

The image features a white circular arrow icon on a green background, positioned to the left of the main title. The icon consists of two curved arrows forming a circle, one pointing clockwise and the other counter-clockwise.

BIO-UPTAKE

Manufacturing & Thermoforming of Sustainable Thermosets

Dr Aratz Genua– 09/Feb/2026 - agenua@cidetec.es



Outline

1. Introduction & concepts
2. Manufacturing processes of 3R composites
3. Enduring preregs
4. Thermoforming process of epoxy vitrimer thermosets
5. Manufacturing of bio-based and thermoformable enduring preregs





1. INTRODUCTION AND CONCEPTS



1. Introduction & Concepts

3R technology

New generation of advanced thermoset polymers and composites based on dynamic covalent chemistry.

The introduction of dynamic covalent chemistry enables a series of “smart” properties, creating a new generation of thermoset polymers and composites that preserve their high performance, while showing new unprecedented features, such as Re-processability, Reparability and Recyclability, called “3R technology”.





1. Introduction & Concepts



**Dynamic 3R
thermosets**

**Self-healing
elastomers**

**3R resins &
composites**



1. Introduction & Concepts



3R Composites

A new generation of **Reprocessible, Repairable and Recyclable** high-performance fibre-reinforced thermoset composites.

They can be manufactured following traditional methods but the resulting material can be reprocessed, repaired and recycled.



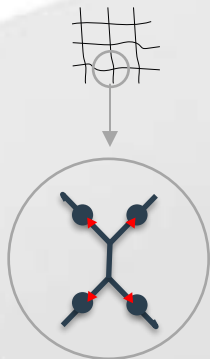


1. Introduction & Concepts

3R technology is based on the reversibility of aromatic disulfide bond:

Schematic representation of conventional epoxy vs 3R dynamic resin.

Conventional polymer network



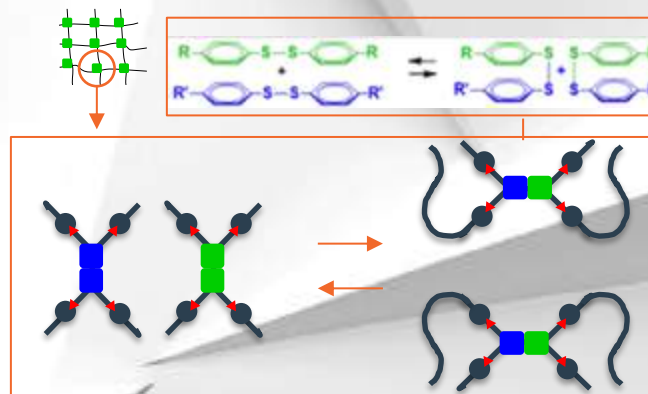
Permanent Crosslinks



Conventional epoxy resin

Non-Reproducible
Non-Reparable
Non-Recyclable

Dynamic polymer network



3R Dynamic epoxy resin

Reproducible
Reparable
Recyclable

Dynamic Crosslinks based on aromatic disulfide exchange



Patent application:

EP 3 149 065 B1 – “Thermomechanically reprocessable epoxy composites and processes for their manufacturing”.

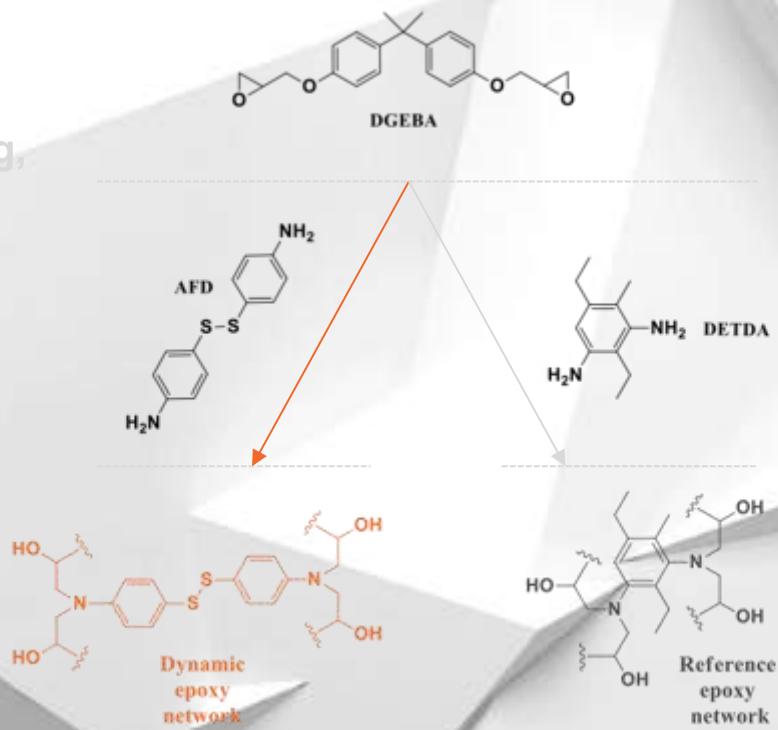


1. Introduction & Concepts

Composites:

> 3R resin

Reprocessing,
Repairing,
Recycling



	Reference network	Dynamic network
Tg (DSC) [°C]	127	130
Tg (DMA) [°C]	130	130
Td [°C]	350	300
E' (25°C) [GPa]	2,5	2,6
E' (150°C) [MPa]	20	20
Stress [MPa]	81	88
Strain [%]	7,3	7,1

Comparable thermal and mechanical properties using our dynamic hardener instead of a conventional hardener.



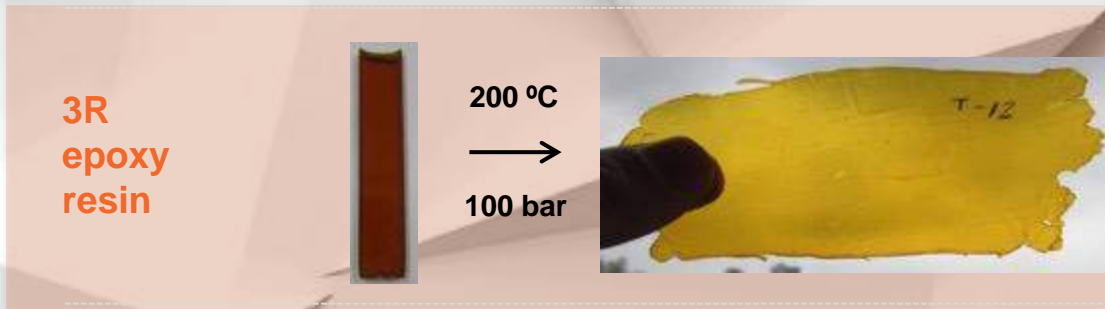
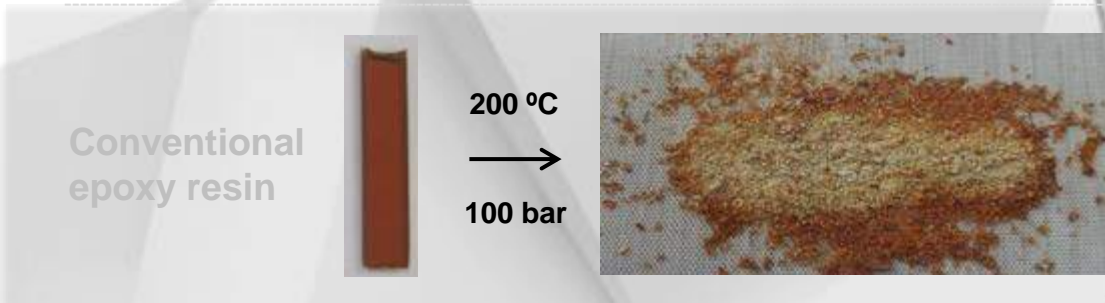
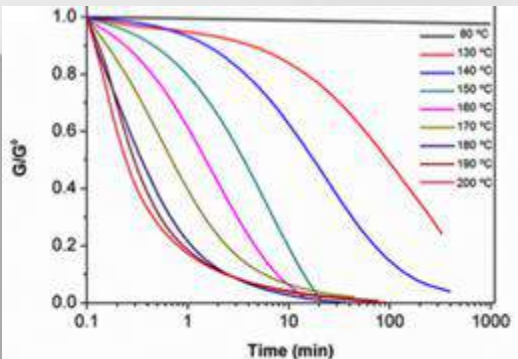
1. Introduction & Concepts

Composites:

> 3R resin

Reprocessing,
Repairing,
Recycling

Characterization of the stress relaxation behavior by DMA



- At temperatures above T_g , the dynamic epoxy network is able to completely relax stress and flow.
- The obtained relaxation times ranged from 3 hours at 130 °C to 20 seconds at 200 °C.



1. Introduction & Concepts



> **3R Composites:**
Reprocessing,
Repairing,
Recycling

3R composite laminates can be heated 80 °C above the T_g and re-shaped in a few minutes applying pressure, which allows the thermoforming of cured 3R laminates to obtain 3D geometries, in a similar way to thermoplastic composites.

https://www.youtube.com/watch?v=5OfEc_yyMJo



35%

reducing the
manufacturing
costs.



This technology enables the development of high production rate manufacturing processes for thermoset composites **reducing the manufacturing costs of thermoset CC parts by over 35% vs autoclave manufacturing.**



1. Introduction & Concepts

> 3R Composites:

Reprocessing,

Repairing,

Recycling

50%

reducing the current costs of MRO.

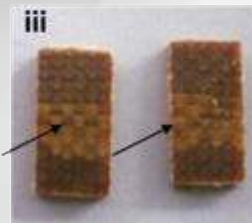
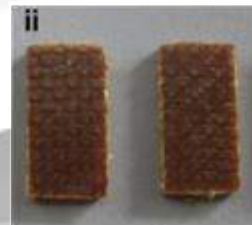
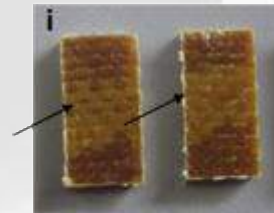


Repair of damages based on resin/fibre delaminations and resin micro-cracks by applying heat and pressure to the damaged part.



This technology enables to reduce the current costs of MRO associated to the reparation or replacement of thermoset CC parts by 50% (nowadays damaged parts are often rejected due to the high costs and repair times of the traditional patch techniques).

ILSS: 37,2 ± 2,81 MPa



ILSS: 38,0 ± 2,4 MPa

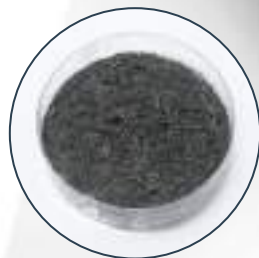
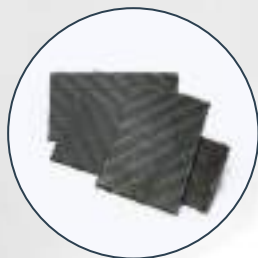


1. Introduction & Concepts



> **3R Composites:**
Reprocessing,
Repairing,
Recycling

Mechanical recycling: the cured 3R composite can be ground into flakes or pellets which can then be reprocessed by heating 80°C above the Tg and pressing, obtaining a new short fibre reinforced 3R composite.



This technology enables the valorisation of the scraps generated during the manufacturing of thermoset CC offering 3 different environmental and industrial advantages:

**REDUCTION
OF LANDFILL
WASTE.**

**REDUCTION
OF THE COSTS
OF WASTE
MANAGEMENT
OF SCRAPS.**

**MANUFACTURING OF
COST COMPETITIVE
AND SUSTAINABLE
NEW THERMOSET CC
PARTS BASED ON
VALORISED SCRAPS.**

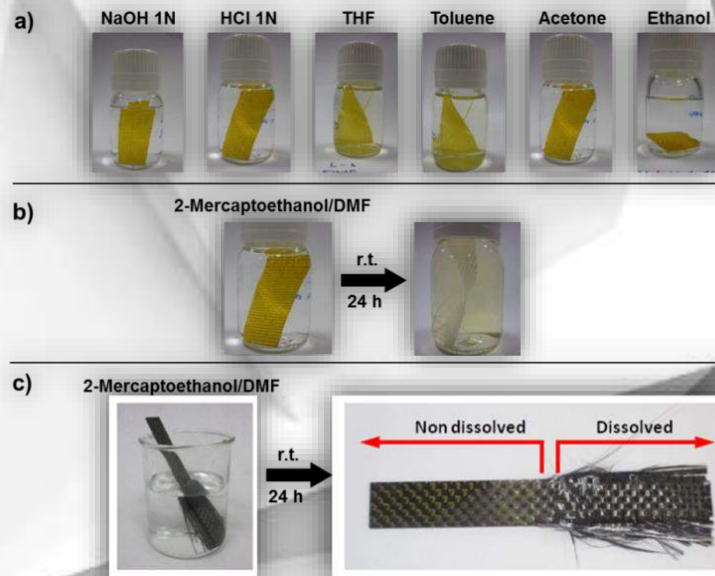


1. Introduction & Concepts



> 3R Composites: **Reprocessing, Repairing, Recycling**

Chemical recycling: the 3R matrix exhibit the same good chemical resistance to conventional solvents and acid or basic media, but it can be completely disrupted by the addition of a specific chemical agent without affecting the reinforcement.



This technology enables the recycling and reuse of the carbon fibre reinforcement offering **environmental and industrial advantages:**

REDUCTION OF LANDFILL WASTE.

MANUFACTURING OF COST COMPETITIVE AND SUSTAINABLE NEW THERMOSET CC PARTS BASED ON VALORISED SCRAPS.



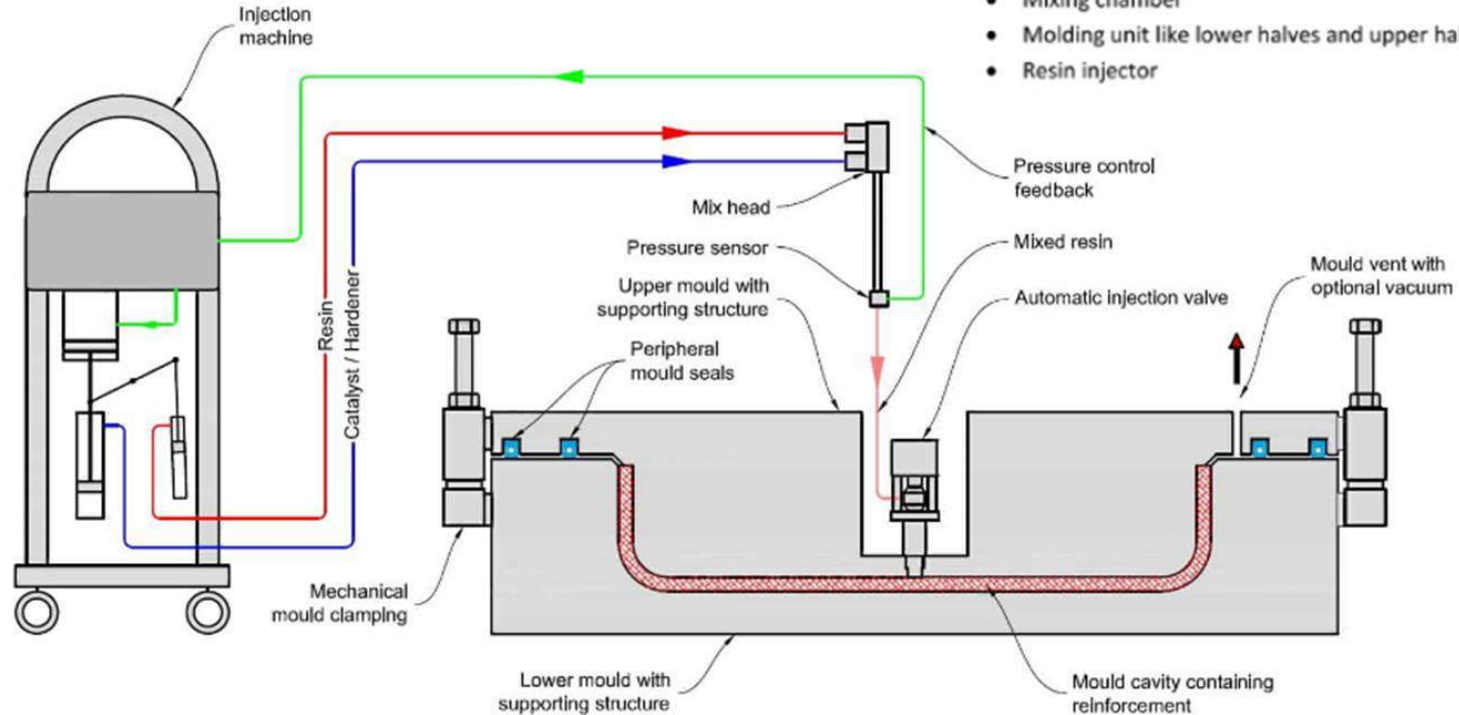
2. MANUFACTURING PROCESSES OF 3R COMPOSITES

2. Manufacturing processes of 3R composites

Resin Transfer Molding

Components of Resin Transfer Molding

- Resin and catalyst container
- Pumping unit
- Mixing chamber
- Molding unit like lower halves and upper halves.
- Resin injector





2. Manufacturing processes of 3R composites

Resin Transfer Molding

Advantages

- **Good surface finish** on both surface of the product
- **Fast cycle time** can be achieved through temperature control device
- The process does not require high injection pressure
- **Wide range of reinforcement**
- Can be manually controlled, semi-automatic, or highly automated
- **Ability to incorporate insert** and other attachment into molding
- Part **thickness is uniform** (determined by the mold cavity)



Applications

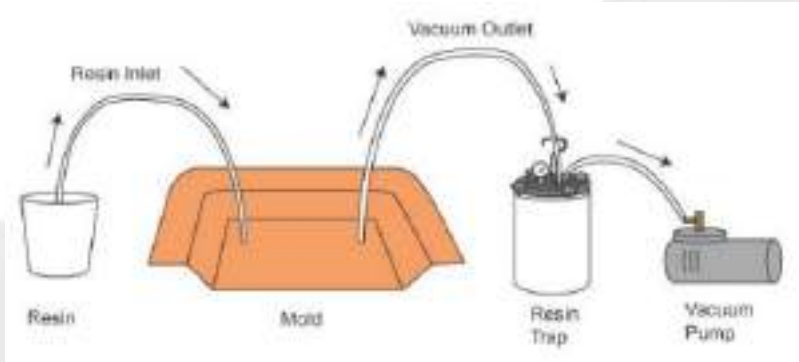
- Complex structure can be produced
- Automotive body parts, big containers, bathtubs, helmets, etc.
- Vehicle panels
- Boat hulls
- Wind turbine blades
- Aerospace parts



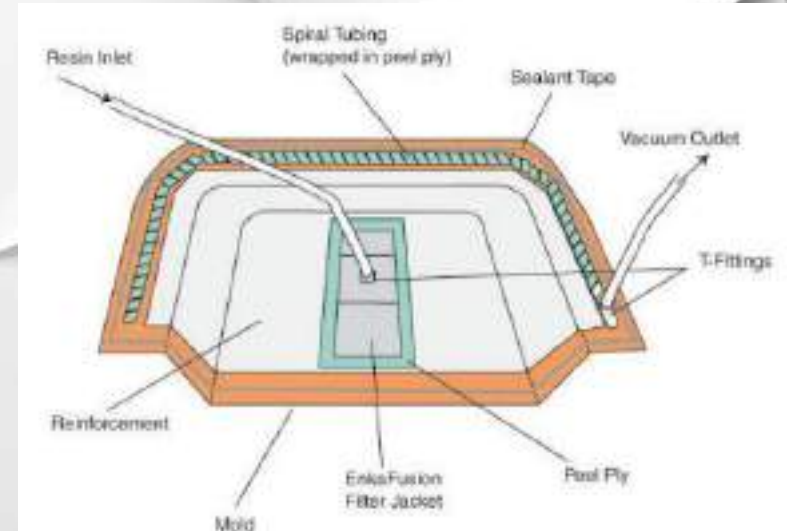
2. Manufacturing processes of 3R composites

Vacuum Infusion

General sequence of events that comprises vacuum infusion



Final arrangement of materials into the mold
(example of one infusion point in the center)





2. Manufacturing processes of 3R composites

Vacuum Infusion

Advantages:

- **High fiber-to-resin ratio** (up to 70% fibers by weight) → High strength and stiffness
- No resin entrapped air/ **very low voids**
- Very consistent laminate with **great process control** (fewer human errors)
- Efficient to laminate **complex fiber layers, ribs, inserts and cores**
- **Cleaner** process with no VOC air pollution

Disadvantages:

- **VIP materials cost** more than standard resins and fabric
- Will consume some **disposable supplies**
- **Complicated set-up** and need to develop the optimal vacuum ports and resin injection locations
- If there is a **vacuum leak**, the part can be scrapped
- Cosmetic finish on the surface is not as good as open mold process due to fabric print through; a barrier coat can be used to improve.

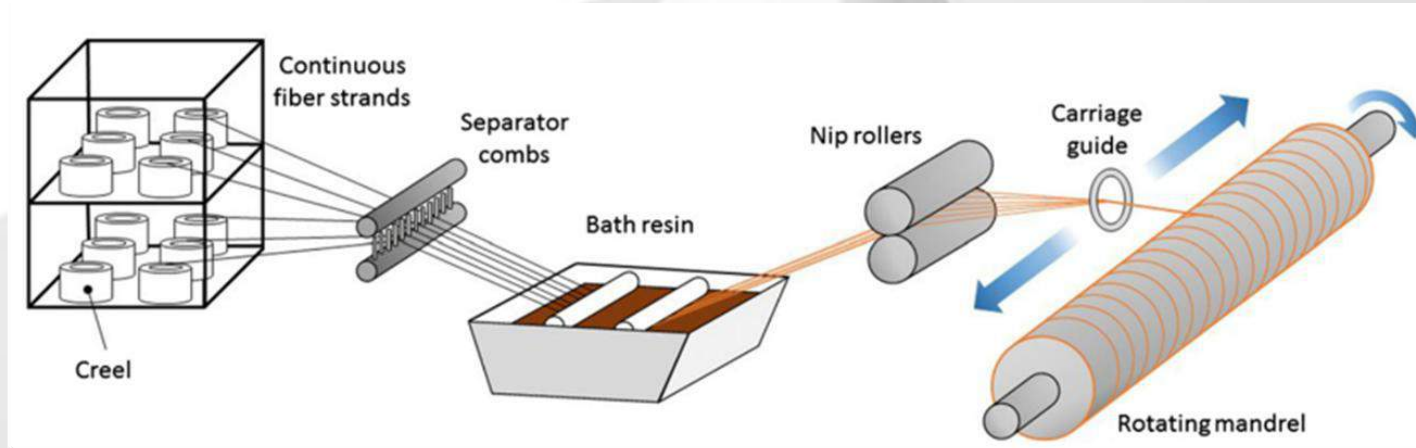
Applications:

- In yachting: boat hulls, structural components.
- In automotive: body panels, components.
- In energy supply: blades for wind turbines.



2. Manufacturing processes of 3R composites

Filament Winding



Typical components:

1. Fiber delivery system (creel)
2. Resin impregnation unit
3. Fiber tensioning mechanism
4. Rotating mandrel
5. Carriage system for fiber placement
6. Computer numerical control (CNC) system

Control parameters:

1. Winding angle
2. Fiber tension
3. Resin content
4. Winding speed
5. Mandrel rotation speed
6. Fiber bandwidth
7. Temperature (for curing)

2. Manufacturing processes of 3R composites

Filament Winding

Advantages:

- **High Fiber Volume Fraction** (50-55%).
- **Precise Fiber Placement and Orientation.**
- High degree of **process automation.**
- **Cost-Effectiveness:** minimal materials waste + lower labor costs due to automation.
- **Versatility** in part size.
- Excellent for **Pressure Vessels:**
 - ✓ Ideal for cylindrical and spherical pressure-bearing structures.
 - ✓ Allows for optimized fiber placement to resist internal pressure.
- **High Production Rates:** continuous process.

Limitations and challenges:

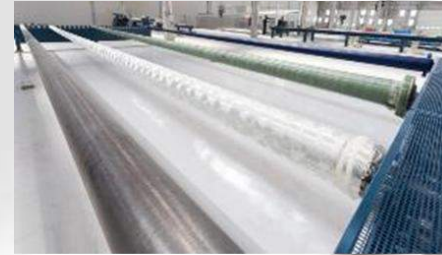
- **Limited to convex shapes**, and difficulty in producing complex or concave geometries.
- **Fiber Angle Limitations:**
 - ✓ Very low angles ($< 15^\circ$) relative to the mandrel axis difficult to achieve.
 - ✓ Additional processes potentially needed for axial reinforcement.
- **Surface Finish:**
 - ✓ External surface generally needs additional finishing.
 - ✓ Resin-rich areas on the external layer.
- **Mandrel Dependency :**
 - ✓ Need for a mandrel for part formation.
 - ✓ Mandrel extraction can be challenging for complex shapes.
- High initial **equipment cost** for automated winding systems:
 - ✓ May not be cost-effective for low production volumes.
- **Material Limitations:** use only continuous fibers, and not all types of reinforcement materials can be used.

2. Manufacturing processes of 3R composites

Filament Winding

Applications:

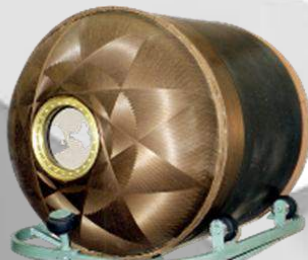
- Pressure vessels and tanks.
- Pipes and tubes for various industries.
- Aerospace components (e.g., rocket motor casings, aircraft fuselage sections).
- Automotive parts (e.g., drive shafts, fuel tanks).



Utility poles



Carbon composite driveshaft



Rocket motor case



Pressure vessels



Tubes for the oil & gas industry



Bicycle frame

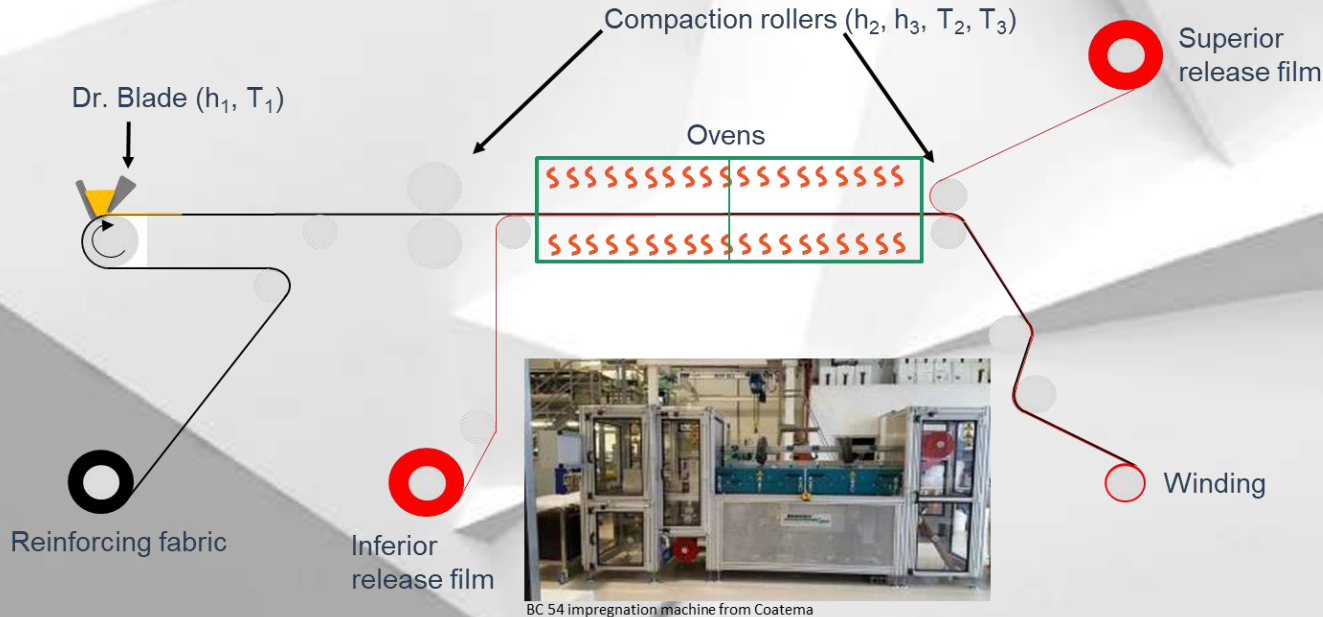


2. Manufacturing processes of 3R composites

Prepreg

Prepreg = reinforcing fabric, such as carbon fiber or fiberglass, pre-impregnated with a resin system.

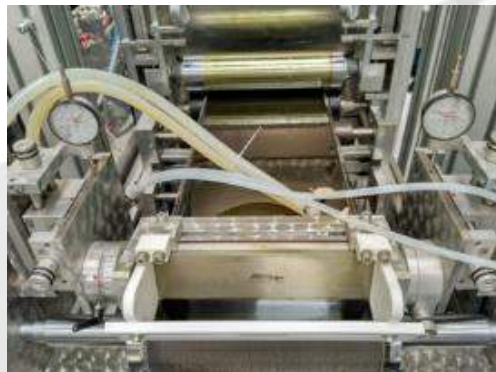
Process:





2. Manufacturing processes of 3R composites

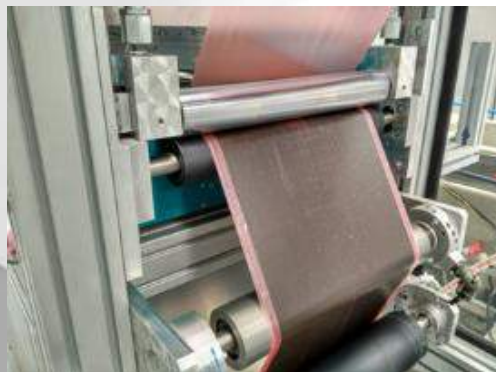
Prepreg



Impregnation of the fabric



First compaction



Second compaction



Winding

2. Manufacturing processes of 3R composites

Prepreg

Using prepreg:

- Sent via **frozen truck** or shipped overnight packed in dry ice. To be **placed in a freezer**.
- Must be given time to **slowly thaw just before use**.
- Must be **placed carefully** because it cannot be repositioned (tacky). Handled, trimmed, pleated and formed using a composite shears.
- After lay-up, need for vacuum bagging to compress the layers of prepreg and reduce air pockets/resin excess.
- **Heat and pressure for curing** -> need for an autoclave, industrial oven or heated press.
- Cured through a curing cycle.

Typical applications include aerospace, racing, sporting goods, pressure vessels, and commercial products.



On-going lay-up



Vacuum bagging of prepreg lay-up



2. Manufacturing processes of 3R composites

Prepreg

Advantages:

Strength properties, ease of use, consistent part production, and high-quality surface finish.

- Controlled Resin Content (30-35%)
- Part Uniformity
- No hand wet layups -> safer, no waste related to resin mixing, consistent parts, no weighting inaccuracy, no resin excess/lack, no fight against the clock to avoid resin setting up
- High-quality products with intricate design features, and adaptable to new parts and changes in design.

Disadvantages:

Cost, shelf life and curing requirements.

- Cost: Fabric impregnation step adds cost (can double).
- Heat Curing : Usually require a combination of heat and pressure to facilitate curing -> need for an oven or an autoclave .
- Shelf Life & Storage: Require refrigeration or freezing prior to use, adding additional transportation and storage cost.



3. ENDURING PREPREGS

3. Enduring prepregs

Enduring prepreg (EPP) concept:

- EPP can **be stored at RT** for years without losing their reprocessability.
- EPP storage is much **cheaper** than for traditional prepregs.
- EPP shipment has **not** any **extra shipping cost**
- The storage at RT offers clear **logistical advantages**
- **Compression forming of pre-cured materials** can take minutes to obtain high performance well consolidated parts.
- They can be **like thermoplastic organosheets**.

Process & use:

- Can be stored in the form of rolls, or flat laminates, at RT (like thermoplastic organosheets).
- T_g and curing degree of the input material can be adjusted on request.



EPPs can be thermoformed to obtain the desired parts using high production rate processes.



3. Enduring prepregs



Input material: EPPs with different curing degrees/ T_g were tested

Final material: $T_g = 180\text{ }^\circ\text{C}$

T = 210 °C for 3 min and after switch off the heating and put the set point at 25 °C ; **P = 50 bar**

Sample	Tg (°C)	Curing degree (%)	Result
1	55,36	58,98	Good
2	174	98,19	Good (some voids are present)

Prepreg reference: **AIR-C-PP-F32-2 (V7)**

- Sample dimensions = 13 cm x 8 cm
- % resin = 36,67 %
- layers = 6
- Doctor Blade Gap = 0,3 mm initial
- Teflon above and below prepreg

58,98 % of curing rate before pressing



Results: prepregs sheets show **good adhesion**, therefore it has a good rigidity and mechanical properties.

98,19 % of curing rate before pressing



Results: Good aspect but some delaminations appear when bending, higher press time and pressure are required



4. THERMOFORMING PROCESS OF EPOXY VITRIMER THERMOSETS



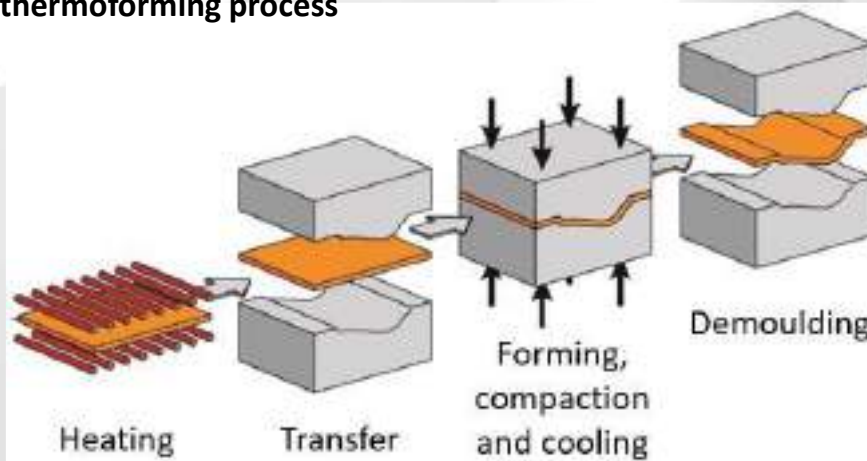
4. Thermoforming process of epoxy vitrimer thermosets

What is thermoforming?

Schematic of the thermoforming process



Carbon fiber composite laminates



Example of thermoformed carbon fiber composite part

Process:

1. Heat the composite laminate
2. Transfer the hot laminate to a press with the tool mounted
3. Close the press to form the hot laminate to the tool geometry
4. Apply pressure and wait for the formed part to cool down to a temperature low enough to freeze the material.
5. Open the press and demold the part



4. Thermoforming process of epoxy vitrimer thermosets

Advantages: fast cycle times, design flexibility, lightweight parts, and potential for large-scale/automated production.

Applications: aerospace interior panels, automotive body panels, protective equipment, consumer goods.



Thermoformed brackets (left) connecting the fuselage frame and skins in the A350 XWB (right)



Thermoformed rib (left) being welded to the leading edge skin (right) of the A380

Materials: limited to thermoplastic composites

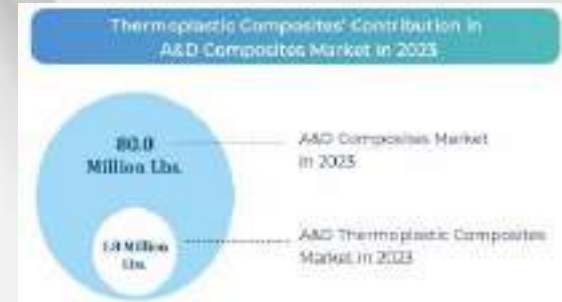


4. Thermoforming process of epoxy vitrimer thermosets

Thermoset composites

Market

- Used in the **majority of advanced composites applications**.
- Over 90% of the carbon fiber reinforced polymer (CFRP) market.



<https://www.composights.com/article/Thermoplastic-Composites-Taking-off-into-a-Clearer-Future>

Strengths

- Excellent dimensional stability.
- High temperature resistance.
- Low viscosity during processing.
- Good fiber wet-out.
- Established certification history

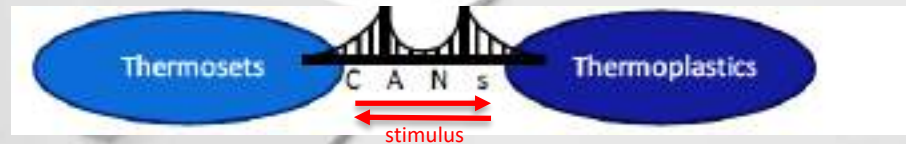
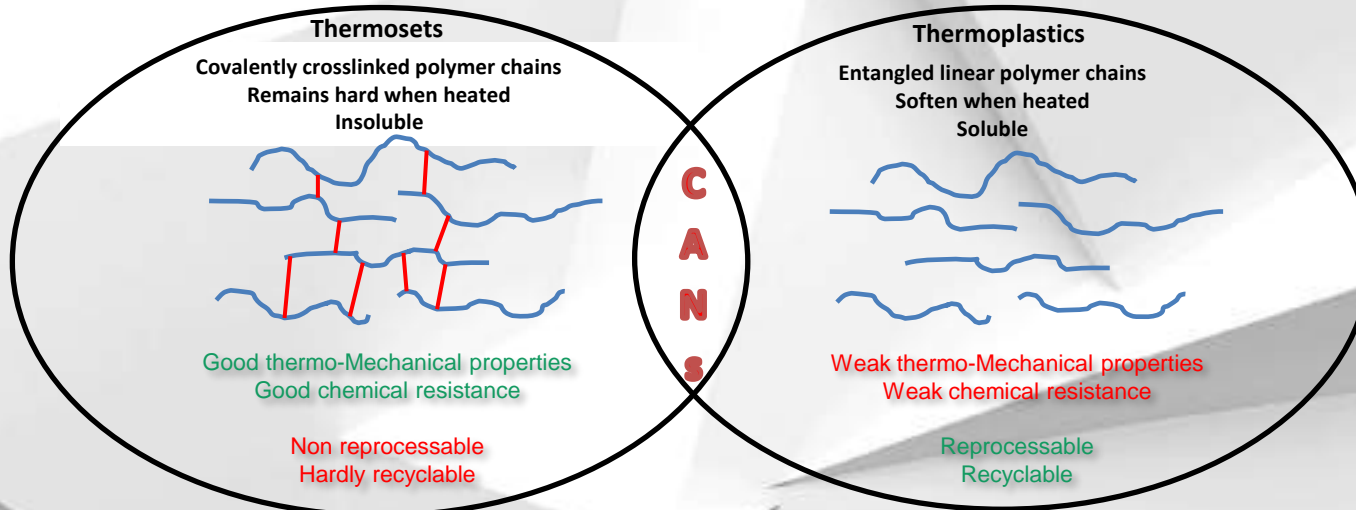
Processing drawbacks

- Longer processing times (manual or automated layup of individual plies, followed by resin transfer (if not using prepreg), and eventually the curing of the resin.
- Cannot be remelted or reshaped after curing → not thermoformable.



4. Thermoforming process of epoxy vitrimer thermosets

Thermosets versus thermoplastics



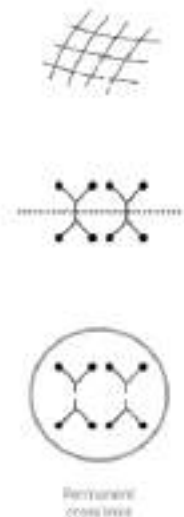
CANs = Covalent Adaptable Networks



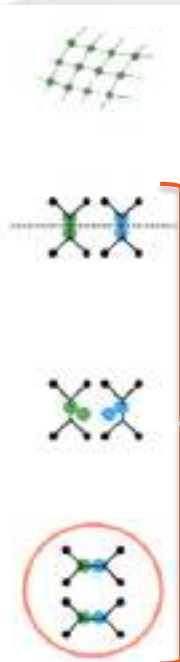
4. Thermoforming process of epoxy vitrimer thermosets

Covalent Adaptable Networks

Conventional thermosets



CANs



Example of epoxy vitrimers based on aromatic disulfide exchange

Reprocessable

Reprocessing of cured composite laminates

Repairable

Easy repair of delamination damages applying local heat and pressure.

Point of delamination damage

Repaired area

Recyclable

Mechanical recycling applying heat and pressure to obtain second generation parts.

Non-carbonate generated

Easy matrix disruption for high quality fiber recovery.





***5. BIO-BASED AND
THERMOFORMABLE ENDURING
PREPREGS***



5. Bio-based and thermoformable enduring preregs

Thermoforming of bio-based 3R composites

Biobased 3R composite laminates can be heated above the T_g and re-shaped in a few minutes applying pressure, which allows the thermoforming of cured 3R laminates to obtain 3D geometries, in a similar way to thermoplastic composites.

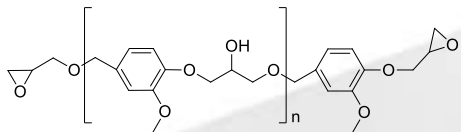
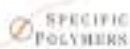
ECOxy





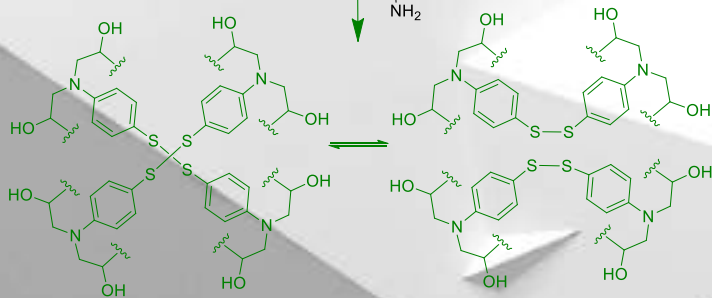
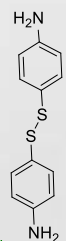
5. Bio-based and thermoformable enduring preregs

Manufacturing of bio-based enduring preregs



DGEVA

4-AFD



	Biobased dynamic network
T _g (DSC) [°C]	82
T _d [°C]	231
E' (30 °C) [GPa]	3,1
E' (135 °C) [MPa]	17
Stress [MPa]	84 ± 3
Strain [%]	4,9 ± 0,7



UD AmpliTex™ 300 g/m²



BX +/-45 AmpliTex™ 350 g/m²



BIO-UPTAKE Project – Sensitive

Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or HaDEA. Neither the European Union nor the granting authority can be held responsible for them.

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5. Bio-based and thermoformable enduring preregs

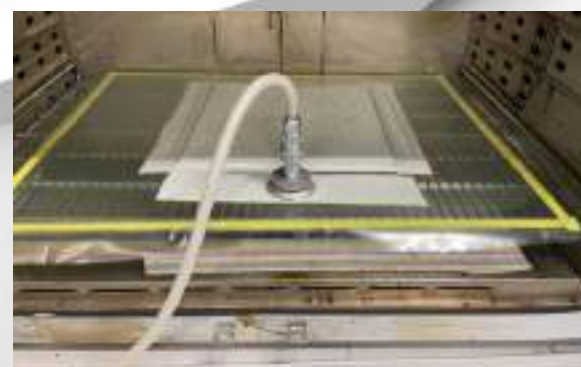
Manufacturing of bio-based enduring preregs





5. Bio-based and thermoformable enduring preregs

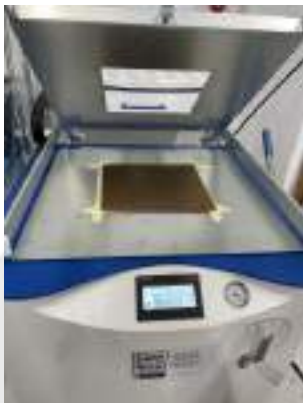
Vacuum bag processing





5. Bio-based and thermoformable enduring preregs

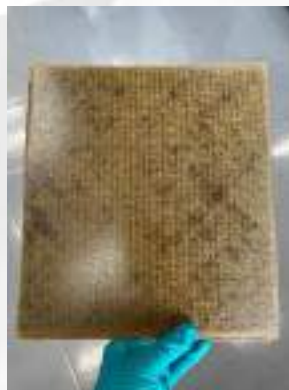
Vacuum thermoforming





5. Bio-based and thermoformable enduring prepregs

Hot-press processing



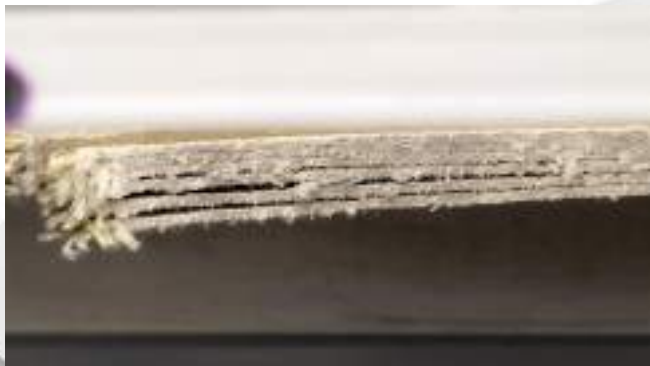
**Better interlaminar
adhesion** is obtained
with press-curing





5. Bio-based and thermoformable enduring preregs

Hot-press thermoforming



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Thank you for your attention

The logo features the text "BIO-UPTAKE" in a bold, white, sans-serif font. The text is centered within a white rounded rectangular border. Two white curved arrows are positioned around the text: one above and one below, both pointing to the right, suggesting a cycle or process.

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Manufacturing & Thermoforming of Sustainable Thermosets - FAQ

Dr Aratz Genua– 09/Feb/2026 - agenua@cidetec.es