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# Glass Reinforced Plastics Pipes
# Manufacturing methods and comparison of their characteristics

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SINTECNICA ENGINEERING

SGUASSERO
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# Manufacturing processes and comparison of their characteristics

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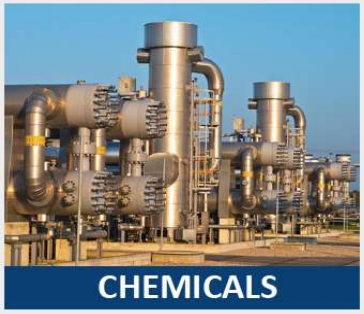




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# Manufacturing processes and comparison of their characteristics

## SINTECNICA

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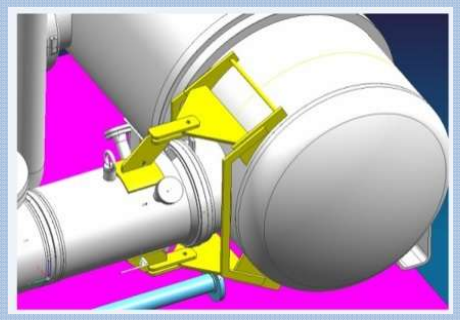
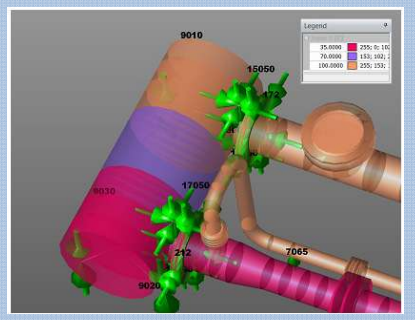
- Enel frame agreement D'Appolonia RINA / Sintecnica
- Consulting contract with RINA for composite pressure vessels applications
- Specialists team for:
  - Pressure vessels - ASME X design
  - Heat Exachanger and equipment design

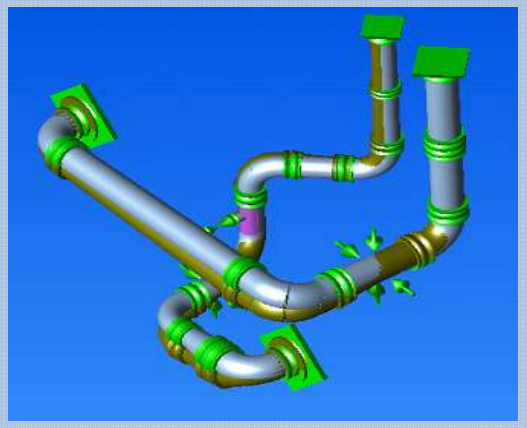
Probe Testing Rig developed together with UNI FI

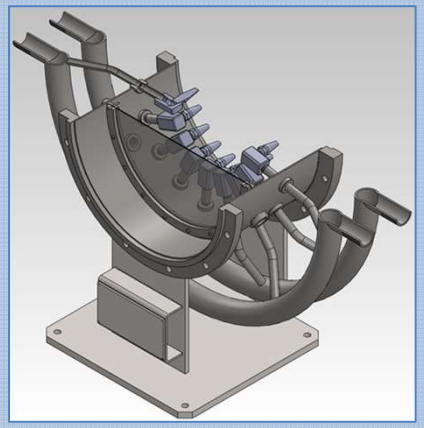
# Manufacturing processes and comparison of their characteristics

- Design assistance including:
  - Piping & vessels Stress analysis
  - FEM analysis
  - Polymer evaluation under end-use conditions
  - Proprietary Software development
  - Equipment general arrangement
  - Plant Layout
  - 3D modelling
  - Detailed design (workshop dwg's)
  - Pipe support optimization
  - BIM (Building Information Modelling)
  - Design by code/standard (ASME)







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Manufacturing processes and comparison of their characteristics

# NUOVA SGUASSERO

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# Manufacturing processes and comparison of their characteristics

**NUOVA SGUASSERO**

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- Established in 1956
- Certified LR ISO 9001:2008
- DNV TYPE APPROVAL – MARINE SYSTEMS
- RECOMMENDED PRACTICES:
  - **DNV GL AS**
    DNVGL-RP-F119 Edition December 2015 - **Thermoplastic composite pipes**
  - **ISO 14692 Petroleum and natural gas industries - Glass-reinforced plastics (GRP) piping**

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# Manufacturing processes and comparison of their characteristics

## On going R&D activities (extract)

### Resins processing

- DSM ATLAC 3100 - Flexibilized Epoxy based bisphenol A resin
- pDCPD - Polydicyclopentadiene resin (POLIMI)

### Products design

- Scrubber tanks (new marine applications)
- Screens ASME X
- Chimney liners (high temperatures – transient conditions)

### Surface treatments

- Thermosetting resin metallic coating:
  - Physical Vapor Deposition
  - Plasma Enounced Chemical Vapor Deposition

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# Manufacturing processes and comparison of their characteristics

## Polydicyclopentadiene

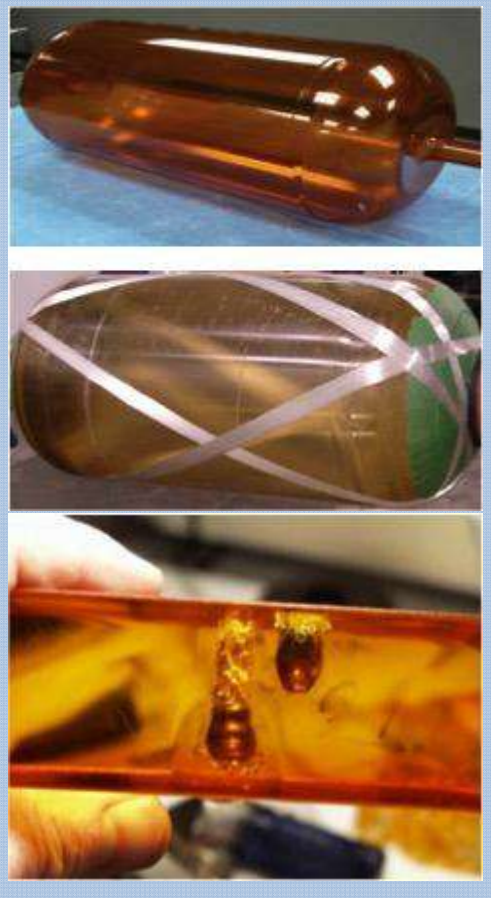
DCPD-based resins are normally processed by Reaction Injection Molding (RIM).

Modified thermosetting DCPD-based resin can be used for impregnating composite fibers.

The matrix has higher toughness at low temperatures with mechanical, thermal and physical properties similar to most common toughened epoxies.

The resin before curing presents also lower viscosity that allows higher fiber fraction in the final composite structure and therefore less weight.

A thin metal layer to be applied on the DCPD-based resin surface to match fluid composition and to provide extra corrosion/damage resistance and gas barrier capabilities.



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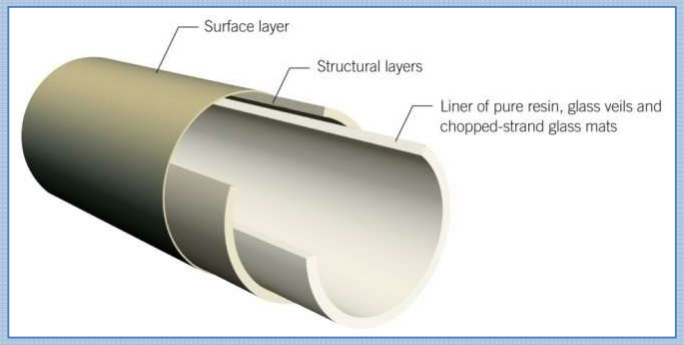
# Manufacturing processes and comparison of their characteristics

The GRP (Glass Reinforced Plastics) pipes and vessels are constituted by three independent coaxial layers obtained by monolithic construction:




**Liner** – it ensures fluid tightness, chemical resistance, hydraulic performance. It is the element that influences the design of the mechanical structure based on the First Play Failure criteria. If reinforced by fibers improves the behavior of the pipeline.

**Mechanical structure, with or without silica sand / calcium carbonate** - provides the mechanical characteristics in longitudinal and circumferential directions (pressure resistance), flexural and bending and circumferential stiffness (buckling resistance and longitudinal strength to withstand loads due to support system)

**Gelcoat or outer liner** - protects against external mechanical agents, such as chemical attack, corrosive soils, UV radiation, abrasion, etc.

**Depending on the manufacturing processes used for their production, GRP pipes may show monolithic joints with or without locking key (in the second case they are able to transmit axial stresses as in the case of welded joints) or external joints of sleeve type that does not transmit axial forces.**

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# Manufacturing processes and comparison of their characteristics

The joining systems of the pipes can be classified according to the type of construction:

**- Joint monolithic with the pipe**
**- Joint not monolithic**

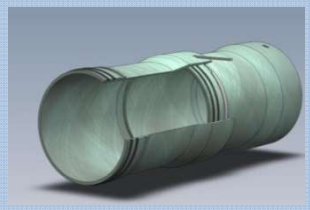
The first generally have less chance of hydraulic leaks having fewer seals.

Or they can be classified based on the point of view of the transmission of forces:

- **Restrained joints** → transmit longitudinal forces
- **Unrestrained joints** → do not transmit longitudinal forces

The type of junction is normally selected depending on the installation (**A/G - U/G**), characteristics of the pipeline, technical characteristics of the system (system design), etc.

Consequently the pipe must then be designed (product design) and its technical characteristics fixed (Ea, Eh, G, niha).



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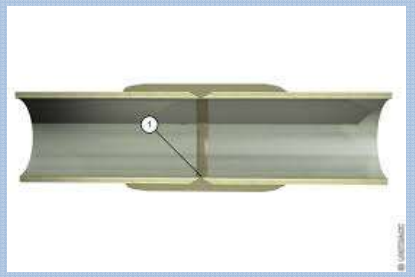
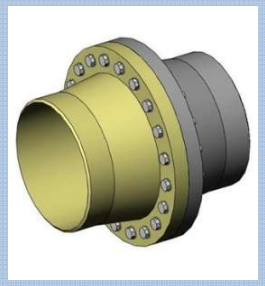
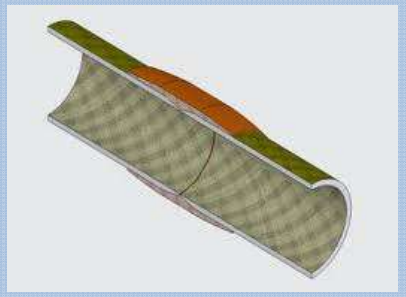
# Manufacturing processes and comparison of their characteristics

- **SYSTEM DESIGN → AG/UG, DN, PN/PA, STISS, Fluid composition, °C**
- **PRODUCT DESIGN (CODE) → resin/glass/inerts/additives, structure, joint**
- **STRUCTURE + JOINT → «appropriate» manufacturing process**







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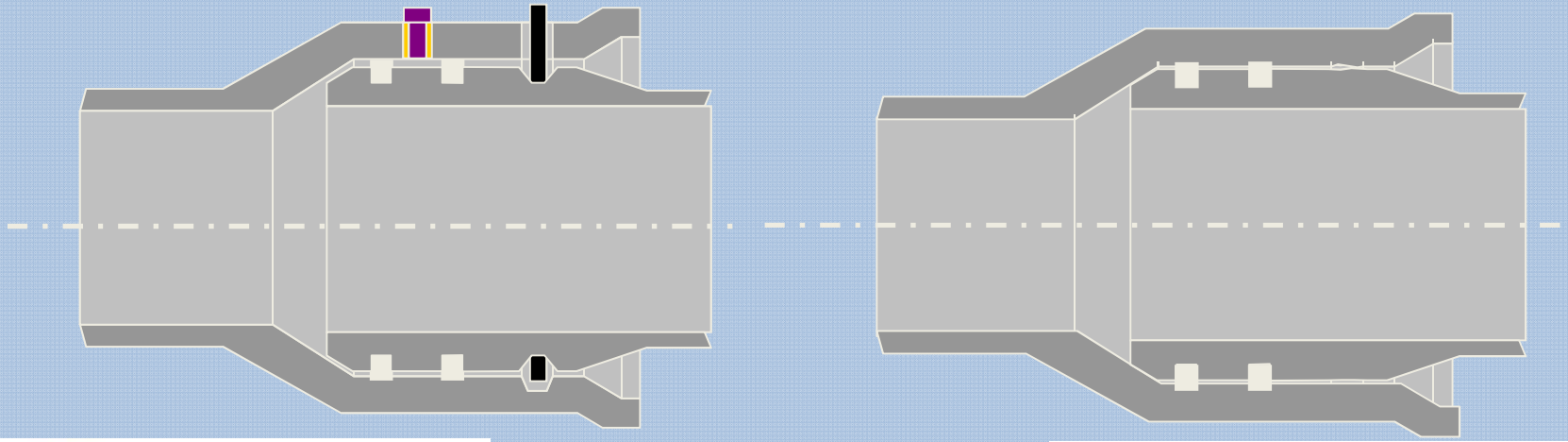
# Manufacturing processes and comparison of their characteristics

Bell & Spigot Lock Joint

(restrained joint)

Bell & Spigot Lock Joint

(unrestrained joint)



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# Manufacturing processes and comparison of their characteristics

**Filament Winding (*)**

The filament winding, in particular the process DFW as we know it today, was developed in the early 60s for the realization of sophisticated high-performance composite structures (ballistic missiles, pressure tanks, aircraft components, etc.) characterized by high specific performance, low weight, high chemical resistance, etc. typical of the military industry and was subsequently extended to all major industries for the construction of tanks, axial-symmetric structures, machine parts, until the construction of pipelines for chemical, nuclear, O & G sector, energy production , automotive sector and finally water supply and sewerage for civil use.

(*) FW process dates back to times of the Napoleonic Wars when wire was wrapped under tension onto cast cannon barrels to improve barrel life.

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# Manufacturing processes and comparison of their characteristics

GRP (Glass Reinforced Plastic Pipes) are produced by means of 2 major manufacturing processes:

- Filament winding **(FW):**
  - Discontinuous Filament Winding process **(DFW)** or Dual helix filament winding with monolithic bell & spigot joints, with or without locking key.
  - Continuous Filament Winding process **(CFW)** with coupling joints
- Centrifugal casting **(CC)** with coupling joints

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# Manufacturing processes and comparison of their characteristics

Composite Pressure Vessels are manufactured by DFW only.

- Internal liner:
  - Resin:
    - Thermoplastic (HPDE, PP, C-PVC, PE, PVDF)
    - Thermosetting (Neopentilic, Isophtalic, Vinylester, Epoxy – novolac, Bisphenol-A Epoxy, Bisphenol-A vinyl-urethanic, etc.)
  - Reinforcement:
    - C-glass, ECR-glass, Polyester
    - Unreinfroced
    - Conductive, antiabrasive, high chemical resistance, etc.

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# Manufacturing processes and comparison of their characteristics

## Composite Pressure Vessels

- Mechanical layer:
  - Resin:
    - Thermosetting (Terephtalic, Orthophtalic, Isophtalic, Vinylester, DCPD polyester, Epoxy – novolac, Bisphenol-A Epoxy, Bisphenol-A vinyl-urethanic, special formulated resins)
  - Reinforcement:
    - ADVANTEX E-CR glass 2400 tex → static tensioners
    - Carbon fibre 1200 TEX → electrictronic tensioner creel
- External gel-coat:
  - Reinforced/Unreinforced
  - Pigmented
  - Conductive, antiabrasive, etc.

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# Manufacturing processes and comparison of their characteristics

- **Discontinuous filament winding process (DFW)**

The manufacturing method consists in the impregnation of reinforcing fibers (continuous fibers of glass) with a polyester type resin or epoxy resin (the matrix) and in the application of the band of impregnated fibers under controlled tensioning conditions and predetermined paths (angles + / - α, normally with α varying between 45 ° and 65 °) on a rigid or collapsible mold (mandrel) in order to optimize the mechanical characteristics of the structure until reaching the required design thickness.

The mechanical structure may contain layers of siliceous aggregates (sand) impregnated with resin and placed in the vicinity of the neutral axis of the wall to increase its rigidity.

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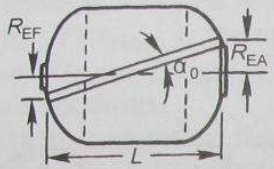
# Manufacturing processes and comparison of their characteristics

## Polar / Helical winding for pressure vessels

A. Polar winding



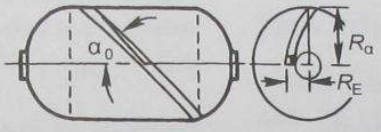

Wind angle through cylinder defined as:

$$\alpha_0 = \tan^{-1}\left(\frac{R_{EF} + R_{EA}}{L}\right)$$

Limitation on use:
$L/D$ < ~ 2 in order to prevent fiber slippage.
Advantage: winding operation is simplified.

Note: Spherical winding uses multiple polar (planar) wrap pattern.

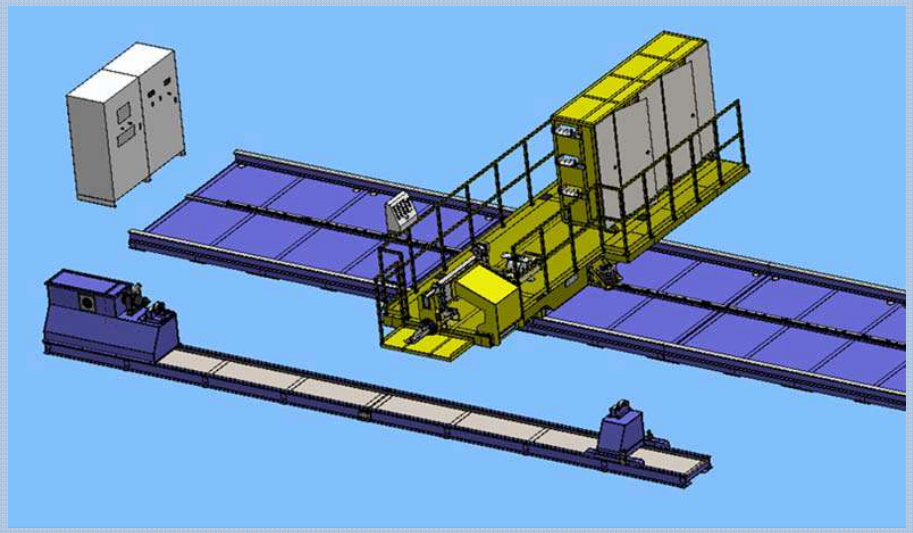
B. Helical winding (geodesic)




Wind angle through cylinder defined as:

$$\alpha_0 = \sin^{-1}\left(\frac{R_E}{R_\alpha}\right)$$

Limitation on use:
both domes must possess same percentage opening.
Advantage: Slip is avoided.
$R_E$ is to the radius to the center of the winding band (1/2 *BW*)

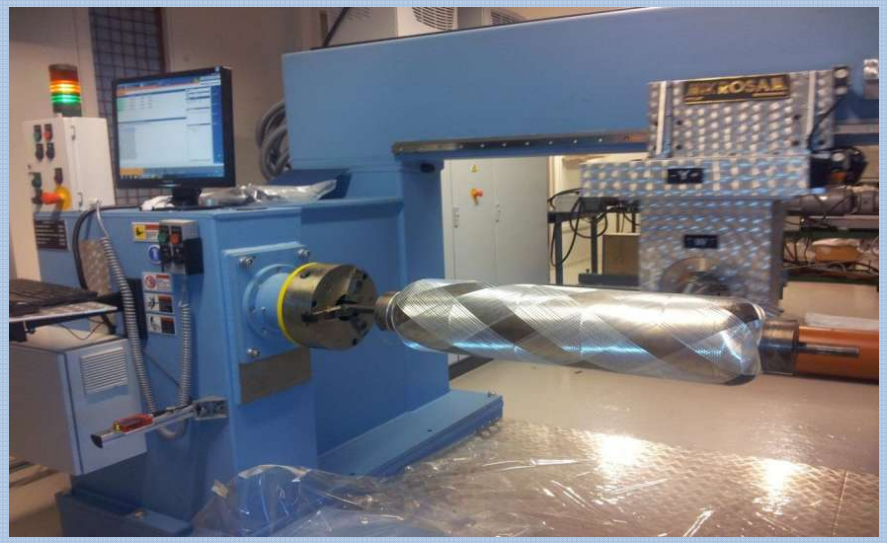


Horizontal FW machine # 4 – axis / single spindle / 24 tensioners on board (Phi 1500mm / L=5000mm)

# Manufacturing processes and comparison of their characteristics

Main topics :

- Liner (thermoplastic/thermosetting)
- Resin (Mechanical layer)
- Interface liner/mechanical resistant layer
- Reinforcement (glass/carbon/both)
- Type of mandrel (fixed, collapsible, other)
- Flanges (metallic, composite, fixed/loosing)
- Welding of thermoplastic
- Interfaces:
  - Liner/flange
  - Structural reinforcenment/steel
- Curing/post curing cycle
- Testing



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# Manufacturing processes and comparison of their characteristics

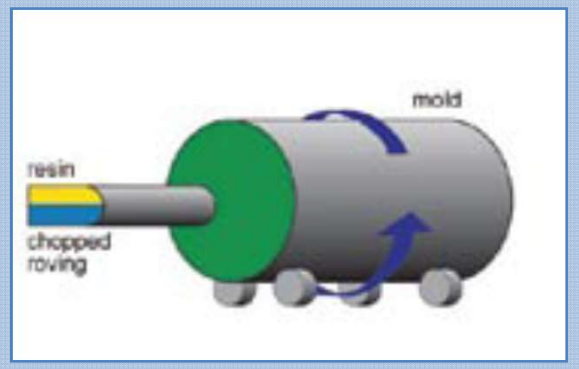
- **Contiunuous filament winding process (CFW)**

The manufacturing method is similar to the previous one, but allows to obtain high content of siliceous aggregates combined with mechanical characteristics on average lower. It consists of the impregnation of reinforcing fibers (continuous fibers of glass) and short cut fibers (chopped fibers) with a polyester-type resin (the matrix) and in the application of the band in parallel direction (winding angle about 90 °) on a rotating collapsible mold (mandrel made of steel bands) with addition of high content of inert silica (sand) to achieve the required thickness.

# Manufacturing processes and comparison of their characteristics

- **Centrifugal casting process (CC)**

This manufacturing method is completely different from the previous ones and does not use continuous reinforcing fibers. It consists in the introduction of aggregates (sand and calcium carbonate) and reinforcing cut fibers (chopped glass) inside a rotating drum (the mold) and the impregnation of the layer with one or more catalysed resin. The thickness of the individual layers constituting the pipe wall may have different compositions, the liner layer is made from pure resin (liner not reinforced). Also the content of aggregates (sand and calcium carbonate) may vary depending on the overall mechanical characteristics of the pipe until it reaches the required thickness. Due to intrinsic properties, on average the pipe thicknesses are much higher than the equivalent pipes made by previous two manufacturing methods.

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# Manufacturing processes and comparison of their characteristics

**SUMMARY**

**Discontinuous filament winding process (DFW)**

This is a very flexible, high perfomance process used in all applications where high mechanical performances, both short and long term, high corrosion resistance (possibility to use reinforced liner made of different resins in combination with same mechanical resistant layers), good hydraulic performance are required.

Pipes can have integral bell & spigot joints with locking key that avoid the use of anchor blocks, reducing the installation time and the overall duration of the site works.

The bell & spigot joints with locking key allow to test the joint, also on small to medium size diameters, immediately after insertion resulting in a drastically reduction of risk of hydraulic leaks at final hydro-test of the line.

The bars have standard diameters (DN= Di) and lengths 12m, 6m or less. This type of pipe is extensively used in all industrial sectors applications either AG/UG and in civil constructions, both for water supply purposes (drinking water) and for sewers.

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# Manufacturing processes and comparison of their characteristics

**Contiunuous filament winding process (CFW)**

This manufacturing method is used when required mechanical performances are medium to medium-low. It allows the use of high percentages of fillers, siliceous aggregates and additives. Typical joints are the couplings, either with O-rings or gaskets with sealing lips, that require the use anchor blocks to withstand trust forces generated by directional changes. When welded joints are required, namely to transmit axial forces, special bars must be used. Same for line adjustments, externally calibrated sections must be used.

The standard diameters are normalized on external diameter (DN=De) to allow using standard couplings on pipes with different stiffness or pressure class. Standard bar length is 12m or less. It is a system of pipes used mainly in civil construction but also has application in some sectors of the industrial constructions, both aerial and underground.

# Manufacturing processes and comparison of their characteristics

## Centrifugal casting process (CC)

It is a production method used when mechanical specifications require medium-low performances, typically low pressure associated with high transversal stiffness. The manufactured pipes have thickness greater than those made with other two manufacturing methods for  same pipes performance since the method allows the use of higher percentages of sand and additives.

The joints are the couplings with lip gaskets type, which require anchoring blocks. The bars have standard lengths of 6m or less. It 'a system of pipes used almost exclusively in civil and underground applications. The high transverse stiffness by itself does not represent an advantage in underground installations as pipes produced with this method will still fall in the flexible pipes and therefore have in each case the need for an adequate support by the backfilling soil. The high stiffness is a consequence of the low mechanical properties.

# Manufacturing processes and comparison of their characteristics

## Conclusions

Among different FW maufacturing methods Discontinuous Filament Winding (DFW) is the process with greatest flexibility and higher possibility of optimization of either mechanical or physical properties, in particular:

1) **Liner** are reinforced with glass veil and have controlled thickness, with possibility of using different resins depending on the fluid and application and are cured separately for improved chemical and mechanical resistance. Furthermore liners have the possibility of using specific additives to the layer to improve conductivity, anti-abrasive performance, high chemical resistance, anti vegetative, anti flame spread, etc.

2) Mechanical structure is reinforced by continuous glass fibers with double helix wound at variable angles which guarantee specific mechanical performances higher than any other manufacturing process, in particular in the longitudinal direction, ensuring a greater axial strength of the pipe, a characteristic of primary importance for above ground applications but also fundamental in the underground installations. Absence of short fibers and sand mixed at the same time into the reinforcement structure with better long-term effects.

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# Manufacturing processes and comparison of their characteristics

3) Joints integral with the pipe, a fundamental element that ensures less assembly time, minimum number of joints, possibility to test immediately after installation, use of locking system which guarantees the longitudinal continuity of the line even in the presence of small rotations in the joint and that allows to avoid the use of anchor blocks for underground applications.

4) Diameter normalization on internal diameters (DN = Di), with higher internal cross section obtained by the use of fixed or collapsible mandrels, that ensures, with inner diameters that do not vary with the pressure class or stiffness of the system, best hydraulic characteristics of the pipe line at constant DN.

5) Higher specific mechanical performances compared to other manufacturing processes with pressure classes from 6 bar up to 100 bar or even higher.

6) Engineering + Prefabrication to avoid or reduce laminations/ trimming at site and cut installation costs (cost reduction > 30% on site activities)

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# Manufacturing processes and comparison of their characteristics

- Proprietary SW for Pipes & Pressure Vessels Design and Costing

**PIPING CLASS**

**Design Code (Safety Factors)**

**Pressure Rating (PA/PN)**

**Stiffness**

**Liner/MR layer**

**Coating**

**Reinforcement**