

Carbon fiber tube manufacturing guidelines

1. Overview and Application of carbon fiber tube

[Carbon fiber tube](#), as a typical representative of advanced composite materials products, with its excellent comprehensive performance, is gradually replacing the traditional metal materials, in the high-end industrial manufacturing, aerospace, sports leisure areas such as show great potential applications. Its core advantage by carbon fiber and resin matrix composite, realize the lightweight, high strength, corrosion resistance, fatigue resistance and a series of perfect combination of excellent properties. From a macro point of view, the density of the carbon fiber tube usually only 1.5 1.8 g/cm after, is far lower than the steel (about 7.85 g/cm after) and aluminum (about 2.7 g/cm after), but the tensile strength can reach more than 3000 MPa, 6 to 12 times that of steel. This "lighter than aluminum, stronger than steel" features, makes it the pursuit of ultimate choice of lightweight and high performance applications. This section will delve into the core advantage of carbon fiber tube and concrete application in the field of key, lay a foundation for the understanding of the subsequent manufacturing process.

1.1 the carbon fiber tube core strengths

The embodiment of the excellent performance of carbon fiber tube is not a single attribute, but the synergy of many excellent properties. These characteristics allow them to maintain stable and reliable performance even in harsh working environments, thus meeting the needs of high-end applications.

1.1.1 of lightweight, high strength properties

Light weight and high strength is the most significant and core advantage of carbon fiber tube. This feature is the result of its unique material composition. Carbon fiber itself is a kind of carbon content in more than 90% of the high strength and high modulus fibers, the axial strength and high modulus. When these fibers and epoxy resin base body material compound, such as formation of high strength carbon fiber tube not only inherited the fiber, also through the role of the bonding resin, will load effectively is passed on to the every fiber, so as to realize the high bearing capacity of the whole structure. For example, in the aerospace field, use of carbon fiber tube alternatives to traditional metal manufacturing aircraft structure, can significantly reduce the structure weight of the aircraft, to improve fuel efficiency, increase the distance or payload. In the automotive industry, especially in the high performance cars and electric vehicles, the application of carbon fiber tube, not only can reduce weight lifting acceleration and maneuverability, also can effectively extend the range of electric cars. This lightweight effect in high speed movement need frequent start, stop, or automation equipment and also very important in robot field, can reduce inertia, improve the motion precision and response speed.

1.1.2 excellent corrosion resistance and anti-aging performance

Compared with the traditional metal materials, carbon fiber tube has excellent corrosion resistance and anti-aging performance. Metal pipes are prone to electrochemical corrosion in harsh environments such as damp, acid and alkali, which can lead to performance degradation, life shortening, and even cause safety accidents. And the resin in the carbon fiber composite materials such as epoxy resin itself has good chemical stability, can effectively isolate the corrosive medium erosion of carbon fiber. At the same time, the carbon fiber itself is an inert material, not easy to react with most chemicals. Therefore, the carbon fiber tube in Marine engineering, chemical equipment, sewage treatment and other fields has a natural advantage. In construction engineering, for example, the carbon fiber tube can be used to reinforce Bridges, towers and other infrastructure, its excellent corrosion resistance, can significantly improve the durability of structure and seismic performance, reduce maintenance costs for a long time. In addition, the carbon fiber tube also showed good fatigue resistance performance, under the high frequency vibration and repeated stress function, the structure performance attenuation is far slower than metal materials, for the drive shaft, such as mechanical arm dynamic load components are particularly important.

1.1.3 Low thermal expansion coefficient and dimensional stability

Carbon fiber tube another key advantage is its low thermal expansion coefficient and excellent dimensional stability. Carbon fiber along the fiber axial thermal expansion coefficient is close to zero, even negative, thermal expansion coefficient and the resin is relatively high. Through reasonable layer design, can skillfully use offset by negative expansion property of carbon fiber resin is inflation, so that the carbon fiber tube in different environmental temperature changes the size of the tiny. The dimensional stability for precision instrument, optical devices, aerospace components and high-speed mechanical roller application scenario is of crucial importance. For example, in the printing, papermaking, lithium battery pole piece winding etc, the size of the roll shaft precision directly affects the quality of the product. Traditional metal roller prone to heat bilges cold shrink, as the temperature changes affect the production of precision, and the size of the carbon fiber roller can maintain a constant, ensure the stability of the production process and the consistency of the product. In the field of aerospace, aircraft under different altitude and speed would undergo severe temperature changes, using carbon fiber tube to make the structure can maintain good aerodynamic shape and structural integrity, to ensure the flight safety.

1.2 Major Application Areas

With its unique combination of performance, the application of carbon fiber tube has penetrated to the several key areas of the national economy, from cutting-edge technology to daily life, the shadow everywhere.

1.2.1 Industrial machinery and automation equipment

In the industrial field, lightweight carbon fiber tube is to realize the equipment and the key to improving performance of materials. In automatic production line, the robot arm, unmanned aerial vehicle (uav) applications, such as carbon fiber tube is widely used in the manufacture of skeleton, telescopic rod, drive shaft and other structures. The lightweight characteristics can reduce the inertia of the moving parts, increase the speed of the robot's movement and positioning accuracy, reduce the energy consumption at the same time. In the textile, printing, film manufacturing and other industries, carbon fiber roller is gradually replace the traditional metal roller. The roll shaft is usually need high speed rotation, the carbon fiber tube of high stiffness, low inertia and excellent fatigue resistance performance, make it able to withstand higher speed and longer running time, reduce vibration and noise at the same time, improve production efficiency and product quality. In addition, the etching machine, PC equipment shaft precision machinery equipment, such as the size of the carbon fiber tube stability and conductivity also makes it the ideal structural material.

1.2.2, aerospace and military industry

The aerospace sector is one of the earliest and most important application markets for carbon fiber composites. Here, the material is directly related to the performance of aircraft performance, safety and cost. Carbon fiber tube was used in the manufacture of various structural parts of aircraft and spacecraft, such as beam wing, fuselage, tail frame structure, satellite support, etc. Its lightweight effect can be directly into lower fuel consumption, the increase of the distance or payload. In the field of military industry, the application of carbon fiber tube also widely, from missile and rocket shell to radome, bulletproof vehicle, etc., its high strength, high stiffness and resistance to impact for weapon and equipment provides a reliable guarantee. For example, in key load-bearing components such as drive shafts, carbon fiber composite drive shafts are not only more than 50% lighter than metal shafts, but also have better fatigue resistance and shock absorption performance, which can significantly improve the reliability and service life of equipment.

1.2.3 Sports equipment and medical devices

Carbon fiber tube in sports and health in the field of application, greatly improving the performance of the related products and user experience. In the high-end sports equipment, such as bicycle frame, tennis rackets, badminton racket, ski rod, fishing rod, etc., the application of carbon fiber tube has become the industry standard. The characteristics of light weight, high strength makes equipment are lighter, stronger, athletes can more easily and more accurate control, so as to improve athletic performance. In the field of medical apparatus

and instruments, the application of carbon fiber tube is also increasing. For example, in the X-ray machine, CT scan imaging devices, such as carbon fiber tube is used in the manufacture of bed board and support structure. Of their excellent permeability can reduce the X-ray imaging of interference, improve the accuracy of diagnosis. At the same time, the light characteristics but also facilitate mobile equipment and operation. In addition, the biocompatibility and high strength of carbon fiber tubes also make them an ideal material choice in some surgical instruments and rehabilitation devices.

2. Analysis of the main molding process of carbon fiber tube

[The manufacture of carbon fiber tube](#) is a involved in materials science, mechanical engineering and process control of complicated process. Its core is how to combine the carbon fiber and resin matrix, forming due to shape and the excellent performance of the composite structure. At present, the mainstream carbon fiber tube forming processes in industry mainly include rolling forming, pultrusion forming, fiber winding forming and molding forming. Each process has its own unique principle, process, advantages and limitations, which are suitable for the production of carbon fiber tube with different section shape, size and performance requirements. These major forming processes will be analyzed in detail in this section to provide a comprehensive technical reference for engineers and producers.

Process Types	Core principles	Key Advantages	Major Disadvantages	Typical applications
Roll forming	The prepreg is wound in layers over a heated core mold and then cured.	Mechanical performance is excellent, layer can design sex is strong, good surface quality.	Limited shape (mainly round pipe), low production efficiency.	Uav arm, sports equipment, precision instrument bracket.
pultrusion	Continuous fibers impregnated with resin are pulled through the heating mold and continuously cured to form.	Highly automated, high production efficiency, high dimensional accuracy, low cost.	Single shape (constant section), poor lateral performance.	Building profiles, cable Bridges, tent poles.
Fiber winding	Wrap the resin-impregnated fibers onto the rotating core die according to a preset pattern.	Fiber orientation accurately controlled, the ring to the high strength, suitable for pressure vessel.	Limited shapes (plane), equipment cost is high.	High pressure gas cylinder, rocket housing, drive shaft.
Molding by molding	Put the prepreg into a heating mold and heat it for curing under pressure.	Can manufacture complex section (square tube, special-shaped tube), high dimensional accuracy.	The mold cost is high and is not suitable for long tubes.	Mechanical arms, automotive structural parts, special-shaped connectors.

Process Types	Core principles	Key Advantages	Major Disadvantages	Typical applications
Hand lay-up + vacuum bag pressure	After laying the layer by hand, vacuum it with a vacuum bag for compaction and curing.	High flexibility, low mold cost, suitable for large complex parts.	The production efficiency is low, the quality depends on labor, and the performance is relatively low.	Hull, aircraft parts, prototype parts.

Carbon fiber tube main molding process

2.1 Rolling forming process

Roll Wrapping is one of the most commonly used and mature processes for the production of carbon fiber round pipes, especially suitable for the manufacture of small and medium-sized batch and high performance pipe. This process by putting a presoak material (Prepreg) after precise cutting, step by step a winding on heating of the core mold, after curing, demoulding process, eventually to form carbon fiber tube.

2.1.1 process principle and characteristics

The basic principle of winding forming is to use the hot roller on the pipe winding machine to heat the prepreg to the state of softening and viscous resin, and then through the friction between the roller and the core die, the prepreg will be evenly wound to the core die until the design thickness is reached. The main characteristics of the process are as follows: high fiber content and performance: because a certain tension can be applied in the process of rolling, the prepreg can be effectively compacted and the air between the layers can be discharged, so the fiber volume content of the product is high, and the mechanical properties are excellent, especially the bending rigidity and strength performance is outstanding.

Accurate layer control: by cutting presoak material in advance, can precisely control the layer Angle and the order of each layer, so as to realize the customization design of mechanical properties of pipes, satisfies the requirement of strength, stiffness in different direction.

Excellent surface quality: during the rolling process, the prepreg is closely fitted to the smooth core die surface, and the inner surface of the pipe after curing is highly polished. The outer surface is usually wrapped with a layer of OPP (oriented polypropylene) film or heat shrinkage film after rolling, which can be removed after curing to obtain a smooth and smooth outer surface.

Equipment is relatively simple: compared to filament winding machine, roll machine structure is relatively simple, low investment cost, is suitable for small and medium-sized enterprises and customized production. 2.1.2 production process: from presoak expect that finished product

The production process of rolling molding mainly includes the following key steps: Design and preparation: determine the inner diameter, outer diameter, length and wall thickness of the pipe according to the requirements of the product drawings. According to the wall thickness and the weight of prepreg per unit area, the number of layers required for prepreg is calculated. Then, cut the carbon fiber prepreg into sheets of the corresponding size and shape according to the designed layup Angle (e.g. 0° , $\pm 45^\circ$, 90°).

Die Preparation: Select or manufacture a core die that matches the inner diameter of the tube. Usually a metal core mold material, such as steel or aluminum. Before rolling, in core mold surface evenly coated with release agent, in order to facilitate the follow-up mold release.

Rolling: install the mandrel on the roll mill, and preheat roll mill of hot roll to reserve temperature (usually between $80-120^\circ\text{C}$ in * * * *, depending on the resin system presoak of material features). Will cut out good presoak sheets in turn winding onto the mandrel. Rolling process, the need to maintain a constant tension, to ensure that each layer between together, no bubble and fold.

Package and finalize the design: when all presoak rolled material layer is completed, in the outer surface of the pipe blank tightly wrapped a layer of OPP film or heat shrinkable film. The membrane in the process of curing a uniform pressure, fixed shape and prevent resin overflow effect.

Curing: The wrapped pipe blank is placed in a curing furnace or hot press tank and cured by heating according to the curing curve (temperature-time curve) provided by the prepreg supplier. The typical curing process consists of three stages: heating, holding and cooling. For example, a common system of epoxy resin curing curve may be under 150 °C heat 1-2 hours.

Demoulding and post-treatment: After the curing is completed, let the pipe cool to room temperature, remove the outer OPP film, and then use a demoulding machine or special tools to extract the core mold from the pipe. Finally, according to the drawing requirements, the ends of pipes for cutting, grinding, polishing machining processing, get the final finished product.

2.1.3 Applicable scenarios and limitations

The rolling and forming process is mainly suitable for the production of carbon fiber round pipes, especially those with high requirements on mechanical properties, dimensional accuracy and surface quality of small and medium-sized diameter pipes. For example, it is widely used in UAV arm rod, automation equipment support, high-end photography tripod, sports equipment (such as fishing rod, golf club) and other fields.

However, this process also has some limitations: the shape is limited: rolling molding is mainly suitable for rotating bodies, especially circular sections. For square, rectangular or other special-shaped sections, although theoretically it can be realized by special molds, the difficulty and cost of the process will increase significantly, and it is difficult to ensure the molding quality at edges and corners.

Production efficiency: Rolling molding is an intermittent production process, and each pipe needs to be individually rolled, cured and demolded. The production efficiency is relatively low, and it is not suitable for large-scale, standardized continuous production.

Length limit: restricted to roll mill work space and the core module of rigidity, rolling forming production of pipe length is limited, usually for super long pipe manufacturing difficulties.

2.2 Pultrusion molding process

Pultrusion (Pultrusion) is an efficient continuous production process, which is mainly used to manufacture carbon fiber composite profiles with a constant cross-section shape, such as [round tubes](#), [square tubes](#), [rectangular tubes](#), bars, corner materials, etc. In this process, a continuous fiber bundle impregnated with resin is pulled through a heated mold by a traction device, which is cured and formed in the mold, and the desired profile is continuously produced.

2.2.1 Principle and characteristics of the process

Pultrusion is to use the core principles of traction pull reinforcing fiber and resin matrix with a specific shape mould, through the role of the extrusion and heated mold, the resin curing, formation and mold cavity shape consistent composite materials products. The process of the main features include: high automation and continuity: pultrusion is a fully automated continuous production process, from the fiber material, resin impregnation, molding curing to the final cut, the whole process can be done continuously, high production efficiency, very suitable for mass production.

Excellent dimensional accuracy and consistency: because the product is in rigid mould curing, so products section dimension precision is very high, and along the length direction consistent, stable and reliable product quality.

High fiber content: in the pultrusion process, the mold can produce extrusion effect to fiber bundle, helps to flush out resin and bubble, so the fiber volume content of products is very high (usually can reach more than 70%), to obtain high axial tensile strength and modulus.

Cost-effectiveness: for mass production of standard profiles, pultrusion unit costs are relatively low, has the good economic efficiency.

2.2.2 production process: continuous production

Pultrusion typical production process is as follows: fiber supply and guide: the rolls of continuous carbon fiber yarn bundle from the yarn shelf, through plate, guide and make the fiber bundle is parallel and uniform

arrangement, and introduce resin impregnating tank.

Resin impregnation: fiber bundle through a liquid resin, epoxy resin (usually) or vinyl ester resin impregnating tank, make each fiber fully infiltration by resin. Dipping groove are usually equipped with roller or rubber roller, to ensure that the resin completely soaked fiber and excluding some air.

Preforming and extrusion: of the resin impregnated fiber bundle before entering the heating mould, will first through a preforming mold. Preforming die cross-section shape gradually close to the shape of the final product, its effect is on a preliminary sorting and compaction of the bundle, and further squeeze out excess resin.

Heat curing: after preforming fiber bundle into the heating of the main forming die. Mold temperature is usually divided into some area, from inlet to outlet temperature rise gradually. Within the mold, resin under the action of thermal crosslinking curing reaction, formation of hard solid, the carbon fiber firmly bonded together.

Traction and cutting: after curing profile continuous pull out of the mould, the traction device to provide stable tension. Pulling speed is one of the key parameters of pultrusion process, need to match the mold temperature, resin curing speed. Finally, according to the required length by automatic cutting saws will continuous profile cutting into the final product.

2.2.3 Applicable scenarios and limitations

The pultrusion process is most suitable for the production of carbon fiber profiles with unlimited length and constant section shape. For example, all kinds of carbon fiber round tubes, square tubes, rectangular tubes, beams, channels and so on standard profile. These products are widely used in building structure, the bridge reinforcement, cable tray, tents, tool handles, and other fields.

The main limitations of the process is: cross section shape is fixed: pultrusion can produce products with constant cross section, unable to make cross section along the length direction of tapered pipe or abnormality.

Weak transverse performance: because the fiber mainly along the axial arrangement, pultrusion profiles of lateral (perpendicular to the fiber direction) strength and shear strength is relatively low. Although can pass in the stage of preforming join horizontal reinforced material, such as woven fiber) to improve, but this will increase the complexity of process.

High equipment investment: pultrusion production lines (including yarn, impregnating tank, mould, tractor, cutting machine, etc.) of the initial investment is relatively high, more suitable for mass production with diluted cost.

2.3 Fiber winding and forming process

Filament Winding molding (Filament Winding) is a kind of continuous fiber or presoak belt Winding on the mandrel according to scheduled rules, then curing of composites manufacturing process. It is manufacturing high performance of rotors structure (such as pressure vessel, pipeline, transmission shaft, etc.) of one of the main methods.

2.3.1 Process Principle and Classification (wet/dry)

Is the basic principle of fiber winding, mandrel rotate around its axis, and fibre supply device (godet head) along the axis of the mandrel reciprocating motion, through the precise control of the movement of the relation between the intertwined in a specific Angle and the fiber path in core mold surface, form with the required thickness and Angle of the layer composite material layer. According to fiber impregnated resin, the main process is divided into three categories: Wet Winding, Wet Winding) : this is the most traditional method of Winding. In continuous fiber winding groove through a resin impregnated before, then directly winding the mandrel. Wet winding equipment is simple, the cost is low, but the resin content is not easy to precisely control, and solvent volatilization in the process of winding can lead to high porosity, affect the product performance.

Dry Winding: Dry winding uses pre-impregnated resin and semi-cured carbon fiber prepreg tape (or narrow tape) as raw material. Presoak belt in front of the winding through the heating device to soften, then wrapped onto the mandrel. The advantages of dry winding are accurate and controllable resin content, stable product quality, clean production environment and easy automation. The disadvantage is that the cost of prepreg tape is high, and the heating and tension control system of the winding equipment is more demanding.

Half dry coil (Semi - dry Winding) : this is a kind of between wet and dry process. Fiber after impregnating resin, through a drying device, removing part of the solvent, resin is made to reach half dry state, and then to entangle. This method combines some of the advantages of the wet and dry methods and can reduce the porosity to some extent while the cost is relatively controllable. 2.3.2 Production process and critical control points

The basic process of filament winding molding include: core mold preparation: similar to rolling forming, need to prepare the surface coated with mandrel stripping agent, and install it on a winding machine.

Program set: according to the requirements of the product design (such as size, Angle of layer, thickness), set the mandrel in winding machine control system of rotational speed, thread head movement speed and trajectory parameters.

Winding: start the winding machine, and the fiber or prepreg tape will be wound on the core die according to the set program. There are three winding rules: ring winding, longitudinal winding and spiral winding. By combining different winding angles, the mechanical properties of the product in all directions can be optimized.

Curing: after the completion of the winding, the mandrel with fibrous layer into the whole curing furnace heating or cooking for curing.

Demoulding and post-processing: curing, after the completion of the mandrel emerge from the products, and make the necessary machining and surface treatment. Process of key control point lies in the accurate control of winding tension and winding Angle. Directly affect the arrangement of the fiber winding tension tightness and resin content, will affect the strength of the products and porosity. Winding Angle determines the bearing of the fiber direction, on the ring to the strength of products that have a decisive influence, axial strength and torsional rigidity.

2.3.3 scenes and limitations apply

Fiber winding is an ideal process for manufacturing high performance rotary parts, especially those that need to withstand high internal pressure or high torque. For example: Pressure vessels: such as compressed natural gas (CNG) bottles, rocket engine casings, etc., through a combination of ring and spiral winding, extremely high ring strength can be obtained.

Pipeline: used for conveying high pressure fluid or corrosive medium pipeline.

Shaft: using spiral wound of plus or minus 45° , can maximize the improve torsional performance of the drive shaft. The limitations of this process are: shape limitations: it can only be used to manufacture rotary bodies, and the product cannot have concave curved surfaces, because the fibers cannot be wound to the concave area.

Unable to wind 0° layers: Standard fiber winding processes cannot achieve pure 0° (axial) lay-up because the fibers need to be rotated around the core die. Although can be realized through the special vertical winding device, but can increase the process complexity.

Equipment and mould cost: high-performance fiber winding machine (especially the multi-axial linkage, the control system of belt tension) and special core mold cost is higher. 2.4 molding process

Moulding (Compression will Molding) is a kind of presoak material or Molding compound in the heating of the metal mould, flow, filling cavity by pressure and curing process. It is a manufacturing carbon fiber square tubes, rectangular tubes, and other special-shaped section pipe is one of the main methods.

2.4.1 Process principle and characteristics

With hot press molding is the basic principle of pressure and heat, make the mould of the carbon fiber presoak material softening under high temperature and high pressure, flow, and full of the whole mold cavity, at the same time crosslinking curing resin, eventually forming and mould shape consistent composite materials products. The main features of the process include: High dimensional accuracy: because the products are formed in extremely rigid metal pairs, very high dimensional accuracy and surface finish can be obtained, especially suitable for the manufacture of structural parts with strict tolerance requirements.

Suitable for complex shapes: Molding can manufacture tubes with various complex cross-section shapes, such as squares, rectangles, polygons, I-shapes, etc., which are difficult to achieve by rolling and pultrusion processes.

With high production efficiency, for mass production, mould can implement more than one module, and relatively short cure period (especially when using the fast curing resin), high production efficiency, suitable for large-scale industrial production.

The outer surface of the good surface quality: the products is determined by the mold cavity, can achieve a high degree of finish, usually without too much post-processing.

2.4.2 production process: from expected curing

The typical production process for mold forming is as follows: Mold preparation: Design and manufacture of metal pairs of molds (usually steel molds) according to the shape of the product. After precision machining, mold needed to ensure dimensional accuracy and surface quality. Preheat before production, mold need to set the temperature, and the cavity surface spraying mold release.

Cutting presoak and layer: according to the mould shape and size, cutting carbon fiber presoak into suitable shape and size. Then, lay the prepreg sheets layer by layer in the lower die of the die according to the designed lay-up scheme. Layer when the need to pay attention to the direction of the fibers, and to ensure that each layer between compaction, avoid to produce bubbles.

Die closing and pressurization: Feed the laid die into the hot press and start the press so that the upper and lower die are closed. The hot press applies a set pressure (usually between a few MPa and tens of MPa) and holds it for a period of time.

Heat cure: the pressure at the same time, mould heating system for heating by hot press. The resin undergoes a curing reaction under the action of heat and pressure. Curing process shall be carried out in strict accordance with the resin curing curve, including heating, heat preservation and cooling stages.

Demoulding and reprocessing: curing is completed, open mold, remove carbon fiber tube forming. Remove the rough edges, and carry out secondary processing such as drilling and cutting as needed.

2.4.3 scenes and limitations apply

Molding process is mainly suitable for the production of various carbon fiber section shape of pipe material, especially the square tubes, rectangular tubes, and other special-shaped tube. These pipes are widely used in building, automobile frame structure, mechanical arm, sports equipment and other fields.

The limitations of the process is: high mould cost: manufacturing metal mould cost is high, high accuracy and life of mould pressing more suitable for mass production, so to diluted mould cost. For small batch or customized products, poor economy.

Size limit: limited by size and pressure of hot press mesa, molding is usually used in the production of the products of the relatively small size. For large tubes, tooling and equipment costs can become prohibitive.

Process complexity: for product shape is very complicated, presoak material laying and resin flow behavior in mold cavity becomes very complex, may cause fiber distribution, lack of materials or defects such as porosity, high requirements for process control.

2.5 manual layer and process pressure of the vacuum bag

Manual layer (Hand Lay - up) and Vacuum bag pressure (Vacuum Bagging) process is a combination of manual operation and Vacuum aided composites forming method. Its high flexibility, suitable for manufacturing large, complex shape and small batch of carbon fiber products, including some of the special shape of special-shaped tube.

2.5.1 Process principle and characteristics

Is the basic principle of this process, the operator or hand will presoak material fiber cloth shop on the single mould, and then the demoulding fabric and felt, breathable coating and other auxiliary materials, the entire layer sealed with vacuum bag finally. By pumping air into vacuum state, under the action of atmospheric pressure, vacuum bag to layer a uniform pressure (0.1 MPa) about an atmospheric pressure, namely, the compaction of each layer, layer between air and excess resin side by side. The main features of this process

include: extremely high flexibility: it is almost not limited by the shape and size of the product, especially suitable for the manufacture of large, complex curved surface or small batch of customized products.

Equipment is simple: the main equipment is a vacuum pump and heating equipment (e.g., curing oven), investment cost is low.

Lower pressure: Compared to the autoclave or molding process, the vacuum bag pressure provides lower pressure, so the fiber content and mechanical properties of the product may be slightly inferior, and the porosity is relatively high.

High requirements for operator skills: layering quality, compaction effect and so on largely depend on the operator's experience and skills, product quality consistency may not be as good as automatic process.

2.5.2 Production Process and Critical Control Points

Mold Preparation: Prepare the single-sided mold (usually FRP or metal mold) and apply the release agent.

Manual layer: the operator will cut carbon fiber presoak material or dry cloth according to the design requirements, layer-by-layer manually on the mold. For each layer, it needs to be carefully compacted with a scraper or press roller to exclude air bubbles.

Encapsulation: Cover the laid laminate successively with the release cloth, isolation film, breathable felt and other auxiliary materials. Then, wrap the entire mold and the layup with vacuum bag film, and seal the edge of the bag with the mold with sealing tape to form a closed space.

Vacuum and leak detection: Connect the vacuum pump to the suction port in the vacuum bag and start the vacuum pump to vacuum. In the process of pumping air into vacuum state, it is necessary to carefully check whether the seal leakage and to ensure that the vacuum degree necessary for the system to achieve and maintain.

Curing: good vacuum mould into curing furnace, according to the requirement of curing of the resin to curing.

Demoulding and post-processing: after the curing is completed, the vacuum is broken, the vacuum bag and auxiliary materials are removed, and the molded products are taken out of the mold, and the post-processing such as trimming and polishing is carried out. The key control point lies in the layer of compaction and vacuum system tightness. Good compaction is the key to reduce porosity and improve bonding strength between layers, while reliable vacuum sealing is the prerequisite to ensure uniform pressure.

2.5.3 Applicable scenarios and limitations

Manual layer and technology is mainly used in the pressure of the vacuum bag: large, complex abnormality tube: when the other processes (e.g., moulded, rolling) due to the mould cost or shape limit cannot be achieved, the process is to create large or complex shape of the carbon fiber tube effective choice.

Small batch, customized production: for small demand, but the need for special shape or performance of the product, the process has high economy and flexibility.

Prototyping: During the product development phase, it is used to quickly make prototype parts to verify the design and process. Its limitations are: low production efficiency: manual operation takes a long time and is not suitable for mass production.

Poor consistency of product quality: product quality is greatly affected by human factors, and it is difficult to ensure a high degree of consistency between batches.

Relatively low mechanical properties: due to the low pressure, the fiber content and density of the product are usually not as good as the autoclave or molding process, and the mechanical properties are relatively low.

3. Manufacturing difficulties and solutions of carbon fiber tubes with different cross-section shapes

The section shape of carbon fiber tube directly determines the selection of its manufacturing process and the technical difficulties in the manufacturing process. From the simplest round to complex shaped, each shape poses different challenges for mold design, material placement, and molding process. This chapter will analyze the specific manufacturing difficulties and provide corresponding engineering solutions for the manufacture of

round, square/rectangular and shaped tubes.

3.1 Manufacture of carbon fiber round pipe

Carbon fiber pipe is the most widely used, one of the most mature of pipe manufacturing technology. Its manufacturing mainly relies on the rolling forming and two filament winding molding process, the two process is suitable for the production of rotors structure very much.

3.1.1 Main manufacturing processes: winding and winding

Rolling and forming is one of the mainstream processes for manufacturing high precision and high performance carbon fiber round tubes. The process through the presoak material layer upon layer winding on heating of the core mold, can precisely control the thickness of the tube wall, the fiber orientation and the combination of quality between the layers. By designing different layer scheme, such as alternate use 0° one-way belt and plus or minus 45° woven cloth, can respectively optimize axial stiffness and torsional properties of circular tube and the ring to the strength, enable it to adapt to the tensile, compression, bending and torsion load cases. The rolled pipe usually has excellent dimensional accuracy and low porosity, as well as good surface quality.

Filament winding molding is more focused on fiber axial strength, especially suitable for manufacturing need to bear high pressure or epipodium to stress in circular tube, such as pressure vessels and pipes. Through the adoption of toroidal coil (nearly 90°) or low Angle spiral wound, can make the fiber direction of the main bearing and hoop stress direction is consistent, to maximize the use of high strength properties of carbon fiber. Winding technology can achieve high fiber volume content, and high production efficiency, suitable for mass production. However, the straightness control of the pipe by the winding process is not as good as that by the winding process, and it is difficult to achieve the fiber lay-up in the 0° direction.

3.1.2 manufacturing difficulties: size and roundness control precision

In the manufacturing of carbon fiber round tube, the core technical difficulty lies in how to ensure the dimensional accuracy of its inner and outer diameter, as well as the roundness and straightness of the tube body. The geometric parameters directly affect the pipe in the assembly precision and as structural bearing capacity. Inner diameter accuracy: the inner diameter is mainly determined by the outer diameter of the core die. As a result, the machining accuracy of mandrel itself and in the long-term use of wear is the key. Any small deformation or size deviation of the core die will be directly copied to the inner wall of the round tube.

Outer diameter accuracy and roundness, outer diameter and roundness by layer thickness uniformity, the molding pressure and the influence of curing process of resin flow and shrinkage. In the process of winding or winding, if the tension or pressure control is not uniform, it will lead to uneven wall thickness, which will affect the roundness. Uneven heating or uneven cooling during curing may also cause deformation of the tube body.

Straightness, especially for circular tube length to diameter is larger, maintain its straightness is a challenge. The straightness of the core mold itself is the foundation, while it is necessary to avoid bending of the tube body due to its own weight or improper support during curing. 3.1.3 solution: core mold material selection and thermal expansion coefficient matching

In order to solve the above difficulties, engineers from core mold design, material selection and process control, and other aspects, put forward a series of solutions. High precision core module: using high precision machining, such as CNC CNC machining metal core mold (such as steel, aluminum) is the base of ensure accuracy of inner diameter. Precision grinding and polishing the surface of the mandrel needed, to reduce the surface roughness, ensure the smooth and improve the mold release pipe wall roughness. For long tube, core mold need to have enough rigidity, in order to prevent the in layer and solidification process for stress and deformation.

Removable/combined mandrel: in order to solve the problem of long tube or closed structure demoulding difficulty, can use removable combined mandrel. For example, the metal cylinder is divided into several parts and assembled into a whole through the end cap and screw, which can be easily demitted by disassembling after forming. This design solves the demoulding problem not only, still can guarantee the mould of cylindricity and

straightness.

Thermal expansion coefficient matching: in the process of solidification, mandrel and carbon fiber composite material coefficient of thermal expansion (CTE) is the important cause leading to the size deviation and residual stress. Ideally, the core module of CTE should match the CTE of the composite material. In some applications, for example, can choose close to carbon fiber composite CTE of Invar (Invar) as the core mold material. Or, using expandable elastic core mold (such as silicone core mold), through to the core mold internal pressure during solidification, make its expansion, and uniform pressure on the inner wall of the tube, compensate shrinkage of resin, and improve the quality of roundness and combination between the layers.

Process parameter optimization: Accurate control of tension, pressure and temperature during winding or winding is the key to ensure the accuracy and roundness of outer diameter. In the process of curing, using segmented heating, heat preservation and cooling process, and ensure the uniform heating, can effectively reduce deformation caused by thermal stress. Using autoclave or heat shrinkable belt provides uniform pressure curing way, also helps to improve the product's final dimension precision and mechanics performance. 3.2 carbon fiber tube and rectangular tube manufacturing

Compared with round tubes, square and rectangular tubes are significantly more difficult to manufacture, mainly because of the stress concentration at the corners and the complexity of the material overlay. Mould pressing and rolling forming is the main method of manufacturing this kind of pipes, but often need to combine or special design.

3.2.1 the main manufacturing process: moulded and developed

Molding is the preferred process for manufacturing high-precision carbon fiber square and rectangular tubes. By using metal molds that are split up and down, square or rectangular tubes with sharp edges and precise dimensions can be precisely formed. The cut prepreg sheet is put into the mold according to the designed lay-up scheme, and the final product can be obtained by curing under high temperature and high pressure after closing the mold. Moulding the advantage of well control the thickness of the tube wall and the shape of the edges and corners, products of high density, good mechanical properties. However, the mold cost is high, and the production efficiency of long pipe is low.

Roll forming can also be used to manufacture square and rectangular tubes, but the process is more complicated. It is common practice to roll the tube on a circular core die, and then press the tube into the desired square or rectangular section through a subsequent molding or shaping process. This method combines the coiling ability of high efficiency and the precision molding mold. Another method is to use a square core die for winding, but this requires special winding equipment and process, which requires high deformation ability of prepreg and lay-up control, and is technically difficult.

3.2.2 manufacturing difficulties: angular shape and internal defects

Manufacturing carbon fiber tube and rectangular pipe main difficulties focused on the following aspects: the stress of the edges and corners of focus: the square tube and the four corners of the rectangular pipe is a natural stress concentration. When bear bending or torsion load, will produce much higher than in other parts of the stress of the edges and corners of, easily lead to premature failure of materials. Therefore, how to layer design and process control to enhance the intensity of edges and corners, is a key challenge.

Material shop cover and fold: at the edges and corners, presoak material or fabric need from the state of plane bending into 90 degree Angle. This process, the outer edge of the material will be affected by stretching, the inside will be compressed, easy to produce the defects such as fold, bridge or fiber fracture. These defects will severely weakened pipe mechanics performance.

Internal defects and pores: in the molding or molding process, if the pressure distribution is uneven or the resin fluidity is not good, the edges and corners are easy to form pores or delamination. Especially when using a combined coiling-moulding process, the thickness of the tube wall will change during the deformation from round to square tube, which, if not properly controlled, will create internal defects at the edges and corners.

3.2.3 solution: mold design and layer optimization

In order to overcome the above difficulties, need from the mold design, material selection and layer process optimization of multiple aspects, such as: to optimize the design of the mould: in die mold, edges can be designed to shape a certain one-side, rather than a sharp 90 degree angles. This can effectively reduce the stress concentration factor and improve the flow and filling performance of the material. At the same time, reasonable exhaust holes are set at the edges and corners of the mold to ensure that air can be discharged smoothly during the pressing process and avoid the formation of pores.

Lay-up Angle and sequence optimization: at the edges and angles, the lay-up scheme of $\pm 45^\circ$ can be used, because the lay-up of $\pm 45^\circ$ has good shear deformation ability, which can better adapt to the shape change at the edges and angles and reduce the generation of wrinkles. At the same time, can add a local reinforcement layer in the region of the edges and corners, using higher strength of unidirectional presoak material for reinforcement, in order to improve the bearing capacity of the region.

Presoak material cutting and splicing: open the layer, can advance the presoak material at the edges and corners to cut (darts), namely in the area of material inside to compress cut triangle gap, then put the materials together. This can effectively avoid wrinkles when the material is bent. You need to start cut the shape, size and location to determine through accurate calculation and test.

Process parameter control: in the process of molding or finalization, it is necessary to accurately control the pressurization speed, pressure and temperature. Slow pressure can give enough time flow and filling material, avoid to produce internal stress. Uniform pressure distribution is to guarantee consistent wall thickness, reduce the internal defects of the key. In the process of solidification, adopt appropriate heating rate, ensure resin can fully infiltrates fiber and even curing.

3.3 carbon fibre special-shaped tube manufacturing

Carbon fibre special-shaped tube, namely the cross section shape is irregular or along the length direction change of tubular structure, the manufacturing is the most challenging of all the carbon fiber tube. This kind of product is usually need to combine a variety of molding process, and the innovation of die mold and core technology.

3.3.1 the main manufacturing process: die with manual layer

Molding is the main method of manufacturing section of irregularly shaped baroque tube. Through the design of complex split mold, can produce all kinds of complex internal and external contours. However, for cross section along the length direction changes or abnormality tube bending, moulding is difficult to achieve.

Manual layer provides great flexibility and the pressure of the vacuum bag, very suitable for manufacturing large, complex and variable cross-section profile tubes. Operator can according to the shape of the mould, the manual will be in cutting, and spread to any complex curved surface. Combined with the pressure of the vacuum bag technology, can be used without expensive autoclave or complex mould, obtain relatively good product quality. This method is to make prototype parts and small batch customization abnormality tube of choice.

Filament winding in some cases can also be used in the manufacture of special-shaped tube, but only back to the plane of special-shaped tube, such as taper pipe or tubular structure with a locally convex sets. For the axisymmetrical special-shaped tube, winding technology is powerless.

3.3.2 rainfall distribution on 10-12 manufacturing difficulties: complex shape forming and demoulding

The core difficulty of manufacturing carbon fiber shaped tube lies in how to achieve accurate molding of complex shape and how to successfully demolding. Complex shape forming: for special-shaped tubes with complex curved surfaces, variable sections or internal structures, it is a great challenge to ensure that the fibers can closely fit the mold surface and avoid wrinkles, bridge building and resin-rich areas. Material of cladding needs high skills and experience.

Mold release: this is the biggest problem in the manufacture of special-shaped. With torque, concave or closed cavity structure, using the traditional rigid core mold (such as metal mandrel) forming, the core module will not be able to take out from the products. For example, a tubular structure with internal convex platform,

the core module will be "stuck" after curing, along the axial extraction. 3.3.3 solution: the application of combined mandrel and expandable core material

In order to solve the demoulding problem of special-shaped tube, engineers have developed a variety of innovative core mold technology: soluble core module: using water-soluble or low melting point alloy materials such as core module. After forming, through the products into the water or heat melt, dissolve or melt flow, the core mould, so as to realize demoulding. This method is suitable for manufacturing closed structures with complex internal cavities.

Expandable/shrinkable core molds: Make core molds using elastic materials such as silica gel, rubber, or expandable foaming materials. Before laying the layer, the core die is in a contractible state; Layer is completed, through to the inside core mold inflatable or heat expansion, thus adding to pressure on the shop floor, and make it fit the mold. After curing, release pressure or cooling, core mold shrinkage, easy mold release. This method is very effective when making pipe fittings with complex shapes.

Combined mandrel: a complex core model is decomposed into several simple parts, these parts can be made separately, and then together. After molding, to remove these sections one by one, remove. For example, a square tube with internal cross reinforcement, its core mold can be broken down into the middle of the cross core and four corner filled block. The precision of this method is a combination of rigid core mold and removable flexibility.

Patented Modular Core: A patented technology proposes an innovative modular core method for manufacturing carbon fiber tubes with irregular shapes. This method will abnormality tube into rules of part of a complex and irregular parts. The regular part uses a traditional metal core, while the irregular part uses a foamed plastic core. After combining the two types of inner core, wrap the prepreg around it. In the process of heating pressure curing, foam plastic is heated inner core inflation, the molding pressure. After curing, the regular metal core is first drawn out, and then the foamed plastic core can be easily removed along with the release film, or even destructively removed. This method skillfully solves the problem of forming and demolding complex shaped tubes, while avoiding the high cost of opening the mold for the entire shaped core die. 4. The key production technology

The final performance of carbon fiber tube depends not only on the choice of forming process, but also on the fine control of each key link in the production process. From mold design and manufacturing, to presoak material layer design, to the curing process of parameter setting, interlocking, every step of deciding the success or failure of the product together. This section will delve into the core main technical points of the production process.

4.1 Mold Design and manufacturing

Mold is the basis of the carbon fiber tube forming, its design and manufacturing quality directly determines the product size precision, surface quality and internal defects. Mold design needs to consider the product shape, size, material characteristics, molding process and cost and other factors.

4.4.1 core mold material selection (metal, elastic material)

Core module is the key to the formation of carbon fiber tube cavity shape parts, it is very important for the choice of materials. Commonly used core die materials include: metal materials: such as steel, aluminum, copper alloy, etc. Metal core mould with high precision, high rigidity, high abrasion resistance and good thermal conductivity, can ensure the dimensional accuracy and surface quality of the product. They are especially suitable for the rolling forming, molding and filament winding process which requires precise diameter, etc. Metal core mold, however, the disadvantage is that the cost is high, processing cycle is long, and with complex buckle the lumen or the structure of the product, demoulding difficulty.

Elastic material, such as silicone, rubber, etc. Elastic core mold the biggest advantage is its deformability, make its can easily ejection from the complex shaped products. Through the air or vacuum, can control the expansion and contraction of the mandrel, thus provides uniform pressure in the molding process, and simplify

the stripping process. Elastic core mold especially suitable for manufacturing special-shaped tube or pipe fittings with complex internal structure. But its drawback is that size precision is relatively low, and easy to wear and tear, limited service life.

Soluble/fusible materials: such as low melting point alloy, water soluble plaster, polystyrene foam, etc. Core molds made of such materials can be removed by heating and melting or dissolving with water after forming, and are very suitable for manufacturing closed or semi-closed complex inner cavity structures. For example, the use of foamed plastics, such as EVA) as part of the core mold, the heat curing, decomposition of foaming agent to make mandrel expansion, provide the molding pressure, after curing can be easily removed.

Composite materials: in order to balance accuracy, cost, and demoulding convenience, often using combined mandrel. For example, the metal core and elastic core mold or soluble core combined mode, the use of metal needs high precision parts, use flexibility in difficult to stripping section or soluble materials. 4.1.2 (die and mould design draft)

The structure of the mould design directly affects the production efficiency and product percent of pass. The design of the key points include: parting surface selection: for molding, choose the parting surface is very important. Parting surface should choose as far as possible the biggest product in outline, so that the mold release. At the same time, the parting surface should avoid the products main bearing area, so as not to affect the structural strength. For special-shaped tube, the design of the parting line needs to be more complex, and may require multiple parting surface.

Draft: to facilitate the demoulding, the sidewalls of the mould should be designed with a draft (usually 1-3 °). For core mold, especially for the length to diameter larger pipe, design of small taper (e.g., 1:15 00-3500) can greatly simplify the stripping process, to avoid damage in the process of mold release products or core module.

Exhaust and flow glue design: in the molding mold, it is necessary to design reasonable exhaust holes or exhaust grooves, so that the air and volatile matter in the mold cavity can be discharged in time during the closing and curing process to prevent the formation of bubbles. At the same time, can design flow glue tank to guide the excess resin flow, avoid the products to form in the local plastic zone. 4.1.3 mould precision and surface quality requirements

The precision and surface quality of the mould directly determine the final quality of products. Dimensional accuracy: the size of the mould precision must be higher than the precision of the product requirements. If required, for example, pipe diameter tolerance of $+/-0.1$ mm, so the mandrel diameter tolerance should be controlled in a smaller range (such as $+/-0.05$ mm).

Surface quality: the mould surface should be smooth, no scratch, no pits. Any defects on the surface of the mold will be copied to the product surface. Mold, therefore, upon the completion of the processing, usually need to polishing processing, in order to achieve the mirror effect. For the high requirement of product, mold surface and hard chromium plating processing, in order to improve the wear resistance and corrosion resistance.

Rigid: die must have sufficient rigidity to withstand the pressure without deformation in the process of forming. Especially for the large size or high pressure molding mould, the structure design of the need for finite element analysis, in order to ensure the strength and stiffness meet the requirements. 4.2 in material selection and layer design

Presoak material is carbon fiber tube "flesh", its performance and quality directly determines the mechanical properties of the product. And layer design is the product of "skeleton", through the reasonable layer design, can maximize the anisotropy of carbon fiber advantages, meet the requirements of the mechanical properties of products in different direction.

2 presoak material type and performance

Presoak material is made of carbon fiber reinforced materials and resin matrix impregnating in advance and half solidification of sheet material. Choosing presoak material, need to consider the following factors: carbon fiber type: according to performance requirement, can choose different strength, modulus, carbon fiber, such as

T300, T700, T800 and other standard modulus carbon fiber, or M40J, M55J high modulus carbon fiber.

Resin system: the commonly used resin system including epoxy resin, double horse resin, polyimide resin, etc. Epoxy resin because of its comprehensive performance is good, good manufacturability and the most widely used. Resin choice need to consider its mechanical performance, temperature tolerance, curing process and other factors.

Fiber form: The carbon fibers in the prepreg can be unidirectional (UD) or woven into a fabric (e.g. plain, twill). One-way presoak material can maximize fiber axial strength, suitable for the main load-carrying structure. Knitting presoak material has better recurrent and impact resistance.

Resin content: resin content requires precise control of presoak material, usually between 35% to 45% in * *
* *. Resin content is too high will reduce the fiber volume content and mechanical properties; Too low may lead to insufficient infiltration, pore. 4.2.2 layer design Angle (0° , plus or minus 45° , 90°)

Carbon fiber has obvious anisotropy, and its strength mainly concentrated on the fiber direction. Therefore, through the design of different orientations, can adjust the mechanical properties of composite materials in different direction. The common orientations and its role is as follows: 0° layer: fiber direction parallel to the pipe axis. Mainly provide tubing axial tensile and compression strength, and bending rigidity. This is the most main carry axial load layer.

90° layer: fiber direction perpendicular to the pipe axis (ring). Strength (mainly provide ring pipes to ability) and lateral stiffness. For pipes under internal pressure or external pressure, 90° layer is crucial.

Plus or minus 45° layer: fiber direction into a plus or minus 45° Angle to the pipe axis. Mainly provide pipe shear strength and torsional rigidity. Under shear load torque or applications, plus or minus 45° layer is indispensable. Holdings layer order and layer effects on performance

Layer layer number of the order and the design of the load situation, manufacturing process and cost should be considered. Symmetry layer: in order to avoid in the process of curing the warping deformation due to the anisotropic shrinkage, layer design often USES the symmetrical structure. On both sides of the layer sequence of neutral surface, layer Angle and the order is completely symmetrical.

Interlayer Angle: the Angle between the adjacent layer difference should not be too big, is generally recommended that no more than 60° , to reduce the interlaminar stress, prevent stratification. For example, a typical layer sequence can be $0/45/90 / -45$ s.

Single layer depth direction: to avoid produce too much in one direction poisson effect and interlayer shear stress, usually need to limit the direction of the single layer depth. Proposals, Angle spread, for example, no more than 4 layers.

Layer calculation: according to the requirements of the pipe wall thickness and the thickness of single-layer presoak material (usually in 0.1 0.2 mm), can calculate the total number of layers required. For example, a tube wall thickness is 2 mm, if single presoak material thickness is 0.125 mm, you need to 16th floor. 4.3 curing process parameters control

Curing is carbon fiber tube from the "soft" becomes the key step in the "hard", is the presoak material from linear molecular structure of resin into the process of 3 d mesh crosslinking structure. Curing process parameters (temperature, pressure, time) control directly determines the curing degree of the resin, products of compaction and the mechanical properties.

4.3.1 curing temperature and time setting

Curing temperature and time is the core of the curing system, usually by resin suppliers recommended value, and adjusting for specific products. Heating rate: Too fast heating may lead to a large temperature difference between the inside and outside of the resin, produce internal stress, and even cause the resin to gel ahead of time, affecting flow and infiltration. Therefore, control the heating rate is usually $1-3^\circ\text{C} / \text{min}$.

Heat preservation temperature and time, heat preservation temperature is the main stage, resin crosslinking reaction must be precisely controlled. Heat preservation time depends on the thickness of the

reactivity of resin system and products. Time is too short, resin curing incomplete; Time is too long, can lead to degradation of resin or producing excessive internal stress.

After the completion of the cooling rate, solidification, need to slowly cooling, in order to avoid the rapid cooling produce thermal stress, lead to products cracking or deformation. Control the cooling rate is usually 1-3 °C / min. 4.3.2 curing pressure control (autoclave, vacuum bag)

The function of curing pressure is compacted layer, discharge air and volatile matter, improve the fiber volume content, and promote the resin flow and infiltration. Hot pot, hot pot can provide uniform and controllable high pressure (usually in 0.6 1.0 MPa) and high temperature environment, is to create the ideal equipment of high performance, high quality of composite products. In cooking cure, can obtain high density and low porosity of the products.

Pressure vacuum bag, vacuum bag using atmospheric pressure with curing pressure, low pressure (about 0.1 MPa). Although pressure than autoclave, simple equipment, low cost, suitable for large or complex shaped products.

Moulding, moulding pressure provided by the compressor, high pressure (up to more than 10 mpa), suitable for manufacturing complex shape, high dimension accuracy requirement of products. 4.3.3 the defects in the process of solidification control (pore, layered)

Pore is the main defect in the process of curing and stratification. Porosity, pore is due to air or volatiles failed to completely discharge. The key to control the pore is:

Precompaction: During the lay-up process, precompaction is carried out periodically to discharge most of the air.

Controlled curing pressure: Provide sufficient curing pressure to "press" residual air and volatiles out.

Optimize the curing regime: A reasonable heating rate can give enough time for volatiles to escape.

Delamination: Delamination is caused by poor bonding between layers. The key to controlling layering is:

Ensure the quality of layering: when layering, ensure that each layer is tightly fitted, free of wrinkles and contamination.

Control of resin content: resin content is too low will lead to inadequate infiltration, weak bonding force between the layers.

Avoid excessive shear stress: Proper lay-up design and curing regime can reduce interlayer shear stress caused by thermal stress or uneven shrinkage. 5. Mechanical properties and quality control

As a kind of high performance structural material, the mechanical properties and quality control of carbon fiber tube are the lifeline of product application. From the incoming inspection of raw materials, to the real-time monitoring of the production process, and then to the comprehensive inspection of the finished product, every link must be strictly checked to ensure that the final product can meet the design requirements and safety standards.

5.1 the key mechanical performance index

The mechanical properties of carbon fiber pipes are the core value of their structural components. Different application scenarios have different requirements for mechanical properties, but they usually include the following key indicators:

Performance indicators	Definition and meaning	Typical test methods	Factors affecting
The tensile strength and modulus	Material under axial tensile load resistance to fracture (intensity) and the ability to resist elastic deformation (modulus). Is the basic indicators of	Universal material testing machine for axial tensile test.	Carbon fiber type, fiber volume content and proportion of 0 ° layer, porosity.

Performance indicators	Definition and meaning	Typical test methods	Factors affecting
	pipes carrying capacity.		
Flexural strength and modulus	Materials in the ability of resistance to fracture under bending load and elastic deformation. For as the beam, such as shaft structure of the pipe is crucial.	Three point bending or four-point bending test.	Proportion of 0 ° layer, wall thickness, the interface bonding strength of fiber and resin.
Torsional stiffness and shear strength	The ability of a material to resist torsional deformation (stiffness) and shear failure (strength). Is the key index for drive shaft torque under such as components.	Torsion testing machine for torsion test.	Plus or minus 45 ° layer ratio, fiber volume content, shear strength between the layers.
The interlaminar shear strength (ILSS)	Composite material's ability to resist shear slip between layer and layer. Is an important indicator to measure the interface bond quality, directly affect the ability to resist stratification.	Short beam shear test or double shear test of incision.	Quality of resin matrix properties, fiber surface treatment and curing, and porosity.
The compression strength	Material's ability to resist damage under axial compression load. For the compressive stress of structures under (such as pillar) is very important.	Axial compression test.	Supported micro buckling stability of the fiber, resin and the straightness of the catheter.

Carbon fiber tube key mechanical performance index

5.2 Quality control and inspection

In order to ensure the quality of the carbon fiber tube is stable and reliable, it is necessary to set up a set of complete quality control system, covering the whole process from raw materials to finished products.

5.2.1 Inspection of raw materials

The quality of raw materials is the basis of product quality. All incoming of carbon fiber, resin, presoak material must be strict inspection. Carbon fiber: inspection items include tensile strength, tensile modulus, density, carbon content, type and content of sizing agent, etc.

Resin: inspection items including viscosity, gel time, curing reaction heat, mechanical properties (such as casting body).

Presoak material: inspection items including resin content, volatile content, unit area spread fiber quality, viscosity, recurrent, etc.

5.2.2 Production process monitoring

Monitoring in the production process is the key to prevent defects and ensure consistency. Environmental control, production workshop of temperature, humidity and cleanliness, must be strictly controlled to prevent it from moisture or presoak pollution.

Process parameters monitoring: the coiling tension, winding tension, curing temperature, pressure, time, key process parameters such as real-time monitoring and records, to ensure the process procedures are met.

Process inspection: after the key working procedure such as layer, coiling, the visual inspection, to ensure that no fold, without impurities, good combination between the layers. 5.2.3 requires finished nondestructive testing (ultrasonic, X-ray)

Finished product inspection is the last line of defense for quality control. Because the internal defects of carbon fiber tube through the inspection found that therefore means of nondestructive testing (NDT) is necessary. Ultrasonic testing (UT) : use of ultrasonic transmission encountered defects in the material will occur the principle of reflection, can detect the products within the layered, porosity, inclusions and other defects. This is the most widely used, one of the most effective composite nondestructive testing method.

X radiographic testing (RT) : use of X rays penetrate materials, different density of material at different levels of ray absorption principle, can detect the defects such as porosity, inclusions and fiber breakage. For testing in vertical direction of the ray crack is very effective.

Computed tomography (CT), CT is the advanced form of X-ray detection, can generate products internal three-dimensional images, can be very precise locating and evaluating the shape, size and location of the equipment cost is higher. Through to the finished product sampling or whole nondestructive testing, there are serious internal defects can be effectively eliminated products, to ensure that each piece delivered to the customer's carbon fiber tube meet the high standards of quality.