials with a thickness of approximately 1.5 mm or less must be based not only on the required joint strength, but also on the risk of local damage, stiffness changes, and manufacturing constraints. Adhesive bonding can generally be regarded as the most broadly applicable approach because it distributes stress over a larger area while preserving face-sheet integrity without the need for perforation [8, 9, 12]. Mechanical joining is suitable mainly in specific cases, but in very thin sandwich materials it is associated with a higher risk of delamination, local indentation, and stress concentration [7, 10, 18]. Hybrid joints represent a promising compromise between load-bearing capacity, safety, and damage tolerance, but their disadvantages include higher technological and economic demands [21]. Thermal and advanced methods are promising mainly for thermoplastic and metal-polymer systems, and their main advantages are high automation potential and short cycle time [11, 22, 23, 25].

No single universally optimal joining method can be identified for thin sandwich materials. The choice of technology depends on the type of face sheets, the nature of the core, the total thickness, the required load-bearing capacity, the allowable degree of damage, and the manufacturing conditions. For general engineering applications in sandwich materials up to 1.5 mm thick, adhesive bonding may be regarded as the most suitable baseline approach, whereas hybrid and selected thermal technologies remain promising avenues for further development [11, 12, 21, 22, 23, 25].

Further research should focus primarily on the experimental comparison of selected methods under identical material and geometric conditions, so that not only joint strength, but also their effects on local stiffness, damage development, and the long-term service reliability of thin sandwich structures can be evaluated more reliably [9, 11, 12].

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