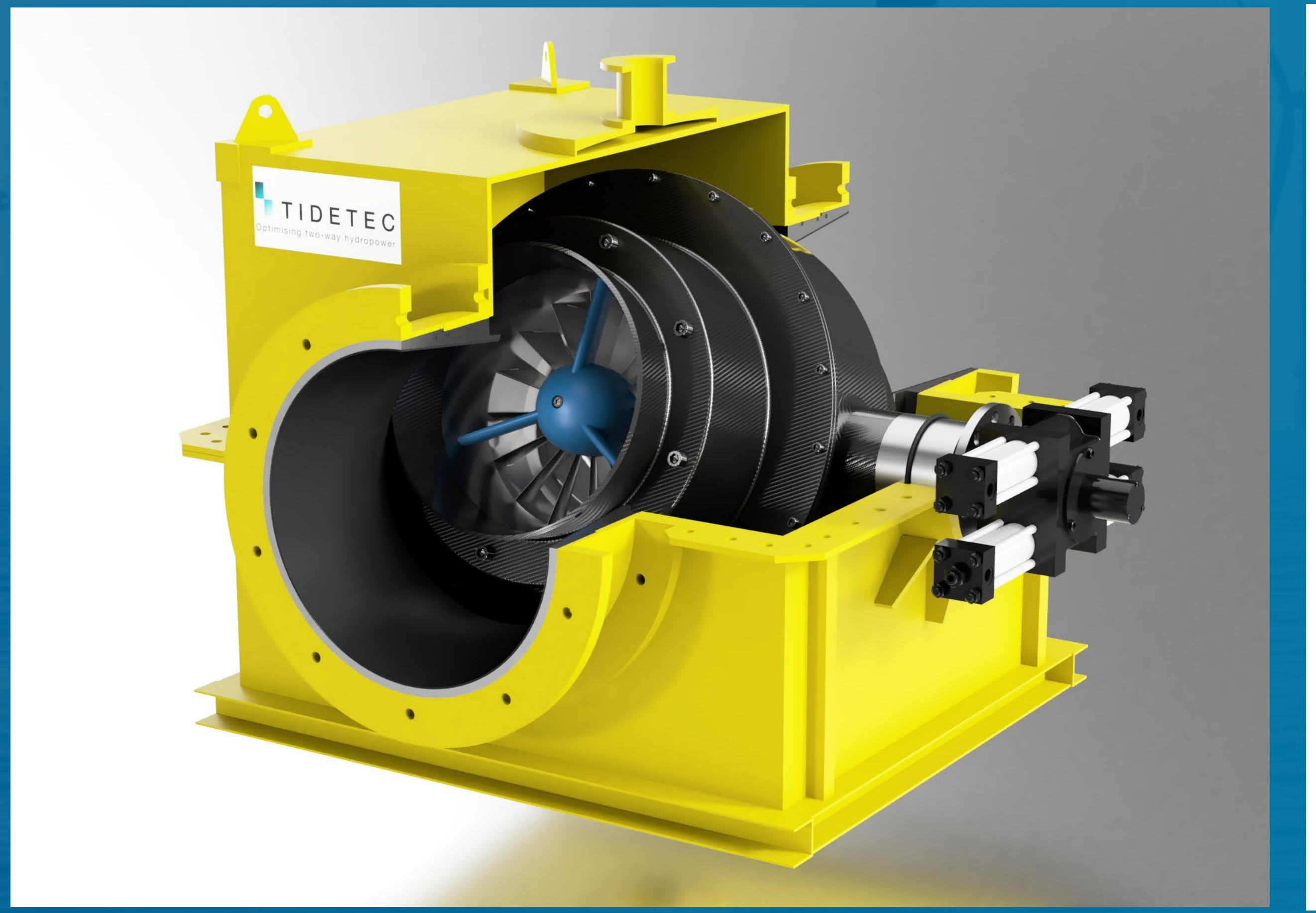
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952966.

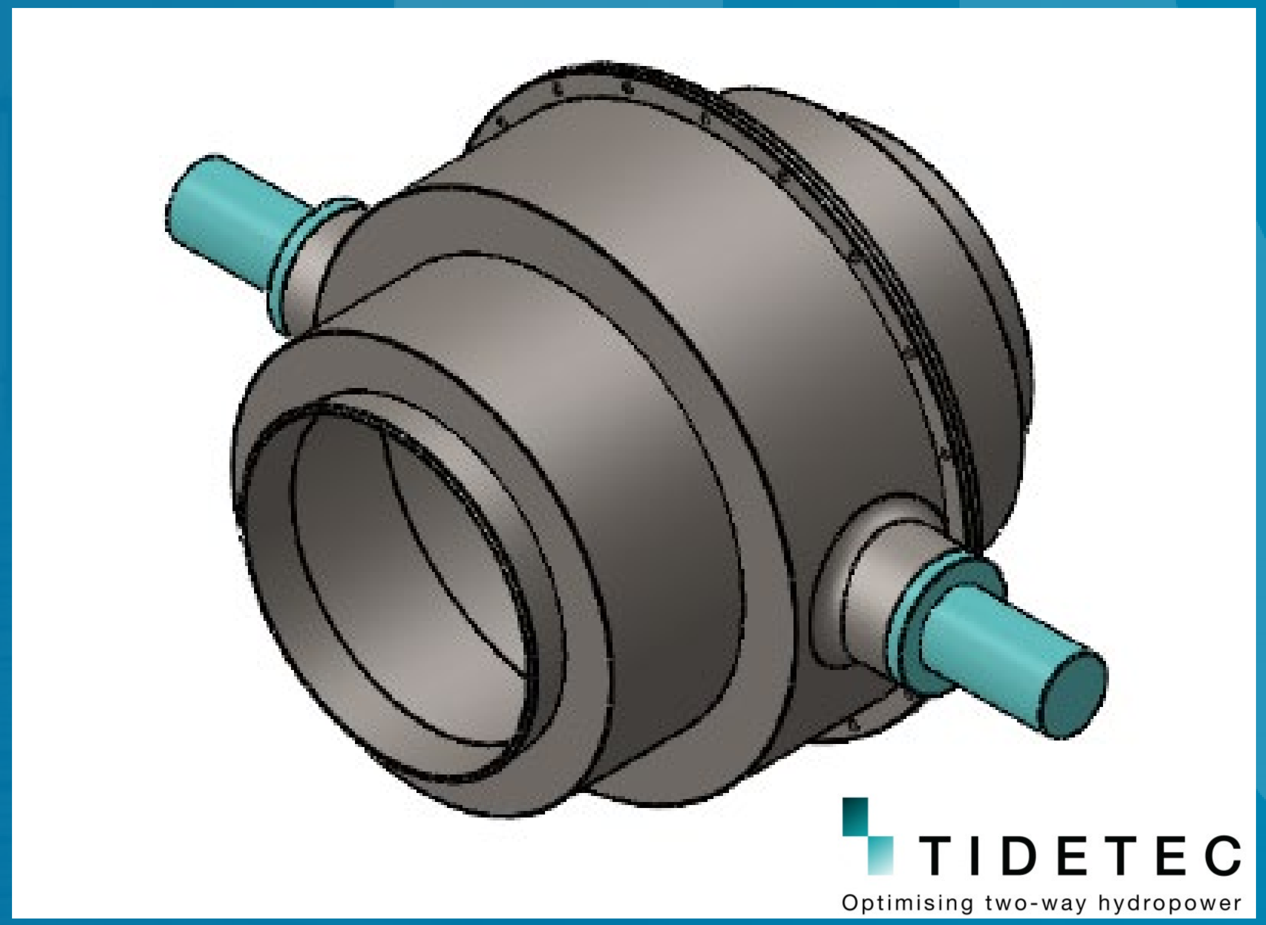
Materials/Processes

For the Turnable Turret (reduced scale prototype by FW)

1st Information day – 01/07/2021

Presenter: Rui Marques, INEGI





Content

- **Filament Winding process overview**

- **WP2 contributes (Task 2.1):**
  - Running and main achievements: INEGI contributed to the matrix and fibre selection for the turnable turret considering Filament Winding (FW) manufacturing Process.
  - Planned activities for coming months: FW Specimen Fabrication and Testing (bending 0º and 90º), and physical tests such FVF, voids, density.

- **WP5 (Task 5.1 and Task 5.2) contributes:**
  - Running and main achievements: Contributes for Geometry adaptation of the turnable turret housing – filament winding process (FW) guidelines and constraints.
  - Planned activities for coming months: Design for manufacturing iterations.

Related Fibregy tasks

- **WP2.** Fibre-Based Materials, Coatings and Connection Solutions for OWTP Platforms – Progress Report
  - **Task 2.1** - Material selection and characterization – ULIM (L), CIMNE, INEGI, CORSO-MAGENTA, IXBLUE, TUCO, TSI, ENEROCEAN, TIDETEC, BV **[M1 – M18]**

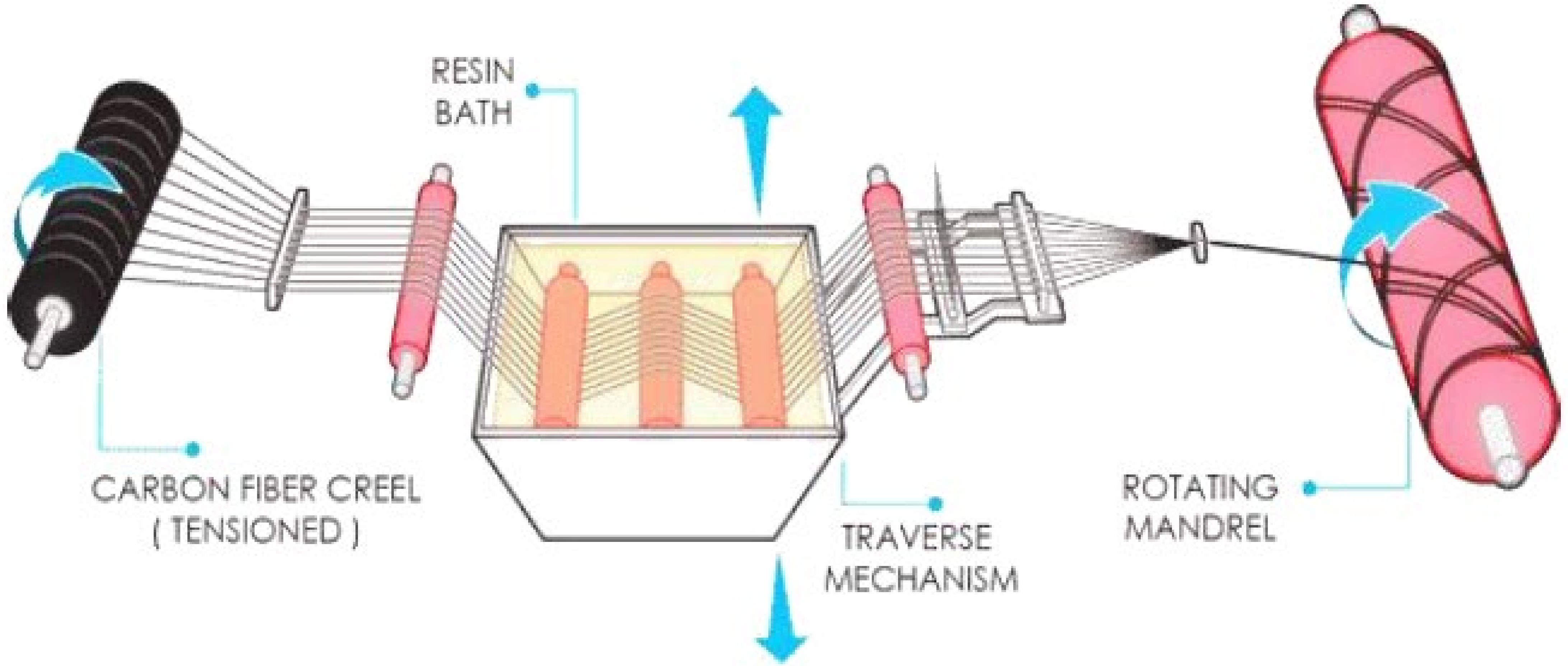
- **WP5.** Optimized Production Procedures and Life Cycle Assessment – Progress Report
  - **Task 5.1** - Optimized manufacturing processes and building strategy for the W2Power and turnable turbine housing - TUCO (L), INEGI, IXBLUE, COMPASSIS, ENEROCEAN, BV, CIMNE, TSI **[M2 – M20]**
    - **Subtask 5.1.1:** Analysis and qualification of manufacturing processes for the different components of the W2Power platform and turnable turbine housing (TUCO (L), INEGI, IXBLUE, CORSO, CIMNE) - (M2-M20)
    - **Subtask 5.1.2:** Analysis of the modular building strategies for the W2Power platform and turnable turbine housing (TUCO (L), INEGI, IXBLUE, COMPASSIS, ENEROCEAN, TIDETEC, TSI, CIMNE) - (M2-M20)
  - **Task 5.2** - Manufacturing and production processes of the OWTS demonstrators – IBLUE (L), INEGI, TUCO, COMPASSIS, ENEROCEAN, TIDETEC, TSI, CIMNE, BV **[M2 – M10]**

Filament Winding process overview

- Description

Filament winding manufacturing process (wet winding setup)

This process is primarily used for hollow, generally circular or oval sectioned components, such as pipes and tanks. Fibre tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fibre feeding mechanism, and rate of rotation of the mandrel.



https://iopscience.iop.org/article/10.1088/1757-899X/342/1/012029

https://www.gurit.com/-/media/Gurit/Datasheets/guide-to-composites.pdf

Material options

Resins: Any, e.g. epoxy, polyester, vinylester, phenolic.

Fibres: Any. The fibres are used straight from a creel and not woven or stitched into a fabric form.

Filament Winding process overview

- Winding of typical geometries

Composite overwrapped pressure vessel (COPV) - Type III

Composite tube

FIBREGY

WP2 contributes

- Running and main achievements: Material selection for FW process

Criteria for resin selection to be used in filament winding:

- Long working times for the production of large composite structures (long gel time at 25°C or long pot life);
- Lower initial mix viscosity at 25°C (~1000mPa.s);
- Good shelf life and easy conditioning;
- Type of polymer and its applicability to filament winding;
- Curing profile using lower temperatures (<60°C);
- Synergies with infusion manufacturing process;
- One Thermoplastic and one thermoset.

Materials	Material type	Gel time @25ºC	Shelf life	Viscosity @25ºC	Peek Temp	Tg	Tensile Strength	Tensile Modulus	Cure Time	Remarks
Epoxy PRIME 27 w/slow hardener	thermoset	2h 40m	24 months	200		68.7	74.3	3.3	16h @50ºC	Specifically suited for vacum assisted resin transfer moulding. Demould time after 17h@20ºC or 13h15m@25ºC. Marine applications
Epoxy PRIME 27 w/ extra slow hardener	thermoset	7h 20min	24 months	180		70	72	3.6	16h @50ºC	Specifically suited for vacum assisted resin transfer moulding. Demould times between 15-30ºC not recommended. Marine applications
Epoxy Ampreg 36 w/ slow hardener	thermoset	3h 35m	24 months	276		94	78	3.37	16h @50ºC	Demould time after 13h @20ºC. FW specific. Marine applications
Vinylester resin Crystic VE679-03PA	thermoset	80m					53	4.9	16h @40ºC	Demould time after 24h @20ºC
Vinylester resin Crystic VE673	thermoset	12m	6 months	250	18min @196ºC		75	3.5	3h @80ºC	Relativily low pot life. FW specific. Peek Temp. Demould time after 24h @20ºC and then cure cycle
Polyester resin Synolite 8488-G-2	thermoset	45m		2	78min @65ºC		70	3.8	16h @40ºC	Specifically suited for vacum assisted resin transfer moulding. Marine applications. Demould time after 24h @20ºC
Vinylester resin Atlac 580 act	thermoset	26m		~500	43min @155ºC		83	3.5	3h @100ºC	FW and marine specific
Crestapol 1210 & 1210A	thermoset	8.5m	>6 months	1.75 Poise	11.5m @153ºC	93	79	3.5		Post cure isn't needed. May be filled with a variety of fillers. For use in closed mould processes
Phenolic CELLOBOND J2027	thermoset	~15m	6 months @-18ºC or 2 months @RT	270			40	3.25		Marine and offshore specific. Not FW specific. Very low shelf life and low gel time. Doesn't specify cure time
Epoxy Litestone 2100E & 2102H	thermoset	12h	24 months	600		120	53	2.8	2h @90ºC + 4h@140ºC	Filament winding and Oil, Gas and Chemical industry specific
Epoxy Litestone 2130E & 2131H	thermoset	48h		450		127.5	84	3	2h @90ºC + 4h @110ºC	Long pot life @RT. Superior fiber wet out and resin penetration. Excellent combination of mechanical performance, thermal stability and moisture resistance. FW specific
Vinylester resin Vipel F010	thermoset	47min	6months	130cps	1h47min @80ºC	130	88	3.2	4h@82ºC	FW and corrosion, heat and chemicals specific
Vinylester resin Vipel F013-AAA-00	thermoset	2h 53min	7 months	350	3h28m @182ºC	111	88	3.2	2h @85ºC	0.1% Cobalt 6% + 0.1% DMA + 0.1% 2, 4-P. FW and corrosion specific
Vinylester resin AME 6001 INF-135	thermoset	up to 4h	3 months	170		113	79	3.5	24h @90ºC	Premium marine resin infusion. great resistance to fatigue failure. low shrinkage. increased hydrolysis resistance. Recommended for infusion process
➡ Infugreen 810 / 8822	thermoset	3h	24 months	185	-	63	66	3	24h @ 23ºC + 24h @ 40ºC	Epoxy resin is produce with about 38 % of carbon from plant origin and has a lower environmental impact than standard Epoxy systems. This system has a very low viscosity at ambient temperature. The different hardeners allow the production of small to very large parts.
➡ Infugreen 810 / 4771	thermoset	12h - 22h	24 months	115 - 235	245	86	73	3.22	24 h @ 23ºC + 24 h @ 40 °C	Epoxy resin is produce with about 38 % of carbon from plant origin and has a lower environmental impact than standard Epoxy systems. This system has a very low viscosity at ambient temperature. The different hardeners allow the production of small to very large parts.
➡ Elium C595 E	thermoplastic	20h	6 months	500		110	66	3.17	2h @80ºC	UV cure. Relativily low shelf life. Recyclable. FW specific. Marine applications
➡ Elium C191 O/SA	thermoplastic	300min	6 months	100	-		56	2.6	24h @ 23ºC / post cure 24h 60ºC	3 parts system. Low exothermic temperature during the polymerization. It is possible to adjust reactivity by changing the peroxide dosage or its nature.
Elium 188XO	thermoplastic	1 - 1.5h	6	100		76 - 107	56	3.04	24h @ 23ºC + 24h 20-60ºC	DNV GL - Low Exothermy

FIBREGY

WP2 contributes

- Running and main achievements: Material selection for FW process

Fibre selection criteria:

- Good mechanical properties (high strength, intermediate modulus);
- Compatibility with selected resins;
- Applicability to filament winding (Single-end roving availability).

Glass Fibre

HYBON® 2002 (Direct Roving Fiber Glass)

Product Information

Type of Fiber	E-Glass (ASTM D 578-05, Section 4.2.2)						
Type of Sizing	Silane						
Roving Tex, nominal (g/km)	275	300	600	900	1200	2400	4800
Roving Yield, nominal (yd/lb)	1800	1650	827	550	413	206	103
Average Fiber Diameter (µm)	14	14	15	15	17	17	24

Other Tex/Yield options are available upon request.
Contact your NEG Account Manager.

HYBON® 2026 (Direct Roving Fiber Glass)

Product Information

Type of Fiber	E-Glass (ASTM D 578-05, Section 4.2.2)					
Type of Sizing	Silane					
Roving Tex, nominal (g/km)	275	600	1200	1984	2400	4400
Roving Yield, nominal (yd/lb)	1800	827	413	250	206	113
Average Fiber Diameter (µm)	14	15	17	16	17 24	24

Other Tex/Yield options are available upon request.
Contact your NEG Account Manager.

Carbon Fibre

MITSUBISHI CHEMICAL
CARBON FIBER AND COMPOSITES

FIBER TYPE	Filament Count	Tensile Modulus GPa	Tensile Strength MPa	Elongation %	Density g/cm³	MUL mg/m
TR 50S	12K	235	4900	2.1	1.82	800
TR 50S	6K	235	4900	2.1	1.82	400

TORAYCA® T700S DATA SHEET

Highest strength, standard modulus fiber available with excellent processing characteristics for filament winding and prepreg. This never twisted fiber is used in high tensile applications like pressure vessels, recreational, and industrial.

F I B E R   P R O P E R T I E S

		English	Metric	Test Method
Tensile Strength		711 ksi	4,900 MPa	TY-030B-01
Tensile Modulus		33.4 Msi	230 GPa	TY-030B-01
Strain		2.1 %	2.1 %	TY-030B-01
Density		0.065 lbs/in³	1.80 g/cm³	TY-030B-02
Filament Diameter		2.8E-04 in.	7 µm	
Yield	6K	3,724 ft/lbs	400 g/1000m	TY-030B-03
	12K	1,862 ft/lbs	800 g/1000m	TY-030B-03
	24K	903 ft/lbs	1,650 g/1000m	TY-030B-03
Sizing Type & Amount	50C	1.0 %		TY-030B-05
	60E	0.3 %		TY-030B-05
	FOE	0.7 %		TY-030B-05
	Twist	Never twisted		

WP2 contributes

- Running and main achievements: Material selection for FW process

	Infusion (ULIM)		Filament Winding (INEGI)		
Material	Preferred	Backup	Preferred	Backup	Backup
Thermoplastic	Elium 188XO	-	Elium 191 O/SA with PMEK (Butanox M50 or Trigonox 249)	Elium C 595 E with Perkadox as thermal initiator (Polimerization 2h 80ºC)	Elium C 595 E with Perkadox 16 and Speedcure BPO (UV initiator)
Thermoset	SR Infugreen 810	-	SR Infugreen 810 + 4470, 4471 or 4472	SR Infugreen 810 + 8822	-
Glass Fibre	Hybon 2026	Hybon 2002	Hybon 2026 (2400 tex)	Hybon 2002 (2400tex)	-
Carbon Fibre	MRC TR50S 1.2k (12k)	-	T700 SC 24K (1650tex) FOE	Mitsubishi TR50S 12K (800 tex) or 15K (1000 tex)	-

WP2 contributes

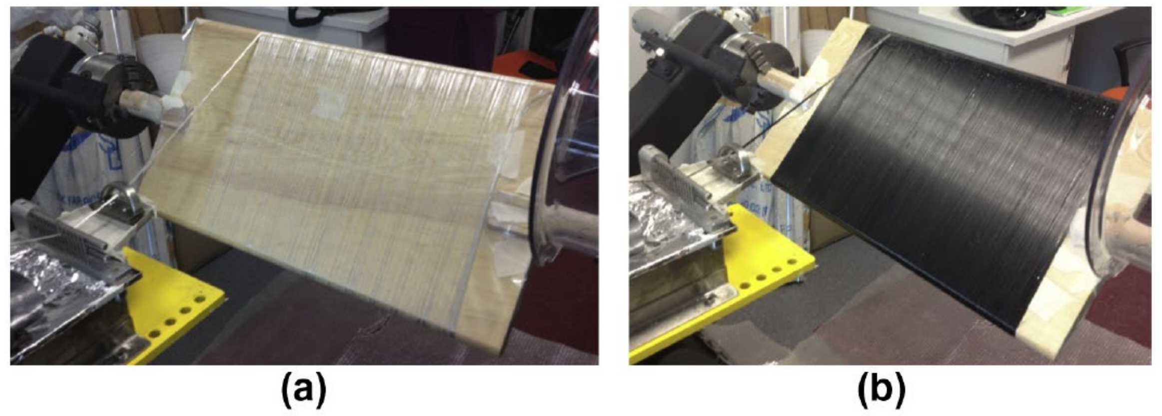
- Planned activities for coming months

FW Specimen Fabrication and Testing:

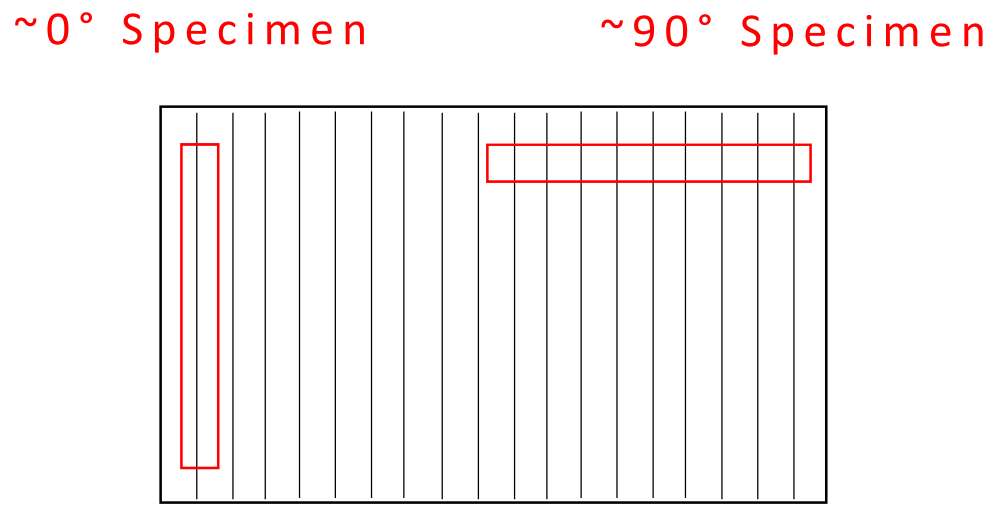
- Selection of 2 combinations (Fibre/matrix);
- Bending - $[0^\circ]_X$ and $[90^\circ]_X$.

Physical tests:

- FVF, voids, density.



Illustrative image of flat panel winding (hoop winding)



Flat filament wound panel

Material performance / selection (task 2.1)			
Description	Partner	Samples	#
Production of test samples of a same composite to evaluate the effect of the production method	ULIM / INEGI	Infusion - RTM Filament winding / Tape placement	2
Morphological and mechanical characterization of the samples.	ULIM / INEGI	Characterization (voids, fibre volume, etc.) Bending 0º / 90º	2x3

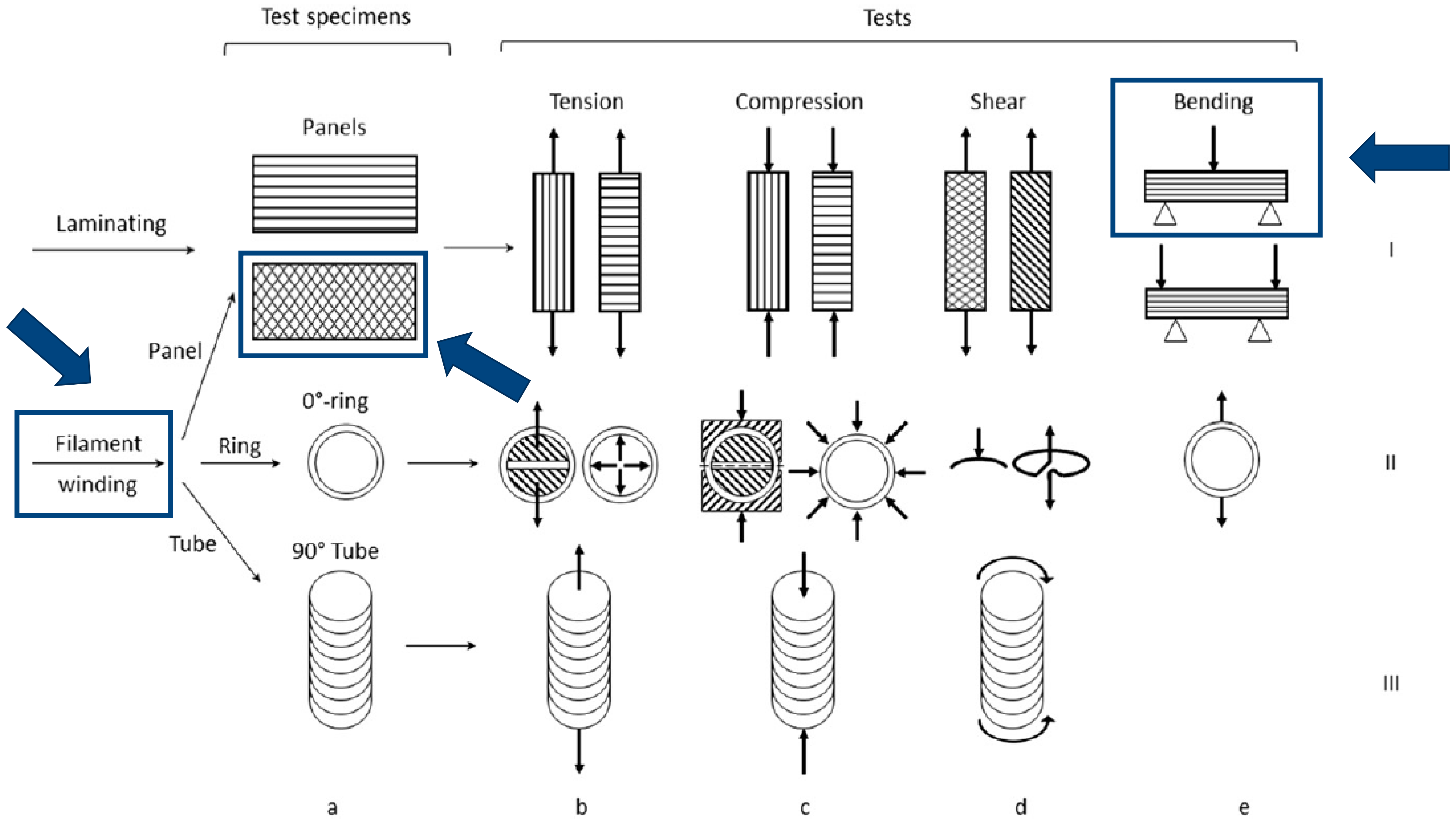
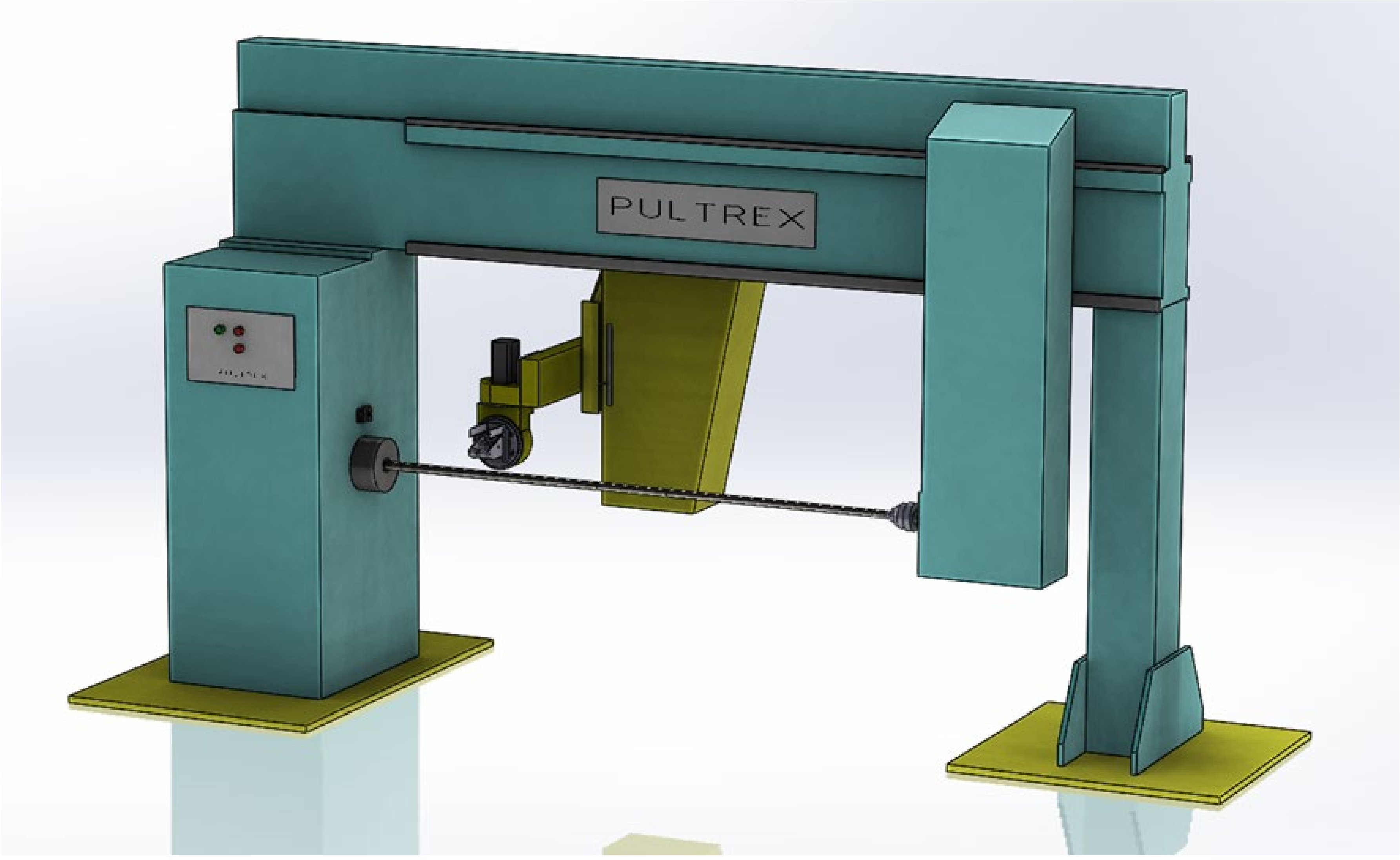


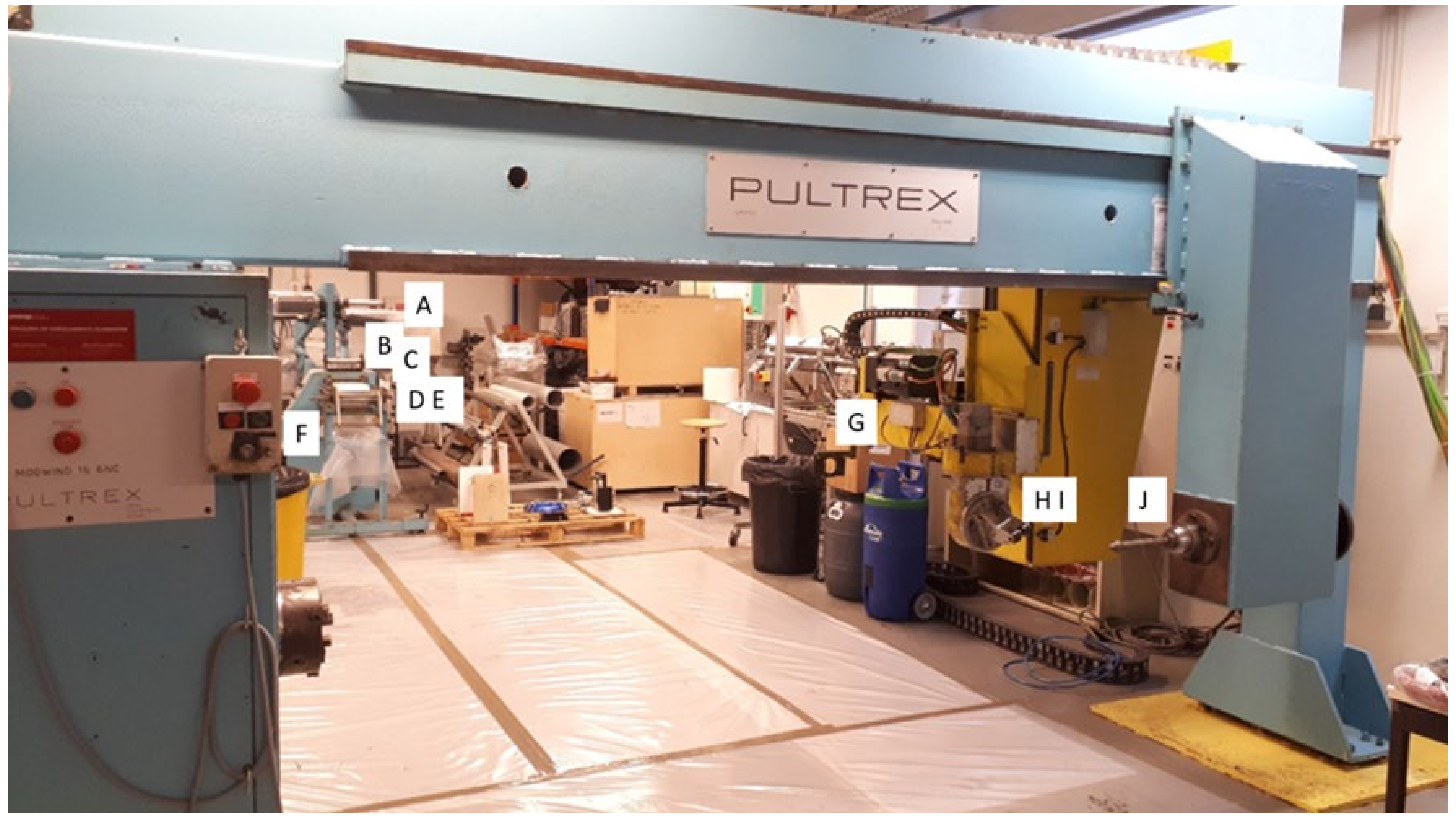
Fig. 7 Test specimens and test techniques for fiber-reinforced composites. Reproduced from Peters, S.T., 2011. Chapter 8: Static mechanical tests for filament-wound composites. In: Peters, S.T. (Ed.), Composite Filament Winding, first ed. Materials Park, OH: ASM International, pp. 95–114; Tarnopol'skii, Y.M., Kulakov. V.L., 1988. Handbook of Composites, second ed. London: Chapman and Hall.

WP5 contributes

- INEGI setup

INEGI Machine and its components



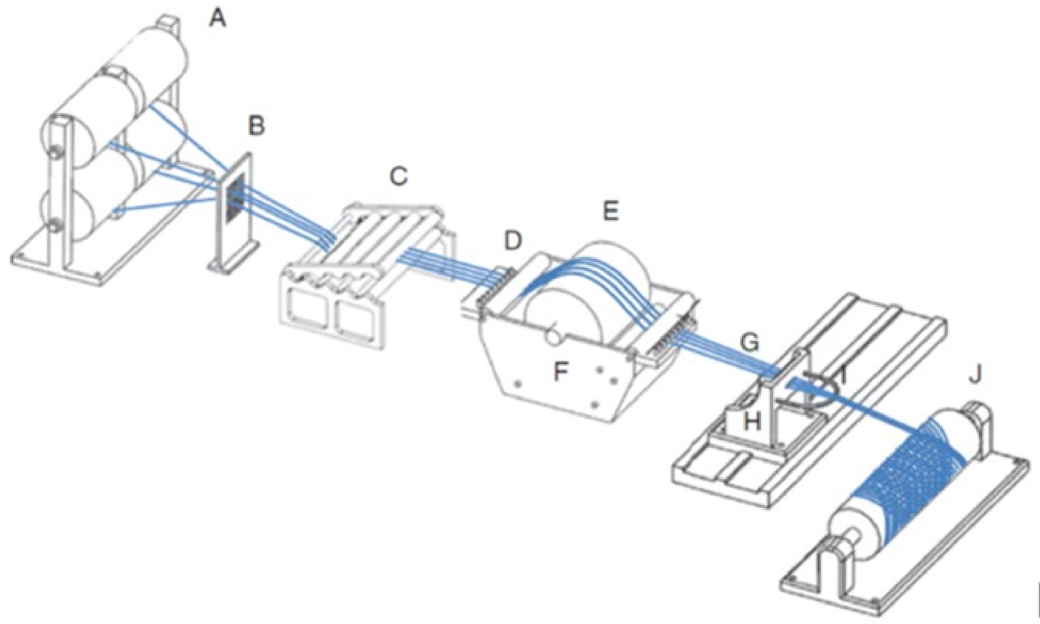


Main Characteristics:

- 6 independent axis
- Parts with diameter up to 600mm
- Parts with length up to 2000 - 3000mm

Components:

A) Rovings; B) Guiding system; C) Tension system; D) Pin guides; E) Impregnation roll; F) Resin Bath; G) Impregnated filaments; H) Deposition carriage; I) Deposition head/eye J) Mandrel mount



FIBREGY

WP5 contributes

- Running and main achievements: Filament winding advantages and disadvantages

Main Advantages:

- This can be a very fast and therefore economic method of laying material down;
- Resin content can be controlled by metering the resin onto each fibre tow through nips or dies;
- Fibre cost is minimised since there is no secondary process to convert fibre into fabric prior to use;
- Structural properties of laminates can be very good since straight fibres can be laid in a complex pattern to match the applied loads.

Main Disadvantages:

- The process is limited to convex shaped components;
- Fibre cannot easily be laid exactly along the length of a component;
- Mandrel costs for large components can be high;
- The external surface of the component is unmoulded, and therefore cosmetically unattractive;
- Low viscosity resins usually need to be used with their attendant lower mechanical, health and safety properties.

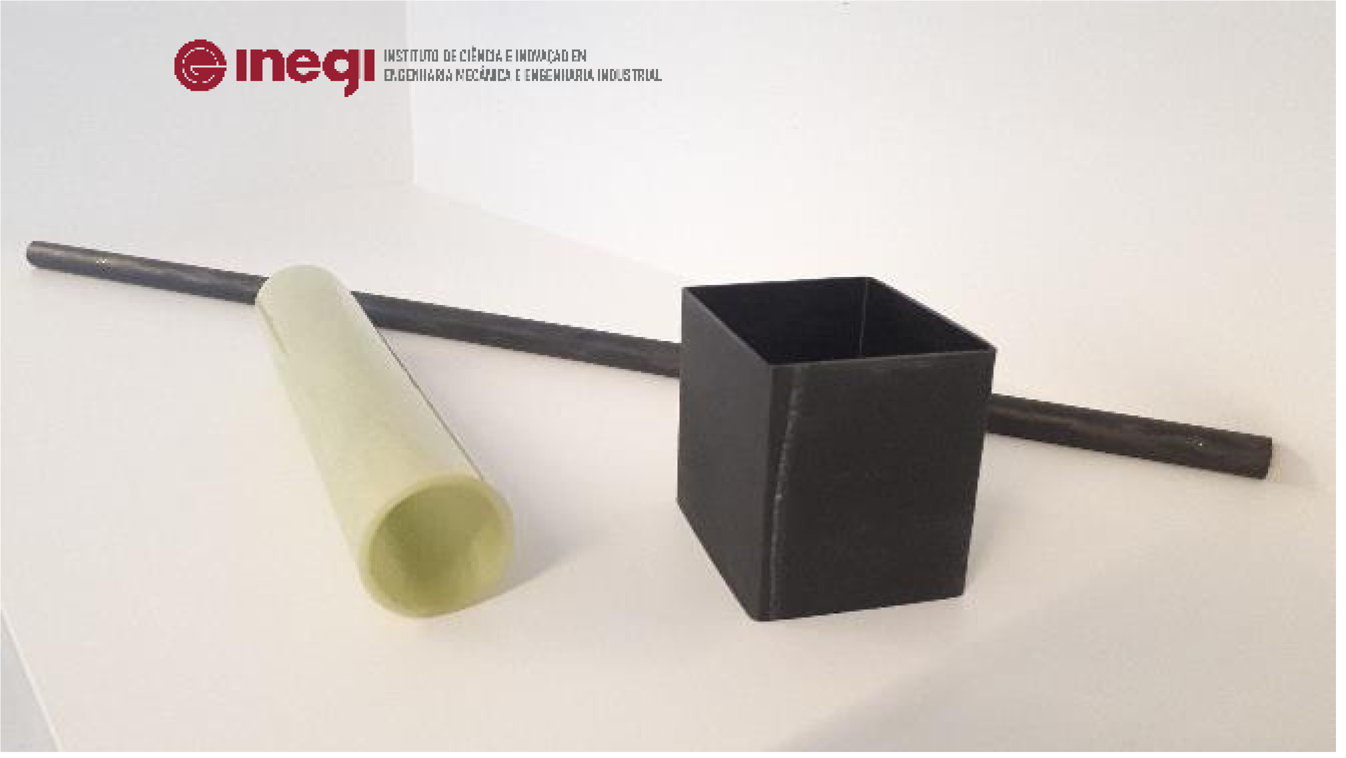
https://www.gurit.com/-/media/Gurit/Datasheets/guide-to-composites.pdf

WP5 contributes

- Running and main achievements: FW typical applications

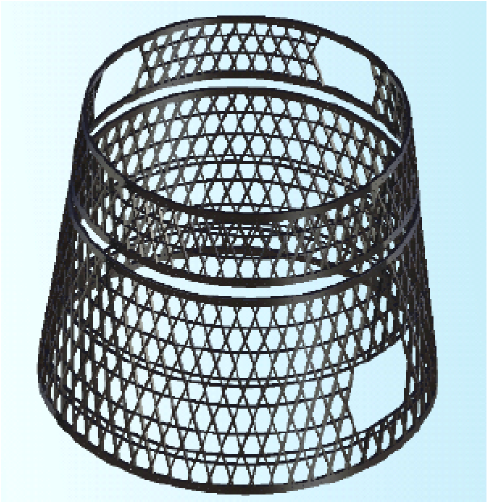
Typical applications:

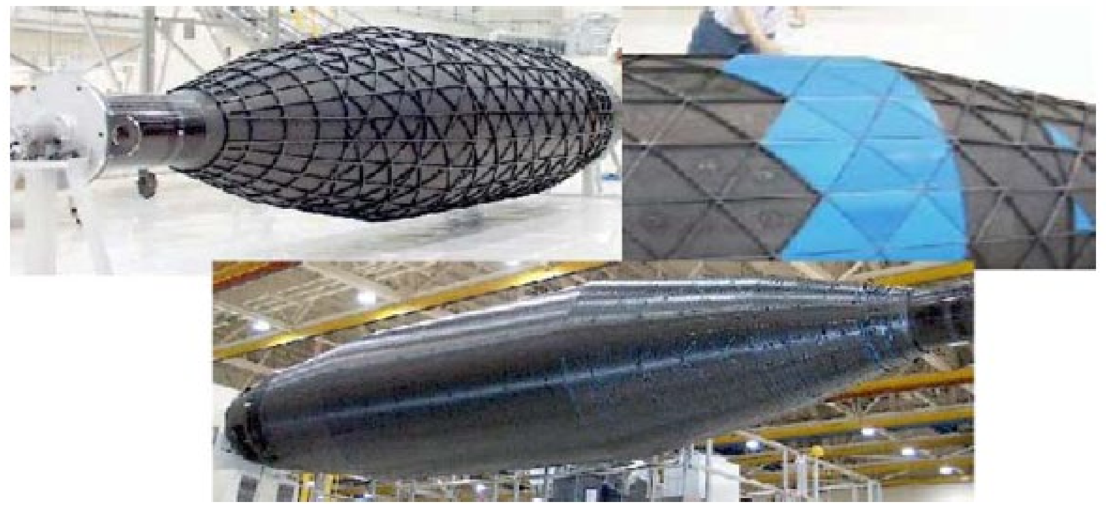
- Chemical storage tanks;
- Pipelines;
- Gas cylinders;
- Fire-fighters breathing tanks.

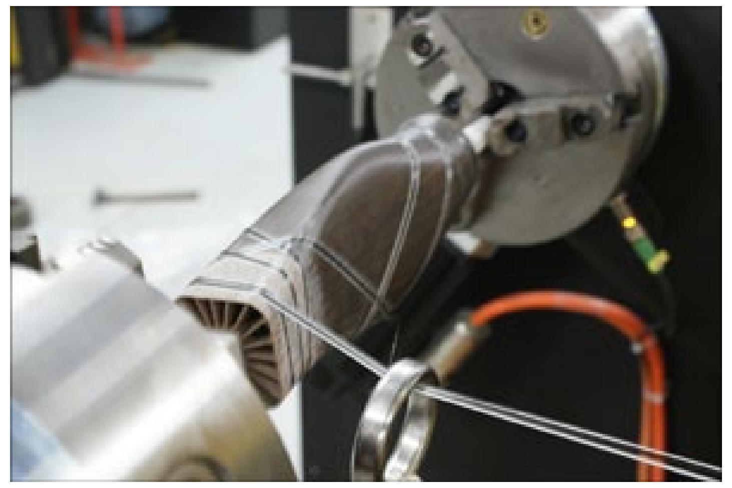


Other Applications

- Rocket motor casings;
- Rocket launch tubes;
- Connecting rods;
- Bottles;
- Golf sticks;
- Shafts;
- Pressure rollers;
- Bushings;
- Bearings;
- Driveshafts;
- Oil field tubing;
- Cryogenics;
- Telescopic poles;
- Tool handles;
- Fuse tubes;
- Hot sticks (non-conducting poles);
- Conduits;
- Fuselage;
- Bicycle frames and handle bars;
- Baseball/softball bats;
- Hockey sticks;
- Fishing rods;
- Ski poles;
- Oars;
- Tubes;
- Missile casings;
- Lamp posts;
- Wind turbine blades.





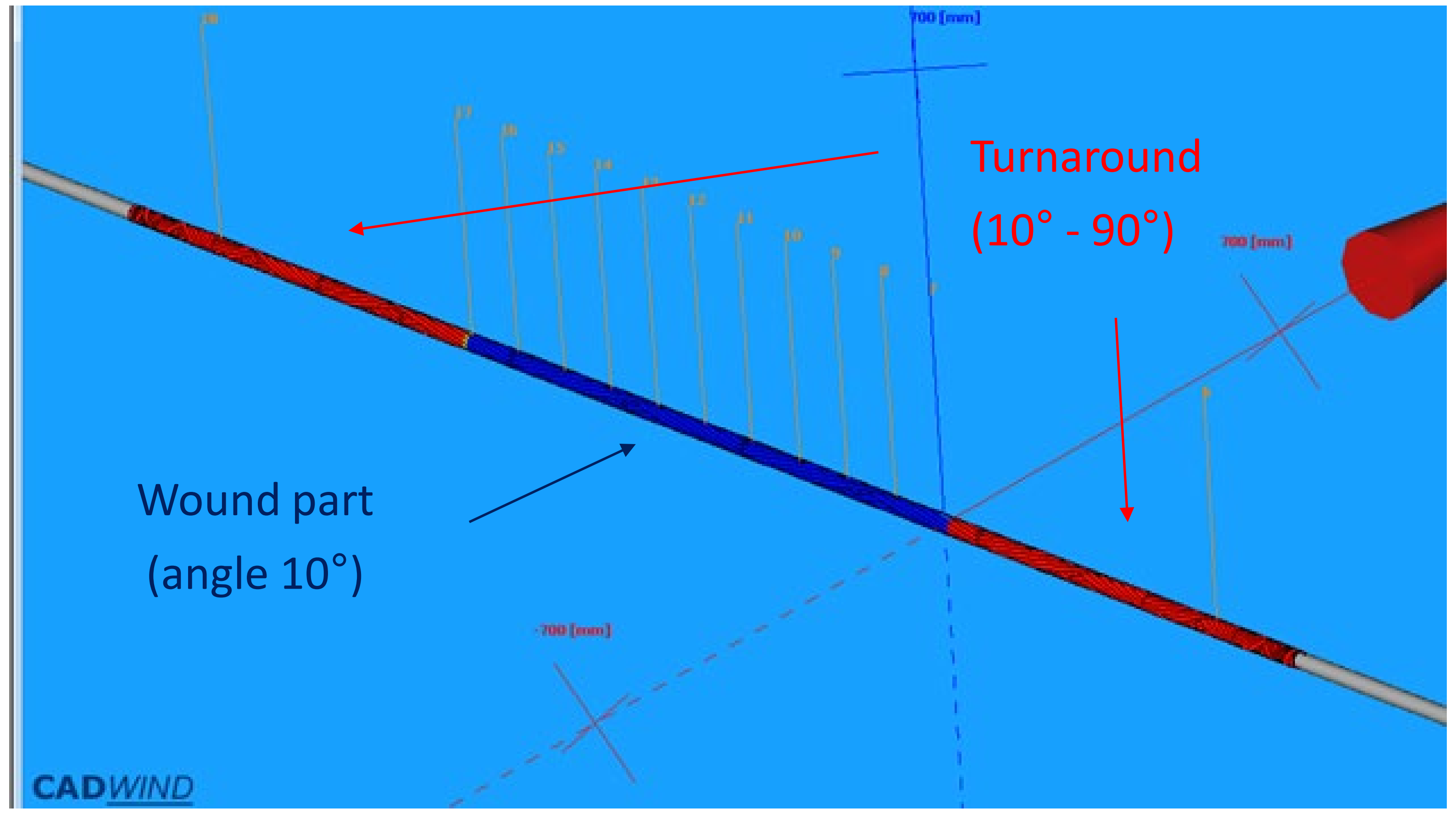


WP5 contributes

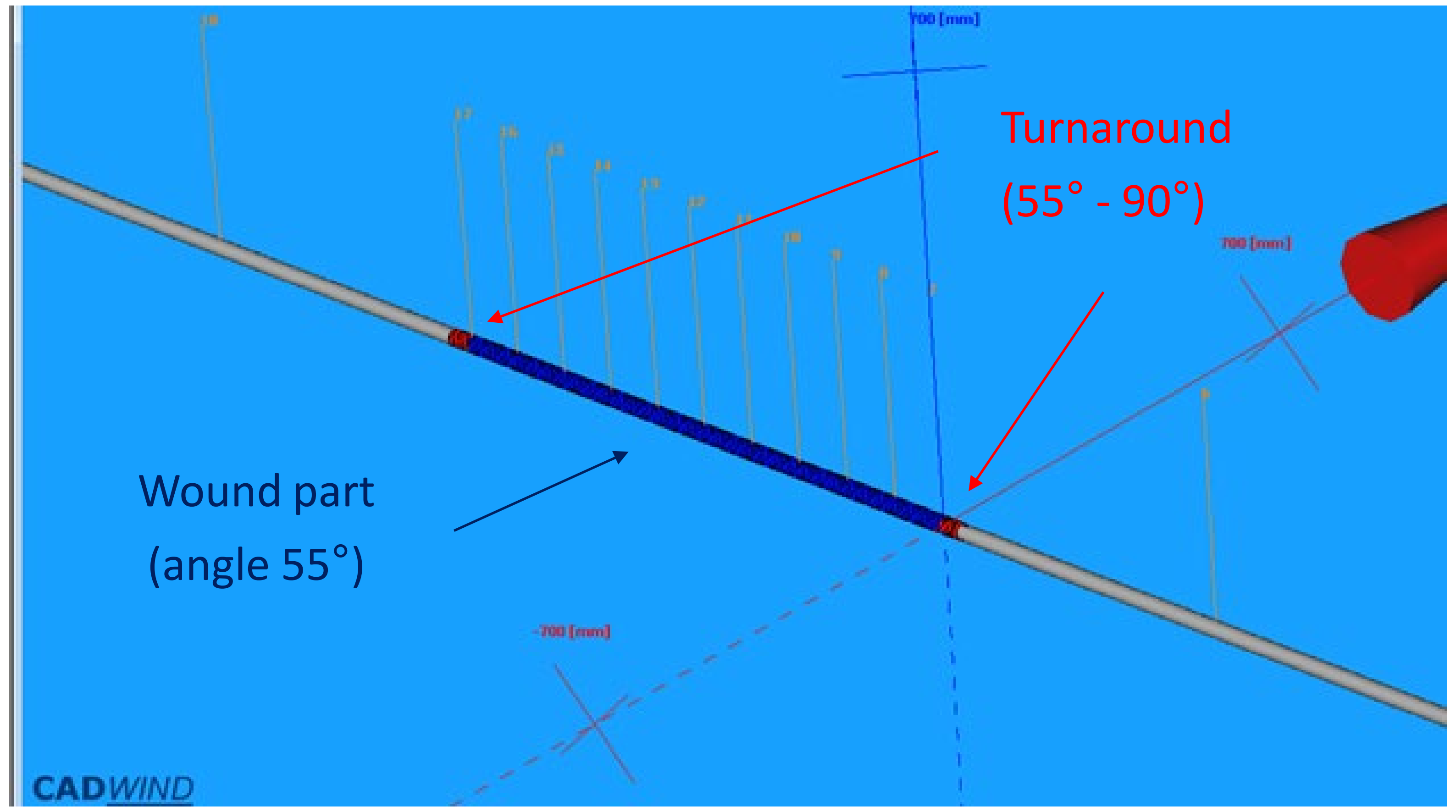
- Running and main achievements: Main process parameters

- Fibre Tension;
- Bandwidth;
- Material/Surface friction coefficient;
- Fibre angle;
- Layup;
- Winding time between layers;
- Fibre overlap;
- Winding pattern;
- Production time;
- Resin viscosity;
- Resin formulation.

Winding angle 10° - Longer turnaround



Winding angle 55° - Short turnaround

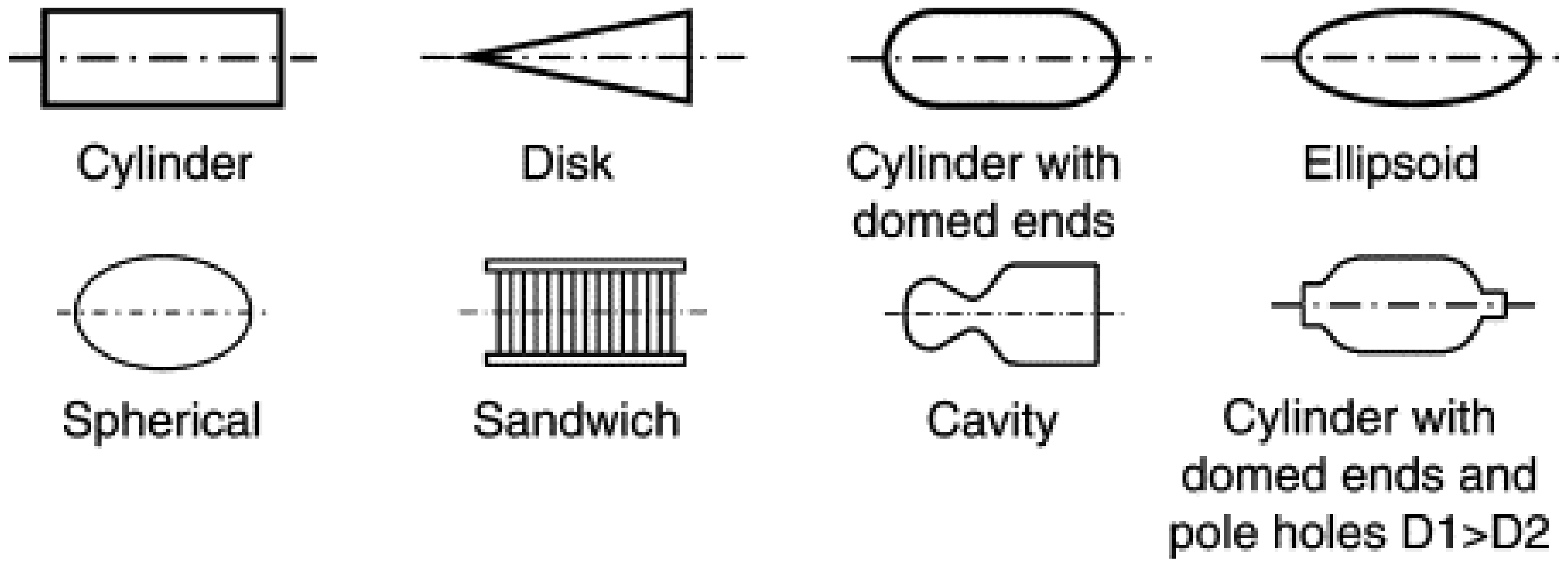


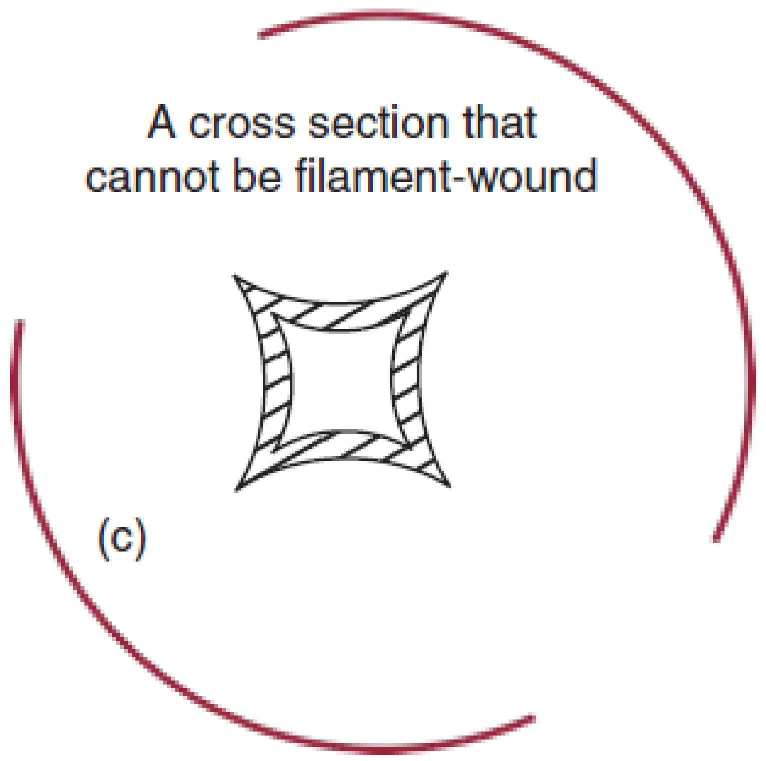
WP5 contributes

- Running and main achievements: Possible winding geometries

Possible winding forms:

- Cylinder;
- Disk;
- Cylinder with domed ends;
- Ellipsoid;
- Spherical;
- Sandwich;
- Cavity (some limitations);
- Cylinder with domed ends and pole holes D1>D2.





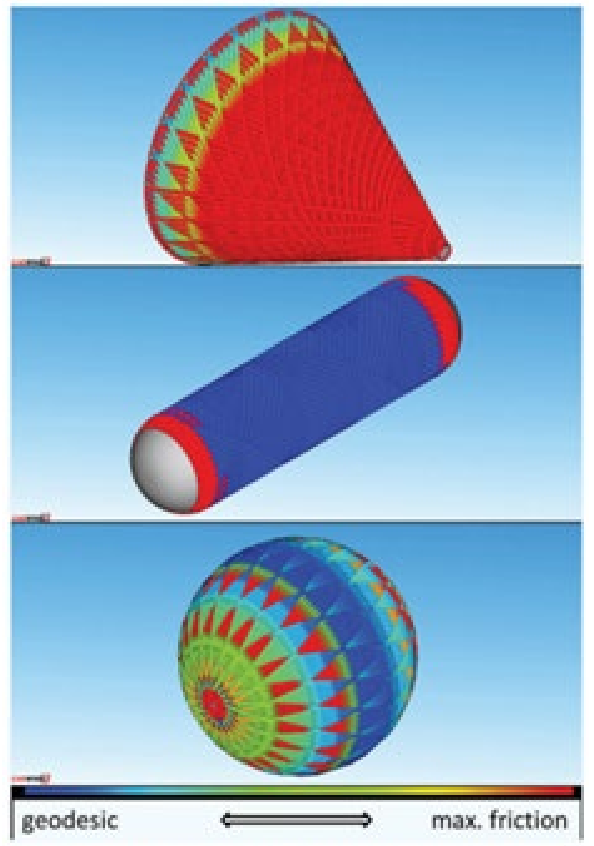
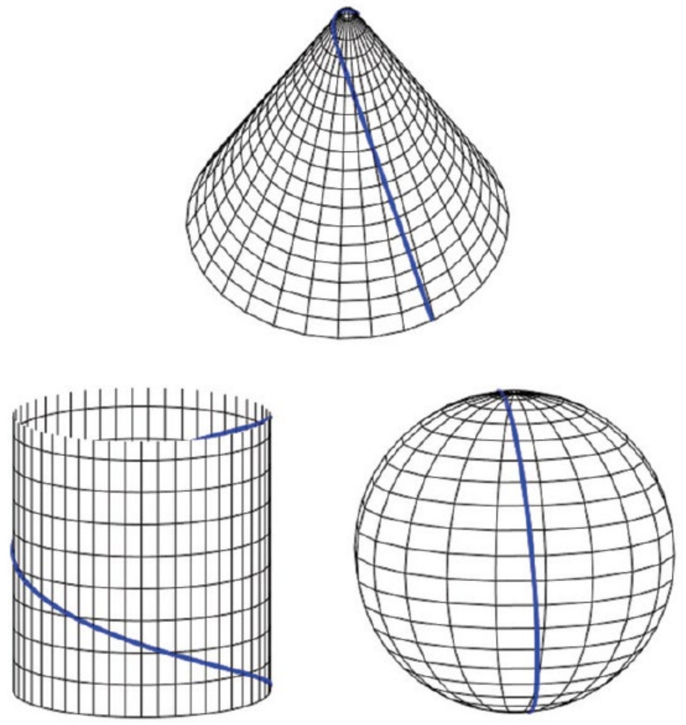
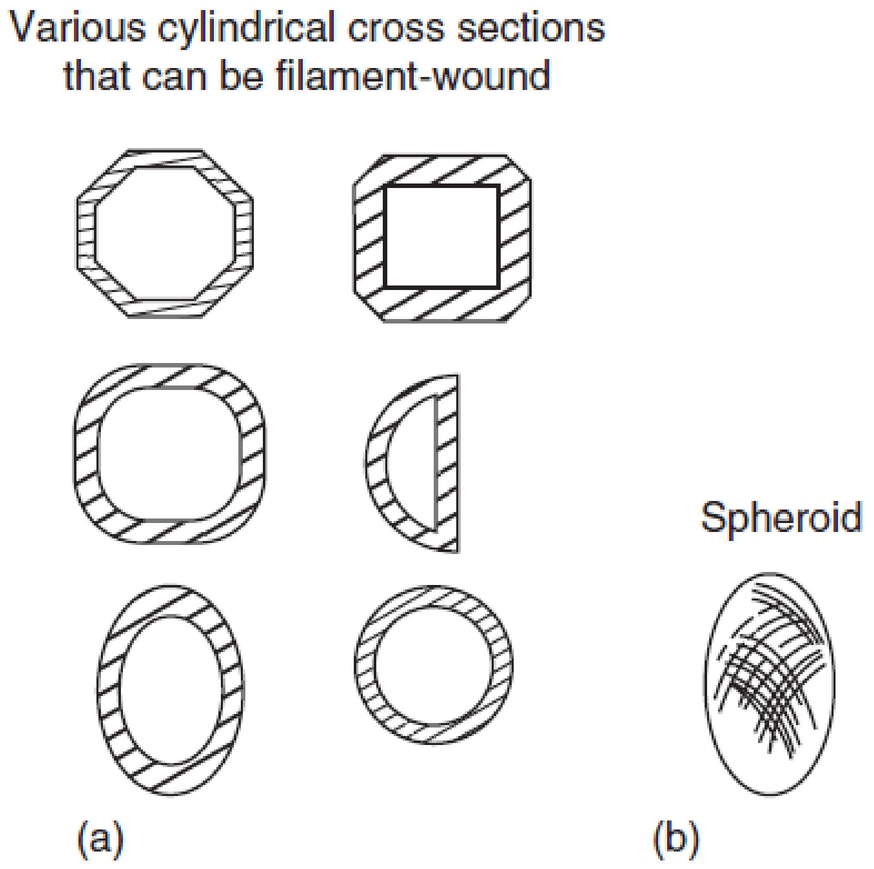


Figure 5. Non-geodesic path on a cone, cylinder and a sphere.





https://www.sciencedirect.com/science/article/pii/B9780857090676500079

WP5 contributes

- Running and main achievements: Filament winding guidelines

- It is limited to producing closed and convex structures. It is not suitable for making open structures such as bathtubs. In some applications, filament winding is used to make open structures such as leaf springs, where the filament wound laminate is cut into two halves and then compression molded.

- Not all fiber angles are easily produced during the filament winding process. In general, a geodesic path is preferred for fiber stability. Low fiber angles (0 to 15°) are not easily produced.

- The maximum fiber volume fraction attainable during this process is only 60%.

- During the filament winding process, it is difficult to obtain uniform fiber distribution and resin content throughout the thickness of the laminate (thickness/fibre buildup on sections that have less surface area).

- Mandrels must have a constant cross section or a slight slope in other to be removed from the wound part.

Mandrels cannot be removed easily on the shapes below, they have to be disassembled, breakable or collapsible.

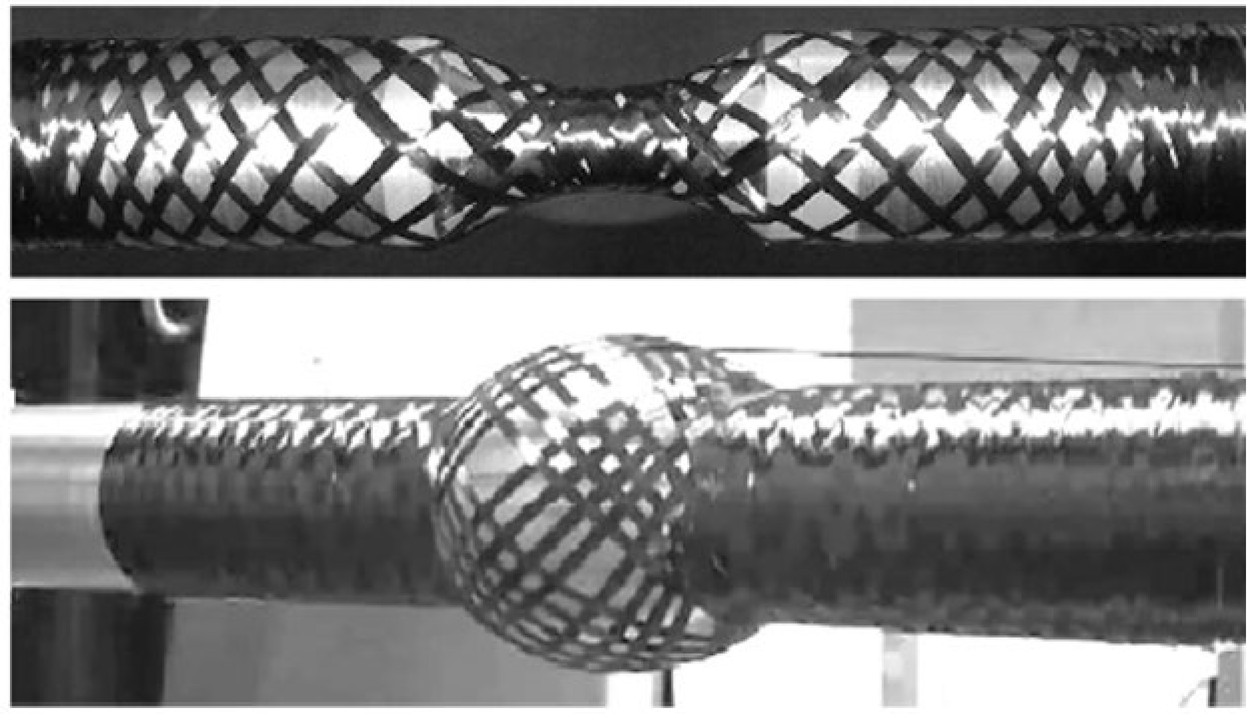
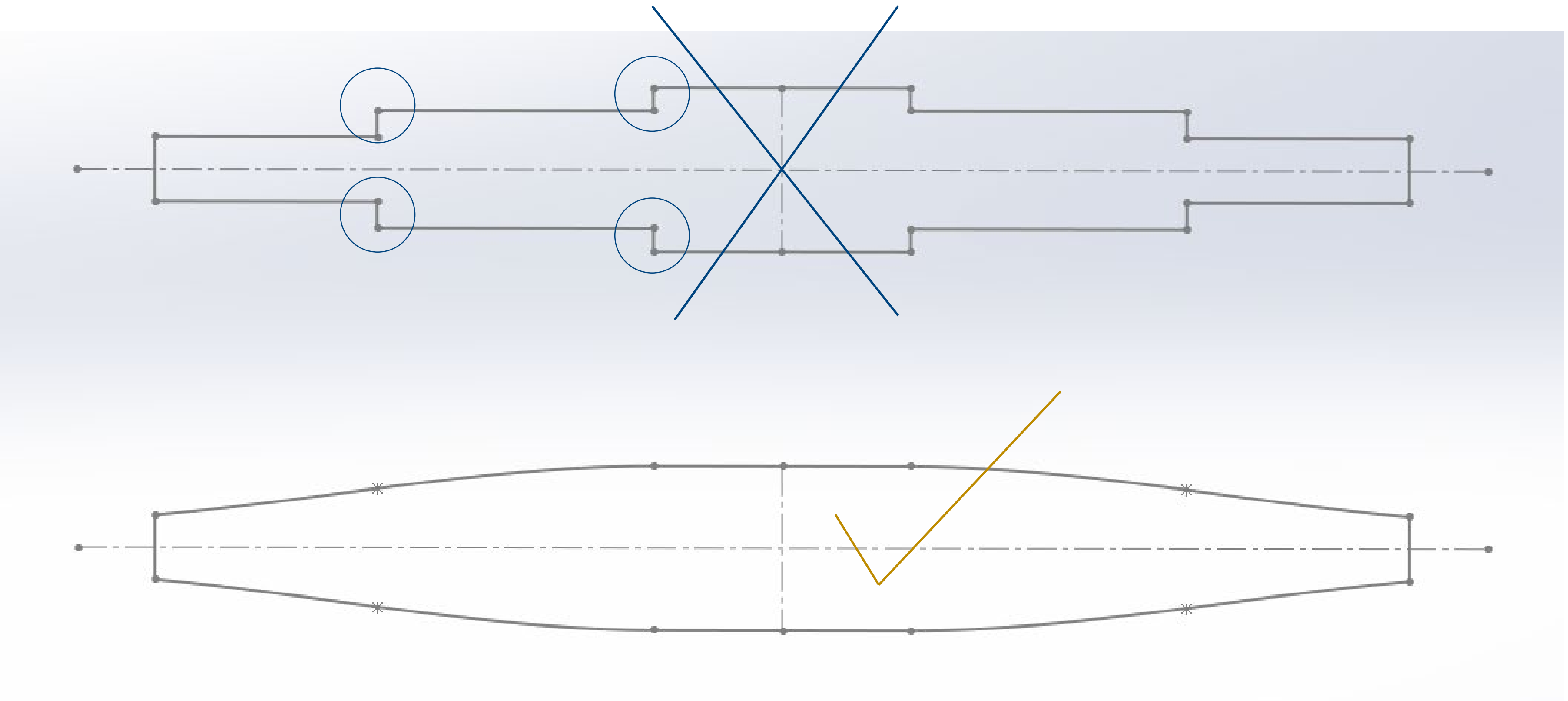


Fig. 11. Filament-wound convex and concave geometry.



Stepped mandrels are also non feasible in filament winding. Cross section variation must be smooth as possible and must take mandrel removal in consideration.

Font: Book - Composites Manufacturing: Materials, Product, and Process Engineering

WP5 contributes

- Planned activities for coming months: design for manufacturing iterations

Geometry presented on initial proposal

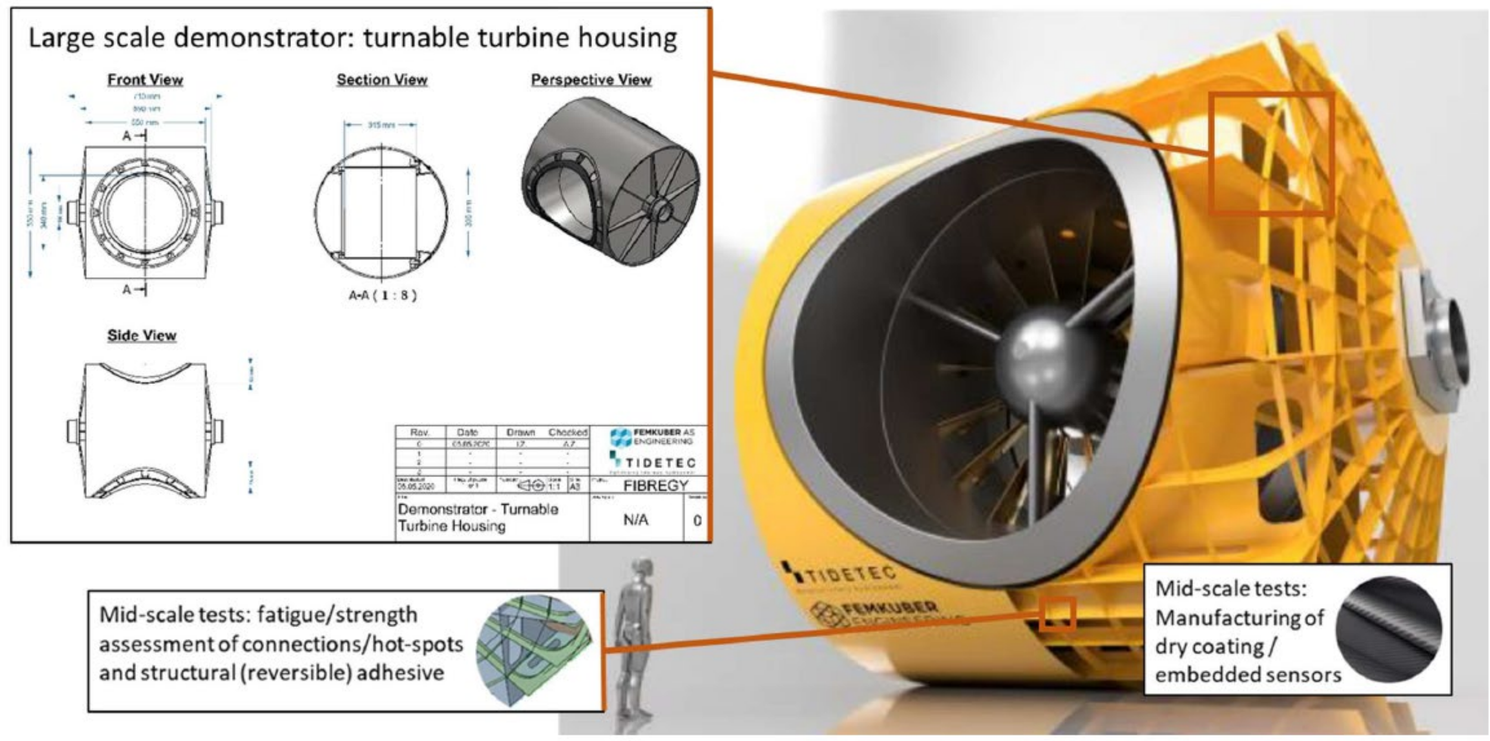
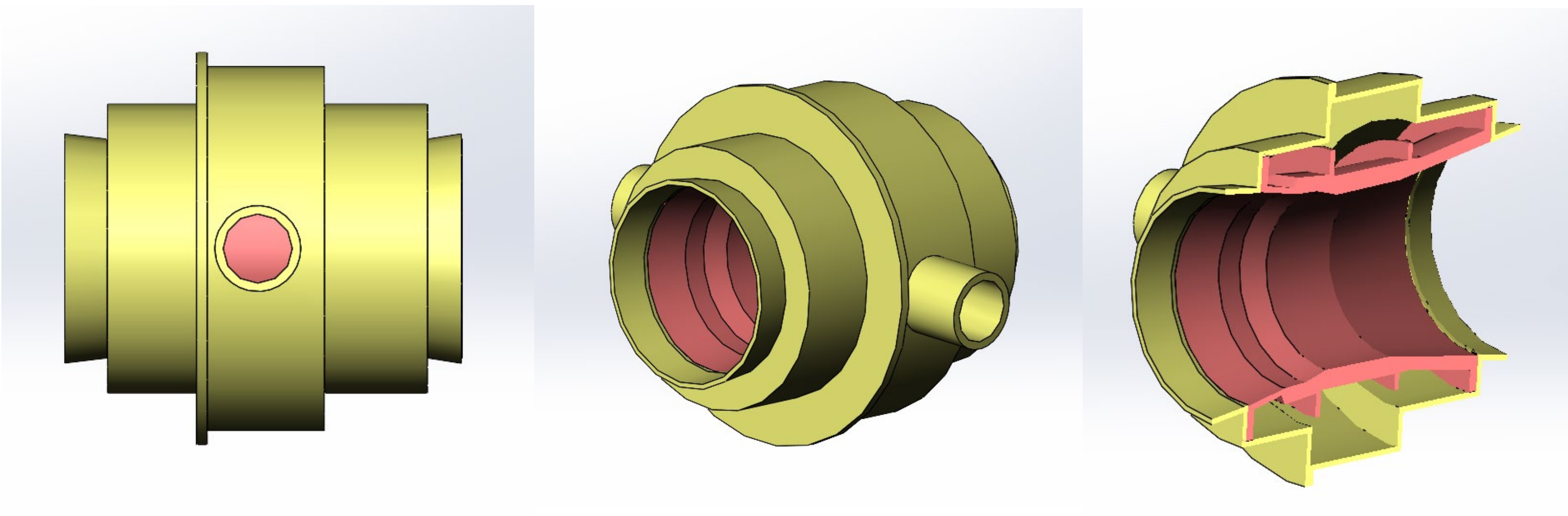


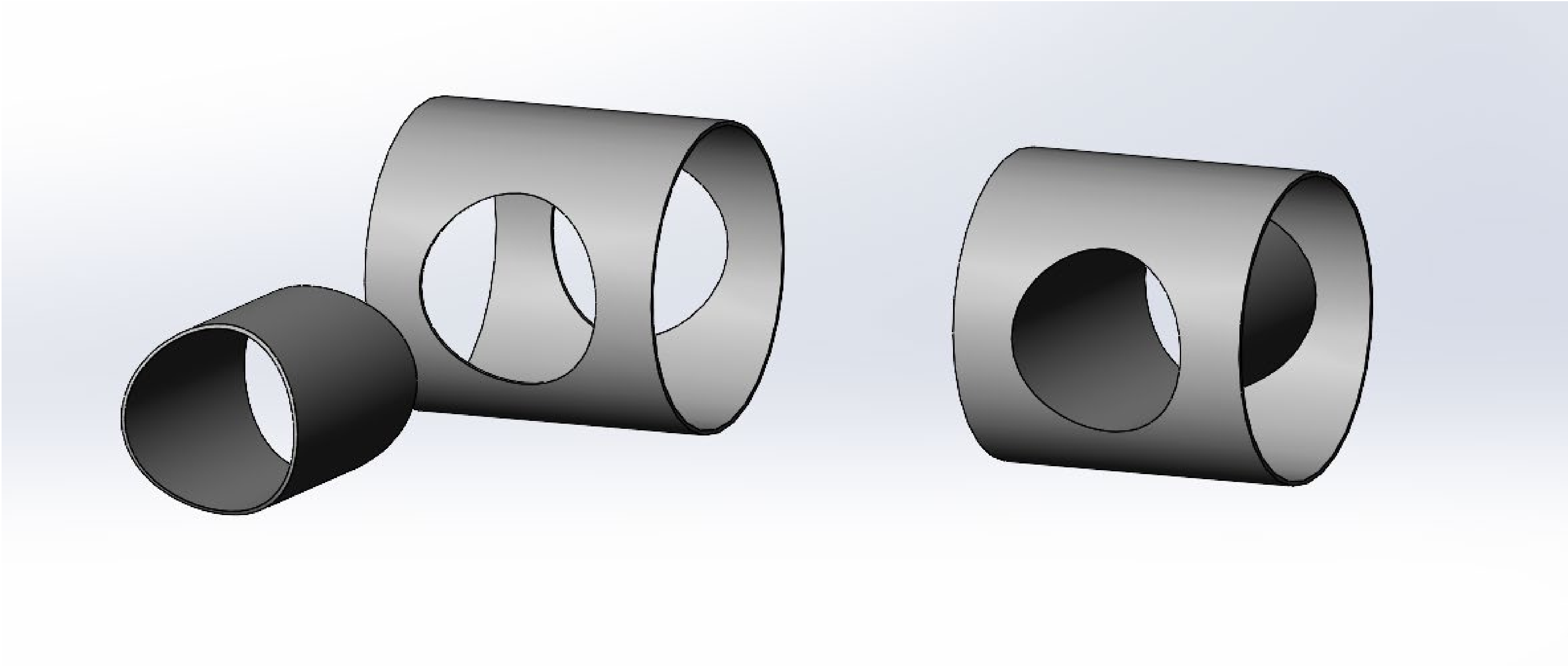
Figure 3. Medium-large scale validation and demonstration activities related to the turnable tidal turbine.

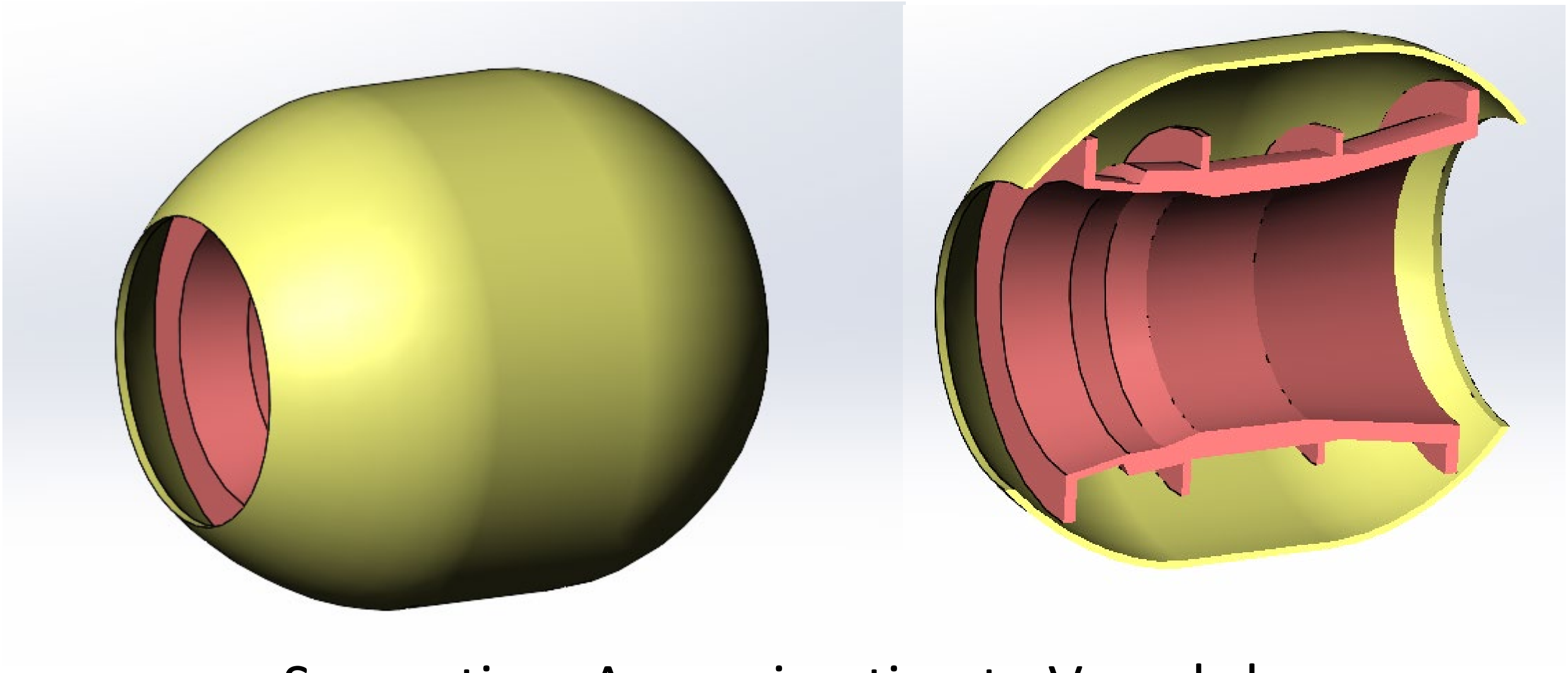
Latest geometry



Parts with such instantaneous cross section variation are not feasible through filament winding (example: stepped cylinder)

Filament winding feasibility





Suggestion: Approximation to Vessel shape
(might have to be cut in two halves for easier access to the inside)

Thank you!

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