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Research Article

Mechanical Fastening Methods of Polymer-Based Composites

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Abstract **–** Polymers and polymeric composites are increasingly used in a variety of products, mainly due to their associated weight savings and ease of installation. There are three main joining methods for polymers and polymeric composites: mechanical fixing, bonding and welding. When combining polymer materials and polymer matrix composite materials, the components must be combined to meet both mechanical loads (static and dynamic) and environmental loads (temperature and humidity). However, especially when combining composites consisting of materials with different physical and chemical properties, such as polymers and metals, it is very difficult to combine them with adhesives and weld them in a way that preserves the structural integrity of the structures. In such cases, mechanical fixing procedures are an important solution.

This article aims to explain the basic principles of the mechanical fixing process the main mechanical fixing methods that can be used in joining polymer-based composite materials and to various features of these methods.

Keywords – Mechanical Fastening, Polymer Composite, Joining of Composites, Hole Preparation, Screws, Bolts

I. INTRODUCTION

The use of composite materials in structural components has increased in recent years. Today, many parts are manufactured from composites and are widely used in applications requiring a joint. Composite materials are especially being used in aerospace, automotive, wind turbine, shipbuilding and infrastructure industries. There are three methods welding, adhesive bonding, and mechanical fastening in the joining of the polymer matrix composites [1, 2, 3]. Recently, welding processes have come to the fore due to the high bonding strength they provide, especially in the joining of thermoplastic polymer matrix composites. Well-established joining technologies for metallic structures are not directly applicable to composites [4, 5.]. However, the welding process cannot be used for thermoset polymer matrix composites [2, 6, 7, 8]. Adhesive connections are not preferred in some applications because they are fixed/indissolvable connections like welding and their strength is much lower than welding [9, 10]. However, the nature of mechanical bonding requires drilling holes into the composite parts for joining. As these holes are drilled, fiber or other reinforcements are cut and so it introduces stress concentrations (Figure 1) in each fastener hole and may not be suitable for load-bearing applications (Figure 2) in some cases [11,12]. However, in many structures, mechanical fasteners must be used to remove components or access the interior of the structure. Therefore, it may be necessary to use mechanical fixing when joining structural components of polymer or polymer matrix materials.

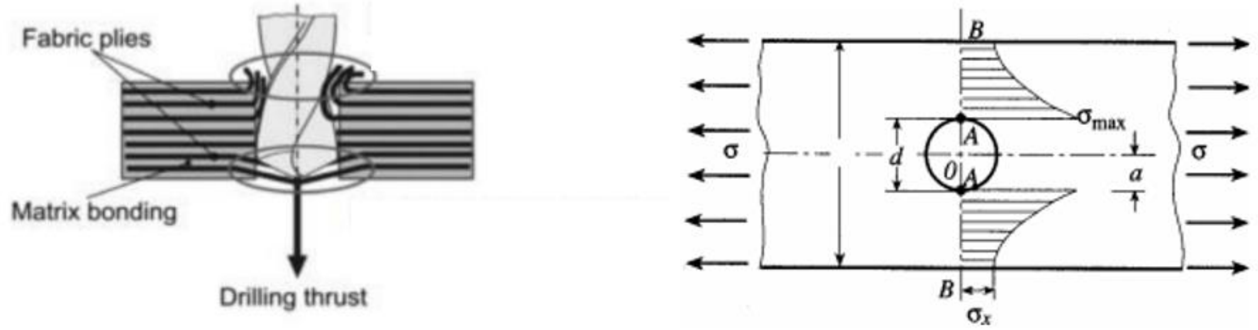

Figure 1. a) Cutting the fibers while drilling the composites [13] b) The stress concentration of a composite plate with a hole under tensile loads [14].

Mechanical joining comes to the fore especially in the joining of composite materials and metals. because these materials cannot be welded together and have advantages such as ease of assembly/disassembly, ease of replacement of parts, ease of repair, and ease of inspection compared to adhesive connections [16, 17,18,19].

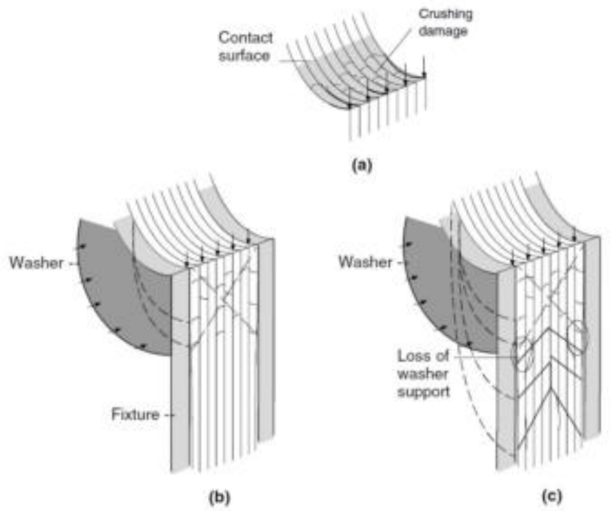

Figure 2. Schematic presentation of the bearing failure mechanisms: (a) crushing damage, (b) damage within lateral constraint (inside-washer region), and (c) damage without lateral constraint (outside-washer-region) [15]

Mechanical fastening methods for polymer-based composites involve the use of various types of mechanical connectors, such as screws, bolts, rivets, and pins, to join two or more composite components together. These methods are generally preferred due to their simplicity, ease of assembly, and ability to remove components when necessary.

Four application steps are used for effectively mechanical fastening polymer-based composites:

a. Fastener Selection: Choose fasteners that are compatible with the polymer matrix and reinforcement materials in the composite. Consider factors like chemical compatibility and thermal expansion coefficients. Select fasteners made from materials that resist corrosion and provide adequate strength. Common materials include stainless steel, aluminum, and titanium. The environmental conditions should be also considered if the composite assembly operates at extreme temperatures, exposed to moisture, and chemicals. Fasteners and coatings are chosen so that withstand these conditions. In some cases, using sealants or adhesives in combination with mechanical fasteners can enhance the joint's performance and seal any gaps or voids.

b. Hole Preparation: holes in the composite components are drilled or punched at precise locations and sizes. Appropriate cutting tools and techniques should be used to minimize delamination or damage to the composite. Depending on the application, it can be needed to countersink or counterbore the holes to ensure that the fastener heads are flush or below the surface of the composite. It should also adhere to recommended edge distances and hole spacing guidelines to maintain the structural integrity of the composite and minimize stress concentrations.

c. Surface Preparation:

Clean the surfaces of the composite components before fastening to remove any contaminants, adhesives, or release agents that can interfere with the bonding of the fasteners.

d. Fastener Installation: It is ensured that fasteners are tightened to the recommended torque specifications to prevent over-tightening, which can cause damage to the composite, or under-tightening, which can result in joint failure. washers, lock washers, or thread-locking compounds are used when necessary to prevent loosening over time due to vibrations or thermal cycling.

After fastening, some inspection and testing of the joint can be performed for any signs of damage, misalignment, or issues with the fasteners. Mechanical tests, such as pull-out tests or shear tests, to verify the strength and integrity of the joint should be performed. It is also recommended to keep detailed records of the fastening process, including torque values, fastener specifications, and inspection results, for quality control and traceability.

II. MECHANICAL FASTENING METHODS FOR POLYMER-BASED COMPOSITES

Some common mechanical fastening methods for polymer-based composites can be given as Screws and Bolts, Riveting, Pins and Dowels, Self-Clinching Fasteners, Snap Fits, Threaded Inserts and Adhesive-Bonded Fasteners.

A. *Screws and Bolts*

These are the most common methods used to fasten polymer-based composite parts together. The typical application is that composite parts are pre-drilled or molded. The screws or bolts are then inserted through the holes and secured by tightening them with nuts or washers on the opposite side. Bolts provide higher strength than screws. For this reason, bolt-nut connections are generally preferred for load-bearing applications (Fig. 3) [20]. Machine screws and bolts used in joining plastic parts should have a flat side under the screw head. Screws with a conical underside produce high tensile stresses (Figure 3b) due to wedging of the screw head into the plastic part [21].

Bolt-nut types of fasteners can be made from not only metal but also a variety of polymers, such as plastic, rubber, or composite materials [22]. So the joint could be designed to be lighter, strong, durable, and resistant to corrosion.

Figure 3. Bolts-Nuts connections in load-bearing applications

B. *Rivets*

Rivets are permanent mechanical fasteners. In the joining process, first, a hole is drilled in the composite parts. A rivet is then placed into this hole. The rivet is then deformed or "set" to create a strong, permanent connection. Figure 4 shows the installation of a rivet in joining composite parts.

Rivets are faster to install than threaded fasteners. However, the tensile and fatigue strength of rivets is lower than bolts and screws.

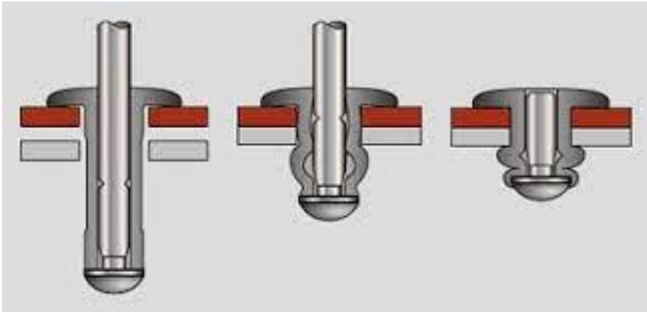

Figure 4. The installation of a rivet in joining composite parts [23]

C. *Pins and Dowels*

Pins and dowels are machine elements that can be used both to align and secure composite parts. Although they are generally cylindrical, they can also be found in different geometric shapes (Fig. 5). Pins are used by placing them in pre-drilled holes.

Figure 5. Different forms of pins and dowels [24]

D. *Self-Clinching Fasteners*

These machine elements are specialized fasteners designed for use with composite materials. They are inserted into pre-drilled holes in the parts and clinch themselves (Fig. 6). These fasteners are often used in electronic enclosures and sheet metal applications.

Self-Clinching fastener is placed in the hole making sure the part is seated squarely. A parallel squeezing force is applied until the head is seated against the panel.

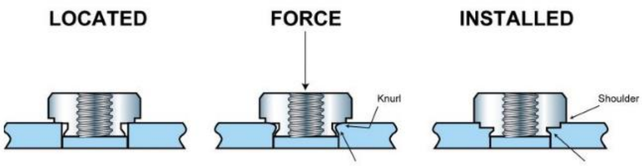

Figure 6. Installation of Self-Clinching Fastener a) fastener is placed into the hole in sheet b) application of load c) shoulder of the fastener is seated with the sheet [25]

E. *Snap Fits*

Snap fits involve designing features in the composite components that interlock when pressed or snapped together. These features, such as hooks, clips, or tabs, provide a temporary or semi-permanent connection. Snap-fits do not require the introduction of additional materials such as other mechanical fasteners. This makes them lower in cost and easier to assemble. Snap-fits can also be used for the joining of dissimilar materials such as metal to plastic. But snap-fits are sensitive to fracture due to fatigue. Because snap fits are temporary connections, they are often used in consumer products and enclosures. The action of 'snapping open something' is usually referring to a snap fit in the background. Tupperware lids, Snap-on bottle caps, and pen lids are all everyday examples of products with snap joints (Fig 7).

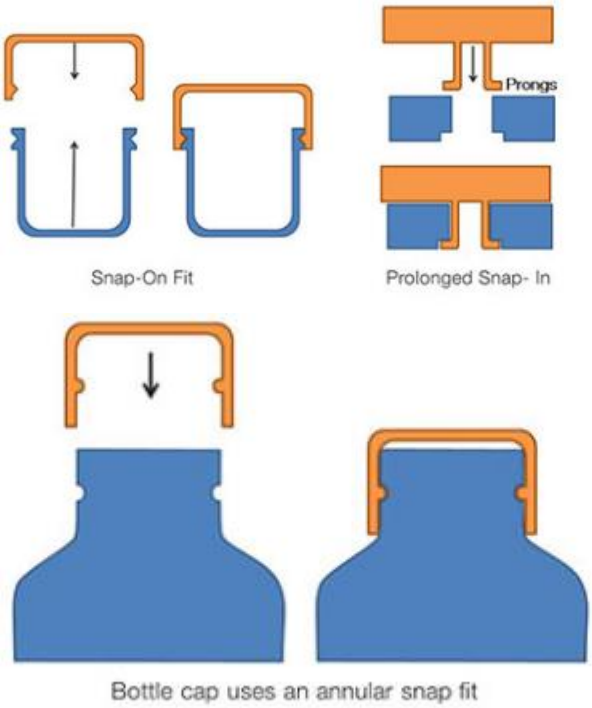

Figure 7. Different forms of Snap Fits and its usage [26]

F. *Threaded Inserts*

Threaded Inserts provide reusable metal threads and secure threaded connections. There are five threaded insert installation methods for plastic composites: Press-in inserts, self-tapping inserts, moulded-in inserts, heat inserts and ultrasonic inserts (Fig. 8). Generally, these inserts are embedded into the composite material during manufacturing, eliminating the need for a secondary inserting operation, providing threaded holes for screws or bolts, allowing repeated assembly and disassembly without damaging the composite material.

Inserts can move off the pins during molding if not positioned properly and can cause damage to expensive molding equipment, in addition to generating scrap material. Plastic material can enter the threads during the molding process, making a retapping operation necessary after molding is complete.

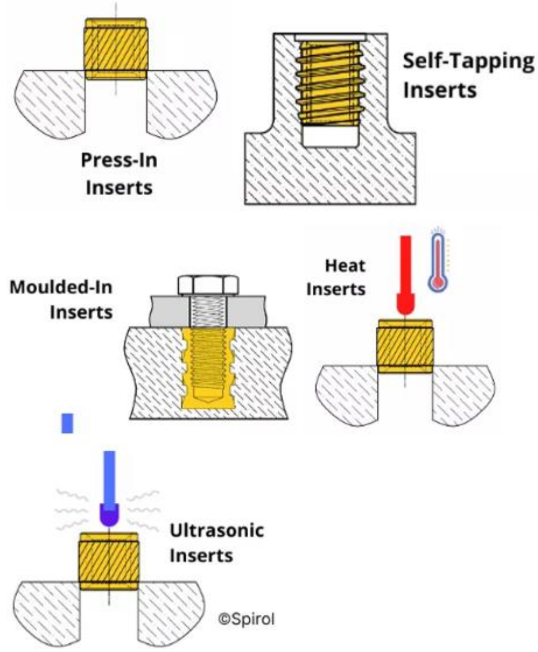

Figure 8. Installation types for threaded inserts for plastics [27]

G. *Adhesive-Bonded Fasteners*

Adhesive-bonded fasteners may be glued or molded during the installation process. The base plate of the adhesive fastener usually has a large surface area to distribute the load over a large area. The resin or adhesive also passes/flows through the holes on the base plate to create a high-strength mechanical bond. Adhesive bonded fasteners provide a high-strength fastener solution for composites, without any additional work such as drilling holes on the part (Fig. 9). As a result of this process, costs decrease, there is no waste of material and production time is shortened.

Figure 9. Adhesive bonded fastener a) female b) male [28] and c) usage of adhesive bonded fasteners [29]

III. CONCLUSION

Mechanical fastening methods offer a versatile and reliable approach to joining polymer-based composites. These mechanical fastening methods are often preferred due to their ease of installation, cost-effectiveness, and the ability to disassemble and repair components, which is particularly valuable in industries such as aerospace, automotive, and construction.

However, both the lack of sealing and the stress concentrations created by the holes drilled into the composite parts under load limit the usage areas of these elements. However, considering factors such as material compatibility, load-carrying capacity and environmental conditions, mechanical fasteners are still widely preferred for various applications today.

The studies to increase the performance of these fasteners will increase and new materials and fastening elements will emerge since mechanical connection solutions are the preferred application in joining polymer-based composites.

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