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Advancements in polymeric matrix composite production: A review on methods and approaches

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Abstract

This study focused on the comprehensive exploration of composite materials, elucidating their properties, and classifying them based on matrix materials. Emphasis was placed on thermoplastic matrix composite production methods, shedding light on their properties. An extensive examination of various production processes, ranging from traditional methods to cutting-edge technologies like automatic fiber placement and additive manufacturing were undertaken. The study extensively examined various production methods for thermoplastic matrix composites, discussing the advantages, disadvantages, and optimal characteristics of each technique. Thermoplastic matrix composite production processes encompassed such as hand lay-up, spray-up, filament winding, vacuum bag molding, vacuum infusion, resin transfer molding, compression molding, pultrusion, injection molding, centrifugal casting and lamination were discussed. While composite materials offered corrosion protection, high temperature resistance, and electrical stability, challenges including costly production, intricated repair processes, and short shelf life persist. Despite the popularity of thermoset matrix composites, the study underscores the need for more efficient thermoplastic composite production methods, addressing emerging trends and digital transformations reshaping the landscape of composite manufacturing. Anticipating the integration of machine learning algorithms for optimizing parameters, the study foresaw a future where composite production processes become significantly more efficient and comprehensive. The review was underscored the transformative impact of machine learning and process modelling on optimization studies, paving the way for more efficient and comprehensive composite manufacturing.

1. Introduction

In the realm of advanced manufacturing techniques, recent studies delved into optimizing processes critical to producing high-quality materials. Islam et al., (2022) [1], attempted to optimize the Automatic Fiber Placement process, a manufacturing technique that has several variables that affect the quality of the finished product. In this study, it was proposed that a hybrid approach to tackle the issue of little data learning by integrating the benefits of machine learning algorithms like data from experiments and photonic sensors, physics-based numerical simulations, and virtual sample generation methods. Continuous carbon fibers were integrated as reinforcement of thermoplastic polymers using a controlled multi-material additive manufacturing technique in literature. The flexural strength varies with loading direction and layer thickness, with 65.96 MPa being the highest flexural strength. Additionally, Scanning Electron Microscopy was used to investigate the effects of supporting resin volume fraction on various fusion interfaces as well as the effects of process factors on the wall thickness of soft and hard resins to perform an advanced adjustable soft-hard hybridization [2].

Hürkamp et al. (2021) [3], presented a numerical twin of the thermoforming process that was based on simulation. In this case, it was thought that the structural integrity of overmolded thermoplastic composites were limited by the bond strength between the thermoformed fiber-reinforced thermoplastic sheet and the injected polymer. Combining physical trustworthy temperature fields in real-time with machine learning techniques results in calculations that were accurate enough to be utilized as in-line quality gates and for design reasons. Continuous carbon fiber reinforced plastic could not be manufactured with traditional additive manufacturing with great speed and energy efficiency. The behaviour of non-isothermal crystallization and the mechanical properties of microwave printed, and thermal specimens had been investigated, and the underlying causes of disparate outcomes had been examined [4]. Zaami et al., (2021) [5], were measured to provide a more obvious explanation of the warming up stage in the laser-based production of composites. Another study Chen et al., (2021) [6], used experimental research to learn more about the effects of processing parameters during automated laser-assisted fiber insertion on the mechanical properties of composites made of carbon fiber and polyphenylene sulphide relative to crystallinity and void content. Prior to processing the polyphenylene Sulfide/carbon-fiber composites, thermal characterization was done to determine the processing window. An internal system for measuring temperature was used to measure the temperature history at the nip point during an automated fiber placement process, and the appropriate ranges for placement speed laser power were established according to the temperature recorded. Instead of crystallinity, it was discovered that the interlaminar void content governed the mechanical characteristics of the composite. The composites were then given one last treatment in an autoclave. The overmolding process was one of the cutting-edge manufacturing techniques that was increasingly being employed in the aerospace and automotive industries to create lightweight composite structures. With the aid of this technique, it was possible to combine polymeric materials that were different from one another and integrate reinforcements of various sizes, from macro to nanoscale, into thermoplastic and thermoset matrices. An overview of new emerging trends in the layout and production of composite systems using technologies for insert molding and multiple material injection molding as well as an overmolding procedure using nano/micro-scale reinforcements was the goal of this review [7]. To achieve good structural performance and bonding quality, by taking into consideration more than one thermoplastic polymer in one mold, multi-material injection molding had been researched. As opposed to that, the insert molding method was assessed by the types of reinforcement and matrix for comprehending the structural and endurance integrity throughout production. The fundamental bond strength bottleneck in the overmolding process was detailed through the debate of dispersion techniques, moreover this fresh viewpoint made it possible to create multifunctional composites utilizing design tools in a single step. The use of lightweight materials like thermoplastic composites and aluminium alloys in the automotive sector required advanced joining techniques for multi-material constructions. The fiber cutting was simple to automatize and suitable for growth into production [8]. For thermoplastic composite profiles with continuous fiber reinforcement, pultrusion was a quick and efficient manufacturing process. Manufacturing difficulties related to heat transmission raised as the cross-links of pultruded profiles expand to satisfy rising performance requirements. The physics of heat transmission and fluid flow in the pultrusion process with increasing diameters from 5- 40 mm were simulated in this work [9] using a two-dimensional finite element model. A unique batch-wise pultrusion idea was developed, allowing for in-situ observation of the impregnation process using a transparent die, to simplify the experimental validation. The pultrusion studies on glass-fiber/amorphous polyethylene terephthalate blended yarns demonstrate that, with suitable design, pultrusion was able to produce repeatable, high-quality profiles up to at least 40 mm.

2. Method

Composite materials were defined as two or more components which form a composition that produces better properties than when the components were used alone. These composites consisting of reinforcement and matrix did not lose their physical, chemical, and mechanical properties as in metal alloys. One of the biggest advantages of composite materials was their high strength despite their low densities [10]. Composites showed largely heterogeneous properties. A significant number of interfaces between phases occurred in the material because of their immiscibility. In composite materials, the continuous phase was the matrix and the discontinuous or fiber phases were contained within the phase as a separate region [11]. Typically, matrices served as load transfer elements between fibers while reinforcing elements served as the primary weight-bearing element. and safeguard the building from adverse environmental factors like high temperatures and humidity [12]. The matrix also aided in the composite's mechanical performance. The usage of fibers alone, other from yarns, was restricted. As a result, fibers were employed to strengthen the matrix. Matrix mechanical qualities were usually inferior to fiber mechanical properties. But many of the composite's mechanical properties were impacted by the matrix. These characteristics included compressive strength, interlayer shear strength, transverse modulus and strength, shear modulus and strength, coefficient of thermal expansion, and fatigue strength [13]. Matrices were classified [14] as shown below in Figure 1.

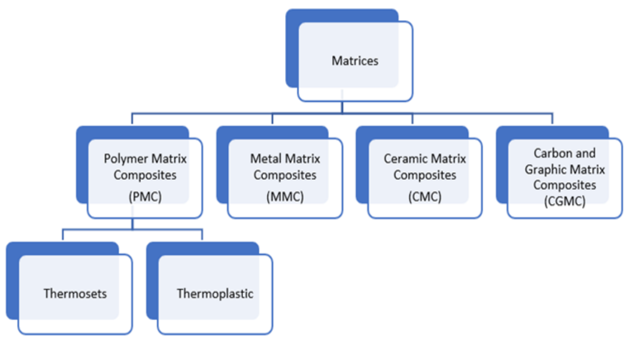

Figure 1. Classification of matrix materials.

Thermosetting polymers were rigid structures in which molecules were connected by cross-links and formed a three-dimensional network structure. The polymerization reaction, also known as the curing reaction, generated these cross-links, which prevented the thermoset polymer from melting under heat [15]. Thermosetting materials could not be recycled in this fashion because they combusted and lost structural integrity during the reheating process. Thermoplastics had several benefits: the ability to be recycled, melted, molded using heat, strong resilience to chemicals and the elements, excellent electrical insulation. Disadvantages were listed as they could not demonstrate heat resistance like thermosets; instead, they flowed and dissolved, their raw materials were more expensive there were not many thermoplastics that could be used in liquid form [12, 16]. Like thermoset polymers, elastomers were made of long-chain molecules that were cross-linked. These were polymers that could withstand very low pressures and still undergo significant deformation. There were two types of rubber that could be studied, natural rubber was rubber extracted from certain biological plants and synthetic polymers were used for thermoset and thermoplastic polymers and were produced by similar polymerization processes. Elastomers became more rigid and had a more linear elastic modulus as they got increasingly cross-linked [17]. Undulating fibers were used to reinforce elastomers, resulting in soft composites that have high endurance thanks to the reinforcing fiber but maintain the flexibility of the matrix's elastomer, in addition to allowing large elongation until the fiber flattens. These composites could be utilized to produce biomedical tools for uses involving soft tissue including skin-like characteristics or synthetical tendons. Elastomers could be strength with helically wrapped fibers, knitted textiles, or undulating planar fibers to make composites. Compression molding could be used to reinforce knitted fabrics used in elastomeric matrix materials to create planar soft composites [18, 19].

2.1. Open molding

There were two process method for open molding: Hand lay-up and Spray-up. One of the earliest and most straightforward processes was the hand lay-up of composite materials. The hand lay-up mold's surface was smooth, polished, and treated with a mold release agent to produce surfaces. The material was made by the release agent. It was crucial because it made it simple to remove the hardened product from the mold (Figure 2). Glass fiber reinforced weaving and felts could be used as a component. This technology had the following benefits as low cost, quick and inexpensive mold creation, possibility of production in different sizes, possibility of obtaining colorful surfaces. However, the issue of manufacturing quality consistency, only one surface was shiny, possibility of deviations in dimensions. All of these could have a negative impact on the material's mechanical properties [12].

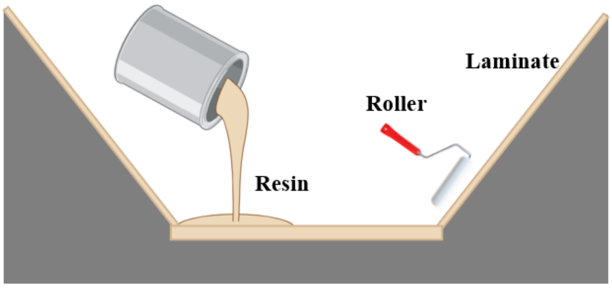

Figure 2. Hand lay-up process.

Spray-up

It might be thought of as the hand-lay-up composite manufacturing technique's gun counterpart. The trimmer in the pistol constantly fed the fibers into the gun where they were chopped. Using a specific gun and the matrix element with the addition of hardener, the chopped fibers were sprayed at the proper speed onto the surface of the mold. As with the hand lay-up method, professionals were not required. Because short fibers were used, the mechanical strength was constrained. It should have therefore been employed in circumstances where direct load bearing was not necessary. By using this technique, the interior surfaces of pools, bathtubs, car bodies, and boats were produced (Figure 3) [12, 20].

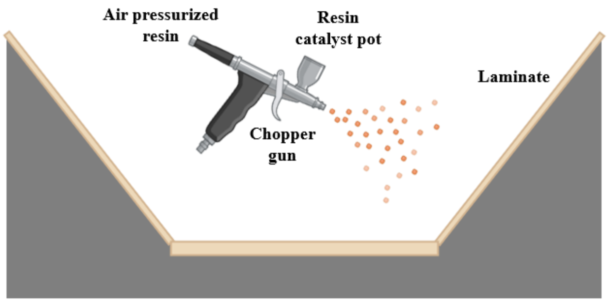

Figure 3. Spray-up process.

2.1.1. Filament winding

This procedure was, roughly speaking, the opposite of typical turning because material was added to the part rather than taken away. Pre-stressing the fibers places restrictions on the winding patterns that could be used; in other words, a geodesic path must have been taken to prevent displacement. A resin system that was effective for the fiber winding process could have been two key characteristics: it could have been suitable for the viscosity before the curing reaction was activated and deposited without any early resin to allow the reinforcement to wet and gel for a long enough pot life. This method required polar or helical reinforcement designs as pressure tanks, airframes, and pipes but also had intriguing environmental benefits. Definition of a software that chose the part's winding pattern. A wiping tool was typically used to remove extra resin, the placement of reinforcement composite curing in an autoclave or at ambient temperature, removing the mandrel (Figure 4) [21, 22].

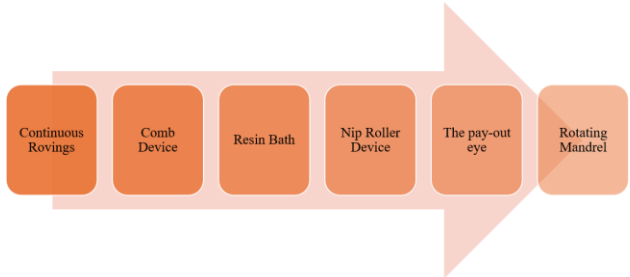

Figure 4. Filament winding process.

2.2. Closed Molding

2.2.1. Vacuum bag molding

The major composite production method to form laminated construction was vacuum bag molding, which was widely used in the aerospace sector. Due to the labor-intensive nature of the process and the potential for lengthy cycle durations, it had limited application in the automotive industry. It had mostly been used to create prototype automotive composite parts, but it might be employed in the future to create huge components like floor pans and roof panels, particularly if laminated construction was used and the amount of output was low. The temperature was then increased in the autoclave or oven up to reaching the predefined curing temperature. If autoclave curing was utilized, the assembly was put under positive pressure to combine the separate layers in the stack to form a solid laminate. Consolidation occurred at one atmospheric pressure when oven curing was applied. The duration of the curing procedure could have ranged from half an hour to a couple of hours, according to the resin that was employed [23, 24].

2.2.2 Vacuum infusion processing

One form of liquid compaction moulding process used in the manufacturing of composite products was the vacuum infusion process. It was a very sophisticated and economical manufacturing method that was vital in the production of composites with intricate structures and great dimensional precision. There were four vacuum infusion processes steps: dry reinforced laminate was first placed in the mold and sealed airtight with sealant taps; resin was then sucked into the closed mold under vacuum pressure; resin was then allowed to cure in the mold part hole; and finally, the composite part was removed from the mould (Figure 5). Traditional parameter selection and mold design had long relied on the "trial and error" approach, but doing so was time- and money-consuming. Process modeling and numerical simulation were therefore becoming more and more significant. When using process to fill the preform's mould cavity, the vacuum pressure was the only driving factor to considered. When compared to parts produced using other methods for the same thickness, manufactured parts had a higher fiber content (usually 60–70% of the overall weight) and reduced porosity (less than 1%) [25, 26].

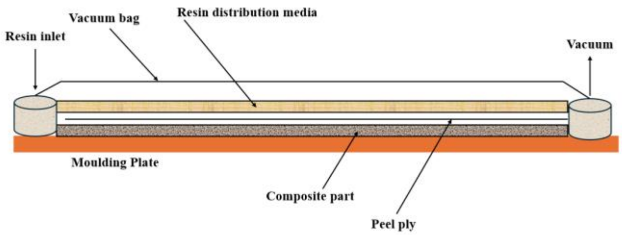

Figure 5. Vacuum infusion process.

2.2.3 Resin transfer molding

One of the out of autoclave technologies employed in the aerospace sector was resin transfer molding. To increase the effectiveness of the process and the quality of the final product, research had been done on the capabilities of resin transfer molding. According to a survey of the literature, technology could produce high-quality components with intricate geometric designs, dimensional accuracy, and consistent good mechanical characteristics. Typically, the technology employed a closed aluminum mold. The procedure included a phase called hand lay-up on the mold. To ensure that the resin and fiber mixed thoroughly, the mold was then sealed, heated, and placed in a vacuum. The mold was then filled with resin, which was left there to harden (Figure 6) [27, 28].

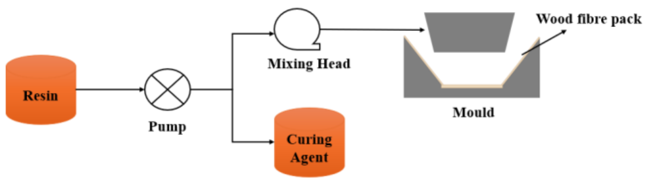

Figure 6. Resin transfer molding process.

2.2.4 Compression molding

Using thermoset or thermoplastic matrices, compression moulding was a well-known method for manufacturing composite materials. Matching-die molding was a common term for the process of forcing a fiber-reinforced composite substance to drain or deteriorate inside a mold cavity. Compression molding was often utilized to create non-continuous fiber reinforced composites in low to intermediate volume values. Utilizing the most recent advancements in compression molding technology, platelet-like materials were produced, including fiber strands or bundles that had been previously infused with a matrix and had qualities like to leftover recycled thermoplastic materials or thermoset prepregs. This technique was appealing because it was simple to automate and could be utilized to create no waste complicated geometries where the component's form could be leveraged to considerably boost the structure's rigidity [29-31]. Preheating or extruding, transfer, molding, and ejection were the four essential phases in hot flow compression molding. Once heated to the processing window or extruded from the composite, the hot charge was transferred to the appropriate steel tool. For mass production, a robotic transfer system holding the heated material in place with needle grippers was used. To achieve consistent tool fill, precise placement on the mold was essential. The charge interior cooled quite slowly during transfer because of the insulating, lofted structure. Transfer times, which could be anywhere between 15 and 90 seconds in commercial operations, became very important when setting molding pressures when working with slow closure rates. The glass fibers in the flowing matrix were subjected to pressure during the molding process to fill the cold tool, cool and solidify the component, and then released the pressure and removed flash. Instead, the charge was under pressure when the tool stopped [32, 33].

2.2.5 Pultrusion

For producing pieces made of fiber-reinforced plastic composites with a consistent cross-link, pultrusion worked well. Because it was continuous, automated, and extremely productive, it was frequently used in the composite manufacturing sector. The words "pull", and "extrusion" were the roots of the phrase "pultrusion." It involved pulling continuous fibers that had been saturated with a polymer through a heated die and extruding them. Starting with the pulling of continuous rovings or mats of reinforcing fibers from a sequence of creels, the pultrusion process began. To get it impregnated, the fibrous material was continually delivered by means of a guiding device into a resin bath. The resin-soaked fibers were directed to a heater assembly where they were heated while being shaped to a close match of the intended finished product. During the pultrusion procedure, continuous rovings or mats of conventional carbon or glass fiber reinforcement were impregnated by being pulled into a thermosetting resin solution. The composite was forced through a temperature and shape-controlled process, where it solidified while being squeezed through (Figure 7) [34, 35].

Figure 7. Pultrusion process.

2.2.6 Injection molding

A variety of sophisticated and equivalent mass-manufactured goods produced using the cutting-edge production technique known as injection molding. To allow for the molding of materials that were thermoplastic and thermoset and new materials like metal powder and liquid silicone rubber, the basic phases of injection molding could be altered. Depending on which of certain material kinds was utilized, the fundamental machine design might have changed, but basic ideas of injecting material, shaping material, and removing manufactured component stayed consistent. Thermoplastics were the most frequently utilized materials for injection molding. An injection molding machine's goal was producing a correct amount of polymer component at a fast enough injection rate during applying enough clamp strength to the injection molding device for keeping it from opening because of injection pressure. The control unit enabled the operator to program and oversaw the production process as well as have direct control over the system [36-38].

2.2.7 Centrifugal casting

Since 1978, centrifugal casting recognized as the most popular technology for producing pipes and tubes in the cement sector. Centrifugal casting required rotating a mold in a minimal size centrifuge to separate the liquid from the solid and speed up the precipitation of suspension to condense powders. Molds were employed in centrifugal casting; they could be formed from a variety of metals and plastics and did not have to be porous. The mold in this method was put in a centrifugal pail's base that could apply centrifugal force to the mold. Casting can be accelerated and greatly expedited using centrifugal force. Instead of slip casting, this method called for scraping the liquid from the top of the cake. Gradients in packing intensity and the resulting contraction fractures that manifested at the time of drying and decomposition were also brought on by these causes. Avoiding flocculated slips would help with the compressibility issues. It was claimed that segregation issues may be avoided by using extremely concentrated dispersion suspensions, flocculation, or coagulation during consolidation. Through the progressive casting of various slip formulations, centrifugal casting was also a typical technique for producing multilayer micro-composites and functionally graded materials. Regulating the slurry's solid content and centrifuging rate allowed for precise layer thickness control. Centrifugal casting was mostly used to create composite materials, including metallic materials with large density discrepancies and low solubility across phases. To create tubular or axisymmetric bodies, the slip could also be placed within a hollow cylindrical plaster mold and twisted around it [39, 40].

2.2.8 Lamination

Multiple tape layers were fused together into a single, composite structure using a low-temperature lamination method. Wet bag isostatic presses with heated fluid baths were used to apply similar amounts of pressure and warmth to the surfaces of the tape stack during isostatic lamination. Due to the uniform pressure applied during isostatic lamination, more uniform laminates were produced, making it more popular in production settings than uniaxial lamination. Protective envelopes kept the tape layers separate from the liquid bath. The envelopes were vacuum sealed to establish full layer contact and avoid air pockets between the tape layers. Furthermore, isostatic lamination using a fluid bath permitted the lamination of several, individually closed stacks in one pressing. Bladder lamination was utilizing both the uniaxial and isostatic techniques, like how dry bag isostatic pressing and wet bag isostatic pressing relate to one another. A multicomponent array could be sintered as a single item and then broken apart by creating weak spots across the array (Figure 8) [41- 43].

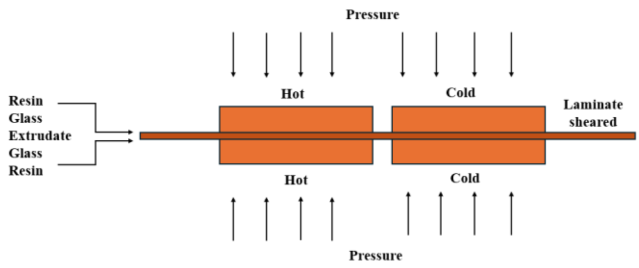

Figure 8. Lamination process.

2.2.9 Thermoforming

A thermoplastic sheet was bent into a new shape during the thermoforming process, which involved heating the sheet to high temperatures and pressure. Medical devices, food containers, and pharmaceutical products were some of the packaging applications where this method was most frequently used. During the thermoforming process, thermoplastic polymers were solely used as a substrate. These polymers were either semi-crystalline, crystalline, or amorphous in nature [44]. The thermoforming procedure, which was used to create a variety of packaging items such as tubs, pots, and trays, may be divided into seven: 1. The cast extrusion technique was typically used to create the plate. 2. Preheating the plate. 3. Extending or dragging the plate over or into a mold to shape the pack. 4. Cooling the packaging that was formed. 5. Cutting and trimming multiple molded plate into individual parts. This might happen simultaneously with the shaping procedure. 6. As needed, printing or embellishing. 7. Stacking each unit before preparing it for shipment to the customer by packing and labeling [45].

2.2.10 Autoclave moulding

There were not many differences between the vacuum bagging process and the autoclave moulding method. The autoclave machine provided the heat and pressure needed by the biocomposites during the curing cycle. In this procedure, prepregs were firmly stacked in a mould in sequence. For avoiding the polymer's adhesion to the mold's surface, a release gel was placed to the surface of the mold. Additionally, inserts and cores were permitted to be used with this procedure. The entire assembly was then transferred to an autoclave machine, where pressure and heat were used to promote effective and uniform matrix dispersion as well as long-term bonding between the fibers and the matrix. After the assembly had cooled and the vacuum bag had been removed, the composite component was then taken from the mold [46].

2.2.11 Tape Winding

A resin prepreg fiber tape was wrapped on a mandrel during the tape winding process, and factors like temperature assisted to assure the development of tape layers. A compression roller produced the compression force on the incoming tape as well as the stacking of the tape. The compression force made winding products less void-filled and improve the adhesion of tape layers. To reduce ply elevation caused by high velocity and temperature gas flow, the rear out cone of the rocket motor nozzle should have had its tape layers oriented at a winding angle to the centerline. The accumulation of layers of tape calculated using the spindle rotation speed and the resin prepreg tape thickness, as demonstrated in the following (Eq. 1):

$$\vartheta_D = \frac{\delta n}{sin(\theta + \alpha)} \quad (1)$$

where ϑ_D was the tape layers' deposition speed, n was the spindle's rotation, θ was the winding angle, α was the nozzle's exit cone angle, and δ was the winding tape's thickness. It was possible for the tape thickness to change along a winding operation due to compaction force, and this phenomenon could lead to mistakes in the resin dipping process as well as errors in the compressing roller's motion and the accumulation of tape layers [47, 48].

2.2.12 Diaphragm forming

Thermoplastic prepregs or organic plates were attached to a female inner mold that was set in a heating chamber to use this technology. The bottom mold and higher mold made up the heating chamber, together with the heating elements that defined where the replacement female inner mold was located. The upper surface of the prepregs was suitably fixed with a polymeric backing material, resulting in a tight separation of the chamber into two sections. The temperature was then lowered to the desired rate to produce a solid component that may have been withdrawn from the mold after the component had formed and cemented [49, 50].

2.3 Numerical results

The investigation [16] on resin-infused thermoplastic tri-block copolymer fiber-reinforced composites demonstrated substantial improvements in mechanical and thermal properties based on varying weight percentages of copolymer. In terms of flexural strength, the composites with 15 wt% copolymers exhibited a remarkable increased of up to 75% in the warp direction and 34% in the fill direction compared to pristine samples. The flexural modulus also showed notable enhancements with a rise of 8% for 10 wt% and 11% for 15 wt% copolymer in both warp and fill directions. Furthermore, interlaminar shear strength saw significant improvements with 20 wt% copolymer yielding increases of 80% in the warp direction. Residual strengths were also positively affected with the residual flexural strength increasing by up to 35%. Thermally, the glass transition temperature increased by up to 11 °C with 20 wt% copolymer, while the storage modulus exhibited a 24% enhancement reflecting improved stiffness and thermal stability.

Researchers [18] investigated the crimping parameters and characteristics of fiber-reinforced thermoplastic elastomers by focusing on mandrel diameters of 1 mm and 1.6 mm, heat-setting temperatures of 220°C and 320°C, and dwell times of 5 and 10 minutes. The highest degree of crimp (1.095) and crimp stability (0.91) were observed with a 1.6 mm mandrel at 320°C for 10 minutes. Tensile testing revealed that untreated filaments had an elongation at break of 3.1% and a breaking force of 0.35 N, while crimped filaments showed approximately a 35% reduction in breaking force and a 25% reduction in maximum elongation after heat-setting. The pressure in the screw vestibule varied from 19.3 bar at 200 °C to 7.0 bar at 240 °C. The stress-strain characteristics showed an onset point of the stress-strain curve from approximately 3% strain to about 12% strain, and the Young's modulus ranged from 20–40 MPa at low elongation to 200–400 MPa at high elongation. The tensile strength of unreinforced extruded strands was 5.5 MPa, while reinforced strands exhibited a tensile strength fifteen times higher.

3. Manufacturing process methods by sectors

Composite materials became integral to virtually every industry finding significant applications due to superior properties. In the automotive, defense, and aerospace sectors, composites were particularly valued for light weight and high strength. These properties made them ideal for use in aircraft, where they had largely replaced traditional metals and aluminum alloys. The substitution was driven by the need for materials that offered low weight, high mechanical strength, and excellent resistance to atmospheric conditions. It was well-known that polymer-based composite materials were used extensively in the construction of aircraft and helicopters including interior components and airframe parts. This shift towards composites in aerospace was due to their ability to enhance performance, increase fuel efficiency, and reduce maintenance costs. In the automotive industry, the trend towards the use of composite materials was particularly prominent in recent years. One of the most discussed topics had been the weight reduction of vehicles, a key initiative aimed at improving fuel efficiency and reducing emissions. The use of composite materials in automotive design not only contributed to lighter vehicles but also enhanced mechanical performance and safety features. This innovation was driven by the industry's commitment to sustainability and technological advancement. As a result, composite materials emerged as a crucial element in the ongoing evolution of vehicle manufacturing, reflecting broader trends towards efficiency and environmental responsibility. This widespread adoption focused the versatile and transformative impact of composite materials across multiple sectors highlighting their role in advancing modern industrial applications [51, 52].

4. Conclusion

Within the scope of this study, firstly composite materials and their properties were explained. Then, composites classified according to matrix materials were mentioned. In this study, thermoplastic matrix composite production methods were emphasized by drawing attention to the advantageous properties of thermoplastic matrix composites, which were not preferred in the industry compared to thermoset matrices due to disadvantages such as production difficulty and high raw material cost. The aim was to elucidate the reasons for thermoplastics to replace thermosets. The first of these was the potential of thermoplastics to be produced using production methods prone to mass production and the prediction that they could shorten the part production process. Another important reason that thermoplastics were recyclable and at the same time environmentally friendly. Another environmental benefit of using thermoplastic materials was that they had good mechanical strength despite their low density. In this case, using lightweight materials could save fuel by reducing the weight of the aircraft, for example in the aviation industry. Another reason why thermoplastic materials started to be used instead of thermosets is that these materials could be reshaped. The reuse of thermoplastics by applying a suitable heat treatment and not being affected by heat treatments and long shelf life could be counted among the advantages of thermoplastic materials. It was among the objectives of this study to emphasise the use of thermoplastic matrix by highlighting such positive features. In this context, the production processes of thermoplastic matrix composites were examined. Hand lay-up process, spray-up process, filament winding process, vacuum bag moulding process, vacuum infusion process, resin transfer moulding, compression moulding, pultrusion, injection moulding, centrifugal casting process, lamination process, thermoforming process, autoclave process, tape winding process and diaphragm forming processes were mentioned and the advantages and disadvantages of these production processes were discussed. In addition, the optimum characteristics of these processes were analysed. In the literature review section, especially the studies on this subject in recent years focussed and evaluated. The data obtained showed that the traditional methods replaced by production methods such as automatic fiber placement, additive manufacturing technique with microwave heating assistance and laser-based composite manufacturing process. Optimization studies were improved with process modeling and machine learning techniques, which had become easier with the developing technology. Composites, which were formed by combining and hybridizing one or more materials, was found use in many different industrial fields. Composite materials were distinguished from traditional materials by their corrosion protection, high temperature resistance, electrical resistance, and stability, and preferred for these properties. The disadvantages of composite materials were difficult repair processes, expensive production and short shelf life compared to metals. It was observed that thermoset matrix composites were frequently used in composite materials. Thermoplastic polymers were not very popular as a matrix, although there were many types. This was because they were difficult and costly to produce. In addition, solvents were needed to shape some thermoplastics. Considering such disadvantages, existing thermoplastic composite production methods were examined in this study to form more effective and efficient production methods. Manufacturing techniques such as compression molding, pultrusion, injection molding and thermoforming were described and the optimum parameters for these techniques were mentioned. In addition, composite production methods using new technologies such as automatic fiber placement, microwave heating assisted additive manufacturing technique, multi-material injection molding were also included in this study, providing an overview of these new trends in recent years, and realizing the digital transformation in composite production. It was predicted that algorithms such as machine learning used for optimum parameters in these newly developed techniques will add a new dimension to composite manufacturing techniques in future and production processes will become much more efficient and comprehensive.

Author contributions

All authors contributed to the study conception and design.

Conflicts of interest

The authors declare no conflicts of interest.

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