AIRPOXY

Thermoformable, repairable and bondable smart epoxy- based composites for aero structures

Deliverable 1.3

Report on the preliminary analysis and definition of specifications for the raw materials

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0.1	30/01/2019	Initial draft for comments	Antoine DE FONTGALLAND Diego CALDERON
0.2	21/02/2019	Addition of details on protections	Antoine DE FONTGALLAND
1.0	26/02/2019	Final version	

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Glossary

Abbreviation / acronym	Description
N/A	Not Applicable
WP	Work Package
CFRP	Carbon Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
DCM	Discontinuous Compression Moulding, process in which the material is hot formed / compression moulded in one or several discontinuous steps
CCM	Continuous Compression Moulding, process in which the material is hot formed continuously by
RTM	Resin Transfer Moulding
SQRTM	Same Qualified Resin Transfer Moulding
Enduring prepreg	The term "enduring" prepreg means that the prepreg ply is partially or completely cured, so it does not need to be stored refrigerated. The 3R material is in this case proposed as a roll or sheets of (almost) cured individual plies. Thanks to the welding properties of the 3R materials, there is no time limitation between the manufacturing date of the prepreg and its processing date
AR/RT	As Received (No conditioning) / Room Temperature (for the test)
HW2	Material moisture saturated at 70ºC/85%RH until equilibrium and test at 70°C
HW4	Material moisture saturated at 70ºC/85%RH until equilibrium and test at 120°C
FVC	Fibre Volume Content
BVID	Barely visible impact damage

References

[1]	D1.1. Report on the preliminary specifications for demonstrators
[2]	D1.2. Report on the preliminary analysis and definition of process technologies requirements for manufacturing, bonding and repair
[3]	RTCA DO-160. Environmental Conditions and Test Procedures for Airborne Equipment
[4]	SONACA Memo: Demonstrator & process definition

1. Executive Summary

In order to achieve the project's objectives, the Work Package 1 aims at defining the specification for the demonstrators, the processes involved and the raw materials.

In this Deliverable D.1.3, end-users partners IDEC and SONACA defined their specifications for the raw material to be used or developed in the project for their respective demonstrators, as well as the expected mechanical properties of the resulting laminates.

This deliverable presents the collected specifications that will be used as input for the development of the different 3R resin system / 3R adhesive / 3R prepreg.

2. Introduction

Several 3R materials will be developed by CIDETEC and evaluated in the AIRPOXY project in order to manufacture the two demonstrators proposed by IDEC and SONACA.

This deliverable presents, for each element of the sub-components, the requirements of the materials that will be used and / or that shall be developed

The specifications include:

- Details on the commercial materials with which the developed 3R material shall be compatible.
- Physicochemical properties related to the manufacturing processes.
- Mechanical properties that the final laminates should be able to withstand.
- Requirements regarding the resistance to fluids.
- Requirements regarding the protections that would be applied in production on the 3R surfaces.

3. Raw materials specifications

3.1. Raw materials specifications for the Fan-Cowl demonstrator

3.1.1. Fan-Cowl demonstrator

Idec's demonstrator is a fan-Cowl sub-component made of three distinct elements: a skin, a transverse stiffener and a longitudinal stiffener.

Both the skin and the transverse stiffener will be manufactured in RTM, using commercial dry Fabric / Unidirectional and 3R resin system (to be developed in this project).

The longitudinal stiffener will be made through thermoforming of 3R materials (Commercial CFRP woven fabric and UD with 3R resin system).

Once the three elements are manufactured, they will be bonded together using a dedicated 3R adhesive. See deliverable D.1.2 for more details on the bonding process.

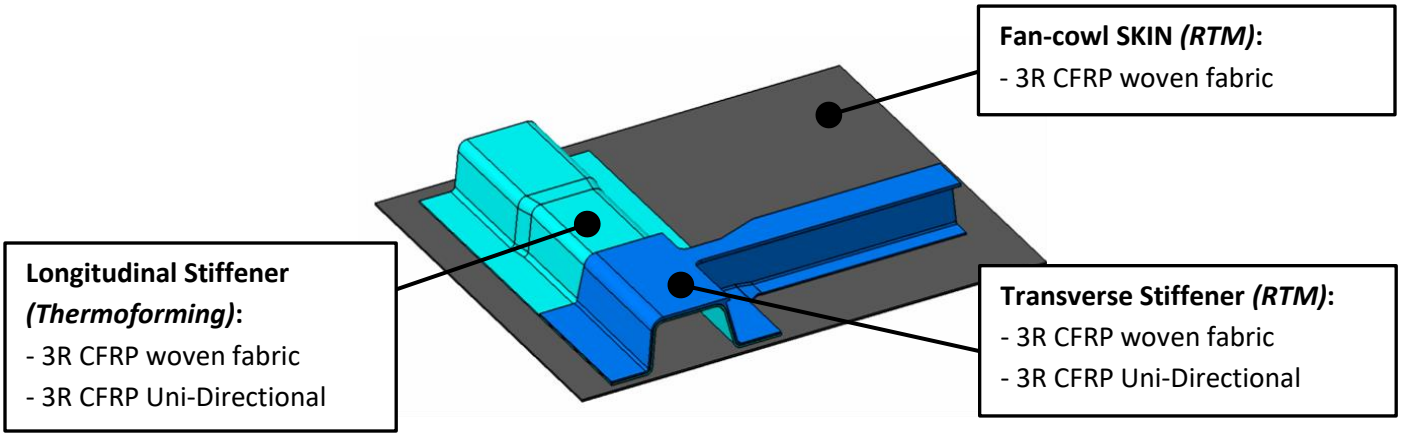


Figure 1: IDEC's Fan-Cowl demonstrator

3.1.2. Raw material specification for the SKIN and the Transverse Stiffener (Fan-Cowl)

The skin of the Fan-cowl and the Transverse Stiffener will be manufactured in RTM (separate moulds).
Two reinforcements should be used: a dry 5 Harness Satin Carbon Fabric and an Unidirectional. The Skin will only use the fabric reinforcement while the transverse stiffener will use both the fabric and the Unidirectional.

The RTM resin will be a 3R RTM system developed by CIDETEC on the basis of a classical certified injection resin with a specifically designed hardener allowing the 3R properties of the material.
Table 1 hereunder defines the specifications for the raw materials of the skin and the transverse stiffener, as well as the mechanical properties of the expected composite materials.

Materials		Material specifications	Unit	Value					
Resin / Hardener		Viscosity	cps	< 30					
		Density	g/cm3	< 1.2					
		Working time (at 80°C)	min	> 60					
		Curing time	min	< 90					
		Glass Transition Temperature (AR/RT)	°C	> 170					
		Glass Transition Temperature (HW2)	°C	> 150					
		Tensile Strength	MPa	75 - 80					
		Tensile Modulus	MPa	2800 - 3300					
		Elongation at break	%	4 - 6					
		Flexural Modulus	MPa	2700 - 2900					
		Flexural Strength	MPa	125 - 135					
		Cost	€/l	70					
Reinforcements		Efibre	GPa	≥ 290					
		Density	g/cm3	< 1.82					
		Weave style	-	**5H Satin**			**UD Plain**		
		Number of filaments	-	6K					
		Nominal Weight	g/m2	250 - 400			150 - 300		
		Sizing	-	3R compatible					
		Powdering	-	2 faces					
		Powdering quantity	g/m2	< 6%					
		Composition or main material of reinforcements	/	Carbon fibre					
		Cost	€/m2	70			30		
Thermoplastic veil		Veil	-	3R compatible					
		Activation Temperature (range)	°C	120 - 180					
		Activation Time	min	< 10					
		Cost	€/Kg	N/A					
Mechanical / Phycical		FVC	%	58					
	Ply properties	Stacking sequence	Degrees	(0)n			(0)n		
		Conditioning		**RT**	**HW2**	**HW4**	**RT**	**HW2**	**HW4**
		Tensile Modulus, warp direction (E11t)	MPa	> 70000			> 155000		
		Tensile Modulus, weft direction (E22t)	MPa	> 70000			> 8500		
		Ultimate Tensile Strain, warp direction (ε11t)	με	> 14000			> 15000		
		Ultimate Tensile Strain, weft direction (ε22t)	με	> 11000			> 5600		
		Comprenssion Modulus, warp direction (E11c)	MPa	> 68000			> 140000		
		Comprenssion Modulus, weft direction (E22c)	MPa	> 68000			> 8500		
		Ultimate Compression Strain, warp direction (ε11c)	με	> 9500	> 6900	> 3900	> 9900	> 8000	> 4500
		Ultimate Compression Strain, weft direction (ε22c)	με	> 9500	> 6900	> 3900	> 30000	> 25000	> 12000
		In-Plane Shear Modulus (G12)	MPa	> 4500	> 3600	> 2300	> 4400	> 3500	> 2200
		Ultimate In-Plane Shear Strain (ε12)	με	> 19000	> 20200	> 21200	> 18700		
		Interlaminar Shear Strength (f13)	MPa	> 60	> 42	> 30	> 70	> 40	> 30
		Interlaminar Tension Strength (f33t)	MPa	> 25	> 18	> 10	> 65	> 45	> 30
	Laminate properties	Stacking sequence	Degrees	Quasi- isotropic laminate					
		Conditioning		RT		HW2		HW4	
		Compression After Impact (CAI) [(1)]	με	> 4600		> 3300		> 2400	
		Open Hole Tension (fxx,oht)	MPa	> 490		> 380		> 360	
		Open Hole Compression (fxx,ohc)	MPa	> 340		> 250		> 180	
		Fracture toughness (G1c)	J / m^2	> 700					
		Filled Hole Compression (fxx, fhc)	MPa	> 430		> 300		> 275	
		Bearing (fxx,b)	MPa	> 900		> 850		> 480	
		Pull-Through Strength (fpt)	MPa	> 60		> 50		> 40	

AR/RT: As
HW2: material
HW4: material
[(1)] :Impact energy for a 0.3mm dent after relaxation, 35J energy cut-off

Table 1: Specifications of the raw materials to be used / developed for the fan-cowl demonstrator

3.1.3. Raw materials for the Longitudinal Stiffener

The longitudinal stiffener will be made through thermoforming of 3R flat panels which will have been produced, in principle, through RTM. During next WPs other manufacturing process, as CCM and DCM will be considered also as alternatives.
The specifications for the reinforcement are the same as for the 5 HS carbon fabric and Unidirectional that shall be used for both the Skin and the transverse stiffener. See Table 1.
Similarly, the specifications for the 3R RTM resin are the same as the ones presented in Table 1.

3.1.4. Specification for the 3R adhesive film

The bonding of the skin with the transverse and longitudinal stiffener will use a 3R adhesive film. This adhesive will have to be able to fill gaps up to 0.3mm between the elements.

The specifications for this adhesive film are given in Table 2 hereunder.

Material	Specification	Unit	Value
Adhesive film	Format		Film
	Thickness	mm	0.1 - 0.4
	Curing time	min	< 90
	Tg	°C	> 170
Bond line	Single Lap shear (AR/RT)	MPa	20
	Single Lap shear (HW4)	MPa	17
	G1c	J/m²	800

AR/RT: As Received / Room Temperature
HW2: material moisture saturated at 70ºC/85%RH until equilibrium and test at 70°C
HW4: material moisture saturated at 70ºC/85%RH until equilibrium and test at 120°C

Table 2: Specification for the 3R adhesive to be developed for bonding the Fan-Cowl elements

3.2. Raw materials specifications for the Leading-edge demonstrator

3.2.1. Leading-edge demonstrator

SONACA's demonstrator is a sub-component from a wing leading edge representative of commercial airplane parts. The demonstrator is a shorter (with a maximum span-wise dimension around 2.2m) and simplified version, composed of three elements: one skin and two webs.

The WEBS use 3R materials (Commercial dry CFRP/GFRP woven fabrics with 3R resin system) to be developed in this project, that will be put in shape through thermoforming.

The SKIN uses commercial prepreg materials and a 3R adhesive film (to be developed in this project), with the SQRTM process.

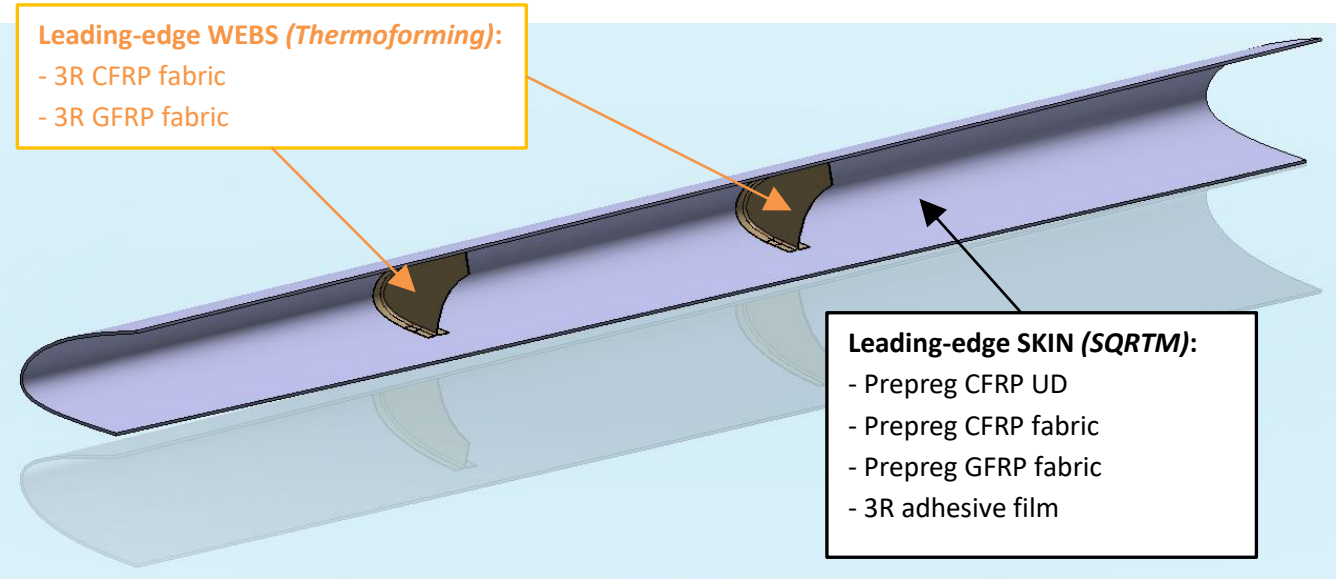


Figure 2: SONACA's leading-edge demonstrator

3.2.2. Raw materials for the SKIN (Leading-edge)

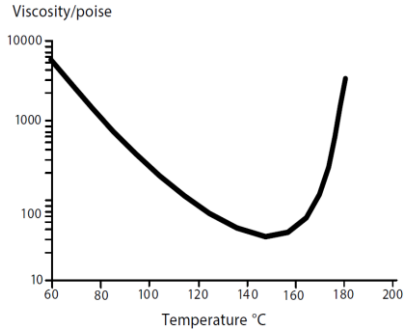
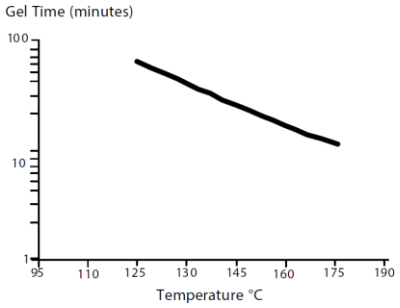
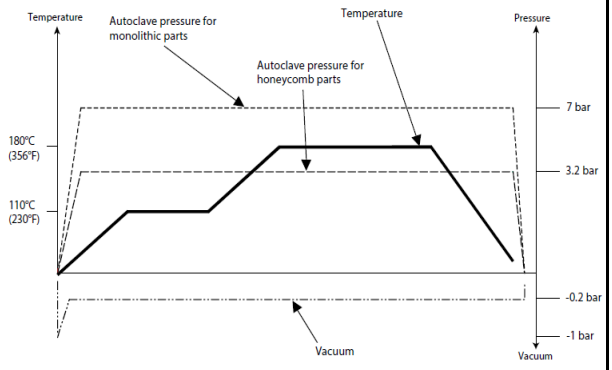
Commercial prepreg materials

Three commercial prepreg materials from Hexcel will/would be used in the skin:

- Hexply AS4/8552 RC34 AW194
- Hexply 8552S/37%/AGP280/C
- HexPly 8552/42%/220/G

The three materials use the same epoxy resin system 8552.

Table 3 hereunder presents the specifications of the commercial prepreg used for the skin of the leading-edge.

Materials			Value		
Prepeg	Reinforcement	style & structure of the prepreg	Unidirectional	Fabric - 5HS	Fabric - 4HS 220 style
		Fibre designation	AS4 (Carbon)		E-Glass
		Fibre density	1.79 g/cm³		-
		Number of filaments	12K	3K	-
		Fibre volume fraction	59 %	55 %	-
		Fibre aerial weight	-	280 g/m²	109 g/m²
	Resin of the prepreg	resin	8552 epoxy resin system from Hexcel		
		Rheology			
		Gel time			
		Generic curing cycle (1)			
		Tg (Onset dry)	>190 °C		
		Tg (Onset wet)	> 150 °C		
		Storage life	12 months at -18°C from date of manuf		
		Work life	15 days tack life		
	Wheight needed for one piece (g, Kg)		~ 20 m²	~ 2 m²	~ 20 m²
	Costs ($)/m²		~ 30 $/m²	~ 50 $/m²	~ 10 $/m²

(1): See Memo - Demonstrator & Processes [4] for mor precise curing data

Table 3: Specifications of the commercial prepreg used in the skin of the leading-edge

3R adhesive film

The 3R adhesive film is one of the materials to be developed by CIDETEC in this project.

It shall serve as an adhesive film on the internal surface of the skin lay-up where the webs will be welded. The 3R adhesive film is co-cured with the rest of the skin prepregs during the SQRTM injection.

Two commercial adhesive films used in production at SONACA will be used as reference materials for the investigation.

Materials		Value
3R Film	Adhesive	Compatible with the prepreg resin and the 3R resin of the webs
	Thickness range	0.1 mm - 0.2 mm
	Carrier	Polyester Mat or Knit
	Viscosity	Higher than the prepreg
	Tg (Onset dry)	> 170 °C
	Tg (Onset wet [(1)])	> 150 °C
	Gel time	Equivalent or slightly faster than the prepreg
	Degasing	Should not degase before 120°C
	Curing cycle	Same as the prepreg (co-curing)
	Storage life	12 months at -18°C from date of manuf
	Work life	15 days tack life
	Qty needed for one piece	~ 0.1 m²
	Single lap shear (Comp/comp) [(2)]	25 - 35 MPa

[(1)]: After Hot / wet conditioning at 70° / 85% RH

[(2)]: Range of value for information. The Single Lap Shear properties of the welding process will be tested and compared to concurrent processes as Co-curing and secondary bonding.

Table 4: Specifications of the 3R adhesive film to be developed for the welding of the skin / webs

3.2.3. Raw materials for the WEBS

The webs will be manufactured through thermoforming of 3R materials. The 3R materials feeding the thermoforming process will be either 3R flat panels manufactured in RTM or stackings of enduring 3R prepregs (see Deliverable D1.2. on processes [2]).

Two types of reinforcements will be used for the webs, a carbon fiber fabric and glass fiber fabric. The specifications for the dry fibers and for the final materials (resulting from the combination of the selected fiber and the developed 3R resin) are presented in Table 5

Materials		Value	
3R Resin	Tg (Onset dry)	>190 °C	
	Tg (Onset wet)	> 150 °C	
Reinforcement	Weave style	Fabric - 5 HS	Fabric - 4 HS
	Fiber designation	Carbon fiber	E-Glass
	Thickness per ply	~ 280 µm	~ 90 µm
	Weight	280 g/m²	107 g/m²
	Number of filaments	3K - 6K	-
Ply properties (*Mean values*)	Ply thickness	0.280 - 0.370 mm	N/A
	E1 [Gpa]	62	N/A
	E2 [GPa]	62	N/A
	G12 [GPa]	4.2 (RT) / 3.5 (HW2)	N/A
	F11t [MPa]	900 (RT) / 800 (HW2)	N/A
	F11c [MPa]	-670 (RT) / -560 (HW2)	N/A
	F22t [MPa]	900 (RT) / 800 (HW2)	N/A
	F22c [MPa]	-670 (RT) / -560 (HW2)	N/A
	F12 [MPa]	100 (RT)	N/A
Laminate properties *(Mean values)*	Thickness	~ 1.3 mm	N/A
	FVC	between 50-60 %	N/A
	Stacking sequence	QI lay-up *Typically : [-45;90;+45;0]* $_s$	N/A
	Plain tensile strength (MPa)	> 550 (RT) / > 550 (HW2)	N/A
	Plan tensile modulus (GPa)	46	N/A
	Open Hole Tensile Strength (MPa)	300	N/A
	Plain compressive strength (MPa)	440	N/A
	Plain compressive modulus (GPa)	41	N/A
	Open Hole Compressive Strength (MPa)	300	N/A
	In Plane Shear Strength (MPa)	95 (RT) > 75 (HW2)	N/A
	Bearing (MPa)	885 (RT) > 680 (HW2)	N/A
	CAI (E BVID = 1mm) (µStrain)	- 4800 (RT) / -4200 (HW2)	N/A

Table 5: Specifications of the raw materials to be used / developed for the webs

3.3. Resistance to fluids

The materials developed in the AIRPOXY project shall resist the following fluids taking into account the exposure time defined by the RTCA DO-160 [3]:

- De-icing fluid (NATO S-745)
- Fuels
- Oils
- Greases
- Lubricant

- Cleaning agents (MEK)
- Hydraulic Fluid (Skydrol LD-4 and Hyjet V or equivalent)
- Extinguishing agents
- Water, waste
- Salted water
- Dusty air.

3.4. Protections

The exposition of the 3R laminates to the exterior will require adequate protection. The objective of the project not being to develop any specific protection system, the 3R materials shall be compatible with the commercial protection systems already applied on exterior surfaces.

For leading-edge parts, typical protections for the exterior surfaces would include: an epoxy primer, a polyurethane erosion painting and a final polyurethane top coat.

Other exterior surfaces less submitted to erosion would require having the 3R laminate covered by one or two layers of epoxy primers before a final polyurethane top coat.

The compatibility of the 3R materials shall be assessed through adhesion tests, scratch tests, etc.

4. Conclusion

The preliminary specifications given in this deliverable shall be used as input for the selection of commercial dry reinforcements and for the development of 3R resin systems.

Dry reinforcements to be chosen are:

- CFRP fabric for the Fan-Cowl (skin, transverse stiffener and longitudinal stiffener)
- CFRP Unidirectional for the transverse and longitudinal stiffeners of the fan-cowl demonstrator
- CFRP fabric for the webs of the leading-edge demonstrator
- GFRP fabric for the webs of the leading-edge demonstrator

The following 3R resin systems shall be developed:

- 3R RTM system for the RTM injections of the skin and the transverse stiffener of the fan-cowl
- 3R adhesive film for bonding the fan cowl demonstrator subcomponents.
- 3R adhesive film for the bonding of the leading-edge's skin with the webs.3R RTM system for the RTM injections of the flat panels for thermoforming.
- 3R resin system for the impregnation of the enduring prepreg for thermoforming.