FIBRESHIP

INTEGRAL COMPOSITE SHIP

1^{st} FIBRESHIP WORKSHOP

Breakout session 1:

MATERIALS

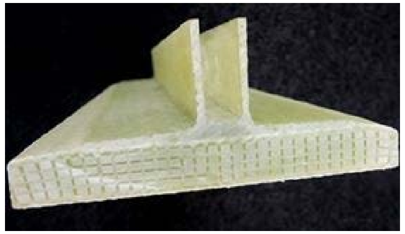
LONDON

June 14^{th} 2018

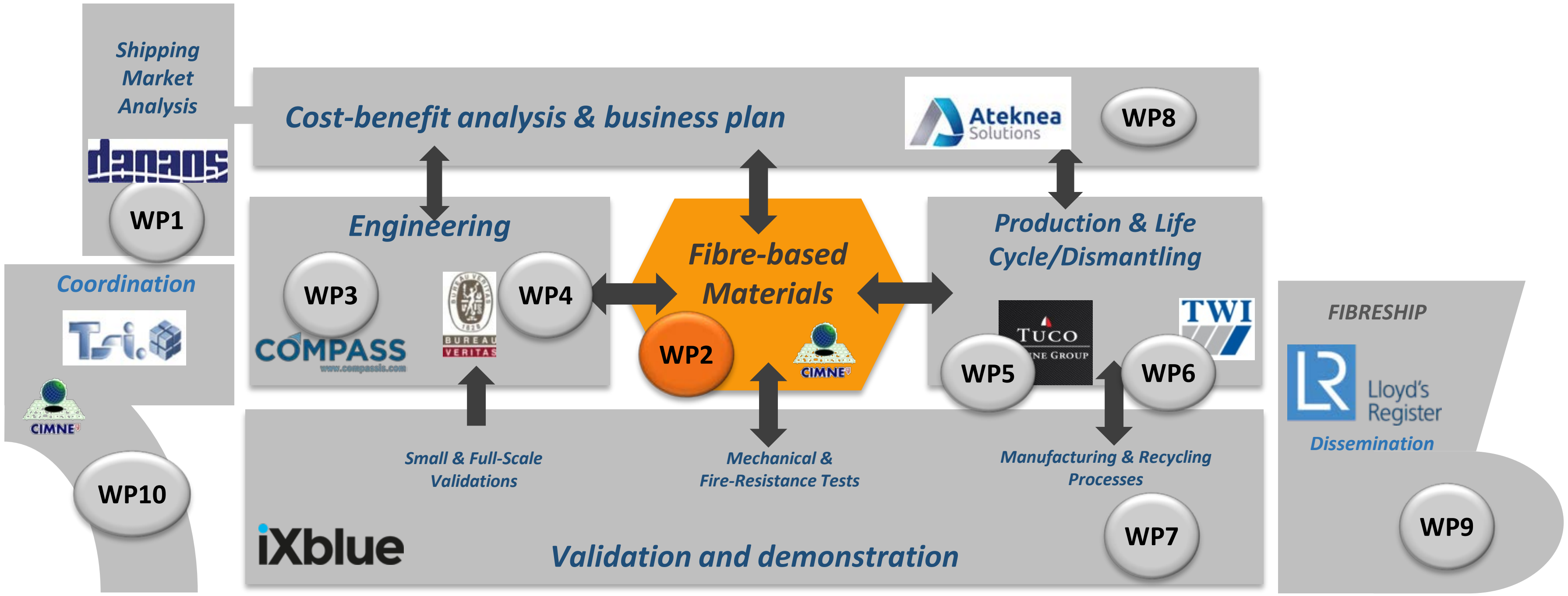
COMPOSITES IN MARINE ENGINEERING:

The use of composite materials in the marine industry is quite large for small crafts, or in high performance crafts such as the competition ones.

Fibreship aims using these materials in large commercial vessels.



Materials are at the core of Fibreship project, as they interact with the rest of workpackages. Specially with the engineering and production ones.



FIBRESHIP

FIBRESHIP SPECIFIC MATERIAL CHALLENGES:

Fibership project will use the expertise of the partners involved and the knowledge obtained form other industrial fields to solve the different technical challenges posed by large length ships. These are:

1. Material selection and characterization. Fatigue performance
2. Fire Performance
3. Structural connections between parts
4. Numerical material modelling

The result of these studies will be outlined in a

Catalogue of applicable materials and joining techniques recommended by class

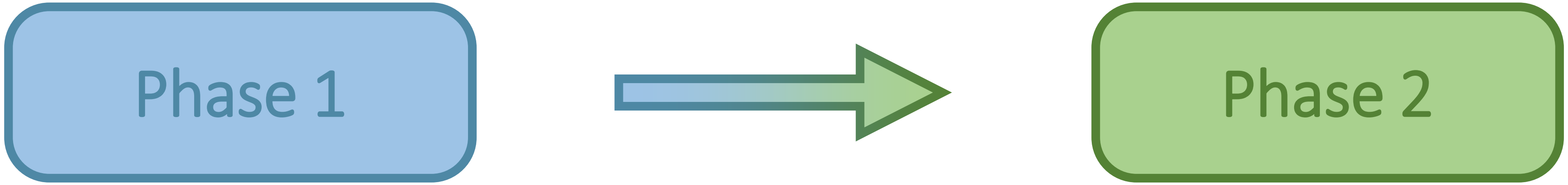
MAIN ACTIVITIES CONDUCTED

FIBRE BASED MATERIALS ANALYSIS AND SELECTION

FIBRE BASED MATERIALS ANALYSIS AND SELECTION

CHALLENGE AND APPROACH

- Identification of new fibre based material systems for large scale vessels is a key objective of Fibreship
- Comprehensive list of candidate constituents



Extensive small scale experimental campaign to down-select the best resin candidates

Selection of reinforcement material and detailed characterization of the best composite candidates for Fibreship application

PHASE 1 – MATERIAL CANDIDATES – Mechanical Properties

RESIN CLASS	RESIN/REINFORCEMENT	v_f (FIBRE VOLUME FRACTION)	DENSITY	APPARENT INTERLAMINAR SHEAR STRENGTH	FLEXURAL STRENGTH	FLEXURAL MODULUS	Resin Cost[3] (€ per kg)	Resin/Hardener Mixture Cost[3] (€ per kg)
VINYLESTER	LEO SYSTEM/ LEO UD 940gsm Glass							
URETHANE ACRYLATE	CRESTAPOL 1210/ UD 996gsm Glass[2]							
EPOXY	PRIME 27/ UD 996gsm Glass[2]							
	SR1125/ UD 996gsm Glass[2]							
BIO-EPOXY	SUPER SAP CLR/ UD 996gsm Glass[2]							
PHENOLIC	CELLOBOND J2027X/ UD 996gsm Glass[2]							
THERMOPLASTIC	ELIUM/ UD 996gsm Glass[2]							

PHASE 1 – MATERIAL CANDIDATES – Mechanical Properties

RESIN CLASS	RESIN/REINFORCEMENT	v_f (FIBRE VOLUME FRACTION)	DENSITY	APPARENT INTERLAMINAR SHEAR STRENGTH	FLEXURAL STRENGTH	FLEXURAL MODULUS	Resin Cost[3] (€ per kg)	Resin/Hardener Mixture Cost[3] (€ per kg)
VINYLESTER	LEO SYSTEM/ LEO UD 940gsm Glass	56% (4.3%)	2.233 g/cm^3 (1.8%)	44.41 MPa (8.8%)	592.0 MPa (22%)	22.03 GPa (21%)	€11.14	€14.00
URETHANE ACRYLATE	CRESTAPOL 1210/ UD 996gsm Glass[2]	57% (0.3%)	2.017 g/cm^3 (0.7%)	42.09 MPa (3.0%)	790.61 MPa (11.3%)	34.52 GPa (2.0%)	€8.50	€8.46
EPOXY	PRIME 27/ UD 996gsm Glass[2]	58% (0.9%)	2.061 g/cm^3 (0.5%)	58.04 MPa (2.4%)	917.1 MPa (2.4%)	35.37 GPa (2.8%)	€9.10	€10.34
	SR1125/ UD 996gsm Glass[2]	58% (3.0%)	2.198 g/cm^3 (2.3%)	50.53 MPa (1.7%)	853.8 MPa (8.5%)	30.35 GPa (8.1%)	€17.60	€18.47
BIO-EPOXY	SUPER SAP CLR/ UD 996gsm Glass[2]	60% (0.6%)	2.158 g/cm^3 (0.9%)	57.78 MPa (3.6%)	865.2 MPa (8.9%)	32.80 GPa (3.8%)	€10	€13.10
PHENOLIC	CELLOBOND J2027X/ UD 996gsm Glass[2]	58% (0.4%)	1.984 g/cm^3 (0.9%)	33.51 MPa (4.8%)	858.8 MPa (6.7%)	34.92 GPa (4.1%)	€4.13	€4.48
THERMOPLASTIC	ELIUM/ UD 996gsm Glass[2]	56% (1.0%)	1.999 g/cm^3 (0.4%)	56.87 MPa (3.6%)	942.8 MPa (3.8%)	33.86 GPa (1.6%)	€27.25	€26.83

PHASE 1 – MATERIAL CANDIDATES – Manufacturing details

RESIN CLASS	RESIN/REINFORCEMENT	RESIN : HARDENER BY WEIGHT	VISCOSITY (from datasheet)	TOOL	INFUSION TIME[4]	INFUSION TEMPERATURE	CURING SCHEDULE	POST-CURING SCHEDULE
VINYLESTER	LEO SYSTEM/ LEO UD 940gsm Glass	100 : 2	340 cP at 20°C	HEATED ALUMINIUM	20 mins	17.3°C (RT[3])	Overnight at 30°C	6 hours at 80°C
URETHANE ACRYLATE	CRESTAPOL 1210/ UD 996gsm Glass[2]	100 : 2 : 1 : 1	175 cP at 25°C	GLASS	11 mins	21.1°C (RT[3])	60 mins at RT[3]	No post-cure required
EPOXY	PRIME 27/ UD 996gsm Glass[2]	100 : 28	285 cP at 20°C 150 cP at 30°C	GLASS + HEATED MAT	15 mins	18.8°C (RT[3])	1 hour at 45°C Overnight at RT[3]	7 hours at 65°C
	SR1125/ UD 996gsm Glass[2]	100 : 14	680 cP at 20°C 305 cP at 30°C 160 cP at 40°C	GLASS + HEATED MAT	40 mins	19.9°C (RT[3])	16 hours at 40°C	8 hours at 80°C
BIO-EPOXY	SUPER SAP CLR/ UD 996gsm Glass[2]	100 : 33	300 cP at 25°C	HEATED ALUMINIUM	92 mins	35°C	Overnight at RT[3]	2 hours at 120°C
PHENOLIC	CELLOBOND J2027X/ UD 996gsm Glass[2]	100 : 4	270 cP at 25°C	HEATED ALUMINIUM	36 mins	60°C	15 mins at 60°C	3 hours at 80°C
THERMOPLASTIC	ELIUM/ UD 996gsm Glass[2]	100 : 2.5	100 cP at 25°C	GLASS	23 mins	21.9°C (RT[3])	Overnight at RT[3]	No post-cure required

FIBRE BASED MATERIALS ANALYSIS AND SELECTION

PHASE 1 – MATERIAL CANDIDATES – DOWN-SELECTION

	Mechanical Properties (Dry Condition)			Manufacturing				Impact				Total Score /110	
Weight	**20**			**50**				**40**					
	ILSS[1]	Flexural Strength[2]	Flexural Stiffness[3]	Elevated Temp infusion/ cure[4]	Post Cure[5]	Infusion capability[6]	Worldwide knowledge (possibility to be used worldwide)	Cost[8]	Claimed FR[9]	Worker health impact[10]	Recyclability[11]		
Weight	**/10**	**/5**	**/5**	**/10**	**/10**	**/20**	**/10**	**/15**	**/21**	**/2**	**/2**		
Synolite 8488 G-2	?	?	?	10	10	20	10	15	0	1	1	67	To be completed
DION 9102-683				10	10	20	10	13	0	1	?	64	
Leo system	7	1.5	1.5	5	0	14	10	12	21	1	0	73	System to be checked with Saertex
Crestapol 1210	7	3	3	10	10	20	0	7	0	1	0	61	
Prime 27	10	3	5	5	0	12	5	10	0	1	0	51	
SR1125	7	3	3	5	0	12	5	8	21	1	0	65	
SUPER SAP CLR	7	3	3	0	0	6	5	7	0	1	0	32	OUT due to high infusion T°
CELLOBOND	4	3	3	0	0	6	0	15	21	0	0	52	OUT due to high infusion T° and gel time too short
ELIUM	7	5	3	10	10	12	0	0	0	2	1	50	

Traction strenght ?

Ranking if FR is an option	1st Leo System, 2nd SR 1125
Ranking if FR is not an option	1st Leo System, 2nd Synolite 8488 G-2 / DION 9102-683, 3rd SR 1125

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PHASE 2 – MATERIAL DETAILED MATERIAL CHARACTERIZATION

SR1125

X3 material systems

Evaluate SR1125 with various reinforcements: Carbon, Basalt, Glass

MATERIALS:	• SR1125 / Glass (Completed) • SR1125 / Basalt • SR1125 / Carbon
OUTPUTS:	• Interlaminar shear strength • Flexural Strength • Flexural Stiffness • Density • Fibre volume fraction

Down-select > Move forward with a single reinforcement

X1 material system

Establish Tensile and Flexural properties of SR1125 with one down-selected reinforcement

MATERIALS	• SR1125 with Glass OR Carbon OR Basalt
OUTPUTS	• Tensile Strength • Tensile Modulus • Flexural Strength • Flexural Modulus • Fibre volume fraction

Sandwich Panel Manufacture and Evaluation (SR1125 with one down-selected reinforcement)

OUTPUTS	• Flexural Strength • Flexural Modulus

Fatigue testing (ASTM D3479) of SR1125

LEO SYSTEM

Move forward with LEO compatible glass reinforcement only

X1 material system

Establish Tensile and Flexural properties of LEO SYSTEM with LEO Glass

MATERIALS	• LEO SYSTEM with LEO Glass
OUTPUTS	• Tensile Strength • Tensile Modulus • Flexural Strength • Flexural Modulus • Density • Fibre volume Fraction

Sandwich Panel Manufacture and Evaluation (LEO SYSTEM)

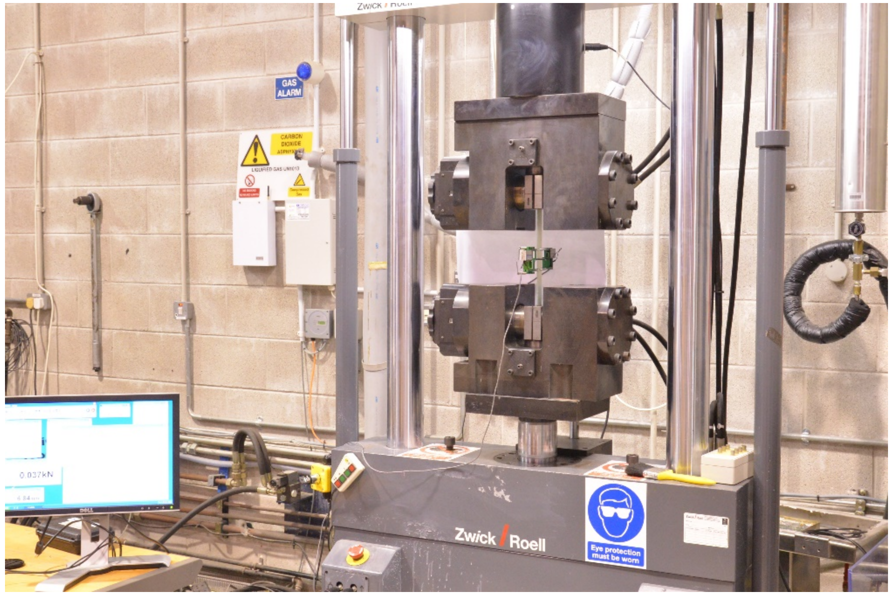
OUTPUTS	• Flexural Strength • Flexural Modulus

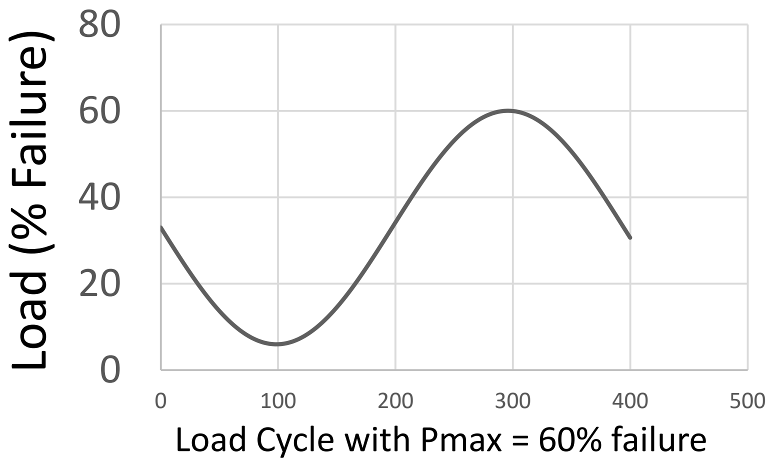
Fatigue testing (ASTM D3479) of LEO SYSTEM

Fatigue Tests

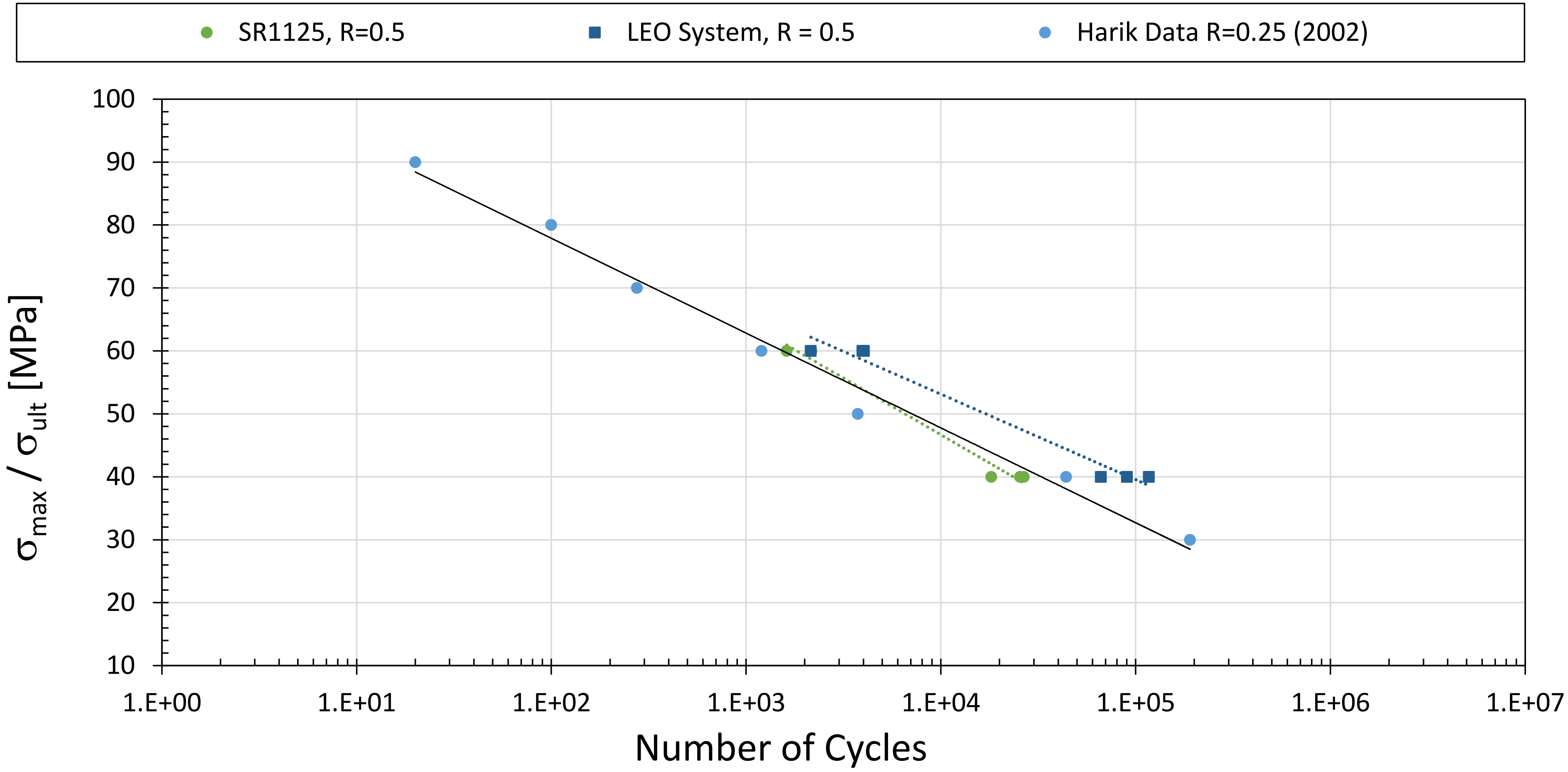
	P_{max}: 60 % failure	P_{max}: 40 % failure
LEO / Glass	3 samples	3 samples
Sicomin / Reinforcement*	3 samples	3 samples

Test Details	
Loading:	Fatigue (Constant Amplitude, Tension-Tension)
Nominal Dimensions:	L (400 mm) W (25 mm) T (3 mm)
Sample Lay-up	Uni-directional
Loading Frequency:	4 Hz
R-Ratio:	0.5
Stop Test:	On Failure or after 300k cycles
Outputs:	Stiffness every 100k cycles (extensometers) | Retained Strength @ 300k cycles





Fatigue Tests

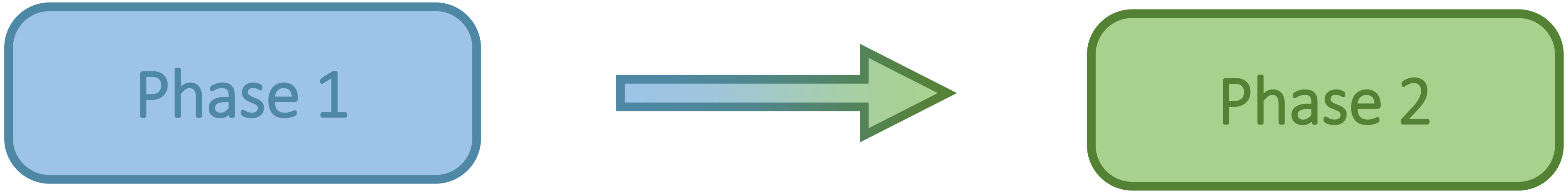


MAIN ACTIVITIES CONDUCTED

FIRE PERFORMANCE

FIRE PERFORMANCE ANALYSIS

- Fire performance is of utmost importance for Fibreship application and has been a key point for phase 1 and phase 2 material selection.
- Fire performance study has been also conducted with a 2-phase approach.



Tests made in different resin systems:

- Thermogravimetric analysis (TGA)
- Cone-Calorimeter (CC)

Test made in down-selected resin systems:

- Micro-scale combustion calorimetry (MCC)
- Differential scanning calorimetry (DSC)
- Transient plane source (TPS)
- Dynamic mechanical thermal analysis (DMTA)

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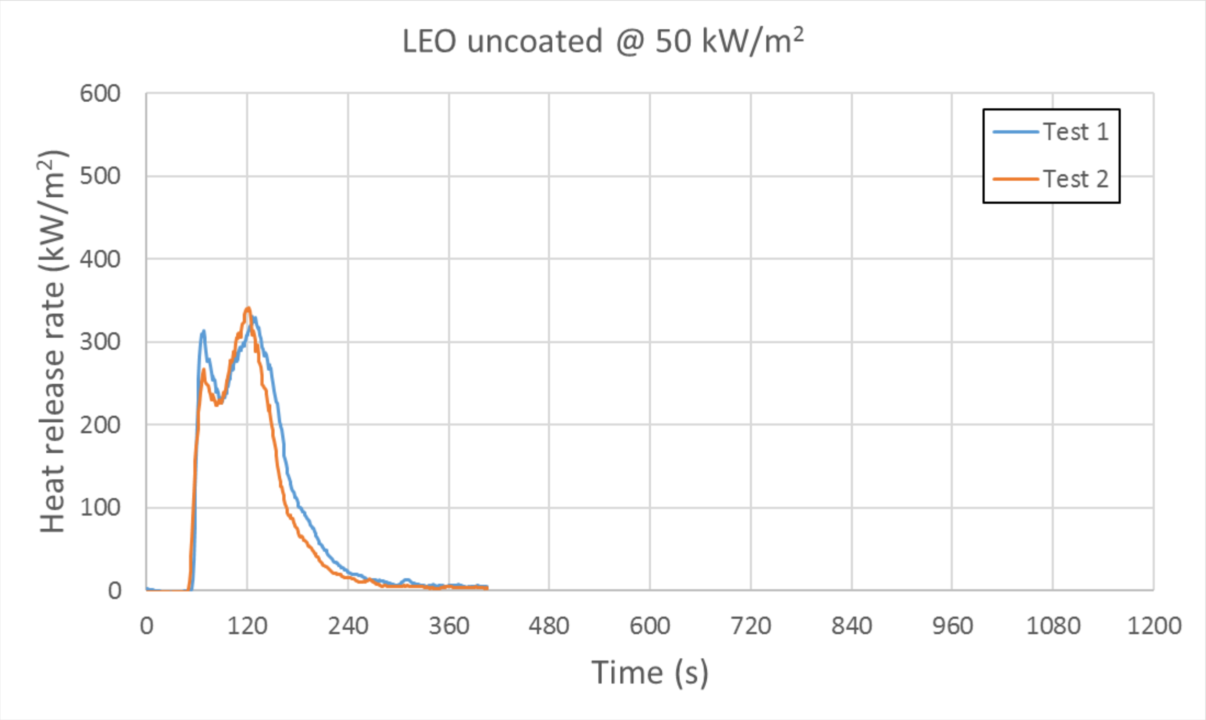
RESULTS FROM 1st PHASE ANALYSIS

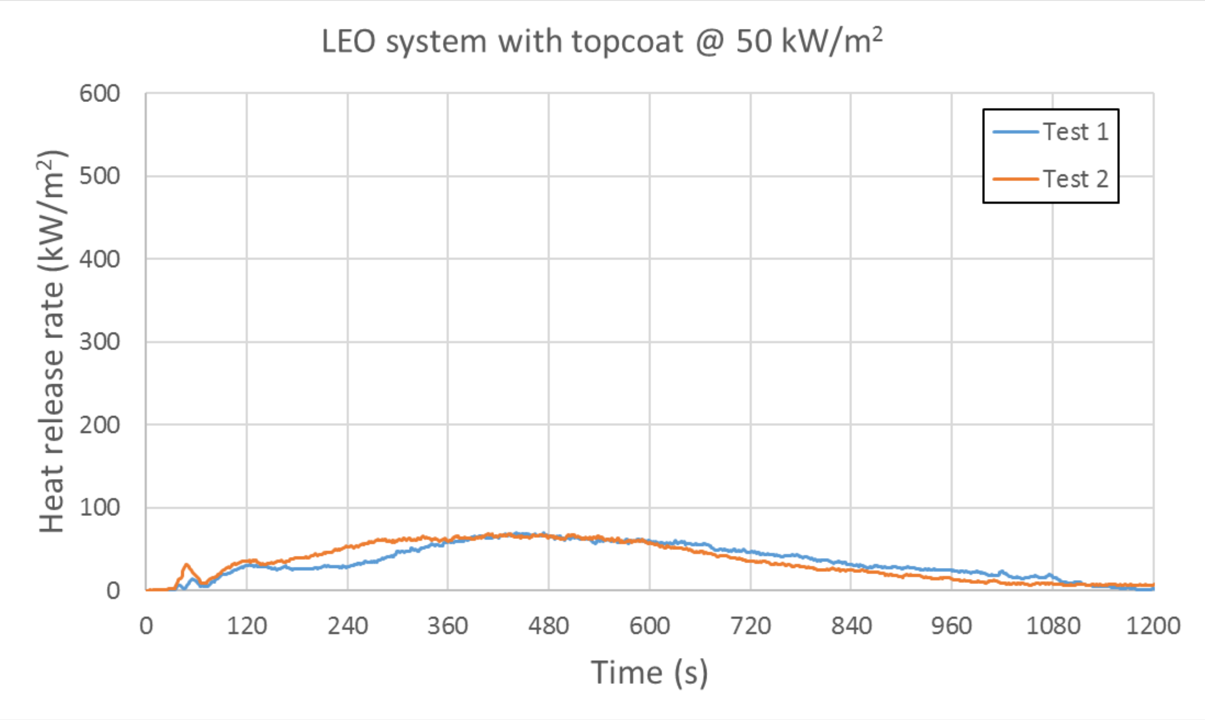
RESIN CLASS	RESIN DETAILS	t_{ig} (s)	HRR_{max} (kW/m^2)	THR (MJ/m^2)	TSP (m^2)
Vinylester	LEO system with topcoat	75	69	42.3	8.8
	LEO without topcoat	50	336	33.5	15.1
Urethane acrylate	Crestapol 1210	44	314	35.4	9.3
Epoxy	Prime 27	60	496	39.4	10.7
	SR1125 with topcoat	53	261	40.7	9.3
	SR1125 without topcoat	53	546	42.5	13.5
Bio-epoxy	Super Sap CLR	61	520	42.0	12.0
Phenolic	Cellobond J2027X	*)	71	9.9	0.4
Thermoplastic	Elium	23	255	40.7	1.8

*) Exceptional ignition behaviour: small local flame in ca. 90 s, 50 % of area ignited in ca. 120 s, whole surface ignited in ca. 180 s

EXAMPLES OF THE RESULTS OBTAINED IN THE FIRST PHASE – LEO SYSTEM

HEAT RELEASE RATE:





SECOND PHASE ANALYSES

Currently the second phase analysis is ongoing and results will be available by mid July.

The test that are being conducted are:

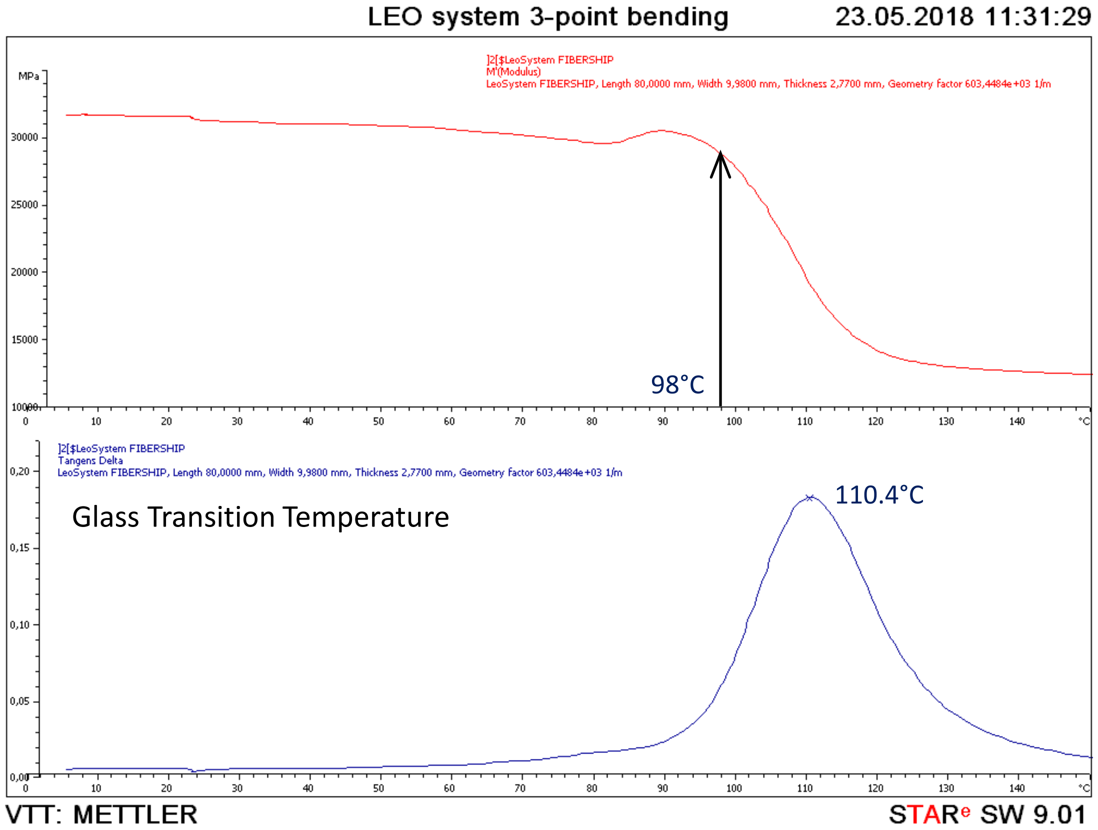
DMTA: Used to measure the mechanical and viscoelastic properties of materials as a function of temperature, time and frequency when they are subjected to a periodic stress with fixed frequency, amplitude and temperature programme.

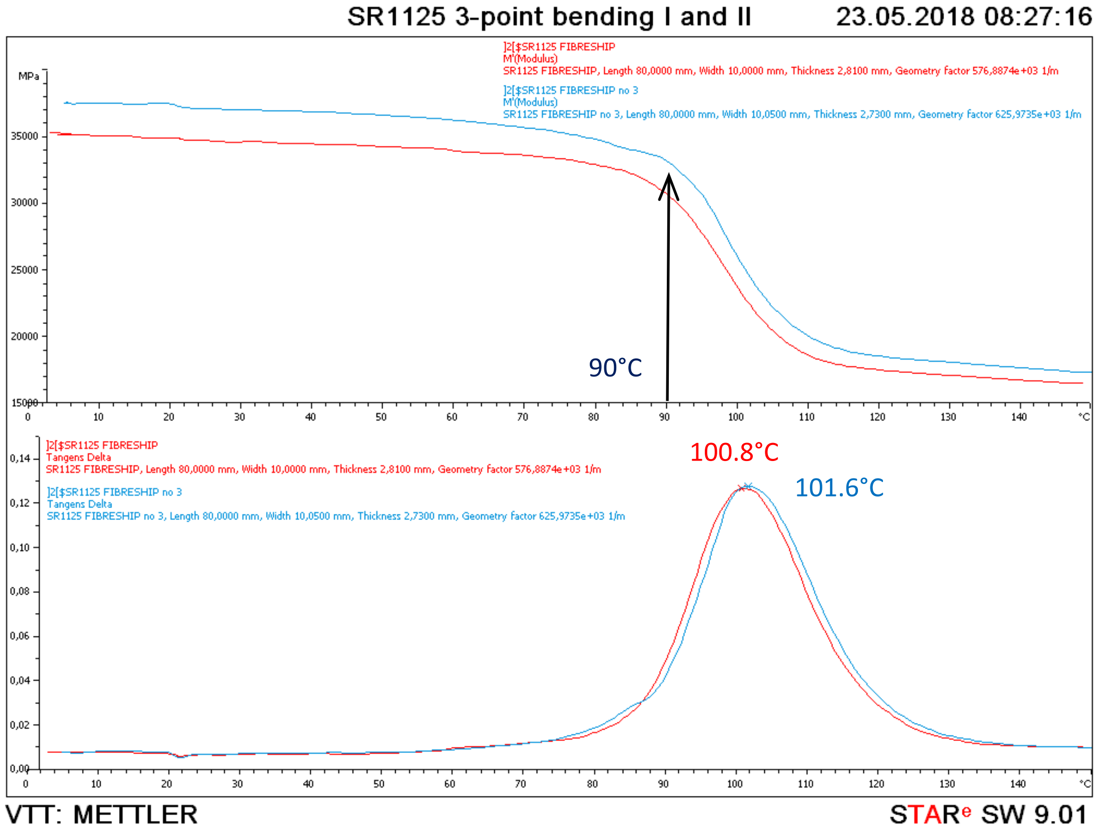
MCC: Used for measuring the heat release rate of a sample. The result is the heat of complete combustion as a function of temperature.

TPS: Used to obtain the thermal conductivity of the material.

DSC: Used to obtain the specific heat capacity and heats of reaction

EXAMPLES OF THE RESULTS OBTAINED IN THE FIRST PHASE – DMTA Results





Storage modulus (in MPa) and loss factor (tangens delta) values as the function of temperature with 1 Hz frequency measured in three point bending.

MAIN ACTIVITIES CONDUCTED

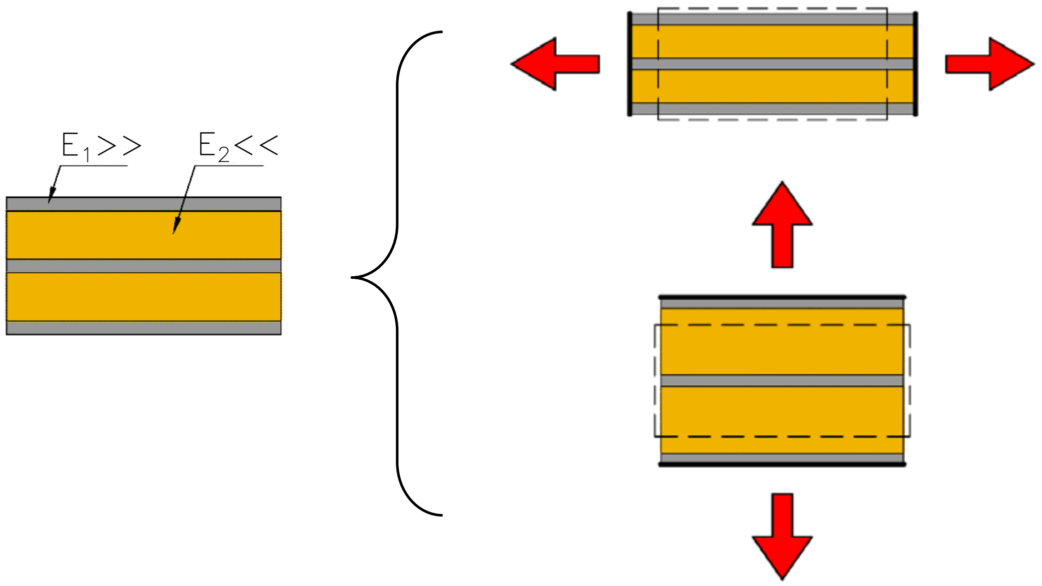
NUMERICAL MODELS

NUMERICAL MODELS

A reliable design of Fibreships require of reliable material models, as well as reliable analysis tools.

Material analysis will be based on the serial parallel mixing theory. This formulation obtains the mechanical behaviour of the composite material from the constitutive performance of its constituents.

The composite constituents are coupled by defining two compatibility equations that relate their strain and stress tensors:



Parallel behavior

$\varepsilon_1 = \varepsilon_2 = \ldots = \varepsilon_n$

$$\begin{cases} {}^{c}\varepsilon_P = {}^{m}\varepsilon_P = {}^{f}\varepsilon_P \\ {}^{c}\sigma_P = {}^{m}k\,{}^{m}\sigma_P + {}^{f}k\,{}^{f}\sigma_P \end{cases}$$

Serial behavior

$\sigma_1 = \sigma_2 = \ldots = \sigma_n$

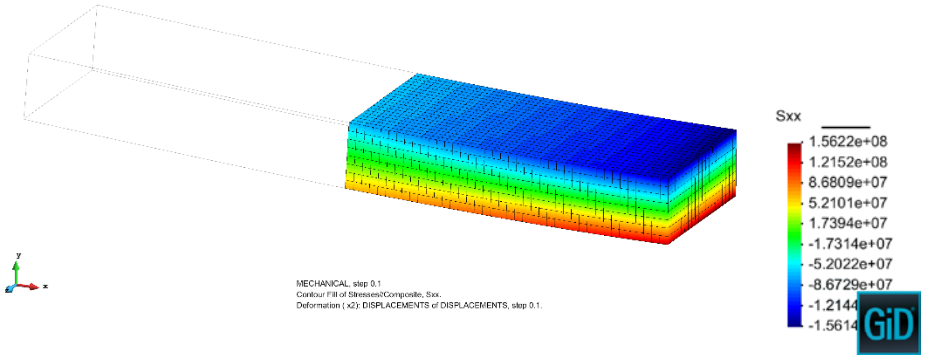
$$\begin{cases} {}^{c}\varepsilon_S = {}^{m}k\,{}^{m}\varepsilon_S + {}^{f}k\,{}^{f}\varepsilon_S \\ {}^{c}\sigma_S = {}^{m}\sigma_S = {}^{f}\sigma_S \end{cases}$$

Compatibility equations

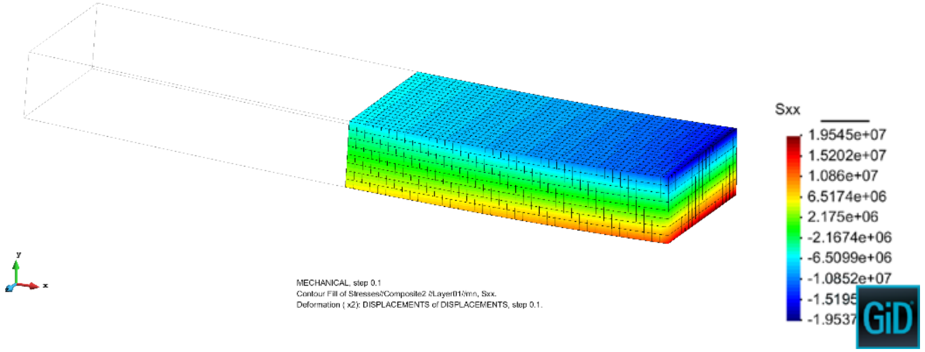
With this approach,

- The simulation provides the mechanical performance of fibre and matrix.

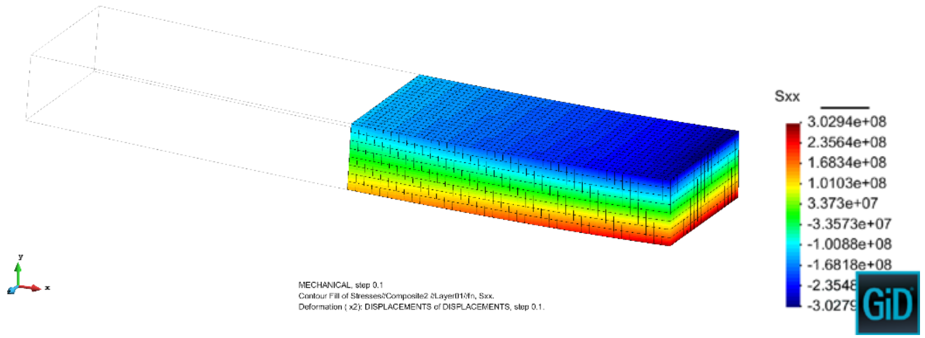
Leo composite stresses
Four Point Bending test (4PB)



Matrix stress



Fibre stress

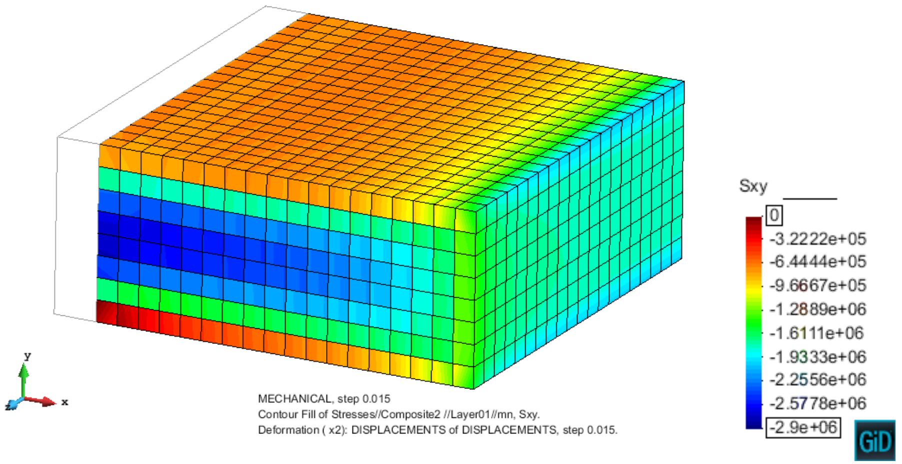


NUMERICAL MODELS

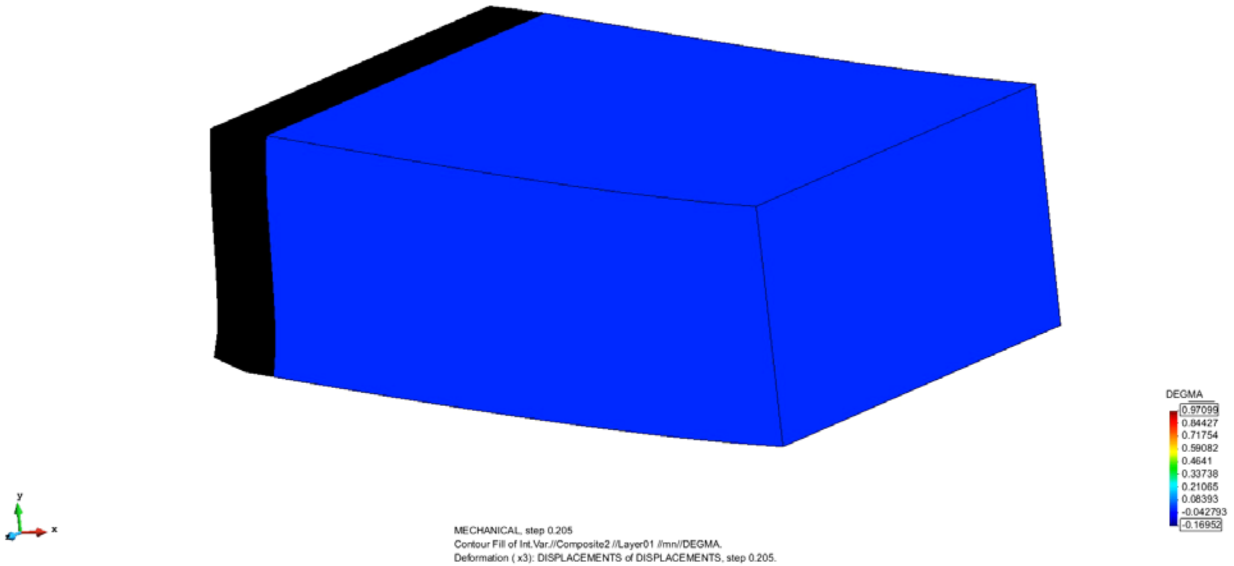
With this approach,

- The simulation provides the mechanical performance of fibre and matrix.
- It is possible to obtain the non-linear behaviour of the composite

Leo composite stresses
Interlaminar Shear Strength test (ISS)



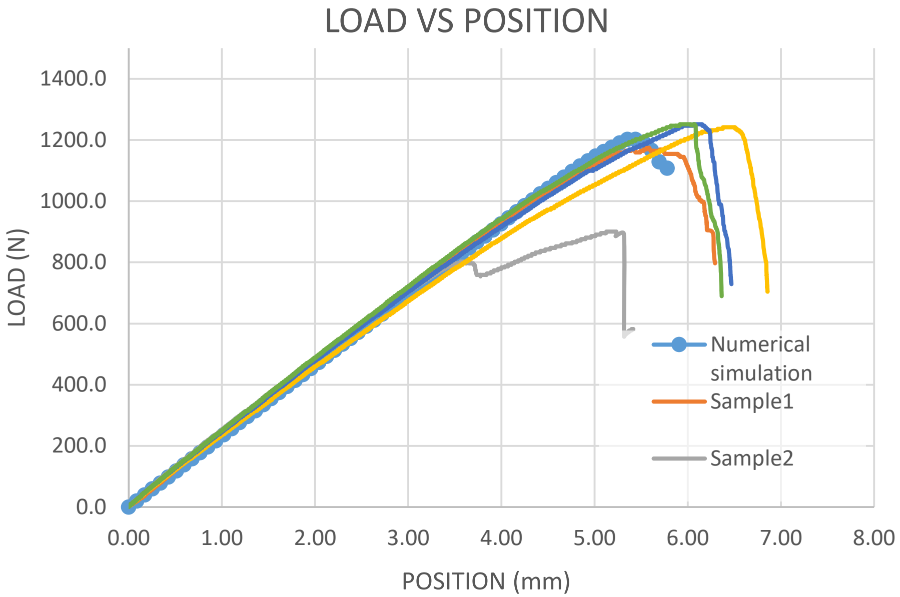
Matrix damage



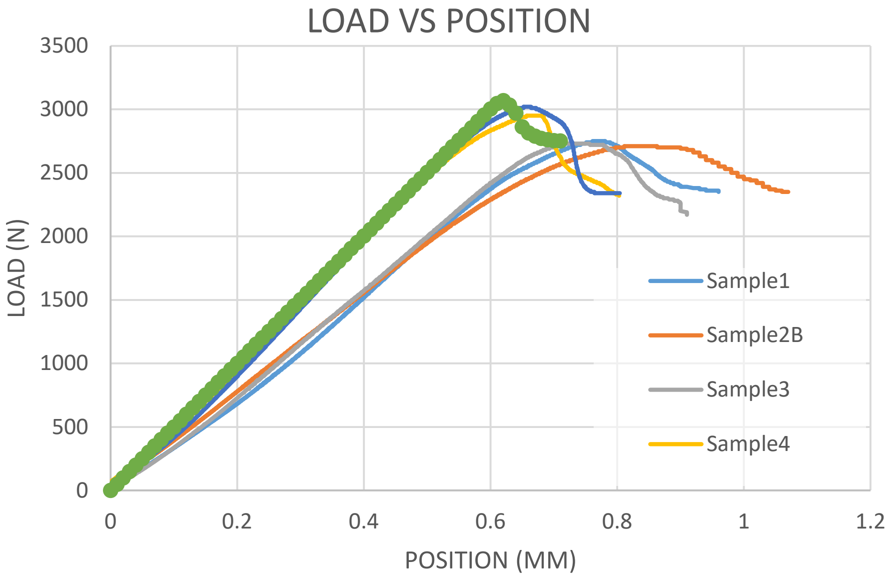
With this approach,

- The simulation provides the mechanical performance of fibre and matrix.
- It is possible to obtain the non-linear behaviour of the composite
- And, once calibrated, the formulation is capable of reproducing the exact non-linear stress-strain response of the composite.

Leo System – 4PB test



Leo System – ISS test



FIRST OUTCOME OF THE WORK CONDUCTED AND TOPICS FOR DISCUSSION

FINAL MATERIAL SELECTION

LEO SYSTEM (Vinylester with glass fibre reinforcement)

Main reasons for this selection are:

1. Equivalent mechanical properties
2. Better fatigue performance than SR1125
3. Better fire performance than the SR1125
4. Good manufacturability
5. Good price
6. Good material knowledge by the shipyards

NOTES:

- The selection of this material does not imply that other materials are disregarded.
- The LEO system is the one better positioned for Fibreship application.
- Other materials can be used in different ship sections if specific properties are required.

TOPICS FOR DISUSSION

1. The LEO system has been found to be the best material for Fibreship. The material selection has been made based on the most relevant parameters. Fibreship will require using different composite materials for specific applications.
2. Fire protection of a Fibreship cannot rely only on the material. There will be need of further passive and active fire protection in specific areas.
3. Connections will play an important role in Fibreship. The definition of these connections will be technically challenging, but can be solved.
4. Numerical models for composite characterization are basic. A non-linear analysis of a Fibreship is a requirement to have a reliable design.
5. There is a need for international material guidelines for Fibreships.

THANK YOU

www.fibreship.eu