Technical Superiority of GRP Pipes Manufactured by Helical Winding Process

The machine-made GRP pipes as indicated in GRP pipe standards are largely manufactured by the **Filament Winding Process.**

The name filament winding process refers to the helical winding process in which the continuous fibers are aligned at a predetermined angle as per the load requirement. Continuous fibers are taken through a resin bath and wound over a steel mandrel, which decides the inner diameter of the GRP pipe. The helical winding process uses a ground and polished steel mandrel with end holders, normally of 12m long to obtain 12m length pipes.

A variation of the filament winding process adapted for GRP Pipe manufacture is the "advancing mandrel process". In this winding process, the mandrel is built with steel bands that advance from one end to the other during the manufacture of pipes. The term "continuously advancing mandrel process" refers to the type of construction of mandrel, which advances from one end to the other.

Since these two methods are largely adopted for GRP pipe manufacture by different manufacturers word-wide, the relative merits of these processes are analysed here from the technical perspective of product integrity & soundness of the final product.

Currently, both the processes are automated through advanced computerized control systems for fiber placement and other controls. While the helical winding process utlises the advanced CNC (Computerized Numerical Control) control that gives the two-axis interpolative path trajectory for accurate fiber placement at required winding angles, the "advancing mandrel process" uses the PLC (Programmable Logic Control) system for winding process automation.

The single most variation between these two processes from the technical perspective is the "winding angle", that by definition is the angle by which the continuous fiber rovings are placed with respective pipe axis. While, in helical winding process, it is possible to place the fibers at required winding angles, in "advancing mandrel process", it is not possible to place the fiber at helical winding angles (only 90^0 hoop windings possible).

Winding angle is the basic design parameter by which the exact strength requirements in the hoop and axial directions of the pipe are achieved. For a typical aboveground piping application with internal pressure, a winding angle of 54.7^0 is the requirement. For a typical underground piping application with internal pressure and soil overburden, a winding angle of $63^0 – 71^0$ is used.

Coming back the processes, GRP pipes are wound at the required winding angles as per the design requirement in helical winding processes.

In advancing mandrel process, pipes are wound only in the hoop direction by 90^0 windings. 90^0 hoop winding gives strength only in hoop direction leaving practically negligible strength in axial direction. Since the axial strength achieved by the primary winding is practically zero, some amount of secondary cut fibers(chopped fibers) are randomly sprayed into the structure during the winding process to give the minimal axial strength for the pipes in the advancing mandrel process.

With this technical foundation, the comparative technical advantages of helical winding process are given below point-wise.

1. Fiber orientation:

In helical process, the reinforcing fibres are aligned at different angles as per the load requirement and an optimum design is achieved by the variation of winding angle. Typically, the aboveground pipes are wound at 54.7° for meeting the internal pressure and underground pipes are wound at 63° - 71° for meeting the internal pressure and soil loads.

In "Advancing Mandrel" process, the reinforcing glass fibres are wound only in hoop direction (90° winding angle) and discontinuous chopped fibres are sprayed between winding layers to achieve the minimal axial tensile strength.

With minimum axial strength achieved through secondary chopped fiber sprayed in the structure, the advancing mandrel gives the uni-axial pipes meant underground applications with unrestrained rubber ring joints.

The advancing mandrel process cannot produce biaxial strength pipes meant for aboveground application.

2. Continuous Fiber Utility:

The pipe structure is built with 100% continuous fibers rovings in helical process while in the advancing mandrel process, the structure consists of a mix of continuous and discontinuous chopped fibres. The basic requirement of a filament winding process as required by technology & GRP pipe standards is that the fiber being used for reinforcement should be continuous; since continuous fiber only gives maximum strength. Since, in helical winding process fiber can be aligned at any angle, this process utilizes 100% continuous fiber as reinforcement by winding at the required angle so that necessary strength in hoop and axial directions are achieved.

In advancing mandrel process, continuous fibers are used only for primary hoop windings and secondary chopped fibers are added in the structure during winding to compensate for loss of axial strength in 90° hoop windings. Hence, advancing mandrel process does not effectively use continuous fibers.

3. Product Intetgrity through Fiber "interweaving"

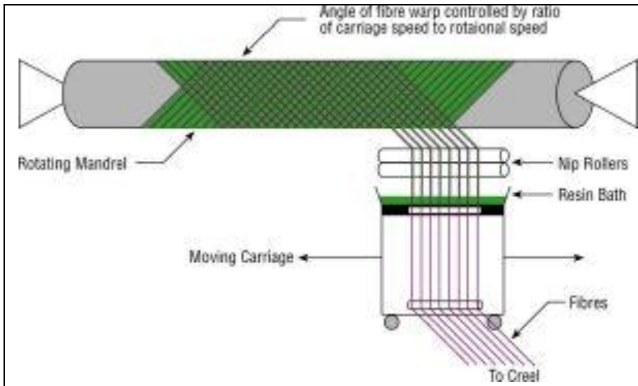
The basic requirement of a continuous fiber as defined in standards refers to the fiber continuity to be made available to the product from start to end. The utility of continuous fiber from start to end in helical winding process ensures uniform strength at any section in the pipe. Moreover, in helical winding process, the continuous fiber rovings are wound as a typical "interweaved layer" construction in which the reinforcing layers are alternatively weaved to form a "weaved mat-like structure". This interweaving improves product integrity against failure and is an essential requirement for high/very high pressure GRP pipes (50, 100, 150 bar) pipes used in oil & gas applications. Hence, for these reasons, all the high/very high pressure pipes are manufactured by helical winding process only.

In advancing mandrel process, 90^0 hoop windings are placed parallel to one another and the layers are not interweaved. The transverse strength is controlled by the weak resin bonds. Again, the primary 90^0 windings and the secondary chopped fibers meant for axial strength are not bound together as a unified reinforcement and are bound only through the weak resin bonds. Due to this reason, the transverse axial pipe separation into two pieces is common in pipes manufactured through advancing mandrel process; especially during transportation through roads and in some cases during pressurization.

Axial separation never happens in helically wound pipes due to transportation or pressurization.

4. Bi-axial Strength Pipes for Above Ground application

GRP pipes meant aboveground application always requires biaxial strength to meet hoop and axial stresses. **Biaxial strength pipes can only be manufactured through helical winding process.**

	
Helical Winding Process	**Helical winding Pattern & Interweaving**
	
Advancing Mandrel Process with 90^0 hoop windings	**Axial Separation of Advancing Mandrel Pipe in Field (Single line failure due to poor axial strength)**
	
Typical Breaking mode of Helical Wound Pipe During Tensile Testing (Helical fibers does not allow a single line failure)	**Another View of Tensile Testing of Helical Pipe**

Comparative Evaluation Summarized:

Description	Helical Winding Process	Advancing Mandrel Process	Remarks
Angle of winding	Possible to wind in any winding angle as per design	Only 90° winding possible. Not amenable to wind in any required angle	• Inefficient fiber strength utility & poor axial strength in 'Advancing Mandrel Process'
Continuous Fiber usage	100% continuous fiber (Rovings) for reinforcement. Aligned fiber at winding angles meet the exact hoop & axial strength requirements	Mixture of continuous and discontinuous fibres. Chopped fibers are sprayed into the structure during 90^0 hoop winding to give minimal axial strength.	• In advancing mandrel process, primary winding reinforcements has no contribution to axial strength. • Axial strength is controlled by weak chopped fibers sprayed in the structure • Primary winding reinforcements and secondary chopped fibers meant axial strength are not bound together as a unified reinforcement; rather bound through the weak resin bonds.
Product Integrity at Extreme Loading Situations	High integrity due to helical layer interweaving.	Minimum axial strength through secondary chopped fibers. No interweaving between reinforcements.	• Pipes manufactured through advancing mandrel process is meant ideal loading conditions, very safe(non-jerky) transportation and ideal burying conditions • Pipes manufactured through helical winding process has in-built ruggedness to meet extreme loading conditions much better
Biaxial Strength Pipes	Possible	Not Possible	• Biaxial Strength Pipes are an absolute requirement for aboveground application and this cannot be delivered by advancing mandrel process.
Winding Process optimization	Continuous fibers are aligned by controlled uniform fiber tension from start to end.	While the primary 90^0 windings are applied with controlled tension, chopped fibers are just sprayed into the structure.	• Uniform axial strength is ensured in helical winding process while this is not ensured at all sections of pipe in advancing mandrel process due to random distribution of secondary cut fibers.
Pressure Rating	Gravity, High & Very high Pressures upto 150 bar design pressure	Meant for gravity & low pressure applications under ideal loading conditions	• For high & very high pressure pressures, it is only helical winding process that can meet the requirements. • For gravity & low pressure applications, helically wound pipes offer better benefits than meeting the minimum requirements.