



Welding or Joining methods of Polymer composite materials

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Abstract- The utilization of polymeric materials is currently on the rise in numerous significant applications such as packaging, construction, household appliances, electronics, automotive, aerospace, and more. Polymers have already demonstrated a wide range of applications surpassing other material classes. The process of joining plays a crucial role in the production of components made from polymers and polymeric composites. As the demands placed on the component increase, the requirements for joining also escalate, particularly in structural applications. Various methods exist for joining plastics and composites, which can be categorized into three main groups: mechanical fastening, adhesive and solvent bonding, and welding. Welding stands out as an efficient technique for permanently connecting plastic components, with a variety of welding methods available. Through a comprehensive analysis and comparison of all welding processes currently in the market, this review aids readers in selecting the most suitable process for their application, while also delving into the limitations and provides an understanding on the limitations and benefits of each process.

Keywords: Polymer composite materials, Adhesive bonding, Mechanical fastening, Welding.

I. INTRODUCTION

The processes for joining polymer composites are categorized into three primary groups: welding, adhesive bonding, and mechanical fastening. The utilization of mechanical fastening techniques is restricted due to the stress concentration resulting from holes in the components, the risk of galvanic corrosion, and the added weight on the connection. Adhesive joints exhibit comparatively lower strength, and in certain instances, the curing duration of adhesives is prolonged. Welding serves as a crucial method for resolving challenges associated with the fabrication of polymer composite materials with intricate shapes that cannot be achieved through a single molding process, necessitating the assembly of multiple parts into a unified structure. Welding emerges as a cost-effective approach for joining polymer composites, particularly in scenarios involving the production of numerous joints.

Approximately twenty distinct techniques exist for the fusion of polymer composites, with the exception of solvent welding, which relies on thermal energy for fusion. The methods that utilize heat energy generate heat in three distinct manners, categorized into three groups: employing an external heat source, generating heat through mechanical motion, and utilizing electromagnetism.

Polymer materials have progressively been replacing metals in the automotive and aerospace industries over the past few decades. This has resulted in significant cost efficiency increases for these industries. A reduction in the cost of manufacturing is not the only factor: weight saving, flexibility and thermal insulation properties are also important. New design opportunities are also introduced by polymers.

The use of polymers as replacements for metals in the automotive industry has been given additional impetus from the introduction of strict emission laws, for example, the European Emissions Standards for new vehicles sold in EU member states. Two decades ago 6% of the average family car was comprised of plastic; this has risen to 15% today. In the aerospace industry, aircraft fuel efficiency is also a major driver of polymer substitution for metal, and the associated research and development. For other consumer products, such as computers and mobile phones, the adoption of polymers has provided advantages which also include electrical insulation and electromagnetic signal transmission.

II STATEMENT OF PROBLEM

Before the adoption of polymer composites, welding or joining traditional materials like metals, wood, and simple polymers presented significant challenges.

Metals:

- **High Weight:** Metals like steel and aluminum, while strong, are heavy, limiting efficiency in weight-sensitive industries like aerospace and automotive.
- **Corrosion:** Metals are prone to corrosion, necessitating regular maintenance and replacement, especially in harsh environments.
- **Thermal Issues:** Welding metals requires high temperatures, leading to thermal distortion, residual stresses, and heat-affected zones that weaken the material around the weld.
- **Conductivity:** Metals conduct heat and electricity well, which can be a drawback in applications needing insulation.
- **Complex Shaping:** Creating complex shapes involves extensive machining and forming processes, increasing manufacturing time and costs.

Wood:

- **Durability:** Wood lacks the strength and durability needed for high-stress applications and is susceptible to rot, warping, and degradation from moisture, pests, and fungi.
- **Joining Techniques:** Mechanical fasteners (nails, screws) can split the wood, while adhesives may not provide sufficient strength and can degrade over time.
- **Design Flexibility:** Wood's anisotropic nature limits its design flexibility and structural applications.

Simple Polymers:

- **Strength:** Simple polymers often lack the necessary mechanical strength and stiffness for load-bearing applications.
- **Thermal Sensitivity:** They can degrade, melt, or lose mechanical properties at relatively low temperatures, restricting their use in high-temperature environment.
- **Joining Challenges:** They may require specialized adhesives or thermal welding techniques, which can result in joints that are weak and lack durability.

Benefits of Polymer Composites:

- **Strength-to-Weight Ratio:** Polymer composites are strong yet lightweight, enhancing efficiency in various industries.
- **Corrosion Resistance:** They resist corrosion and environmental degradation, reducing maintenance costs and extending service life.
- **Design Flexibility:** Composites can be molded into complex shapes, offering greater design flexibility.
- **Insulation Properties:** They provide excellent thermal and electrical insulation, broadening their application range.
- **Tailored Properties:** Properties can be customized by varying the type, orientation, and proportion of reinforcing fibers, optimizing performance for specific applications.

III REVIEW OF LITERATURE

Kahraman, F. & Kahraman, A. D. (2023), Carried-out a work on Welding Method of Polymer Composites. This article discusses on welding methods for polymer composites presents a detailed examination of various techniques utilized in the joining of polymer composite materials, which have seen increased utilization in sectors such as automotive and aerospace.

The primary welding methodologies discussed encompass: Ultrasonic welding that employs high-frequency vibrations to create heat and establish bonds, particularly effective for thermoplastics.

There are various types of welding methods:

Friction/Vibration welding

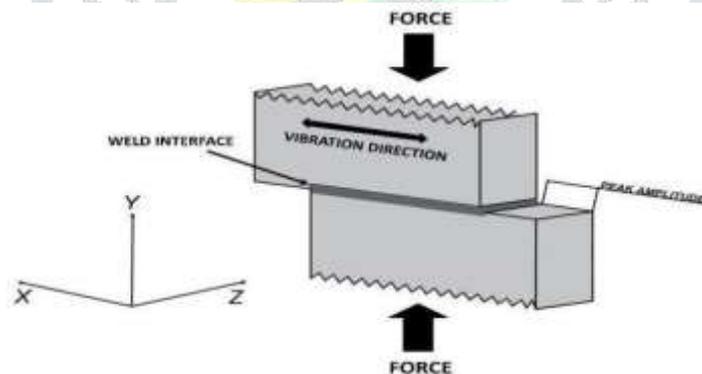


Figure 3.1 Vibration welding

Vibration welding, also referred to as linear friction welding, represents one of several welding methodologies where heat is produced through the mechanical motion of the components intended for connection. The process involves bringing the two components together under a specific load, with one component being restricted while the other experiences swift linear reciprocating movement within the joint plane. Friction between the two surfaces generates heat, leading to localized melting. Following this, the vibration ceases, the components are aligned, and the joint undergoes a cooling process under pressure to solidify the weld.

Hot gas welding

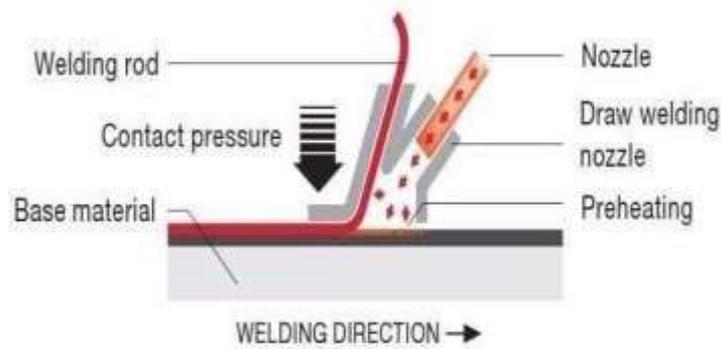


Figure 3.2 Hot gas welding

Hot gas welding of thermoplastics is a manual welding process that bears resemblance to the gas welding method used for metals. Within the hot gas gun, a flow of gas, usually air, is propelled across an electrically heated component and exits through a nozzle. This heated gas flow is aimed at the connection point between two thermoplastic components, causing them to melt or soften along with a filler rod. The resulting weld is created through the fusion of the thermoplastic components and the filler rod, which shares the same polymer composition as the components. The primary benefit of hot gas welding lies in the portability of the equipment. Nonetheless, this technique is characterized by a slow pace, and the quality of the weld is contingent upon the proficiency of the operator. Common applications encompass the fabrication of chemical storage tanks and pipelines.

Hot plate welding

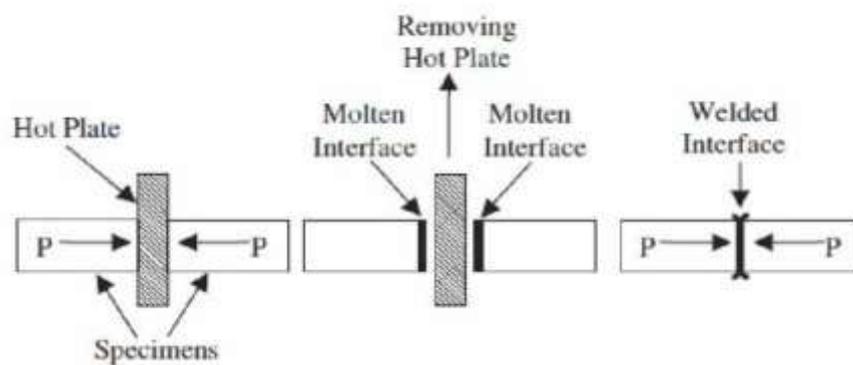


Figure 3.3 Hot plate welding

In hot plate welding, the components earmarked for fusion are clamped in fixtures, which apply pressure to them against opposing sides of a heated platen. Subsequent to achieving a molten state, the platen is extracted. The elements are then merged and kept in position until solidification occurs. Hot plate welding is a versatile methodology that offers equipment options suitable for industrial settings or as portable units for field applications. While the heated platen is typically planar, intricate three-dimensional joint configurations can be realized through the utilization of a more elaborate plate structure. This welding technique is characterized by a drawback of relatively slow processing speeds, with varying weld durations from 10 seconds for minor parts to up to 1 hour for components featuring extensive joint surfaces.

Induction welding

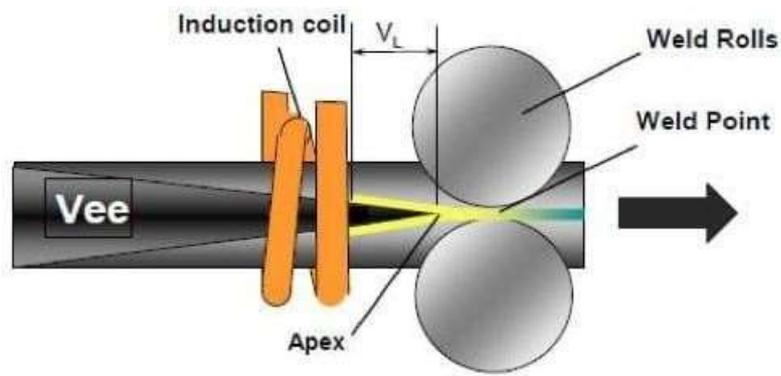


Figure 3.4 Induction welding



Induction welding bears resemblance to resistive implant welding as it necessitates a conductive implant. In this scenario, the generation of heat occurs through the establishment of an induction field, which can be attributed to either eddy currents or hysteresis losses. A work coil, linked to a power source, is positioned in close proximity to the joint. Upon the flow of electric current at a high frequency through the work coil, a dynamic magnetic field is produced, the flux of which interacts with the implant. With the implant experiencing a rise in temperature, the surrounding thermoplastic material softens and eventually liquefies. Upon the application of pressure to the joint, a weld is created as the joint undergoes the cooling process. Induction welding proves to be highly suitable for the attachment of metallised tops to plastic bottles and can be effectively employed with a variety of composite materials.

Resistance welding

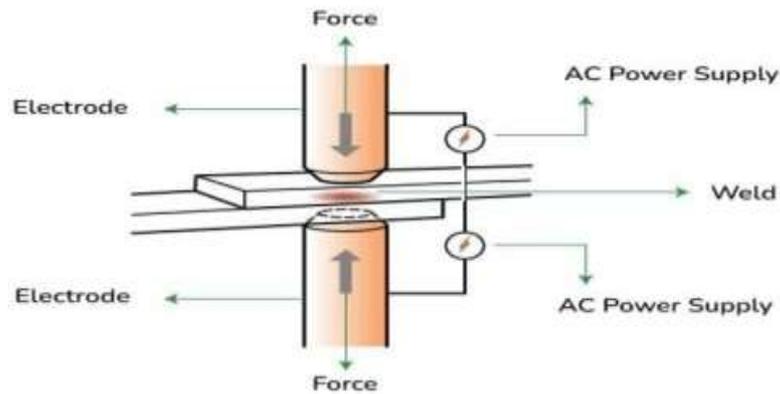


Figure 3.5 Resistance welding

Electric resistance welding (ERW) is a welding technique where metal components in contact are fused together permanently through the application of heat generated by an electric current, causing the metal to melt at the joint. This method, known as electric resistance welding, finds widespread application, such as in the production of steel pipes and in the construction of vehicle bodies. The electric current can be directed through electrodes that exert clamping force, or it can be induced by an external magnetic field.

Spin welding

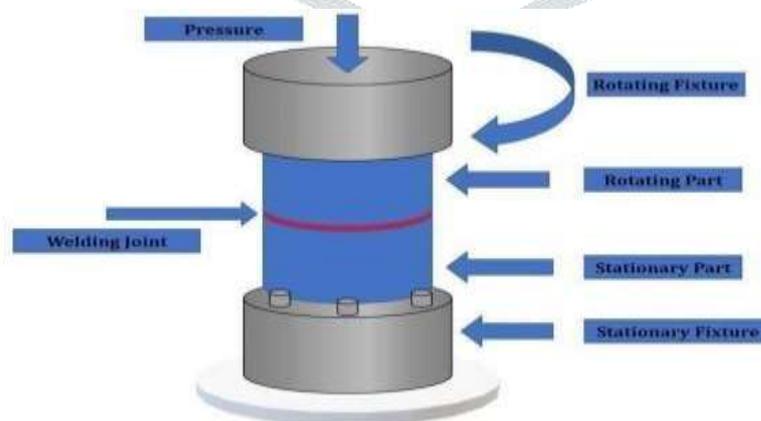


Figure 3.6 Spin welding

Spin welding, a type of friction welding, utilizes rotational movement, making it specifically suitable for circular joint surfaces. The process of spin welding can utilize basic equipment like lathes or drilling machines.

A lathe maintains a consistent speed throughout the frictional heating phase, known as continuous drive friction welding, whereas a drilling machine exhibits a decreasing speed pattern during the frictional heating phase, referred to as inertia friction welding.

Typically, specialized machines are preferred for spin welding to ensure precise control, with options available in both continuous drive and inertia configurations. The versatility of spin welding is evident in its applications, ranging from ball cocks and aerosol bottles to transmission shafts and PVC pipes with fittings.

Friction stir welding

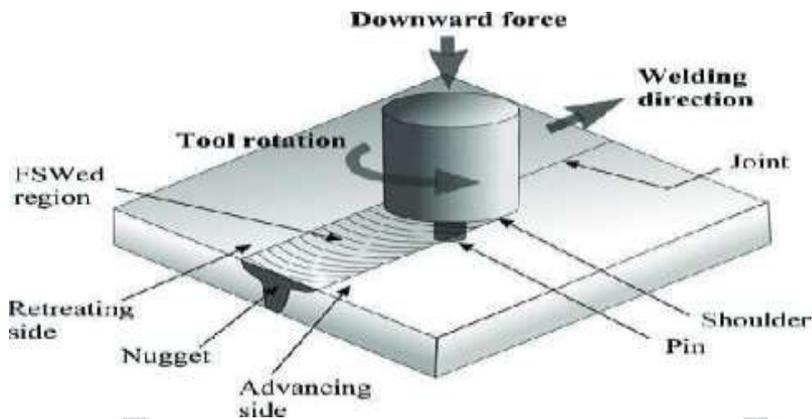


Figure 3.7 Friction stir welding

Friction stir welding (FSW) is a solid-state fusion technique that employs a non-consumable implement to connect two opposing work pieces without inducing fusion in the workpiece material. Heat is produced through the frictional interaction between the revolving implement and the work piece material, resulting in a softened zone adjacent to the FSW implement. As the implement traverses the juncture, it mechanically blends the two metal pieces and shapes the warmed and softened metal through mechanical pressure exerted by the implement, resembling the process of joining clay or dough. This method is predominantly utilized for wrought or extruded aluminum, especially in applications requiring exceptional weld durability.

Ultrasonic welding

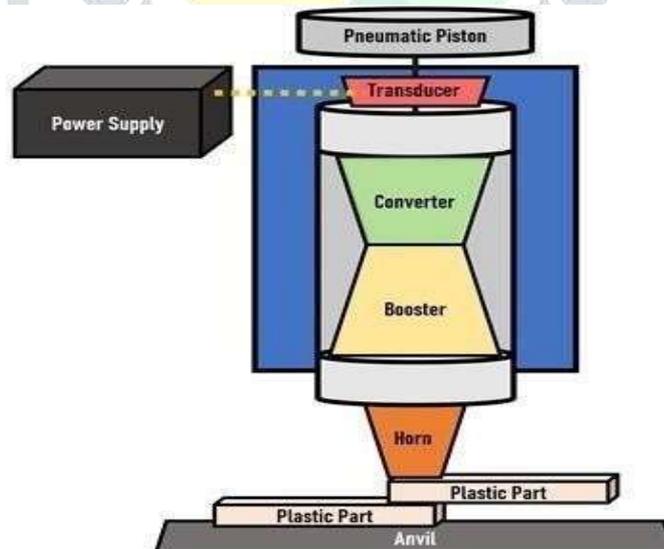


Figure 3.8 Ultrasonic welding

Ultrasonic welding entails the utilization of high frequency mechanical sound energy for the purpose of softening or melting the thermoplastic material at the joint interface. The parts intended for joining are compressed together and subsequently exposed to ultrasonic vibrations through the welding horn, typically operating at frequencies of 20 or 40 kHz. The thermal impact of the ultrasound is contingent upon the crystallinity level of the material undergoing welding. The efficacy in successfully welding a component is contingent upon the configuration of the machinery, the mechanical characteristics of the material to be welded, and the design of the components. This method of welding is characterized by its swiftness (with weld durations typically under one second) and can be readily mechanized, making it particularly suitable for welding components in large-scale manufacturing. Nonetheless, the design of the joint and horn are crucial factors, with a limitation of around 250mm on the feasible length of the weld.[1]

Mladen Sercer and Pero Raos, Conducted an experiment on joining of plastics and composites. They highlighted that, The utilization of polymeric substances is on the rise in various sectors such as packaging, construction, electronics, automotive, aerospace, among others. Global polymer output amounted to 300 million tons in 2006. Polymers offer benefits such as a high strength-to-weight ratio, adaptable design, resistance to corrosion, and cost-effectiveness in manufacturing. A multitude of polymer grades are accessible, each with a diverse array of characteristics. The necessity for joining polymer components frequently arises due to intricacy, utilization of different materials, the requirement for disassembly/repair, and other factors.

Primary methods for joining include mechanical fastening, adhesive/solvent bonding, and welding.

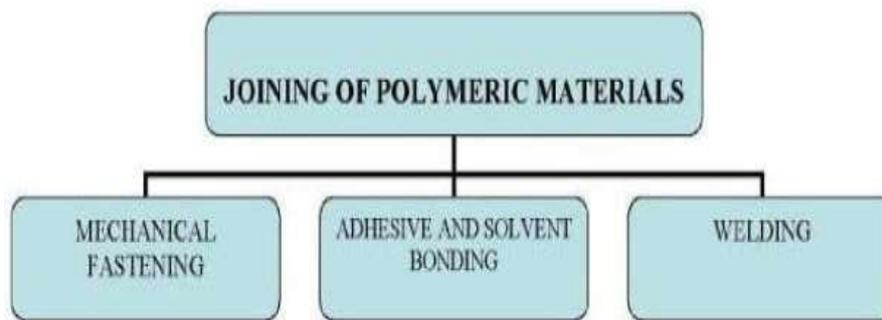


Figure 3.9 Classification of polymeric materials

Welding, known as fusion bonding, employs heat to liquefy the polymer on contacting surfaces, enabling molecular diffusion for joint formation. This manuscript concentrates specifically on techniques for welding polymers.

Thermoplastics that can be remolded repeatedly, thermosets that cannot be reshaped after the initial curing, and elastomers which are lightly crosslinked and highly elastic. Thermoplastics can be further sub-categorized into amorphous and semi- crystalline types, with common examples being outlined. This document delivers a thorough overview of polymer materials, their classifications, and joining techniques, with a specific emphasis on welding methods for plastics and composites.[2]

Frank H. Magness, Carried out a survey on joining of polymer composite materials. The document presents a synopsis of the principal points regarding the utilization of polymer composite materials:

1. This document outlines three primary techniques for joining polymer composites: Adhesive bonding. Mechanical fastening (bolted joints). Welding (specifically for thermoplastic composites).
2. Adhesive bonding: Typically favored over mechanical fastening due to continuous bonding and fiber preservation. Common configurations include single lap, double lap, and scarf joints Important considerations encompass adhesive characteristics, adherend stiffness compatibility, and bond length optimization

Adhesive Bonded Joint Technology:

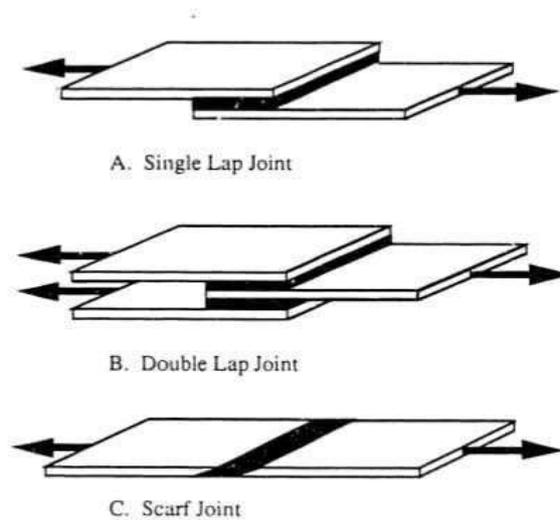


Figure 3.10 Bonded joint Configuration

A single lap joint is a prevalent type of adhesive joint that involves two overlapping members with adhesive placed in between.

A double lap joint is same as single lap joint, but it incorporates an extra overlapping member, resulting in a structure resembling a sandwich.

A scarf joint is characterized by tapering the ends of two pieces to be joined, facilitating overlap and the creation of an elongated, angled surface for the application of adhesive.

3. Mechanical fastening: - Failure modes consist of net tension, shear-out, and bearing failure. Critical parameters include fastener diameter, spacing, edge distance, and clamping pressure. Joint strength is influenced by stacking sequence and fiber orientation.

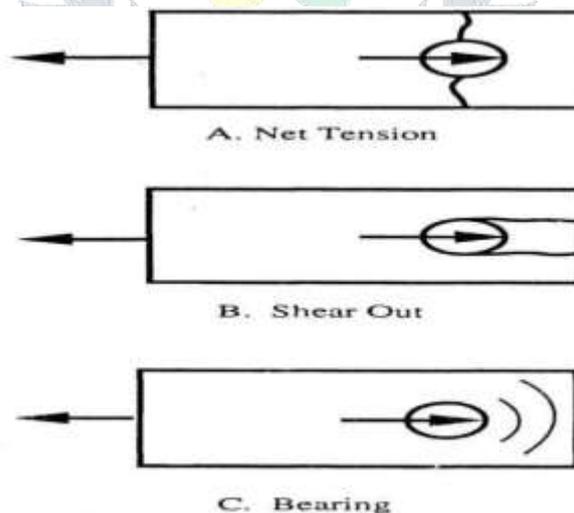


Figure 3.11 Bolted Joint Failure Modes

Net Tension: The net section of the plate considering the reduced area due to bolt holes fails in tension.

Prevention : Increase the net area by using fewer or smaller bolt holes, or select materials with higher tensile strength.

Shear Out: The material tears out from the edge of the bolt hole towards the edge of the plate. **Prevention:** Ensure adequate edge distances and use materials with sufficient shear strength.

Bearing: The material around the bolt hole deforms or crushes due to excessive bearing stress.

Prevention: Increase the bearing area by using larger washers or thicker plates, or use materials with higher bearing strength.

4. Welding (specifically for thermoplastics): Techniques involve thermal bonding, friction welding, and electromagnetic bonding. Benefits include rapidity and absence of additional materials, but application is limited to thermoplastics - Structural application of process parameters lacks comprehensive characterization.

5. General recommendations: Initiate the design of structural components based on loads/environment, followed by joint optimization. Incorporate considerations such as manufacturability and inspectability along side strength aspects. This document delivers a thorough outline of joining techniques for composites, stressing the intricate nature of the subject matter and the necessity of empirical data in the design process.[3]

Ayca Demirer Kahraman, Fatih Kahraman, Carried out a survey on Mechanical Fastening Methods of Polymer-Based Composites. Here are the key points about mechanical fastening methods for polymer-based composites based on the information provided in the article:

1. Three main joining methods for polymers and polymer composites are mechanical fixing, bonding, and welding. Mechanical fastening is often preferred when joining composites to metals.

2. Advantages of mechanical fastening include ease of assembly/disassembly, part replacement, repair, and inspection compared to adhesive bonding.

3. Four main steps for effective mechanical fastening:

a) Fastener selection - It involves the careful consideration of choosing fasteners that demonstrate compatibility with both the polymer matrix and reinforcement materials utilized in the composite. It is advisable to opt for fasteners crafted from materials that exhibit resistance to corrosion while also offering sufficient strength. Materials commonly utilized for this purpose include stainless steel, aluminum, and titanium.

b) Hole preparation - The composite constituents are created through drilling or punching with meticulous attention to specific positions and dimensions. It is essential to employ suitable cutting instruments and methodologies to reduce the occurrence of impairment to the composite material. Tailored to the particular use case, there might be a necessity to engage in countersinking or counterboring the perforations to guarantee that the heads of the fasteners are either aligned with or situated beneath the surface of the composite material.

c) Surface preparation - The preparation of surfaces is a critical step in the process of composite component assembly. It is imperative to meticulously clean the surfaces prior to fastening in order to eliminate any potential contaminants, adhesives, or release agents that may impede the bonding effectiveness of the fasteners.

d) Fastener installation - Fastener Installation: The tightening of fasteners is meticulously carried out in accordance with the specified torque levels to avert the risks associated with excessive tightening, such as potential harm to the composite material, or insufficient tightening, which may lead to the failure of the joint.

Additional measures such as the utilization of washers, lock washers, or thread-locking compounds are implemented as needed to mitigate the potential loosening of fasteners over time due to vibrations or thermal fluctuations.

3. Common mechanical fastening methods:



Figure 3.12 Bolts-Nuts connections in load-bearing Applications

These techniques are widely utilized for joining polymer-based composite components. A common practice involves pre drilling or molding the composite parts. Subsequently, screws or bolts are inserted through the prepared holes and fastened by tightening nuts or washers on the opposing side. Bolts offer superior strength compared to screws.

Rivets

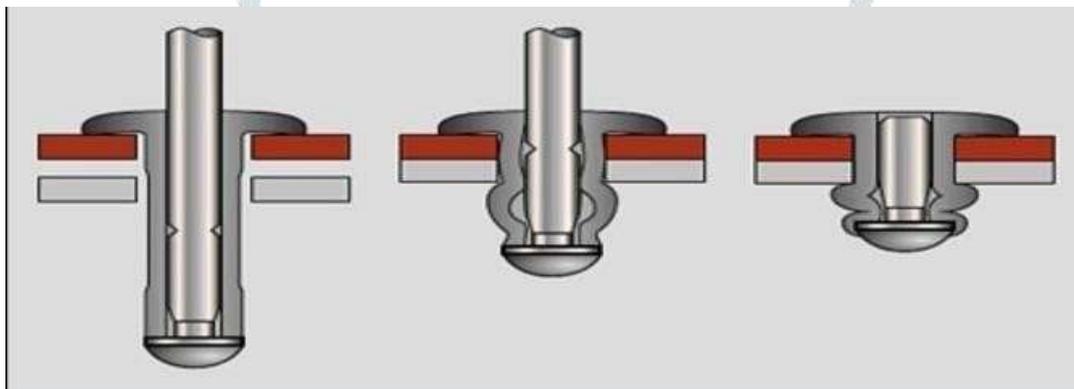


Figure 3.13 The installation of a rivet in joining composite parts

Rivets serve as enduring mechanical connectors. During the process of joining, an initial step involves the creation of a hole in the composite components. Subsequently, a rivet is inserted into the aperture. This rivet is subsequently altered or "set" to establish a robust and lasting linkage.

Pins and dowels



Figure 3.14 Different forms of pins and dowels

Pins and dowels are mechanical components utilized for the purpose of aligning and fastening composite structures. While typically exhibiting a cylindrical form, these elements may also manifest in various geometric configurations. The application of pins involves their insertion into previously drilled.

Snap fits

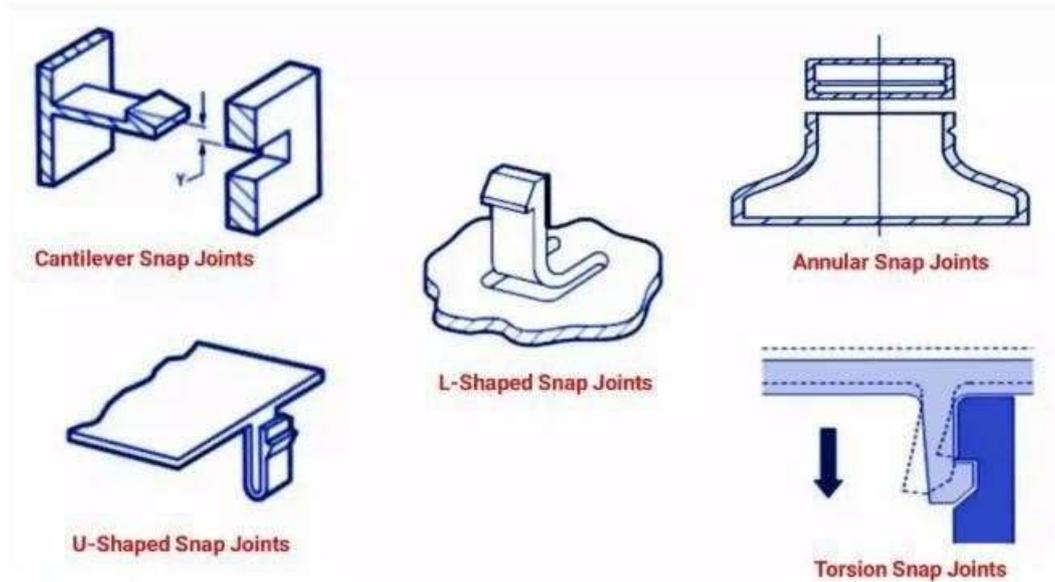


Figure 3.15 Different forms of Snap fits

Snap fits entail the creation of characteristics within the composite elements that intertwine upon being pressed or joined together. Such characteristics, like hooks, clasps, or tabs, offer a provisional or partially enduring linkage. The utilization of snap fits eliminates the necessity of incorporating supplementary substances such as alternative mechanical fasteners, leading to reduced expenses and simplified assembly procedures.

Threaded inserts

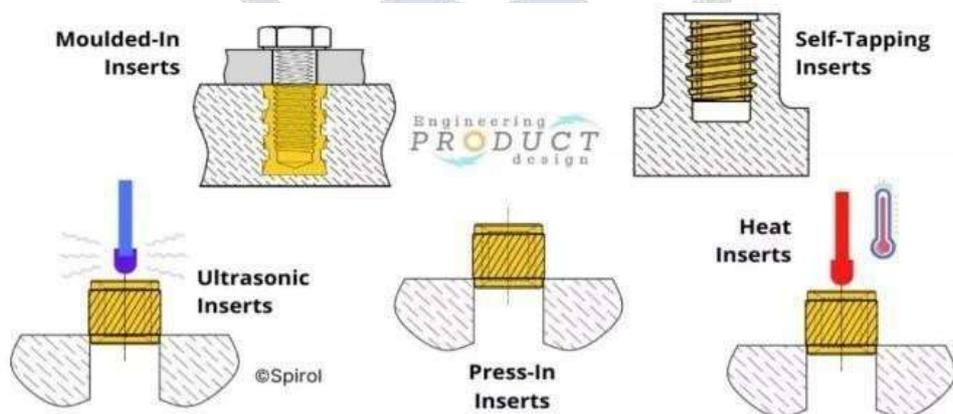


Figure 3.16 Installation types for threaded inserts for plastics

Threaded inserts offer metal threads that can be utilized repeatedly and ensure the security of threaded connections. There exist five distinct methods for installing threaded inserts into plastic composites: Press-in inserts, self-tapping inserts, moulded inserts, heat inserts, and ultrasonic inserts. Generally, these inserts are integrated into the composite material during the manufacturing process, thereby eliminating the necessity for a secondary insertion operation. This integration provides threaded holes for screws or bolts, enabling multiple assembly and disassembly cycles without causing any damage to the composite material.

Adhesive-bonded fasteners



Figure 3.17 Adhesive bonded fastener a) female b) male and c) usage of adhesive bonded fasteners

Fasteners joined by adhesion can be bonded through the application of glue or through molding procedures at the time of assembly. The foundational component of these adhesively secured fasteners commonly features an expansive surface area intended to effectively disperse the applied force across a broad expanse. Moreover, the resin or adhesive substance is channeled through perforations in the foundational base plate, thereby generating a robust mechanical connection characterized by high levels of strength.

5. Key considerations:

- Stress concentrations from drilled holes can be a limitation
- Material compatibility and environmental conditions are important factors
- Inspection and testing of joints is recommended
- Proper installation techniques are critical

Mechanical fastening remains widely used despite some limitations, due to versatility and ability to disassemble. Ongoing research aims to improve performance and develop new materials/fasteners. The article provides a comprehensive overview of mechanical fastening approaches for polymer composites, highlighting both advantages and key considerations for effective implementation.[4]

Negin Amanat et.al, Conducted an experiment of Welding methods for joining thermoplastic polymers for the hermetic enclosure of medical devices. They highlighted that on welding of thermoplastics, specifically for implantable medical device encapsulation. Three common thermoplastic welding techniques are described: thermal two-stage, transmission laser welding, and friction welding. Thermal two-stage techniques, such as hot-plate and infrared welding, involve introducing a heat source between the joining surfaces until they melt, then removing the heat source and applying pressure to solidify the joint.

Transmission laser welding uses a laser beam to melt the polymer at the interface, while friction welding involves moving one substrate parallel to the other to generate heat and pressure. The advantages and disadvantages of each technique are summarized, with laser welding being presented as the most suitable method due to its localized heating and minimal effect on sensitive contents. The text also discusses the importance of joint strength, which can vary depending on the polymer being welded and the joint configuration. Finally, the application of these welding methods to micro systems and implantable devices is discussed, with a focus on the challenges of achieving hermetic encapsulation and the potential of transmission laser welding for micro scale polymer enclosures.[5]

Ramesh Rudrapati, Carried out a survey on Effects of welding process conditions on friction stir welding of polymer composites. Here is a summary of the key points from the review article on friction stir welding (FSW) of polymer composites: - FSW is an emerging solid- state joining technique for lightweight materials like polymers and composites. It offers advantages over traditional welding methods for these materials.

This article reviews recent advances in FSW of similar polymers, dissimilar polymers, and polymers with other lightweight materials or metals. Key processing parameters that affect weld quality include tool rotation speed, welding speed, tool geometry, tilt angle, etc. Proper selection of these parameters is critical for achieving good joint strength and quality.

For polymer-polymer FSW, parameters like tool rotation speed, dwell time, and plunge depth are found to be most significant for joint strength. For dissimilar welding of polymers with metals, factors like surface treatment, heat input, and tool design play important roles. Advantages of FSW for polymers include low energy use, minimal emissions, and reduced material degradation compared to other methods. Areas needing further research include understanding thermo-mechanical interactions, material flow behavior, and optimizing Parameters for different material combinations. Friction stir welding and its derivatives, namely friction stir spot welding and friction stir processing, application in various industrial sectors such as shipbuilding and offshore, aerospace, automotive, rolling stock for railways, general fabrication, robotics, and computers.

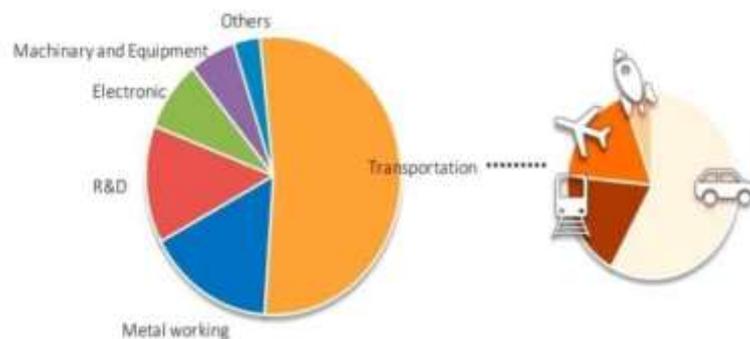


Figure.3.18 Applications of FSW Process

Overall, FSW shows promise for joining polymer composites and other lightweight materials, but systematic analysis and optimization of the process is still required for industrial applications. The article provides a comprehensive overview of the current state and research directions in FSW of polymer composites and related materials.[6]

Joining Composite Materials and Structures: Some Thought-provoking Possibilities a Survey by Robert w. Messler jr. Here is a summary of the key points from the document on joining composite materials and structures.

Composites offer many advantages like high specific strength and stiffness, but joining them effectively remains a major challenge. Traditional joining methods like mechanical fastening and adhesive bonding have significant limitations for composites. The author argues that new approaches to joining composites are needed to match the revolution in composite materials. This proposes four key changes:

1. Look in new places/directions for solutions, not just traditional methods.
2. Make joining a primary process integrated with material synthesis, not just a secondary assembly step.
3. Extend and scale up successful joining techniques from other areas.
4. Accept higher costs for high-value applications that justify it - Some innovative joining concepts proposed: 1. Moving Boundary Curing - Controlled curing from inside out for thick thermoset composites.

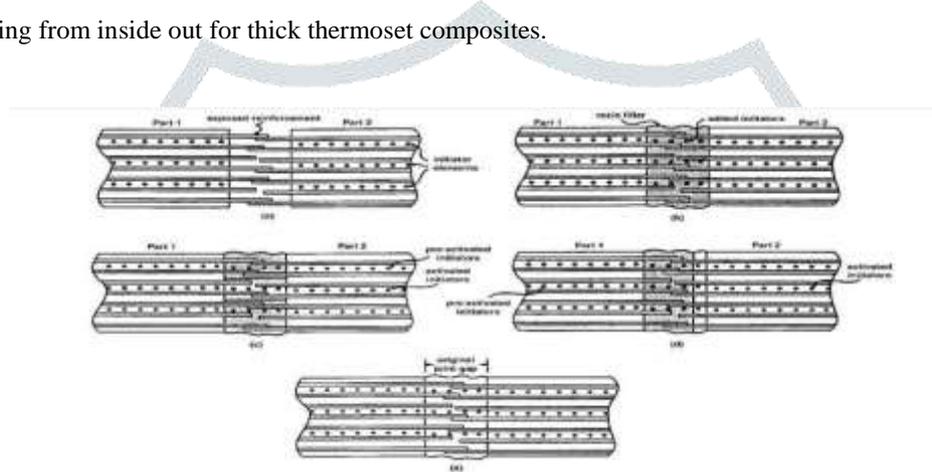


Figure.3.19 Moving Boundary Curing

The process known as "Moving Boundary Curing" is depicted schematically in this illustration for the purpose of joining thick-section thermosetting composites: (a) Prior to the commencement of the process, the joint elements are suitably prepared and positioned. (b) Subsequently, the joint gap is filled with a compatible thermosetting resin along with additional initiator elements depending on the gap width. (c) The curing process is initiated by driving the initiator elements to facilitate curing from the interior towards the exterior. (e) Finally, the completion of curing is observed after the process has concluded.

2. Self-Joining: Using self-healing or self-assembling concepts to join Functionalized reinforcements. Materials with self-repairing capabilities are able to undergo restoration upon damage, utilizing either incorporated healing agents or reversible linkages. On the other hand, materials with self-organizing properties spontaneously form well-structured, robust connections driven by inherent forces such as hydrogen bonding or van der Waals interactions. These methodologies yield robust and dependable joints that eliminate the need for external interventions, thereby boosting the durability and robustness of materials utilized in diverse sectors like construction and aerospace.

3. Integral Micro-Mechanical Interlocks (IMMIs):

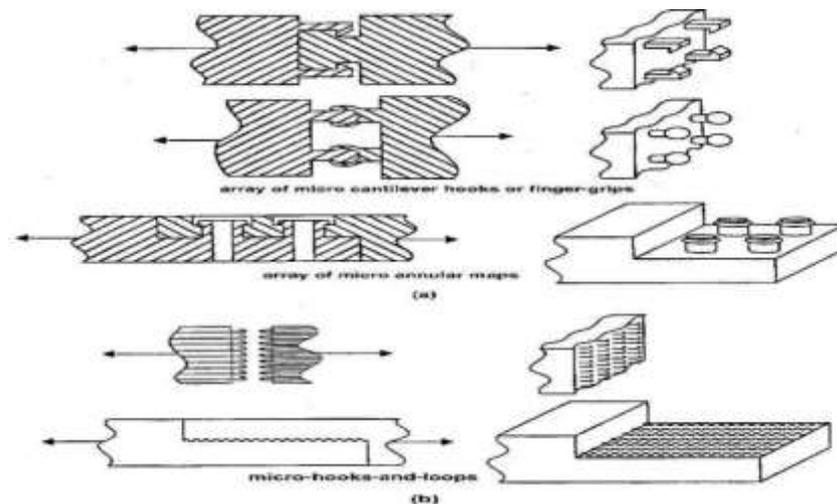


Figure.3.20 Examples of rigid IMMIs

Micro scale interlocking features molded into composite parts are minuscule mechanisms designed to the failure of larger mechanical systems. They function by intricately linking small components to guarantee the seamless and secure operation of the entire system. Enhancing their designs to reduce size, enhance durability, and accommodate novel materials can further build upon their effectiveness. This strategic enhancement can broaden the application of IMMIs in cutting-edge technologies such as robotics and medical apparatus, thereby enhancing overall safety and efficiency of systems.

The author argues joining must increasingly become an enabling technology integrated with material/structure synthesis, not just a pragmatic final assembly step. This may be key to realizing the full potential of advanced composites. The overall message is that radically new approaches to joining are needed to keep pace with advances in composite materials and enable their use in the most demanding applications. Traditional joining methods are often inadequate for advanced composites.[7]

Balazs marczis and Tibor czigany, Conducted an experiment of Polymer Joints.

The current document examines various categories of polymer connections with a specific emphasis on fusion as a bonding technique for polymers.

The following are the principal aspects to consider:

1. Varieties of polymer connections: Connections that transmit force (e.g., threaded connections). Connections that transmit force through shape (e.g., snap fits, riveted connections). Connections that transmit force through a continuous material layer (e.g., glued connections, welded connections).
2. Fusion connections for polymers: - Exclusive to thermoplastic polymers with linear or slightly branched chains. Involves the application of heat for polymer melting and pressure for surface joining. Various fusion technologies are explored: hot-gas, extrusion, hot plate, laser, spin, vibration, ultrasonic.
3. Experimental analysis on hot-gas fusion: Developed a computerized fusion platform to enhance automation and reproducibility. Examined 5 polymer materials at 5 distinct fusion speeds - Assessed joint efficiency factor and identified varying optimal fusion speeds based on polymer type - Crystalline polymers typically exhibit superior fusion compared to amorphous ones - Polymers with lower melting temperatures tend to offer better weldability.
4. Inspection through acoustic emission: Utilized to identify stress waves during tensile testing of fused samples.

5. Overall deductions: Fusion speed significantly affects the quality of joints. The molecular structure of the polymer significantly influences its weldability. The implementation of an automated fusion system enhanced reproducibility. The manuscript delivers an exhaustive review of polymer bonding methods, concentrating on enhancing fused connections through meticulously controlled experimental examinations.

The implementation of an automated fusion system enhanced reproducibility. The manuscript delivers an exhaustive review of polymer bonding methods, concentrating on enhancing fused connections through meticulously controlled experimental examinations.[8]

Joining of Fibre-Reinforced Thermoplastic Polymer Composites by Friction Stir Welding A Review by Miguel A R Pereira et. al
Here is a summary of the key points from the document this article deliberates on the capabilities of friction stir welding (FSW) and its various forms of fiber-reinforced thermoplastic polymer (FRTP) composites. The scholars underscore the merits of FRTP composites, including their commendable performance, low density, recyclability, and superior mechanical attributes in contrast to metallic substances, rendering them well-suited for sectors such as automotive, aerospace, and marine engineering.

FSW is portrayed as a technique for connecting FRTP composites, surmounting the constraints of traditional joining methods like mechanical fastening and adhesive bonding. Mechanical fastening contributes to weight gain and induces stress concentrations, while adhesive bonding grapples with surface tension challenges and necessitates specific curing durations and conditions. In contrast, FSW proffers a solid-state joining methodology that generates heat through friction, thereby preserving the material characteristics. The analysis also divided into two significant offshoots of FSW: friction stir spot welding (FSSW) and Refill friction stir spot welding (RFSSW).

Friction stir welding (FSW) main steps:

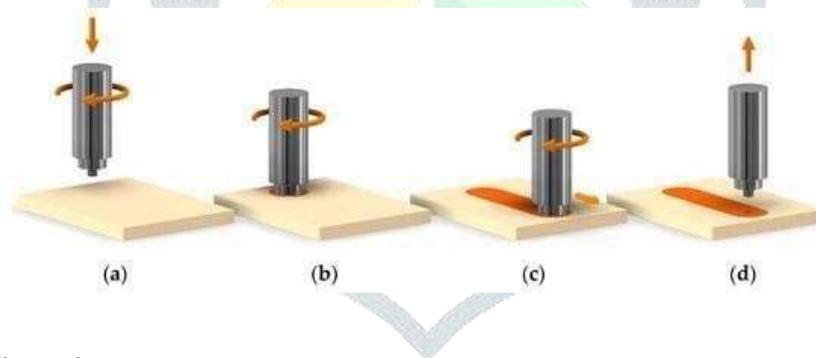


Figure.3.21 Friction stir welding main steps

(a) Plunging stage, (b). Stirring stage, (c). Retraction stage.

Friction Stir Spot Welding (FSSW) involves the application of a rotating tool under significant force onto two overlapping sheets. This process generates frictional heat and high pressure, causing the material to become plasticized and allowing the tool's tip to penetrate the joint between the sheets.

Refill friction stir spot welding (RFSSW) main steps:

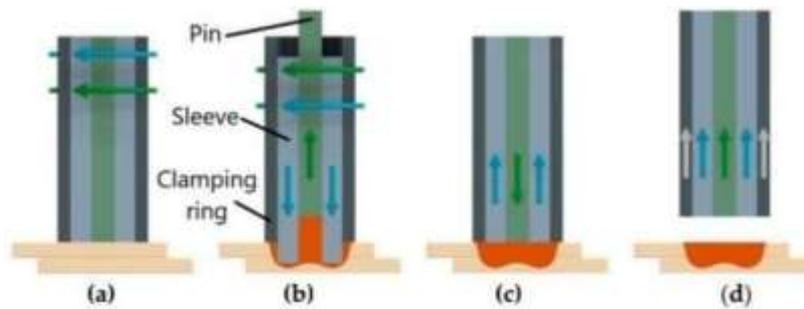


Figure.3.23 Refill friction stir spot welding

(a) initiation stage, (b) sleeve penetration stage, (c) weld seam compression stage and (d) tool retraction stage.

Refill Friction Stir Spot Welding (RFSSW) is a solid-state joining technique that represents an evolution of Friction Stir Welding (FSW). In contrast to FSW, RFSSW does not involve any transverse movement during the welding process, leading to the formation of a concentrated 'spot' weld.

These methodologies exhibit potential for uniting FRTP composites, with FSSW showing particular promise despite the extensive investigation. Crucial factors impacting the integrity of FSW joints encompass rotational velocity, welding pace, and tool configuration. While the research is still at a preliminary stage, the outcomes indicate substantial promise for these welding methodologies to propel the utilization of FRTP composites across diverse sectors.

In essence, this evaluation furnishes an exhaustive depiction of the present status and forthcoming potential of FSW and its variations for bonding FRTP composites, underscoring their benefits and the exigency for further exploration to refine the welding parameters and methodologies.[9]

SUMMARY

Welding or joining methods of polymer composite materials is a crucial process in industries like aeronautics, railway, and automotive, where these materials are increasingly used as lightweight substitutes for metals. Thermoplastic composites can be joined like fusion bonding/welding, an attractive alternative to mechanical fastening and adhesive bonding used for thermoset composites. Various welding technologies, such as resistance welding, induction welding, ultrasonic welding, laser welding, and infrared welding, are being developed, effectively managing interfacial phenomena and ensuring structural quality within the assembly zone remains a significant challenge and It is a complex process that requires careful consideration of various factors to achieve strong, reliable, and durable bonds. Polymer composites, consisting of a polymer matrix and reinforcement materials, pose unique challenges due to their heterogeneous nature and anisotropic properties. The choice of joining method depends on the specific application, material properties and performance requirements. Key considerations include joint strength, durability, and resistance to environmental factors, as well as production rate, cost, and operator safety and also utilization of reliable predictive process simulation software and the implementation of inline monitoring and control of welding process parameters are also needed. By reviewing and comparing all review papers it helps to select the best-suited welding methods and provides an overview on the limitations and benefits of each process.

IV OBJECTIVES

To Check the feasibilities of joining methods

Technical Objectives:

Joint Strength: Evaluate the joint strength and its ability to withstand various types of loads (e.g. tensile, compressive, shear). **Joint Integrity:** Assess the joint's resistance to environmental factors, such as temperature, humidity, and chemical exposure. **Material Compatibility:** Determine the compatibility of the joining method with the composite material, including its matrix, reinforcement, and additives.

Processability: Evaluate the ease of processing, including the complexity of the joining process and the required equipment. **Scalability:** Assess the ability to scale up or down the joining process, depending on the application and production requirements.

Economic Objectives:

Cost-Effectiveness: Evaluate the cost of the joining method, including equipment, labor, and material costs. **Production Rate:** Assess the production rate of the joining method, including the time required to complete a joint.

Material Efficiency: Determine the material efficiency of the joining method, including the amount of material waste generated.

Environmental Objectives:

Environmental Impact: Evaluate the environmental impact of the joining method, including energy consumption, emissions, and waste generation.

Sustainability: Assess the sustainability of the joining method, including the use of recyclable materials and the potential for end-of-life recycling.

Quality Objectives:

Consistency: Evaluate the consistency of the joining method, including the variability of joint quality. **Reliability:** Assess the reliability of the joining method, including the likelihood of joint failure.

Aesthetics: Determine the aesthetic quality of the joint, including its appearance and surface finish.

V CONCLUSION

Concluding the welding or joining of polymer composite materials highlights the importance and complexity of this advanced engineering practice. It involves understanding the unique properties of polymer composites, such as their thermal behavior, mechanical strength, and chemical resistance. Various techniques, including ultrasonic welding, laser welding, and adhesive bonding, offer distinct advantages and challenges. Successful application requires careful selection of methods based on specific requirements, considering factors like joint strength, environmental conditions, and cost. Ongoing research and technological advancements are expected to further optimize these processes, enhancing the durability and performance of polymer composite structures in diverse industries.

Overall, welding can be a viable option for joining polymer composite materials, offering advantages in terms of efficiency, cost, and joint strength. However, the choice of welding technique and joint design are critical to ensure a successful weld.

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