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Development, engineering, production and life cycle management of improved FIBRE-based material solutions for the structure and functional components of large offshore wind enerGY and tidal power platforms

D2.3 (WP2): Environmental protection of composites

Responsible Partner: Corso

Contributor(s): Ulim

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EXECUTIVE SUMMARY

In order to protect composite material (one thermoset Infugreen and one thermoplastic Elium) against environmental actions, this task evaluates the performance of a new coating technology (named dry coating here) developed by Corso Magenta compared to traditional liquid paint.

Taking into account the offshore environment, an appropriate paint has to be chosen. Then paints selection has been made on their long-term durability, their use for ships and shipyards, their recommendation to be applied on composite substrate and finally their chemical compatibility with the composite resin selected for this project: thermoset Infugreen 810 and thermoplastic Elium 188 X0.

Three paints were selected and transformed into dry coating:

- Hempathane 55210: W2Power paint, not compatible with Elium.
- Alexit 471: Compatible with Elium.
- Alexit 411-77: Compatible with both composite resins.

After that, vacuum infused samples with the dry coating at the bottom of the mould were produced following the next table and control samples were painted with wet process.

Coating	Composite Resin
Dry coating A: Hempathane 55210	Thermoset Infugreen
Dry coating B: Alexit 471	Thermoplastic Elium
Dry coating C: Alexit 411-77	Thermoset Infugreen
	Thermoplastic Elium
Liquid paint: Hempathane 55210	Thermoset Infugreen
	Thermoplastic Elium

Table 1 – Coating selection

To quantify the durability of the coatings and their performance to protect to composite material, the samples were exposed to:

- Salt water immersion.
- High humidity.
- Neutral salt spray test.
- Ultraviolet UV.

Then evaluations have been carried out:

- On the coating itself by the measure of the colour evolution.
- On the evolution of adhesion between the coating and the composite substrate.
- On the composite water uptake.
- And on the composite mechanical performance.

After testing, it was shown that:

- Dry coating performed as liquid paint about the protection of the composite against water absorption.
- Dry coating is more adherent to the composite substrate than liquid paint.
- UV aging is the most severe test. It degrades in colour the yellow coatings Hempathane 55210 or Alexit 471 (liquid or dry) but also the adhesion of the coating on the composite substrate, the cohesion of the coating or the cohesion the composite.
- UV impacted the composite material as mechanical performance or behaviour evolved (seen on flexural test). This means the degraded coatings Hempathane 55210 (liquid or dry) and dry coating Alexit 471 did not protect as well as excepted the composite.
- No important different mechanical response is obtained when compared liquid and dry coating.

If one recommendation has to be made, the use of the dry coating appears the best solution. It permits to save time on the manufacturing process. It adheres better on the composite substrate than liquid paint. It has the same protection as liquid paint against water absorption. It evolved as the liquid paint in terms of colour when expose to UV. In one sentence, dry coating performed as well or better than liquid paint.

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TABLE OF CONTENTS

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

LIST OF FIGURES

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

LIST OF TABLES

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

LIST OF ANNEXES

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

1. INTRODUCTION

Composites, as many other materials, have to be painted to be protected against environmental actions. Traditional (liquid) painting implies inconvenient: sanding steps to facilitate the paint adhesion, drying time, exposition to chemical components, need of multiple layers of paints.

When doing composites by vacuum infusion, the possibility of using a paint already dried is promising. This paint, called dry coating, is applied at the bottom of the mould, paint side in contact with the mould, before fabrics lay-up. This technology, developed by Corso Magenta, permits to have a laminate already painted after demoulding and remove all hours of painting after infusion.

Within this task, the use of dry coating is studied in replacement of traditional liquid paint. The composite protection capacity will be at the central study.

An extensive experimental campaign will be set where:

- High durability paints will be selected and transformed into dry coating,
- Samples will be manufactured by vacuum infusion with the dry coating inside.
- Aging tests will be conducted on the samples.
- Evaluation of the influence of the aging tests on the samples (on the coating and/or the composite material) will be studied.

2. COATINGS SELECTION

2.1. First paint selection

To ensure a high protection of the composite materials against environmental actions, a suitable paint has to be selected. The choice was based on the main criteria below:

- The use of the paint adapted to composite substrate, which also means that they have to be chemically compatible with the resins.
- The resistance to sea environment, especially for ships and shipyards.
- The long-term durability of the paint.
- A Recommendation from partners.

Trade name	Brand/ Manufacturer	Chemistry	Layer	To be used with composite	Used for ships and shipyards	High durability
Interthane 870	International / AkzoNobel	Polyurethane - Acrylic	Topcoat	Yes	No	Yes
Hempathane 55210	Hempel	Polyurethane - Acrylic	Topcoat	Yes, with primer	Yes	Yes
Acryltop PU 77	MapYatching	Polyurethane	Topcoat	Yes	Yes	Yes
PU 320	MapYatching	Polyurethane	Topcoat	Yes	Yes	Yes
Epoxygyard IM 409	MapYatching	Epoxy	Primer	Yes	Yes	Yes

Table 2 – First paint selection

Interthane 870 was recommended by Corso.

Hempathane 55210 is the topcoat used on the column of the actual W2Power.

MapYatching was suggested by IXBLUE.

One last criterion is important when working with the dry coating technology: the feasibility to transform a market paint, which is delivered in a liquid form into a dry paint film.

2.2. Paint transformation into dry coating

Corso Magenta technology permit to transform liquid paint into dry paint film (dry coating). The dry coating is composed of a paint film and impregnated glass fibres as described in the next figure.

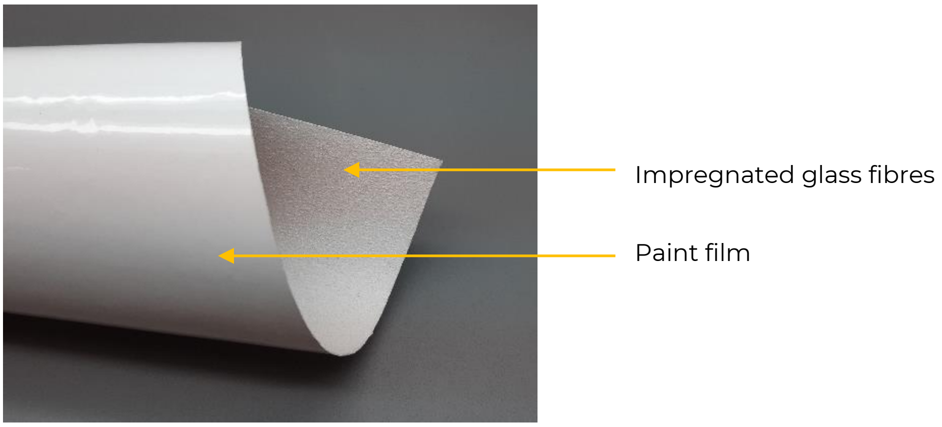

Figure 1 – Dry coating composition

The feasibility of the liquid paint transformation into dry coating are described below.

Trade name	Brand/ Manufacturer	Chemistry	Transformation into dry coating
Interthane 870	International / AkzoNobel	Polyurethane - Acrylic	Yes
Hempathane 55210	Hempel	Polyurethane - Acrylic	Yes
Acryltop PU 77	MapYatching	Polyurethane	Yes
PU 320	MapYatching	Polyurethane	Yes
Epoxyguard IM 409	MapYatching	Epoxy	Yes

Table 3 – Transformation feasibility from liquid paints into dry coatings

Each paint was transformed with success, their compatibility with composite resins has to be checked.

2.3. Dry coatings and composite resins compatibility

- The use of dry coatings permits to have a final composite structure such as FRP (Fibre-reinforced Polymer) after the manufacturing process. The possibility to have a final product after the manufacturing process is the desired approach and become an attractive technology solution for the industry. The manufacturing process used is the Vacuum-Assisted Resin Transfer Moulding, where the resin travelled on the liquid stage, impregnating all the dry fibre-reinforced and bonding the dry coating on the surface of the composite structure which will be exposed to an aggressive environment. This manufacturing process was selected because of the capability to manufacture large structures and well stability manufacturing technology.
- During the coating selection stage, two laminates had been manufactured at Ulim. The results of this preliminary test show that the polymer matrix could potentially react with the dry coating.
- To evaluate this parameter, a quick test has been developed. The compatibility test consists of depositing a drop of the liquid composite resin (Infugreen or Elium) on the back side of the dry coating (where there is the glass fibre tissue) and evaluating the visual aspect of both side of the dry coating after the contact.
- Preliminary results showed that there is a chemical reaction between the Elium resin and dry coating. Three possibilities to avoid this phenomenon were proposed by the manufacturer Arkema and explored.

1. Increase the thickness of the dry coating: the idea is to have a significant thickness so that the chemical reaction can occur in the first layer of the dry coating (in contact with the resin) without impacting the external paint layer of the dry coating. This option is explored but will not be preferred as a degraded dry coating induced by the chemical reaction may have an important impact on the adhesion of the dry coating on the material and so affect protection performance.

2. Decrease the contact time between the resin and the dry coating by increasing the resin curing time. This implies to change the hardener. As material selection has been fixed, this option is also put aside.

3. Work on the chemical resistance of the dry coating. Two potential solutions have been explored.

3.1. The first solution is to develop a dry coating composed of the high chemical resistant paint: indeed, chemical resistant of the dry coatings comes from the structure and the chemical nature of the polymer used for the paint. Here, most of selected paints are polyurethane based. A screening of high chemical resistant paints, sourced from different manufacturers, were performed. Their transformation into dry coating and their compatibility with the Elium resin were tested. Two candidates were identified. Their properties are presented in Table 3.

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Trade name	Brand/ Manufacturer	Chemistry	Layer	To be used with composite	Used for ships and shipyards	High durability
Alexit 411-77	Mankiewicz	Polyurethane	Topcoat	No	No	Yes
Alexit 471	Mankiewicz	Polyurethane	Topcoat	No	No	Yes

Table 4 – High chemical resistant paints properties

Alexit 411-77 is a used for aircraft external paint. This application implies to comply hard chemical exposure such as an immersion in Skydrol, which is an aggressive hydraulic fluid in the aeronautic field.

Alexit 471 was suggested as Mankiewicz most chemical resistant paint. It used for special structure.

3.2 The second solution is to develop a dry coating composed of a multiple layer of different paints where the first layer of dry paint (which will be in contact with the resin) will act as a barrier against the composite resin. An epoxy-based paint was chosen to test this solution. As a consequence, the following dry coating will be created and tested trough the compatibility test.

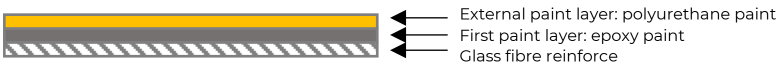

Figure 2 – Multiple layer dry coating composition

Results from compatibility test are described in the next table and examples pictures are below.

Solution	Dry coating paint system	Thickness (µm)	Infugreen compatible	Elium compatible
Prelaminar trials	Hempathane 55210	~220	Yes	No
	Interthane 870	~220	Yes	No
1 Increasing of the paint layer thickness	Hempathane 55210	~320	Yes	No
3.1 High chemical resistant paint	Alexit 411-77	~350	Yes	Yes
	Alexit 471	~300	Yes	Yes
3.2 Creation of a barrier layer	Hempathane 55210 Epoxyguard IM 409 (barrier)	~250	Yes	No
	Acryltop PU 77 Epoxyguard IM 409 (barrier)	~290	Yes	No
	PU 320 Epoxyguard IM 409 (barrier)	~270	Yes	No

Table 5 – Compatibility of dry coatings with Infugreen or Elium results

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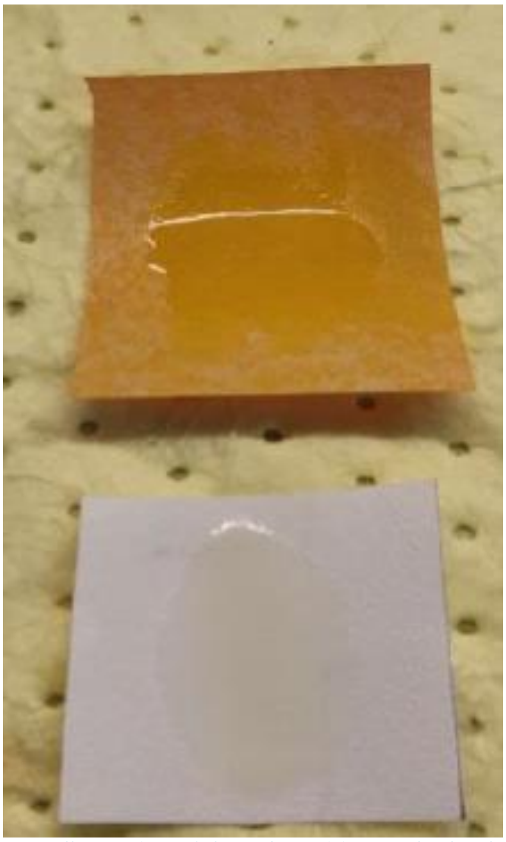
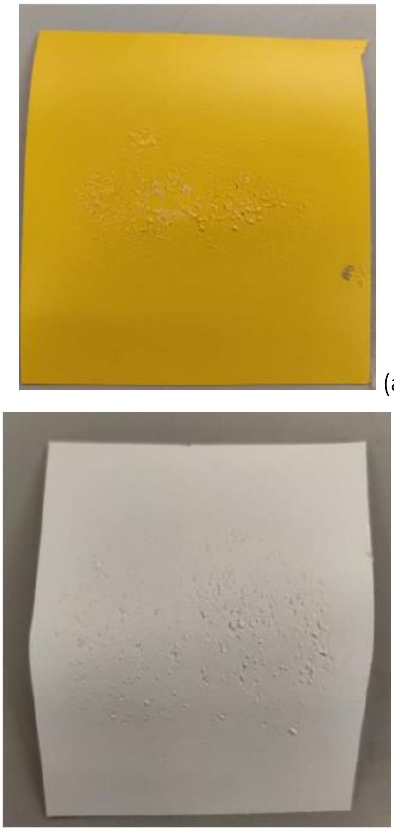


Figure 3 – Illustration of drop depositing at the back of the dry coating to test dry coating/resin compatibility



(a)

(b)

Figure 4 – Dry coating paint side after chemical reaction when compatibility testing ((a): Hempathane 55210, (b): Interthane 870))

Two paints system appear to be resistant to Elium and Infugreen resin: Alexit 471 and Alexit 411-77. However, both are not initially used for sea environment. A decision has to be taken in order comply with requirements stated in chapter 2.1.

2.4. Final proposition

The goal of the work at coupon level is to evaluate the durability of dry coatings on two composite materials: one thermoset epoxy Infugreen and one thermoplastic acrylic Elium. Two dry coatings have to be selected and compared to a reference liquid paint. This can be illustrated in the next table.

Coating	Composite Resin
Dry coating A	Thermoset Infugreen
	Thermoplastic Elium
Dry coating B	Thermoset Infugreen
	Thermoplastic Elium
Liquid paint	Thermoset Infugreen
	Thermoplastic Elium

Table 6 – Coating selection: Initial proposition

Regarding requirements of protection and durability against sea environment and technical aspects about the compatibility between dry coatings and composite resins, see above, it was decided to test three dry coatings instead of two stated above. Explanations about this choice is given in the next table.

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Coating	Composite Resin	Advantages	Disadvantages
Dry coating A: Hempathane 55210	Thermoset Infugreen	- W2Power paint - Used in severe sea conditions	- Not compatible with Elium
Dry coating B: Alexit 471	Thermoplastic Elium	- Compatible with Elium - High chemical resistant paint	- Not used in sea conditions
Dry coating C: Alexit 411-77	Thermoset Infugreen	- Common paint - Compatible with Elium - Compliant to exterior aircraft paint requirements	- Not used in sea conditions
	Thermoplastic Elium		
Liquid paint: Hempathane 55210	Thermoset Infugreen	/	/
	Thermoplastic Elium	/	/

Table 7 – Coating selection: Final selection, advantages and disadvantages

With this proposition:

- Performance between two forms of the same paint can be evaluated. The common paint used is Hempathane 55210 and the two forms tested are dry and liquid.
- The paint already used for W2Power is evaluated.
- Influence of the composite resin (Elium or Infugreen) on the durability can be seen: Dry coating C.
- 6 configurations are kept to comply with the proposal needs.

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3. IDENTIFICATION OF FOULING RELEASE TECHNOLOGIES / MICROTEXTURES

Offshore platforms can have submerged parts exposed to fouling.

Fouling or biofouling is the action of colonisation of living organisms (microorganisms, plants, small animals, etc) on surfaces where it is not wanted. Such accumulation, that can reach several centimetres, have always been a major issue as it adds weight to the structure (to the ship for example), so increase the energetic use.

To fight this, the use of paints only dedicated to this is employed. 2 types can be identified: antifouling paints and fouling release paints.

1. Antifouling paint is the traditional paint used in this sector. It fights fouling thanks to biocides present in the paint. Indeed, if an organism grips to the painted surface, it will be killed by the biocide. It can also work as a prevention from organism hanging.
   This system is controverse as biocide, which are toxic substances, can be released in the sea and pollute sea environment. Workers can also be exposed to biocides when doing paint maintenance operations.

2. The fouling release paint are nontoxic coatings, with no biocide. It will not kill the organism but prevent its attachment thanks to a low surface energy where it is known that it is difficult to adhere. This can be possible by the use of silicon or fluoropolymers chemistry. This option has also inconvenient. Silicon paint application is very difficult and no other paints can be used on top of it.

Both options presented above are not perfect. But as dry coatings can be functionalized, it is proposed to texture the dry coating to permit to find a solution to resist to fouling. 2 possibilities are identified: creation of a highly smooth surface and creation of sharklet texture, which is known to inhibit bacterial growth.

1. Dry coating with highly smooth surface
   Based on the strategy of fouling release paints where it prevents the fouling by the low surface energy, the same idea can be done on dry coatings. By the creation of a highly smooth surface, it is hoped that the fouling resistance will be enough. Compared to traditional liquid silicon paints, whatever paints can be used to produced dry coating so the inconvenient saw before, will not be anymore.

2. Dry coating with sharklet texture
   Sharklet texture is a patented technology were the texture copies the sharkskin structure (see picture below) which are known to be resistant against fouling.

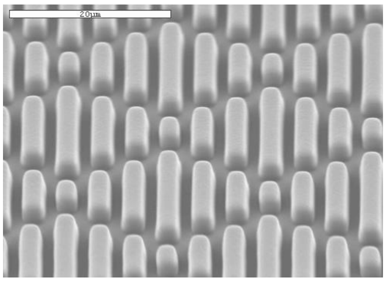

Figure 5 – Sharklet texture [1]

Today, it is used to inhibit bacterial growth on not immersed situation but the structure has a potential to work against fouling.

To evaluate the 2 options to fight fouling by the use of dry coating, no test at coupon level exists so this will be explored in the framework of the WP6 where immersion, in real sea water, of samples with both presented textures will be performed.

4. SAMPLES PRODUCTION

Two options were proposed for making the samples:

- The first option is the integration of the dry coating directly into the manufacturing process by placing it in the mould before the lay-up.
- The second option is to applied the dry coating by self-adhesion to the final surface of the piece produced by infusion.

According to Corso's experience, the first option offers the best adhesion properties between the dry coating and the material so this method will be used for samples production.

4.1. Dry coating production

One of the materials needed for the samples production is the dry coating. The 3 types of dry coatings (described at 2.4) were produced at Corso facilities, dimensions and pictures are given below.

Batch	Dimensions	Dry coating Hempathane 55210	Dry coating Alexit 471	Dry coating Alexit 411-77
1	Length (m)	1.46	0.78	1.35
	Width (mm)	430	550	500
	Thickness (µm)	350	320	400
2	Length (m)	1.02	1.20	2.60
	Width (mm)	680	320	570
	Thickness (µm)	220	250	250
Visual		 Figure 6 – Dry coating Hempathane 55210	 Figure 7 – Dry coating Alexit 471	 Figure 8 – Dry coating Alexit 411-77

Table 8 – Dry coating dimensions for sample manufacturing

4.2. Production

To compared dry coating performance to traditional liquid paint, coupons made by infusion with and without the dry coating inside the composite mould are produced. For coupons infused without the dry coating, they are painted after the process by spray gun.

The principle of the resin infusion process with integrated dry coating is represented in the figure below. The dry coating is intended to be used at the bottom of composite mould when doing infusion. The dry coating is located as an extra layer during the fabric layup, as the coating will protect the structure, it is placed directly in contact with the mould, and then dry-reinforce fibre is laid up on the top and peel ply layer consequently. The vacuum bag will seal and create the vacuum atmosphere requested for the process of resin infusion.

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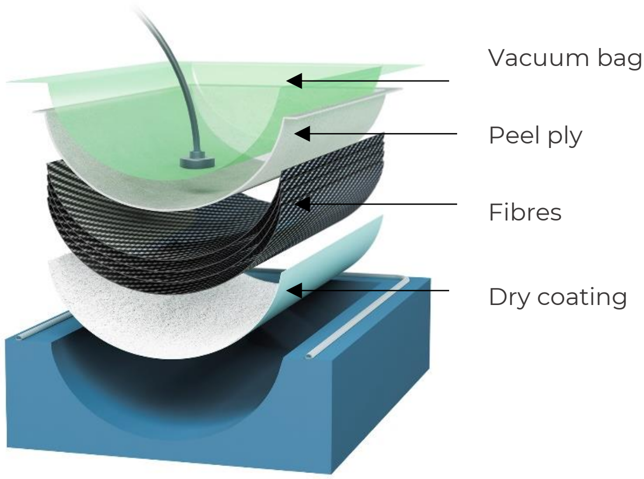

Figure 9 – Use of dry coating in vacuum infusion process principle

4.2.1. Infusion first trials

As it is Ulim first experiment with dry coating and to avoid the flow of resin between the dry coating and the mould, trials are necessary. Those have been made on A4 format and will permit to establish guidelines for the final production.

Below are pictures of the process during the vacuum infusion and the piece after demoulding.

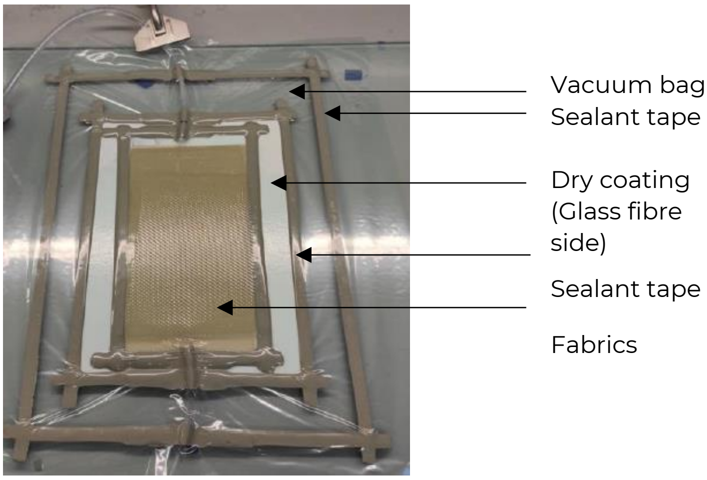

Figure 10 – Infusion first trial

Figure 11 – Sample after demoulding, resin flash identified in red

Several tapes have been tested to avoid the flow of resin between the dry coating and the mould but the grey sealant tape (that can be seen in the above picture) has been chosen to permit the sealant between the mould and the dry coating. However, resin flash occurs trough the dry coating and appears randomly. That means that the resin flows through the porosities of the coating. This defect is unacceptable and has to be removed. Quality of the dry coating should be improved to avoid the porosities.

4.2.2. Final vacuum infusion with dry coating inside the composite mould

After first trials, the following infusions have been performed to produce 15 coupons of each configuration presented at chapter 2.4:

- Infugreen with dry coating Hempathane 55210
- Elium with dry coating Alexit 471
- Infugreen with dry coating Alexit 411-77
- Elium with dry coating Alexit 411-77
- Infugreen without coating
- Elium with coating

Below the parameters used.

Resin	Infugreen 810	Elium 188X0
Curing agent	SD8824	BP-40-SAQ
Ratio	100/22	100/3
Thickness	~3.4mm	~3.4mm
Fabric	Glass Fibre - H2026 - U-E-1182g/m²-1270mm	Glass Fibre - H2026 - U-E-1182g/m²-1270mm
Lay up	[0]2s (4 Layers)	[0]2s (4 Layers)

Table 9 – Parameters used for vacuum infusion with Infugreen, Elium and dry coating

The number of infusions needed to produce all coupons and pictures of the samples are described below. Samples were extracted from a large laminated (nominal dimensions of 600x420mm) and all the laminates were submitted to a post-curing process following the manufacturing guidelines. Elium 24h at 60°C and Infugreen 16h at 60°C.

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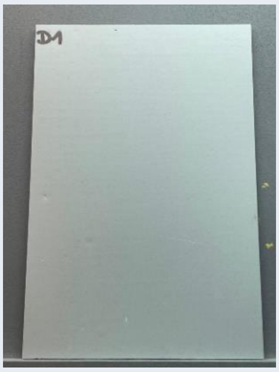
Coating	Composite Resin	Number of infusions	Pictures
Dry coating A: Hempathane 55210	Infugreen	2	 Figure 12 – Infugreen infused with dry coating Hempathane 55210
Dry coating B: Alexit 471	Elium	2	 Figure 13 – Elium infused with dry coating Alexit 471
Dry coating C: Alexit 411-77	Infugreen	2	 Figure 14 – Infugreen infused with dry coating Alexit 411-77
	Elium	3	 Figure 15 – Elium infused with dry coating Alexit 411-77

Table 10 – Infusion with dry coating matrix

The following remarks on the production can be raised:

- Resin flash through the coating observed at preliminary trials step still occurred on some batches, mostly with the dry 411-77. When looking under light, pores are visible. Upgrade of quality of the dry coating with this particular paint has to be study.
- Chemical reaction on infusion of Elium with the dry coating 411-77 (batch 2) occurs. The result obtained is a very rough surface on the paint side with a lot of paint hole as it can be seen in the figure below (D3). As a comparation a good infusion without chemical reaction leaves the dry coating with a smooth surface (D1 below).

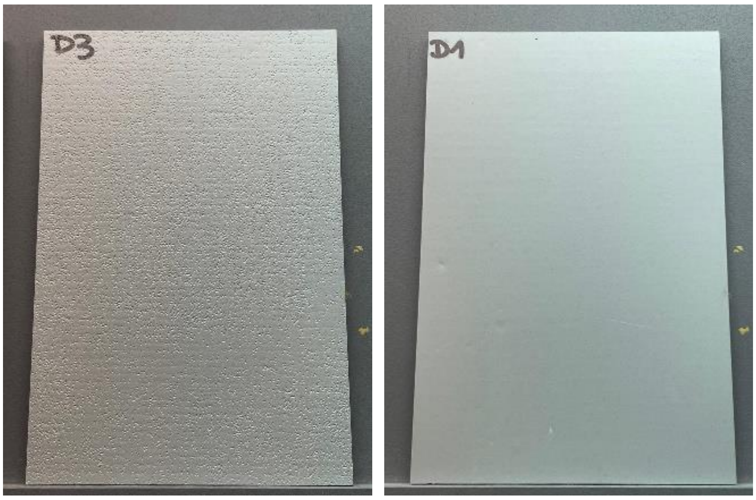


Figure 16 – Samples from infusion where chemical reaction occurred (D3) and no chemical reaction occurred (D1)

This might come from the thickness of the coating. Indeed, compatibility test was done on a sample of 350 µm and showed no sign of chemical reaction. Infusion of batch 1 of this dry coating was about 400 µm and showed no sign of chemical reaction. The last infusion was done with batch 2 with 250 µm thickness and have the result in the above picture. This means that this paint resists to Elium resin not only by the chemical nature of the paint but also by the thickness of the dry coating. However few coupons appear with this defect linked to the chemical reaction, environmental tests still had been done (to fulfil project timeline). Influence of this defect on the protection performance is also interesting to understand.

- The coupon specimens were extracted from a large composite laminate by a water jet cutting process. It has been noticed no delaminate issues were observed during the extraction.

4.2.3. Liquid paint process on composite samples made by resin infusion

In order to compare the dry coating performance with traditional liquid paint, coupons of Infugreen and Elium have been produced by infusion VARTM (without any dry coating, parameters are the same as at chapter 4.2.2 and reminded below) and have been painted with liquid paint after demoulding. The following steps have been performed.

Resin	Infugreen 810	Elium 188X0
Curing agent	SD8824	BP-40-SAQ
Ratio	100/22	100/3
Thickness	~3.4mm	~3.4mm
Fabric	Glass Fibre - H2026 - U-E-1182g/m²-1270mm	Glass Fibre - H2026 - U-E-1182g/m²-1270mm
Lay up	[0]2s (4 Layers)	[0]2s (4 Layers)

Table 11 – Parameters used for vacuum infusion with Infugreen and Elium

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Layer	Paint	Thickness	Application method	Drying
1: Primer	Hempadur 15579	~100 µm	Spray gun	24hours
2: Topcoat	Hempathane 55210	~30 µm	Spray gun	24 hours
3: Topcoat	Hempathane 22510	~30 µm	Spray gun	24 hours

Table 12 – Liquid paint process
(Side prepared and painted: smooth (in contact with the mould), surface preparation: sanding)

Below pictures of what it looks like.

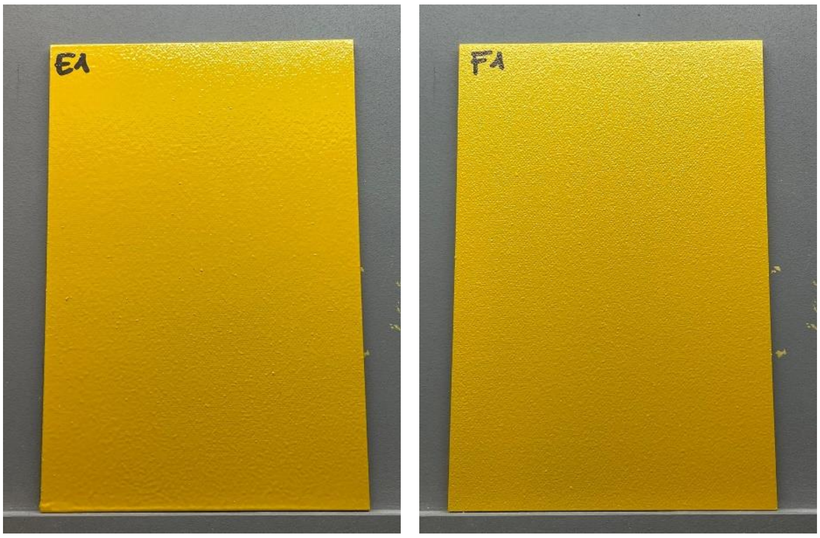

Figure 17 – Liquid painted samples (E1: Infugreen, F1: Elium)

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5. EVALUATION OF COATINGS (DRY COATING OR LIQUID PAINT) ADHESION ON COMPOSITE (ADHESION TEST)

To ensure the protection of the composite, the coating must have a very good adhesion with the surface. If not, the coating can be damaged at the first environmental action and leave the surface without protection.

5.1. Tests description

To evaluate the adhesion performance, two tests are proposed: the pull-off test and cross-cut test.

5.1.1. Cross-cut (ISO 2409)

This test is based on the standard ISO 2409:2020 - Paints and varnishes - Cross-cut test.

It consists of evaluating the adhesion of the coating on a surface where a damage is voluntarily created. This damage is a pattern composed of twenty-five squares (dimensions depend of the thickness of the coating) and it is done by the cutting of the coating.

The mains steps to perform the test are:

- Cut the coating to achieve the pattern: 6 parallel lines and 6 parallels lines and perpendicular to the previous ones. Regarding the thickness of all the samples, 3mm spacing is recommended between the lines. Below a picture to illustrate this step.

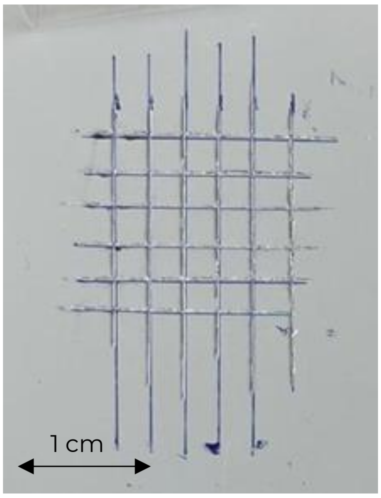

Figure 18 – Cross-cut pattern

- Lightly brush the pattern to remove any dust from the cutting step.
- Apply a tape on the pattern and peel it.
- Evaluate the adhesion following the next guidelines.

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Table 1 — Classification of test results

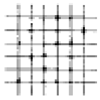
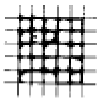
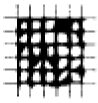
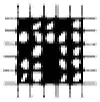
Classification	Description	Appearance of surface of cross-cut area from which flaking has occurred (Example for six parallel cuts)
0	The edges of the cuts are completely smooth; none of the squares of the lattice is detached.	—
1	Detachment of small flakes of the coating at the intersections of the cuts. A cross-cut area not significantly greater than 5 % is affected.	
2	The coating has flaked along the edges and/or at the intersections of the cuts. A cross-cut area significantly greater than 5 %, but not significantly greater than 15 %, is affected.	
3	The coating has flaked along the edges of the cuts partly or wholly in large ribbons, and/or it has flaked partly or wholly on different parts of the squares. A cross-cut area significantly greater than 15 %, but not significantly greater than 35 %, is affected.	
4	The coating has flaked along the edges of the cuts in large ribbons and/or some squares have detached partly or wholly. A cross-cut area significantly greater than 35 %, but not significantly greater than 65 %, is affected.	
5	Any degree of flaking that cannot even be classified by classification 4.	

Figure 19 – Cross-cut result classification

As an example, find below pictures of results.

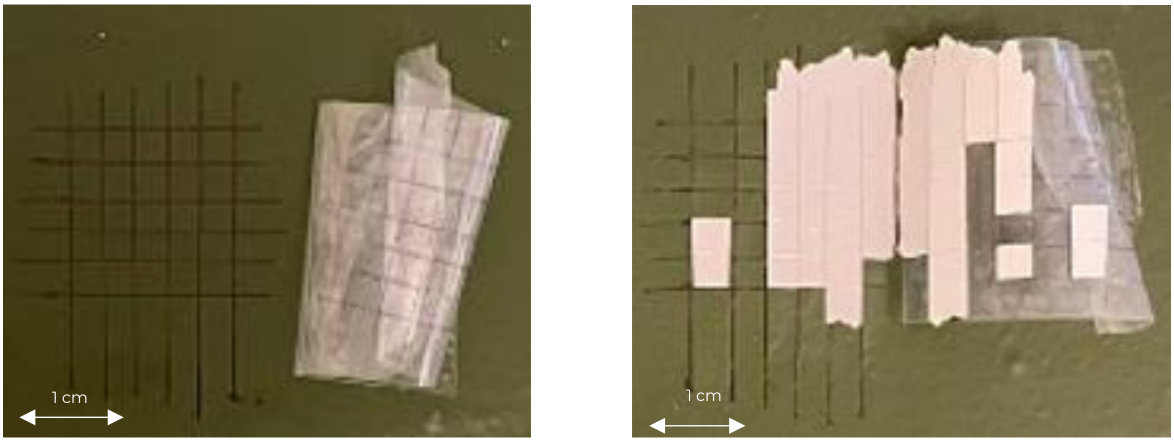


Figure 20 – Cross-cut result examples, left: very good adhesion class 0 / right: very bad adhesion, class 5

5.1.2. Pull-off (ISO 4624)

This test is based on the standard ISO 4624:2016 Paints and varnishes — Pull-off test for adhesion.

The pull-off test consists of measuring the tensile stress necessary to break the weakest interface of the sample. It is a qualitative test by the detection of the weakest interface but also a quantitative test by the quantification of the tensile stress needed to break this interface.

To achieve this, a dolly is glued to the coating surface. After curing of the adhesive, an instrument pulls the dolly and measure the strength to break the interface between the coating and the substrate. To do that, the choice of the adhesive is important. Indeed, the adhesion between the adhesive and the dolly and the adhesive and the coating surface must be higher than the adhesion at the interface which is evaluated (mostly the interface coating/substrate).

The mains steps to perform the test are:

- Sand the dolly and the coating to activate both surfaces. Then dust and degrease.
- Glue the dolly to the surface (apply a homogenous thickness of glue on the dolly and remove any excess). Let it cured according to technical data sheet information.

Figure 21 – Pull-off preparation

- Pull the dolly with the dedicated instrument, report the force value and analyse the weakest interface.

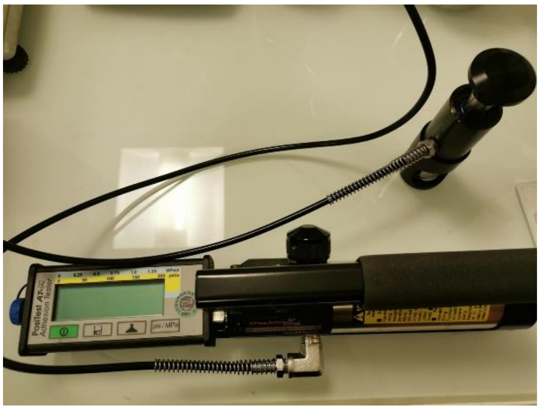


Figure 22 – Example of pull-off instrument

For analysing of the results (value and interface), three terms are defined:

- Esubstrate = Substrate cohesion energy
- Einterface = Adhesion energy between the coating and the substrate
- Ecoating = Coating cohesion energy

Keeping in mind that the interface coating/substrate Einterface is to evaluate, several cases can occur, each one will be described below.

The interface adhesion performance can be classified as: case 2 > case 4 > case 3, where case 2 is the best scenario.

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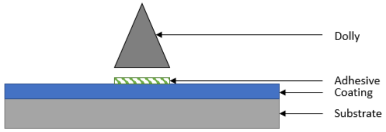
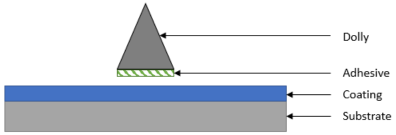
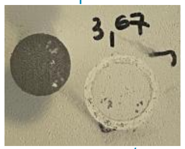
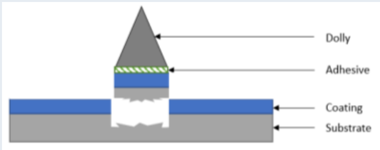
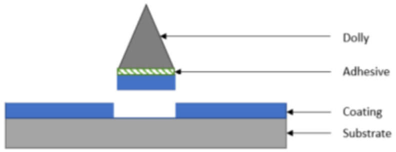
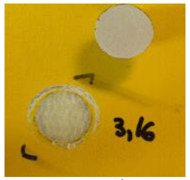
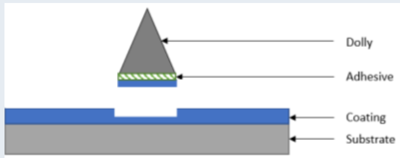
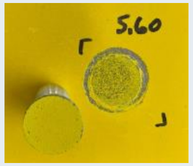
Cases	Weakest interface	Illustration	Visual	Interpretation
1	At both interfaces of the adhesive used for gluing the dolly: - Dolly/ Adhesive - Adhesive/ Coating	 Figure 23 – Adhesive/Dolly failure  Figure 24 – Adhesive/Coating failure	 Figure 25 – Dolly/Adhesive failure example  Figure 26 – Adhesive/Coating failure example	1. Wrong adhesive choice: adhesive/dolly or adhesive/coating adhesion lower than Einterface. 2. Lack in test preparation: not enough amount of adhesive or not enough activation by sanding. → Repeat the test by solving issues below or →Einterface> adhesive/dolly or adhesive/coating adhesion.
2	Inside the substrate	 Figure 27 – Inside the substrate failure	 Figure 28 – Inside the substrate failure example	Einterface>Esubstrate and Ecoating>Esubstrate → This can be read as the best result: the adhesion coating/substrate is higher than the substrate cohesion so the coating performed well in terms of adhesion and cohesion
3	Coating/substrate	 Figure 29 – Coating/Substrate failure	 Figure 30 – Coating/Substrate failure example	Einterface<Esubtrate Einterface<Ecoating Good adhesive choice and test preparation. → Values obtained by the instruments are representative of the interface examined. → Poor adhesion on the substrate.
4	Between coating layers (if relevant)	 Figure 31 – Between coating layers failure	 Figure 32 – Between coating layers failure example	Einterface>Ecoating Esubtrate>Ecoating → Cohesion of coating can be improved.

Table 13 – Pull-off result interpretation

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5.2. Results

Target values for the adhesion of coatings on the composite substrate are given in the next table.

Test type	Test method	Target value	Number of samples / specimens	Total
Cross-cut	ISO 2409	Class 0	3	18
Pull-off	ISO 4624	Dry coating/substrate adhesion > Liquid paint/substrate adhesion	3	18

Table 14 – Adhesion specifications

5.2.1. Adhesion by cross-cut

Cross-cut has been performed on each sample configuration; results are given below.

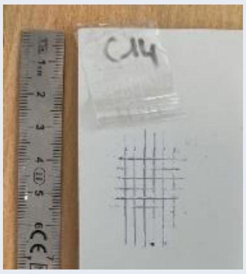
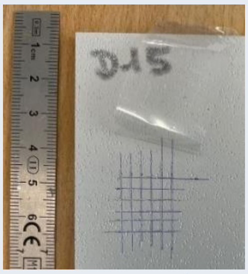
Composite Resin	**Infugreen**		
Coating	Dry coating A: Hempathane 55210	Dry coating C: Alexit 411-77	Liquid paint: Hempathane 55210
Target	Class 0		
Result	Class 0	Class 0	Class 0
Pictures	 Figure 33 – Dry coating Hempathane 55210/Infugreen cross-cut result	 Figure 34 – Dry coating Alexit 411-77/Infugreen cross-cut result	 Figure 35 – Liquid paint Hempathane 55210/ Infugreen cross-cut result
Composite Resin	**Elium**		
Coating	Dry coating B: Alexit 471	Dry coating C: Alexit 411-77	Liquid paint: Hempathane 55210
Target	Class 0		
Result	Class 0	Class 0	Class 0
Pictures	 Figure 36 – Dry coating Alexit 471/Elium cross-cut result	 Figure 37 – Dry coating Alexit 411-77/Elium cross-cut result	 Figure 38 – Liquid paint Hempathane 55210/Elium cross-cut result

Table 15 – Cross-cut results

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

Class 0 is obtained for each configuration; the test can be considered as not relevant to compared adhesion to the composite substrate of the dry coating with liquid paint. However, it can be said that dry coating adhesion performance are equivalent to liquid paint one.

5.2.2. Adhesion by pull-off

To complete results from cross-cut test, pull-off has been carried out. The graph below represents the force needed to break the weakest interface in the samples coated. These results have to be analysed in combination with pictures (under) showing which is the weakest interface.

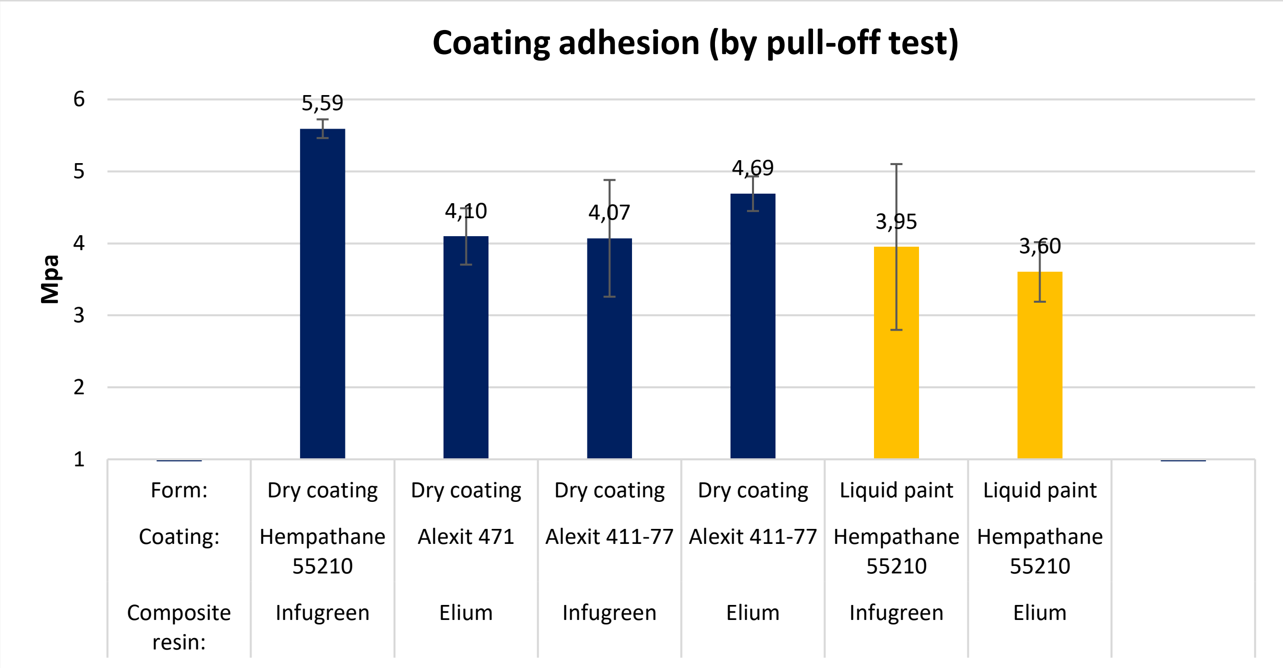


Figure 39 – Coating adhesion by pull-off results on 3 repetitions (standard deviation)

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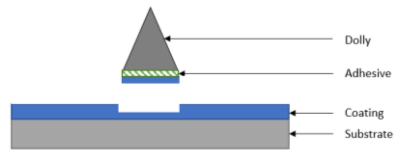
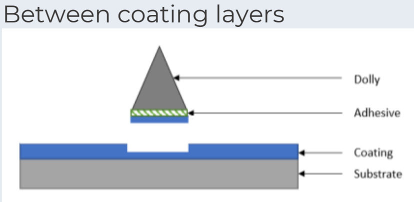
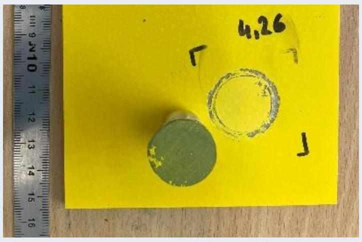
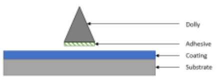
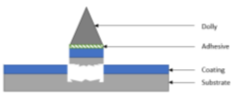
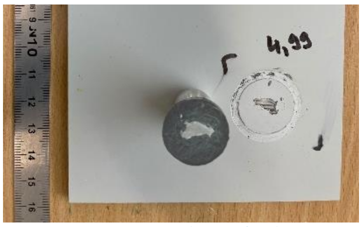
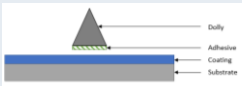
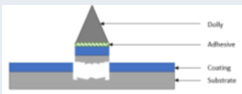
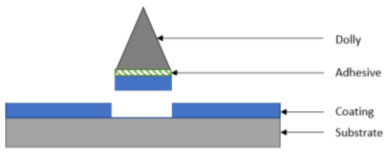
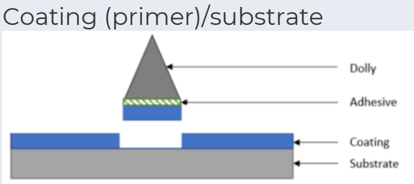
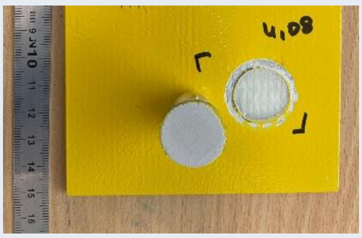
Coating	Composite Resin	Weakest interface	Pictures
Dry coating A: Hempathane 55210	Infugreen	Between coating layers  Figure 31	 Figure 40 – Dry coating Hempathane 55210/Infugreen pull-off result
Dry coating B: Alexit 471	Elium	Between coating layers  Figure 31	 Figure 41 – Dry coating Alexit 471/Elium pull-off result
Dry coating C: Alexit 411-77	Infugreen	Mix : coating/adhesive + inside the substrate  Figure 24  Figure 27	 Figure 42 – Dry coating Alexit 411-77/Infugreen pull-off result
	Elium	Mix : coating/adhesive + inside the substrate  Figure 24  Figure 27	 Figure 43 – Dry coating Alexit 411-77/Elium pull-off result
Liquid paint: Hempathane 55210	Infugreen	Coating (primer)/substrate  Figure 29	 Figure 44 – Liquid paint Hempathane 55210/Infugreen pull-off result
	Elium	Coating (primer)/substrate  Figure 29	 Figure 45 – Liquid paint Hempathane 55210/ Elium pull-off result

Table 16 – Weakest interface after pull-off test results

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According to pictures, the failure on samples coated with dry coatings occurred in the dry coating or in the substrate whereas it occurred at the interface coating/substrate on samples coated with liquid paint.

Combined with the value in the graph where the force to extract the dolly is the higher when samples are coated with the dry coating, it can be concluded that the force needed to disbound the interface dry coating/substrate is superior to the force needed to break the cohesion inside the substrate or inside the dry coating, which is also superior to the force needed to disbound the interface liquid paint/ substrate.

This can be illustrated by the next figure.

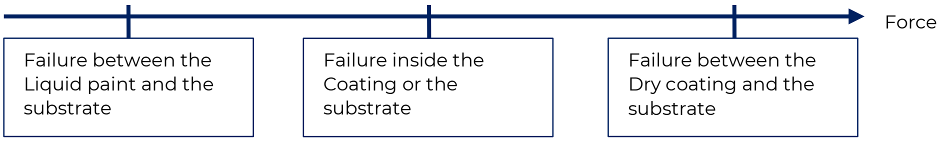

Figure 46 – Comparison of coating adhesion according to failure interfaces

Concerning the influence of the substrate on the adhesion of the coating, same results and observations are obtained when comparing same coating system and the two different substrates Infugreen and Elium:

- Same level of values is obtained to pull the dolly with the dry coating Alexit 411-77 or the liquid paint Hempathane 55210.
- Same interface failure is obtained:
    - A mix of failure inside the substrate and between the dolly and the adhesive for the coating Alexit 477-77 on both composite substrates.
    - Failure on the interface coating/substrate for the (liquid) coating Hempathane 55210 on both composite substrates.

To conclude, both coatings: dry and liquid adheres well to both composite substrates Infugreen or Elium.

Pull-off test demonstrates that liquid paint/composite adhesion is equivalent to the composite material cohesion (Infugreen or Elium) and Dry coating 411-77/composite adhesion is higher than composite material cohesion.

At this stage, it is difficult to quantify and compare liquid/composite and dry coating/composite interface. However, in a qualitative way, the interface between dry coating and the composite is higher.

Regarding the deviation (in the graph), the previous statement has to be validated, an increasing of the tests for a better repeatability can be done to achieve this issue.

It can be supposed that, as the adhesion is higher with the dry coating, the protection of the composite material will be more performant. This will be evaluated through environmental tests in the next chapter as well as the evolution of the coating adhesion on the composite substrate after the tests.

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6. COATINGS DURABILITY

6.1. Evaluation of composite protection by coatings (dry coating or liquid paint) through environmental tests

Taking into account the off shore environment, 4 tests have been chosen to test the durability of the coatings:

- Salt water immersion and exposition to high humidity, as composites are water sensitive.
- Neutral salt spray test: simulate a severe corrosion atmosphere.
- Exposition to ultraviolet (UV): epoxy composites are sensitive to UV radiation.

The tests will be followed by 3 types of evaluations, characteristic from coating evaluation:

- Water uptake.
- Colour.
- Adhesion.

Evaluation description will be described in each specific chapter and tests explanations will be presented in the chapter 6.1.1.

The next table represents the environmental test matrix. The results are showed in chapter 6.1.2 to 6.1.4.

Test type	Test method	Evaluation after test	Target value	Number of samples / specimens	Total
Salt water immersion	ISO 2812 Duration : 1 month	-Visual aspect -Water absorption -Colour (ISO 7724-3) -Adhesion by pull-off (ISO 2409)	-No degradation -Mass increase <1% -Colour change ΔE<1 -Adhesion ≥ Adhesion before test	3	18
Exposition to high humidity	ISO 6270 Duration : 1 month			3	18
Neutral salt spray test	ISO 7253 Duration : 1 month			3	18
Exposition to UV	ISO 11507 Duration : 1 month			3	18

Table 17 – Environmental test matrix

Evolution of the colour of the coating, the mass of the samples and the adhesion between the substrate and the coating will be presented in the following chapter.

6.1.1. Tests description

Each test lasts one month.

For each exposition, samples have been protected at the back and the edges in order to only evaluate the coating performance.

6.1.1.1. Salt water immersion (ISO 2812)

This test is based on the standard ISO 2812-1:2017 - Paints and varnishes — Determination of resistance to liquids — Part 1: Immersion in liquids other than water.

In order to test the coating liquid absorption resistance when fully immersed, an immersion can be done. The liquid selected is salt water in order to be representative of sea water. The samples are immersed at room temperature (23°C) in a salt water bath with a concentration in salt of 35 g/L.

6.1.1.2. Exposition to high humidity (ISO 6270)

This test is based on the standard ISO 6270-1:2017 - Paints and varnishes — Determination of resistance to humidity — Part 1: Condensation (single-sided exposure).

The aim of this exposure is to evaluate the protection role of the coating against a highly humid atmosphere. To simulate these conditions, samples are put in chamber at 40°C and with a relative humidity of 100%.

6.1.1.3. Neutral salt spray test (ISO 7253)

This test is based on the standard ISO 7253:1996 - Paints and varnishes — Determination of resistance to neutral salt spray (fog).

The neutral salt spray test is a common test to evaluate paints applied on metallic substrate to resist to corrosion. Samples with scribes created in the coated are exposed in a chamber at 35°C where saline solution is sprayed on the samples (NaCl at 50g/L, pH between 6,5 and 7,2).

6.1.1.4. Exposition to UV (ISO 11507)

This test is based on the standard ISO 11507:2007 - Paints and varnishes — Exposure of coatings to artificial weathering — Exposure to fluorescent UV lamps and water.

Exposition to UV is a way to simulate the aging of the coatings. To perform this, samples are exposed to UV lamps, which are representatives to UV sun rays, and condensation which is representative of atmospheric humidity.

For the framework of this project, method A of the ISO 11507 standard was used and fluorescent tubes UVB 313 were employed for the light source.

6.1.2. Impact of environmental tests on the water uptake of the materials

6.1.2.1. Evaluation of the water absorption by a material

This evaluation permits to know if the material is sensitive to water. The percentage of water absorbed by the material is obtained by the measure of the mass before (m(before)) and after (m(after)) exposure and it is calculated with:

$$\%\, mass\ evolution = \frac{m(after) - m(before)}{m(before)} * 100$$

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6.1.2.2. Results

The mass increase (in percentage) of the tested samples is presented in the graph below. A mass increase lower than 1% is considered compliant, which means that the coating protected the composite against water uptake.

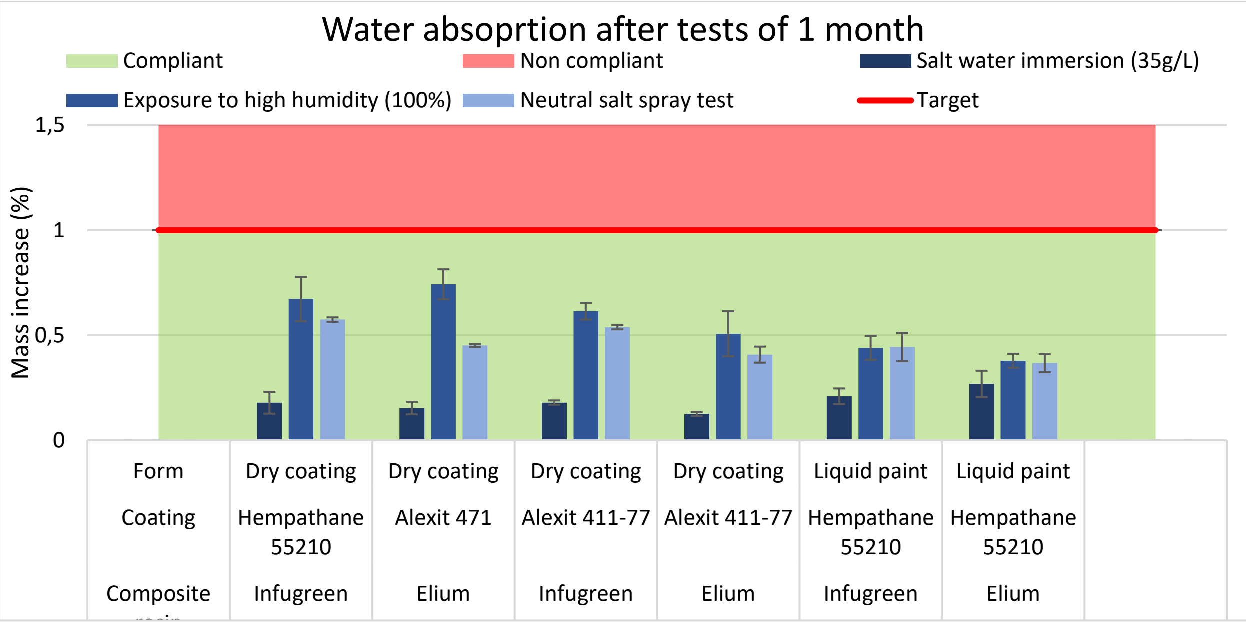

Figure 47 – Water absorption results on 3 repetitions (standard deviation)

For each type of resin (Infugreen or Elium), each coating form (dry coating or liquid) and each specific coating, there is no significant water uptake on any type of samples.

Each coating protected well against water aggression and so the dry coating behaviour is the same as liquid on this protection.

However, it can be highlighted that samples fully immersed in water absorbed less water (~0.2%) than ones exposed to humidity (0.5%, exposure to high humidity and neutral salt spray). Further investigation is needed to explain this phenomenon.

6.1.3. Impact of environmental tests on the colour of the coatings

6.1.3.1. Colour evaluation principle (ISO 7724-3)

The colorimetry is science and techniques allowing to define and measure colour and couleur difference. In the system called CIE L*a*b*, one colour can be defined with three parameters: L, a, and b corresponding to point coordinates belonging to colour space. "L" represents the lightness, "a" a position between red and green, "b" a position between yellow and blue. This can be illustrated as follow.

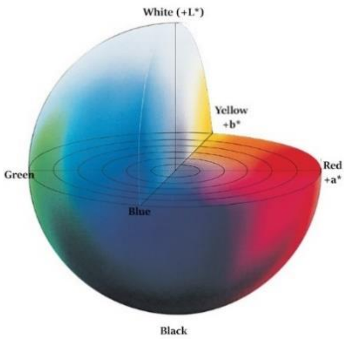

Figure 48 – CIE L*a*b* colour space [2]

In practical, the material used to measure the value is called a spectro-colorimeter. Its operating mode is described in the next figure.

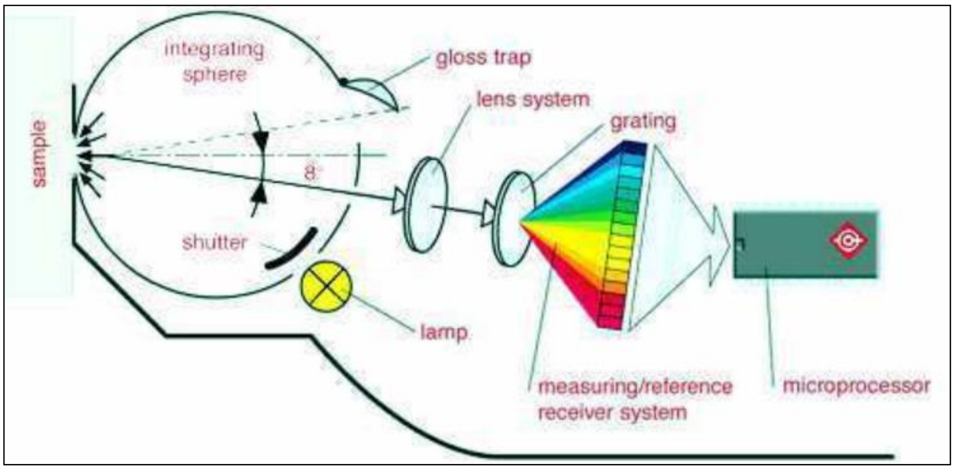

Figure 49 – Spectro-colorimeter principle [3]

When working on the difference between two colours (colour (1) and colour (2)), the following calculation is made:

$$\Delta E = \sqrt{\left(L(2) - L(1)\right)^2 + \left(a(2) - a(1)\right)^2 + (b(2) - b(1))^2}$$

It is commonly considered that a ΔE<1 means that the difference between two colours cannot be seen by human eyes. This statement will be selected in this project to evaluate colour changing after aging.

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6.1.3.2. Results

On a first review of the pictures presented below, it can be clearly seen on the samples coated in yellow, by liquid paint or dry coating, a colour difference between the area protected and unprotected. However, no such evolution is observed on the samples coated in grey colour by the dry coating.

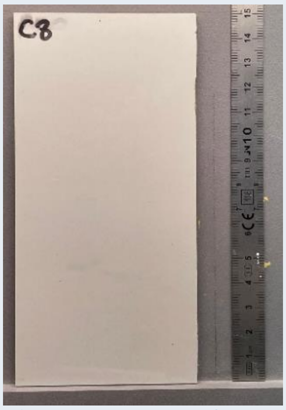
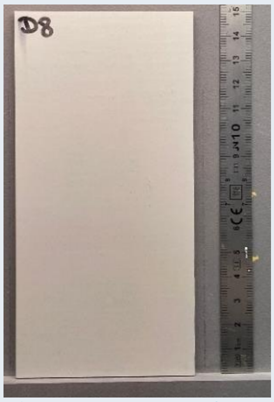
Coating	Composite Resin	Pictures from UV test	Coating	Composite Resin	Pictures from UV test
Dry coating A: Hempathane 55210	Infugreen	 Figure 50 – UV aged Dry coating Hempathane 55210/Infugreen	Dry coating B: Alexit 471	Elium	 Figure 51 – UV aged Dry coating Alexit 471/Elium
Dry coating C: Alexit 411-77	Infugreen	 Figure 52 – UV aged Dry coating Alexit 411-77/ Infugreen	Dry coating C: Alexit 411-77	Elium	 Figure 53 – UV aged Dry coating Alexit 411-77/Elium
Liquid paint: Hempathane 55210	Infugreen	 Figure 54 – UV aged Liquid paint Hempathane 55210/Infugreen	Liquid paint: Hempathane 55210	Elium	 Figure 55 – UV aged Liquid paint Hempathane 55210/Elium

Table 18 – UV aged samples results

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The observation made below can be confirmed by the measurement of the colour after aging and the comparison with the initial colour: results are presented in the next graph.

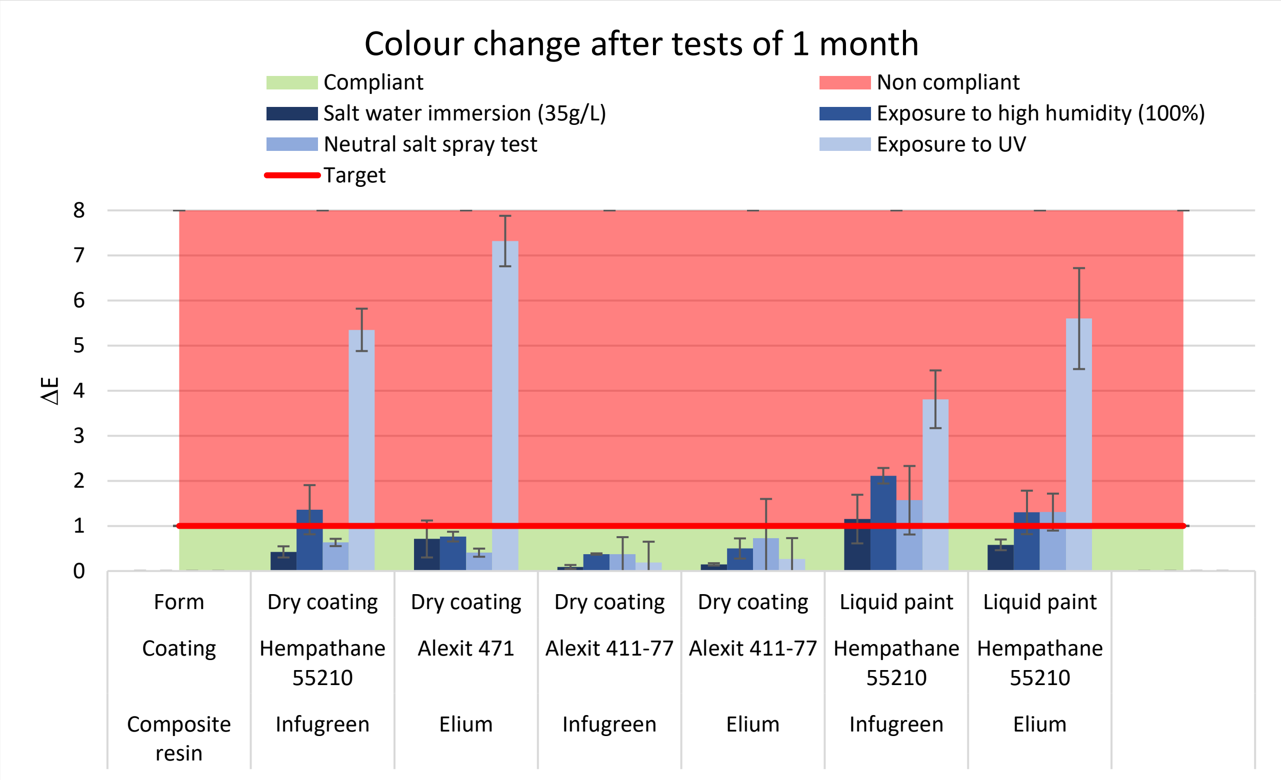


Figure 56 – Colour change results on 3 repetitions (standard deviation)

In general, and based mostly on the results from UV exposure, it appears a bad behaviour of yellow coatings: in dry coating or liquid form and on any type of composite substrate (Infugreen or Elium).

If a focus is made between Dry coating/Hempathane 55210/Infugreen samples and Liquid paint/Hempathane 55210/Infugreen samples, where the only difference in the coating from, it be said that dry coating seems to be more colour stable when exposed to salt water immersion, humidity and neutral salt spray test (not observed for UV): the colour difference is less important with samples painted with the dry coating.

Finally, samples (Infugreen or Elium) painted with dry coating Alexit 411-77, showed no sign of colour change (ΔE>1). This means that this paint is very colour stable. The fact that it is linked to the dry coating form needs to be stated with additional tests (for example by performing the same tests with samples painted with the liquid paint Alexit 411-77).

At this stage, it cannot be stated if the degradation of the colour of coating has an impact the material properties. If it is the case, it will mean that the degradation of the colour implies a lack of the coating protection performance. This will be evaluated in the next chapter.

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

6.1.4. Impact of environmental tests on the adhesion of the coatings

The impact of the exposure of coatings, against different actions, on the adhesion is evaluated through pull-off test. The principle of this test is described at the chapter 5.1.2.

To evaluate the adhesion evolution:

- The weakest interface before and after exposure will be compared,
- If this interface is the same before and after exposure, the force needed to break it will also be compared.

The next table and graph present the results of the pull-off test performed after each aging tests and compared to the initial adhesion. In the table, the results highlighted in red are not exploitable (probably due to lack in test preparation), ones in orange are results different from the initial result before aging. More explanations are given after the graph. Pictures are given in the Annex.

Coating	Composite Resin	Initial Weakest interface	Aging test	After aging Weakest interface
Dry coating A: Hempathane 55210	Infugreen	Between coating layers	Salt spray immersion	Between coating layers
			Humidity	Dolly/adhesive
			NNS	Between coating layers
			UV	Between coating layers
Dry coating B: Alexit 471	Elium	Between coating layers	Salt spray immersion	Between coating layers
			Humidity	No tendency
			NNS	Mix: Between coatings layers + Dry coating/substrate
			UV	Between coating layers
Dry coating C: Alexit 411-77	Infugreen	Mix: coating/adhesive + inside the substrate	Salt spray immersion	Mix: adhesive/coating+ inside the substrate
			Humidity	Mix: Dolly/adhesive + adhesive/coating
			NNS	Mix: Dolly/adhesive + adhesive/coating
			UV	Dolly/ Adhesive
	Elium	Mix: coating/adhesive + inside the substrate	Salt spray immersion	No tendency
			Humidity	Mix: Dolly/adhesive + adhesive/coating
			NNS	Mix: Dolly/adhesive + adhesive/dry coating
			UV	Inside the substrate
Liquid paint: Hempathane 55210	Infugreen	Coating (primer)/substrate	Salt spray immersion	Coating (primer)/substrate
			Humidity	Mix: Coating (primer)/substrate + dolly/adhesive
			NNS	Coating (primer)/substrate
			UV	Mix: Coating (primer)/substrate + between coating layers
	Elium	Coating (primer)/substrate	Salt spray immersion	Coating (primer)/substrate
			Humidity	Coating (primer)/substrate
			NNS	Coating (primer)/substrate
			UV	Mix: Coating (primer)/substrate + between coating layers

Table 19 – Weakest interface after aging results

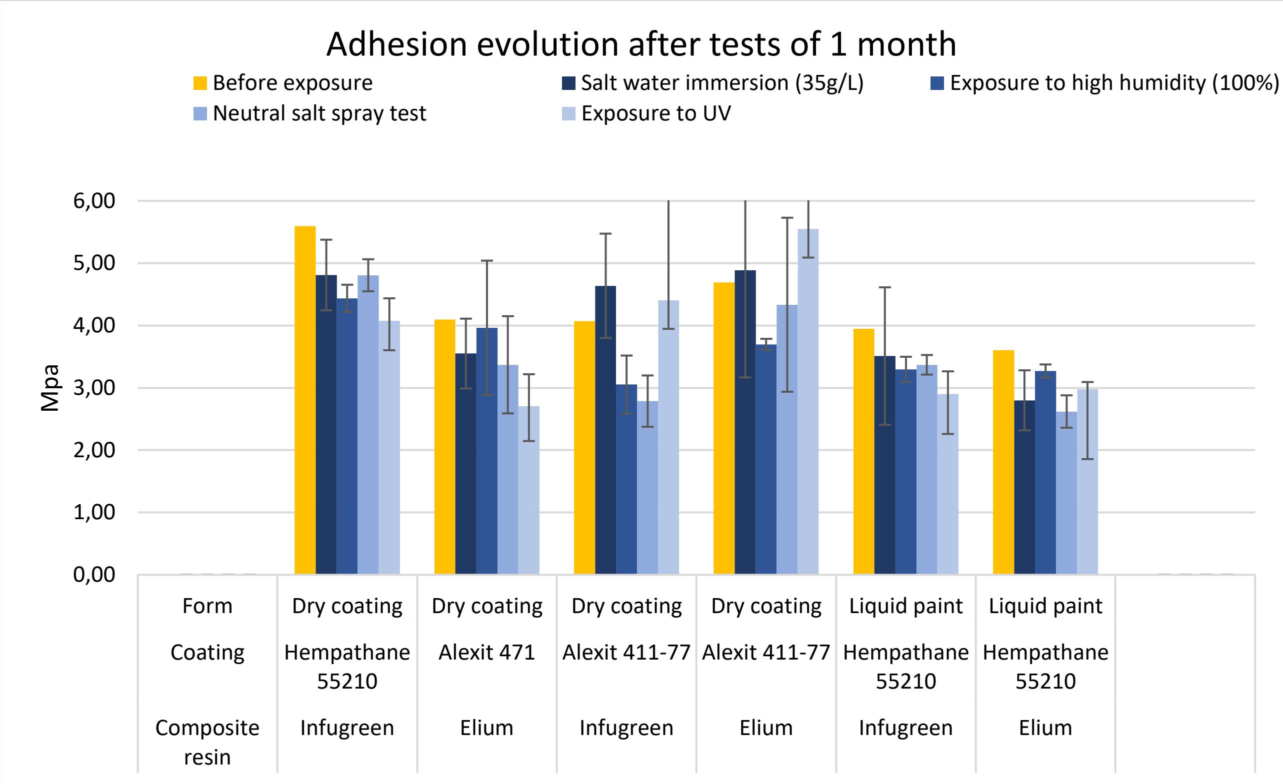


Figure 57 – Adhesion after aging results on 3 repetitions (standard deviation)

Concerning the liquid paint on both Infugreen and Elium, the weakest interface is the same: between the primer and the substrate. However, when looking at the value in the graph, we can observe a decrease of approx. 15% of the resistance of this interface after aging.

Same phenomenon is observed on dry coating Hempathane 55210 on Infugreen and dry coating Alexit 471 on Elium: same weakest interface (between coating layers) and a decreasing in the adhesion performance (about 20%). As a decreasing in the coating cohesion is observed, it can be said that environmental tests, in particular UV, aged both coatings.

Regarding the dry coating Alexit 411-77 on both composite substrate, most of the interface results are unexploitable if we want to compare with the initial weakest interface. It can only be concluded that the adhesion between the dry coating and the substrate is higher to the force needed to disbound the adhesive from the dolly or the coating.

Finally, a major impact on the adhesion between the coating and the substrate of one of the tests is not evident here. The cross-cut test might have been interesting.

To conclude on the coating adhesion evolution:

- With liquid paint: the adhesion between the coating and the composite (Infugreen or Elium) is the lowest and this adhesion decreases when doing aging test.
- With the dry coating Hempathane 55210 or Alexit 471: the interface with the composite is strong. The cohesion of the dry coating itself decreases when exposed to environmental tests, especially UV. This is linked with the colour results and will be put in parallel with the next results from mechanical tests.
- No conclusion can be made on the adhesion evolution of the dry coating Alexit 411-77

6.1.5. Conclusion on coating behaviour against environmental test

When tested coated (liquid or dry) samples trough the following tests: salt water immersion, exposure to humidity, neutral salt spray test and exposure to UV, the following impacts are obtained:

- No impact on the mass of the samples. This means the coating (liquid or dry) protected well the samples against water absorption by the composite. Dry coating protected as well as the liquid paint.
- Important impact on the colour of the yellow coatings (Hempathane 55210: dry or liquid / Alexit 471 dry coating) especially on UV exposure, this is not true for the grey Alexit 411-77 coating. It cannot be concluded at this stage if this change in colour impact the coating protection performance so if it will have an influence on the composite material performance.
- A tendency of adhesion decreasing of the coating on the composite substrate for the combination liquid paint on Infugreen and Elium and on the yellow dry coatings Hempathane 55210 on Infugreen and Alexit 471 on Elium.
- UV test appears as the most severe exposition for the colour of coating and may have an impact on the coating adhesion on the substrate.
- Dry coating behaves the same as liquid paint in terms of colour evolution and water absorption protection but performed better in terms of adhesion on the substrate.

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

6.2. Influence of the protection of composite by dry coating on mechanical resistance

We saw that aging tests impacted the coating, mostly in colour and on the adhesion on the substrate. It cannot be concluded at this stage if a degraded coating has an impact on the protection of the composite material. To evaluated this, four samples from UV aging (considered the most severe test regarding the composite material and regarding the UV colour result) were selected and tested trough bending test (0° and 90°). The results are presented in the next chapters.

The samples tested are reminded in the next table. The aged samples will also be compared with a control sample: not aged and with no coating. With that selection, the impact of UV can be evaluated depending on:

- The composite resin: Infugreen or Elium.
- The coating form: Dry coating or liquid.
- The influence of a coating on the composite properties.

Coating	Composite Resin	Aging test	Mechanical test after aging
Dry coating A: Hempathane 55210	Infugreen	Exposition to UV ISO 11507 Duration: 1 month	Bending test at 0° and 90°
Dry coating B: Alexit 471	Elium		
Liquid paint: Hempathane 55210	Infugreen		
	Elium		

Table 20 – Aged samples to be mechanical tested matrix

6.2.1. Bending test description

Flexure samples were tested in a three-point-bending loading mode in accordance with ISO14125. Samples were measured using a vernier callipers and a micrometre for the thickness. The lay-up, and nominal dimensions and span-to-thickness ratio are summarised in Table 20. For 0° samples, the fibres are predominantly aligned with the length of the test specimen. For 90° samples, the fibres are predominantly aligned with the width of the test specimens. Samples were stored in PE bags under ambient conditions prior to testing. The samples were tested on a Tinius Olsen electro-mechanical straining frame with load cell of 10 kN rating for Flexural 0° and 1 kN for Flexural 90° specimens. LVDT (Linear Variable Differential Transformer: A displacement transducer) was used to record the deflection of the central region of the specimen for Flexural 0° specimens. In the case of Flexural 90°specimens, the cross-head stroke was recorded to obtain the deflection of the specimen. The tests were conducted under displacement control with a displacement rate of 1 mm/min. The roller diameters at the load nose and support points were 10 mm and 4 mm respectively. Figure 58 depicts a flexural sample being tested under 3-point loading. Data reduction was performed for the calculations of the required properties. The following results were extracted from the Flexure 0° and 90° test data, viz. Flexural Strength (σ_F), Flexural Modulus (E_F) and Flexural strain (ε_f) at failure. The strain to failure is the strain at which a first sign of load drop is observed in the mechanical response curves.

The calculations were performed using the following formulae,

$$Flexural\ Strength\ (\sigma_F) = \frac{3 \times F \times L}{2 \times b \times h^2}$$

$$Flexural\ Strain\ (\varepsilon_f) = \frac{6 \times s \times h}{L^2}$$

$$Flexural\ Modulus\ (E_F) = \frac{(\sigma_F'' - \sigma_F')}{(\varepsilon_f'' - \varepsilon_f')}$$

Where, F is the applied load, L is the span, b is the sample width, h is the sample thickness, s is the deflection, σ_F'' is the stress at which strain is 0.0025 and σ_F' is the stress at which strain is 0.0005. The strength/load at failure and the strain at failure are reported at the point of initiation of the failure in the specimen. In the Flexural stress vs strain plots, the failure initiation point corresponds to the first drop observed in the curve. However, for the representation of overall material response, the complete curves have been plotted beyond the point of first load drop.

Material	No. of samples	Lay-up	Thickness excluding coating (mm)	Width (mm)	Span (mm)	Span-to-thickness ratio
Elium / Glass fibres	3	$[0]_{2S}$	3	15	60	20
	3	$[90]_{2S}$	3	15	60	20
GF Infugreen / Glass fibres	3	$[0]_{2S}$	3	15	60	20
	3	$[90]_{2S}$	3	15	60	20

Table 21 – Flexure test sample lay-up and nominal dimensions

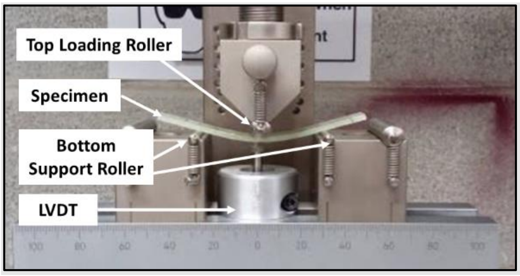


Figure 58 – Flexure test sample under 3-pt bend loading configuration

Below, 4 definitions are defined:

- Flexural Stress: stress on the surface of the material under the load nose on either the tension or compression side.
- Flexural Strength: largest flexural stress capable of being supported by the material. In the current work, the flexural strength is taken as the first load drop in the stress-strain curve.
- Strain: change in length divided by original length measured on the surface of the sample under the load nose on the tension side.
- Flexural Modulus: flexural stiffness of the material.

For the framework of the project, the samples were tested with the coating at the top, as seen in the next figure. In 0° samples the material strength is mainly controlled by the material located directly under the load nose (where the measure is taken). If ageing had a damaging affect on the coating and the material, then a reduction in the flexural strength and/or modulus will be seen.

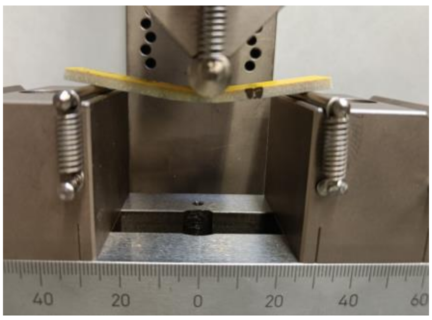


Figure 59 – Flexure test with coated sample

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

6.2.2. Result

6.2.2.1. Flexural 0°

Linear stress-strain response curves are observed with a rapid drop in load towards the end of the test, the corresponding graphs are presented below (Figure 60 to 65). The point of first drop in load in the curve is being reported as the failure load and corresponding strain is reported as the failure strain.

For most of the 0° samples the maximum load and the failure load are very close or equal. Values extracted from the graphs are summarized in the next table.

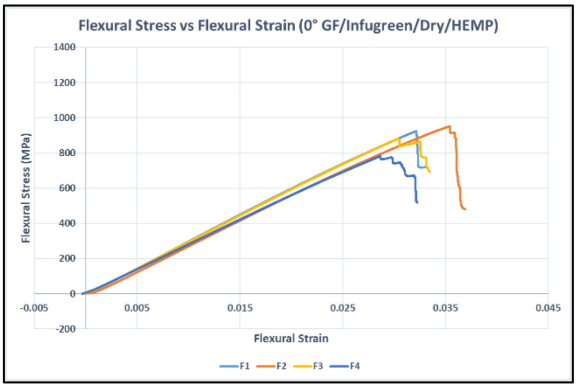


Figure 60 – Flexural stress vs flexural strain plots for 0°, UV aged Dry coating Hempathane 55210/Infugreen

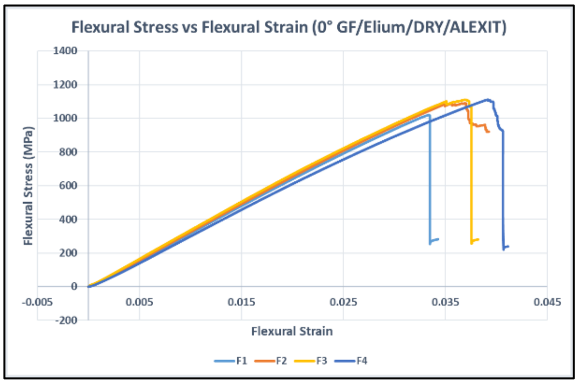


Figure 61 – Flexural stress vs flexural strain plots for 0°, UV aged Dry coating Alexit 471/Elium

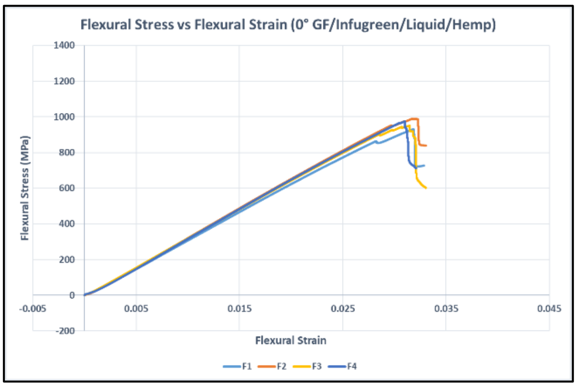


Figure 62 – Flexural stress vs flexural strain plots for 0°, UV aged Liquid paint Hempathane 55210/Infugreen

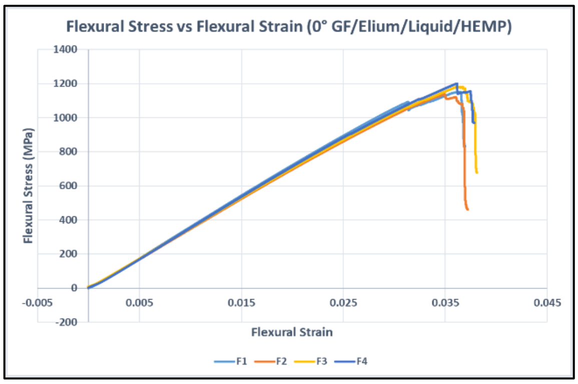


Figure 63 – Flexural stress vs flexural strain plots for 0°, UV aged Liquid paint Hempathane 55210/Elium

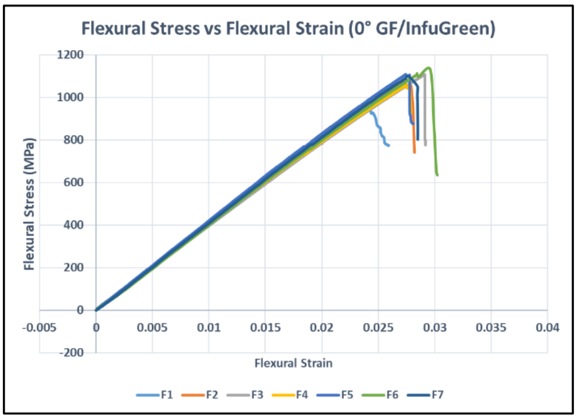


Figure 64 – Flexural stress vs flexural strain plots for 0°, Infugreen control (no coating)

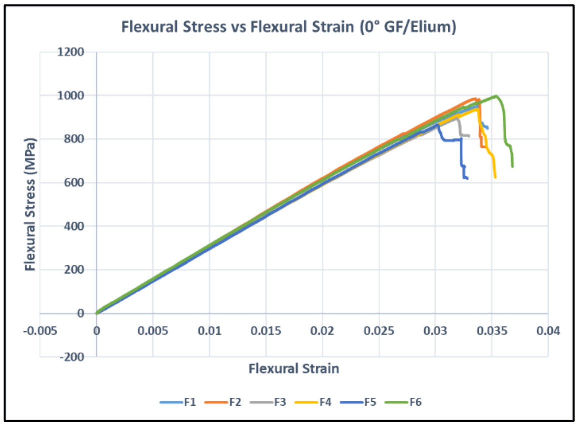


Figure 65 – Flexural stress vs flexural strain plots for 0°, Elium control (no coating)

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

Composite Resin	Coating	Number of samples	Load at Failure (kN))	Failure Strength (MPa)	Flexural Modulus, E_f (GPa)	Strain-at-failure (%)
Infugreen	Control (no coating)	7	1.759 (0.108)	1075 (61.8)	39.3 (1.8)	2.75 (0.17)
	Dry coating Hempathane 55210	4	1.777 (0.146)	872.2 (90.5)	25.9 (1.6)	3.27 (0.20)
	Liquid Hempathane 55210	4	1.678 (0.087)	929.5 (47.8)	28.8 (1.6)	2.97 (0.11)
Elium	Control (no coating)	6	1.436 (0.092)	939.5 (51.3)	30.3 (1.8)	3.31 (0.18)
	Dry coating Alexit 471	4	1.889 (0.116)	1079.5 (41.4)	29.5 (2.0)	3.49 (0.25)
	Liquid Hempathane 55210	4	1.875 (0.077)	1142.3 (36.8)	32.2 (1.5)	3.51 (0.27)

Note-Standard deviation in parenthesis.

Table 22 – Flexural 0° results

In general, the liquid coating appears to exhibit higher strength and modulus compared to the dry coating:

- Regarding Infugreen resin, the liquid coated sample exhibits higher flexural strength (+6%) and modulus (+10%) compared to the dry coating sample.
- Regarding Elium resin, the liquid coating appears to exhibit higher strength (+5%) and flexural modulus (+8%) than dry coating.

Even though a difference can be made between liquid coated and dry coated samples, the results are close when taking into account deviations.

Comparing to the control samples:

- The Infugreen control samples exhibit much higher strength (+16%) and modulus (+30%) than aged coating samples.

  There could be a possibility of UV ageing affecting this observation. This aspect needs further investigation. A comparison by considering the fibre volume fraction and SEM analysis could further provide more insight into this in future investigations.

  However, it must be noted that the absolute strength and modulus of the coated Infugreen samples are still quite good (872 and 25.9 in the lowest case) and that a drop of properties is not observed which means that the coating protected, in a certain way, this epoxy composite, known to be UV sensitive.
- The coated Elium samples (dry coating or liquid) have higher strength and comparable moduli so they performed well compared to the control. The coating is not expecting to contribute structurally in the case of 0° samples and the aging does not appear to have damaged the laminates in terms of reducing the strength or modulus.
- In general, a drop of properties is not observed. So, even if the modulus of coated Infugreen samples changed.

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

Pictures after mechanical testing are shown below.

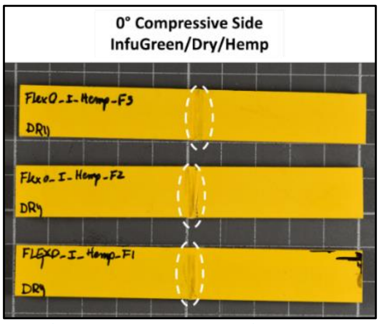
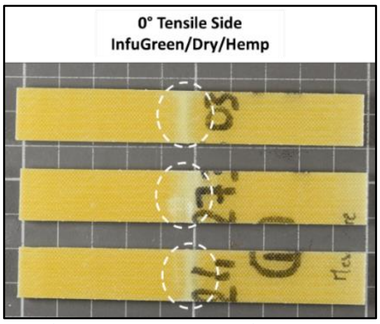
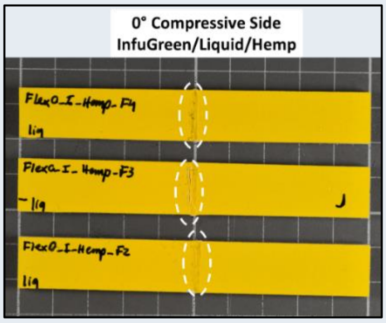
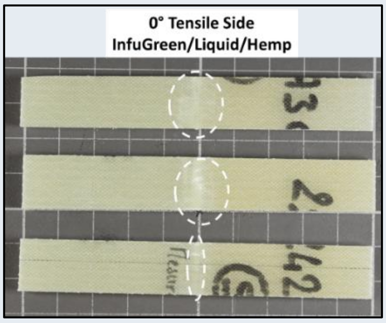
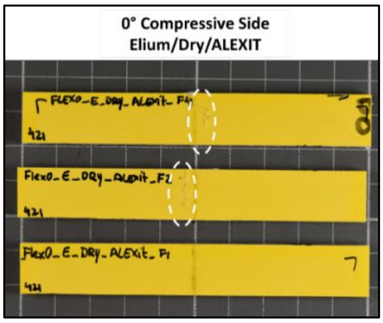
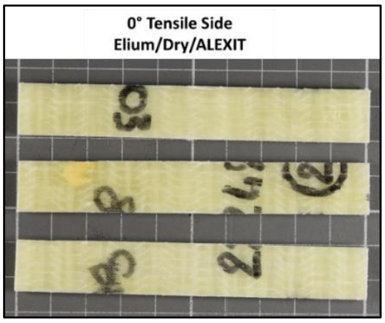
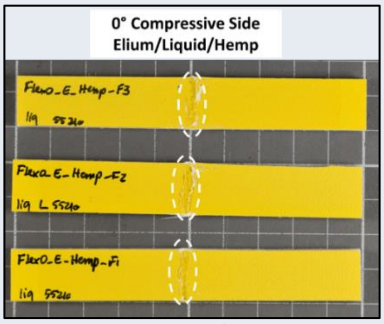
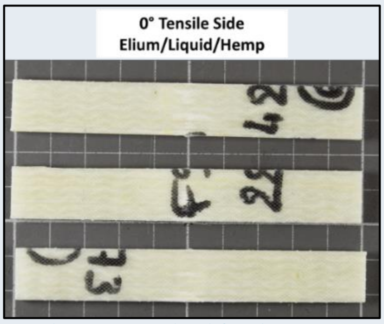
Composite Resin	Coating	Compressive side pictures	Tensile side pictures
Infugreen	Dry coating Hempathane 55210	 Figure 66 – Dry coating Hempathane 55210/Infugreen compressive side after flexural 0°	 Figure 67 – Dry coating Hempathane 55210/Infugreen tensile side after flexural 0°
	Liquid Hempathane 55210	 Figure 68 – Liquid paint Hempathane 55210/Infugreen compressive side after flexural 0°	 Figure 69 – Liquid paint Hempathane 55210/Infugreen tensile side after flexural 0°
Elium	Dry coating Alexit 471	 Figure 70 – Dry coating Alexit 471/Elium compressive side after flexural 0°	 Figure 71 – Dry coating Alexit 471/Elium tensile side after flexural 0°
	Liquid Hempathane 55210	 Figure 72 – Liquid paint Hempathane 55210/Elium compressive side after flexural 0°	 Figure 73 – Liquid paint Hempathane 55210/Elium tensile side after flexural 0°

Table 23 – Samples pictures after Flexural 0°

Visual inspection as depicted in pictures primarily validate the tests conducted. In 0° samples, the signs of the damage on the coating are very evident visually. The coating is primarily damaged close to the region of the loading nose. However, a comparison amongst different coating types requires further detailed investigations, possibly involving microscopy (dry coating seems more elastic as liquid coating seems to break into flakes).

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6.2.2.2. Flexural 90°

Bilinear stress-strain response observed in 90° coated Elium resin samples (with liquid or dry coating): Figure 75 and 77.

For all the 90° specimens, typically small drops in load observed at various stages initiating at lower strains. As the test progresses multiple small drops are observed and with a rapid drop towards the end of the test at higher strains (Figure 74 to 79).

Failure load is reported as the load where the 1st drop in load is observed. In Elium coated specimens, this typically lies closer to the end of 1st linear portion of the curve. The failure strain and load are reported corresponding to this point in the curve.

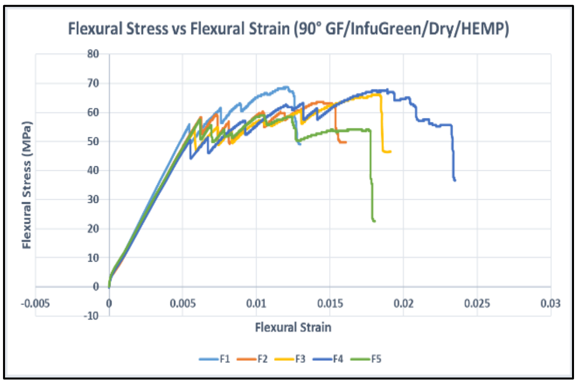

Figure 74 – Flexural stress vs flexural strain plots for 90°, UV aged Dry coating Hempathane 55210/Infugreen

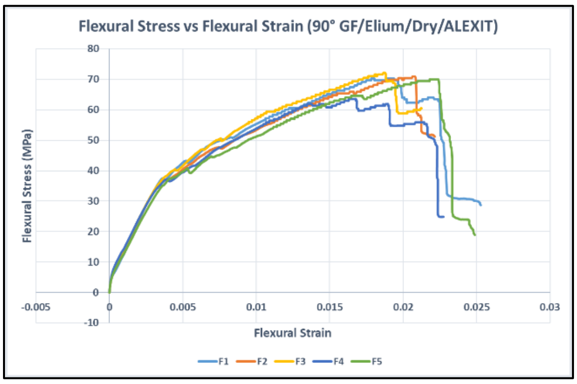

Figure 75 – Flexural stress vs flexural strain plots for 90°, UV aged Dry coating Alexit 471/Elium

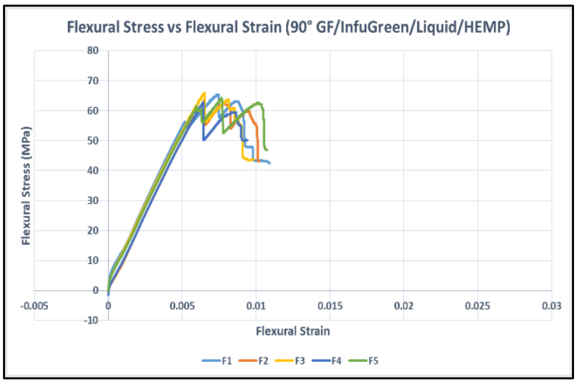

Figure 76 – Flexural stress vs flexural strain plots for 90°, UV aged Liquid paint Hempathane 55210/Infugreen

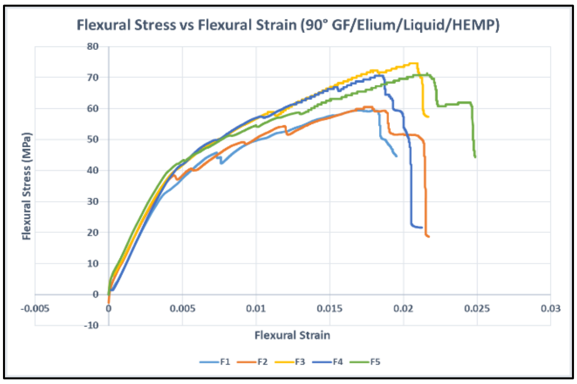

Figure 77 – Flexural stress vs flexural strain plots for 90°, UV aged Liquid paint Hempathane 55210/Elium

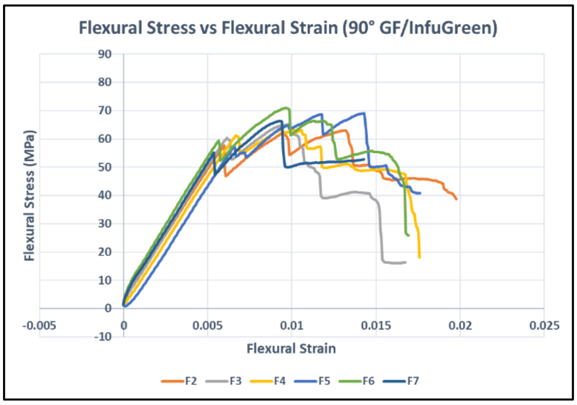

Figure 78 – Flexural stress vs flexural strain plots for 90°, Infugreen control (no coating)

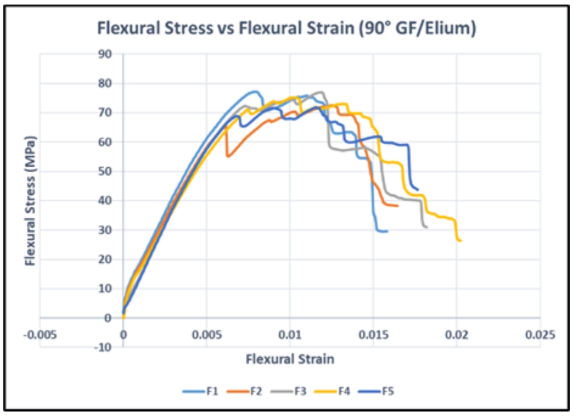

Figure 79 – Flexural stress vs flexural strain plots for 90°, Elium control (no coating)

Further the max load is reported as the maximum load observed throughout the curve and the corresponding strain is reported as strain at maximum load.

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

Values extracted from the graphs are summarized in the next table.

Composite Resin	Coating	Number of samples	Load at Failure (kN))	Failure Strength (MPa)	Flexural Modulus, E_f (GPa)	Strain-at-failure (%)	Max Load (kN)	Max Strength (MPa)	Strain at Max Load (%)
Infugreen	Control (no coating)	6	0.116 (0.004)	58.4 (2.2)	9.1 (0.4)	0.61 (0.05)	-	-	-
	Dry coating Hempathane 55210	5	0.116 (0.007)	56.3 (4.3)	9.2 (0.5)	0.63 (0.08)	0.134 (0.007)	65.0 (3.9)	1.49 (0.38)
	Liquid Hempathane 55210	5	0.111 (0.008)	62.0 (3.5)	10.1 (0.2)	0.61 (0.06)	0.115 (0.003)	64.4 (1.3)	0.69 (0.06)
Elium	Control (no coating)	5	0.117 (0.007)	70.6 (4.4)	11.1 (0.8)	0.72 (0.07)	-	-	-
	Dry coating Alexit 471	5	0.069 (0.003)	38.0 (1.4)	9.6 (0.5)	0.40 (0.03)	0.125 (0.006)	69.4 (3.4)	1.96 (0.21)
	Liquid Hempathane 55210	5	0.067 (0.008)	40.1 (4.5)	9.6 (0.3)	0.48 (0.07)	0.113 (0.012)	67.3 (6.9)	1.92 (0.19)

Note-Standard deviation in parenthesis.

Table 24 – Flexural 90° results

In general, the liquid coating appears to exhibit marginally higher strength and at least comparable modulus compared to the dry coating:

- Regarding Infugreen, the liquid sample exhibits marginally higher flexural strength (+9%) and higher modulus (+8%) compared to the dry coated sample.
- Regarding Elium resin, the liquid sample exhibits marginally higher flexural strength (+5%) and the same modulus as the dry coated sample.

Comparing to the control samples:

- Elium has a bilinear behaviour. This behaviour change is synonym to a structural change inside the composite matrix: so, this means UV has an impact.
- The coated Elium samples appear to exhibit the lower strength. The reason is that the reported failure strength in coated Elium samples is at the point closer to that section of the curve where the bilinear behaviour is observed. This point is lower than maximum load. However, the maximum load of Elium 90° coated samples is of the similar range of that of the failure load (at point of initiation of failure) observed in Control Elium 90° samples. Then the bilinear behaviour can be acceptable (if comply with final demonstrator/structure requirements).

  At the moment and until further investigation, the first point is the most important to consider for Elium coated samples because it is the most conservative. We can speculate that the UV ageing may be causing the bilinear behaviour in the coated samples and possibly damaging the laminate constituents in some way noting that the bilinear behaviour with the control sample is not present.

  Two different coatings are used so the behaviour appears to be coating independent. The initial slope is a bit lower than the control sample. We could speculate that the laminate material is less affected by aging below 40MPa (marginal softening). However, a much greater softening effect is apparent above 40MPa perhaps due to softening of the matrix or increased ductility of the matrix due to the UV aging.
- From a mechanical perspective, the result is positive for Infugreen as the coated samples are performing very similar to the control sample in terms of flexural strength and modulus. This suggests that the coating is protecting the laminate.

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Pictures after mechanical testing are shown below.

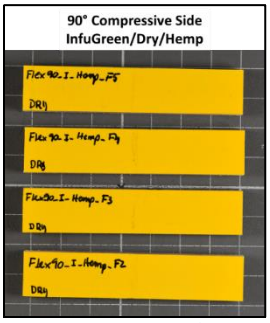
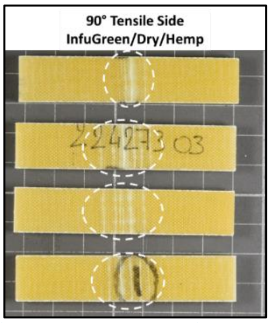
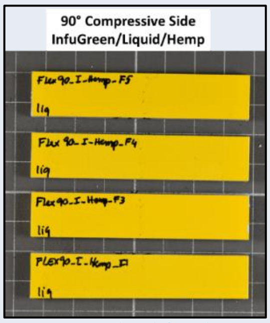
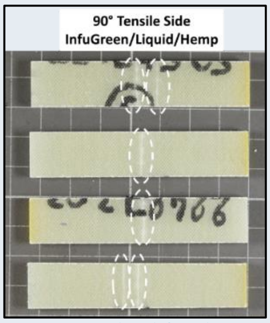
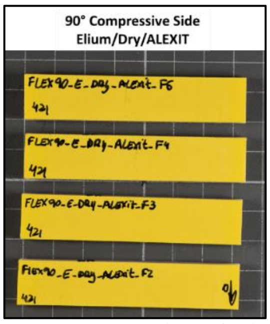
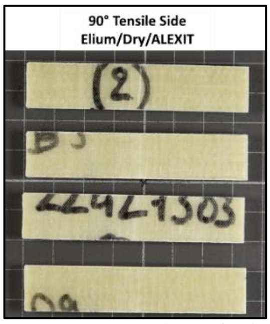
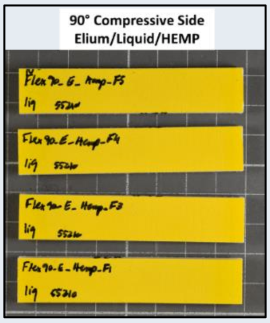
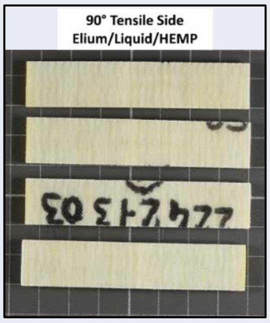
Composite Resin	Coating	Compressive side pictures	Tensile side pictures
Infugreen	Dry coating Hempathane 55210	 Figure 80 – Dry coating Hempathane 55210/Infugreen compressive side after flexural 90°	 Figure 81 – Dry coating Hempathane 55210/Infugreen tensile side after flexural 90°
	Liquid Hempathane 55210	 Figure 82 – Liquid paint Hempathane 55210/Infugreen compressive side after flexural 90°	 Figure 83 – Liquid paint Hempathane 55210/Infugreen tensile side after flexural 90°
Elium	Dry coating Alexit 471	 Figure 84 – Dry coating Alexit 471/Elium compressive side after flexural 90°	 Figure 85 – Dry coating Alexit 471/Elium tensile side after flexural 90°
	Liquid Hempathane 55210	 Figure 86 – Liquid paint Hempathane 55210/Elium compressive side after flexural 90°	 Figure 87 – Liquid paint Hempathane 55210/Elium tensile side after flexural 90°

Table 25 – Samples pictures after flexural 90°

In the 90° samples, the signs of the damage were not very evident over the surface of the coating, unlike the 0° samples by visual inspection. A detailed inspection could possibly involve an inspection using microscopy.

6.2.3. Conclusion

To analyse if the coating protects well the composite material against environmental actions, here UV exposure, a study of the coating itself have been made in chapter 6.1 and bending tests have been performed on aged samples.

First, colour measurement has shown that UV exposure impacts the coating (liquid or dry coating) applied on both composite materials.

This degradation of the coating seems to imply a lack of performance in the composite protection so a degradation on some mechanical properties.

- Indeed, Infugreen coated (liquid or dry samples) performed less compared to non-coated samples when tested through flexural 0°. This means Infugreen has been partially impacted by UV.
- Concerning, flexural 90°, coated Infugreen performed as well as non-coated samples but then Elium coated samples not only showed less performance compared to control sample but also responded with a bilinear behaviour synonym to a structural change in the composite. This also means that Elium has been impacted by UV.

The two flexural tests 0° and 90° highlighted impacts of UV on the composite material (Infugreen or Elium) so the coating didn't protect at 100% the composite.

No important different mechanical response is obtained when compared liquid and dry coating.

To go further, environmental exposures of non-coated specimens and mechanical tests on coated but not aged specimens and aged non-coated specimens are needed.

This would tell us if the coating had any effect on the flexural strength and stiffness of the laminate. In general, it is not expecting the coating to have any significant effect on the flexural strength and modulus of a 0° sample as the sample is much stronger and stiffer than the coating.

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

7. CONCLUSION

Dry coating, applied on thermoset or thermoplastic composite, performed as well or better than liquid paint. It permits to save time on the manufacturing process. It adheres better on the composite substrate than liquid paint. It has the same protection as liquid paint against water absorption. It evolved as the liquid paint in terms of colour when expose to UV and protect the composite with the same performance of the liquid paint.

So dry coating can be used in replacement of traditional liquid paint.

To have a better protection of the composite against UV, so there is no impact on the mechanical performance, the paint selection has to be reviewed. Hempathane 55210 seems to not be an acceptable choice. Whereas Alexit 411-77 appears to be a good candidate as it didn't evolve in colour and adheres well on both Infugreen and Elium. However, its adhesion evolution and his protection against UV radiation on the composite mechanical performance has to be demonstrated.

8. REFERENCES

[1] https://www.sharklet.com/

[2] https://sensing.konicaminolta.asia/what-is-cie-1976-lab-color-space/

[3] Corger D. La colorimétrie, décembre 2018

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

9. ANNEX

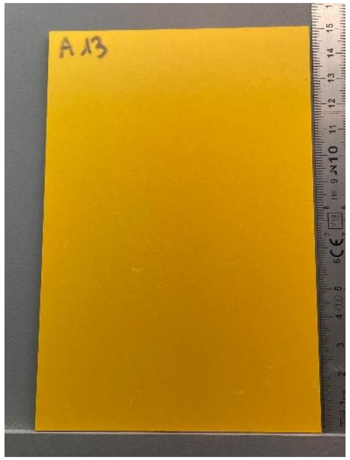
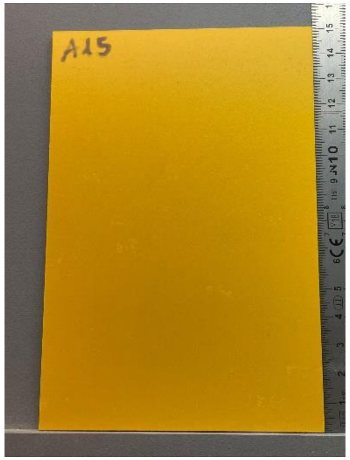
Annex 1 - Dry coating Hempathane 55210/Infugreen samples pictures before aging

Dedicated to	Pictures		
Exposure to humidity			
Neutral salt spray test			

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

Dedicated to	Pictures		
Exposure to UV			
Salt water immersion			

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

Dedicated to	Pictures		
Adhesion			

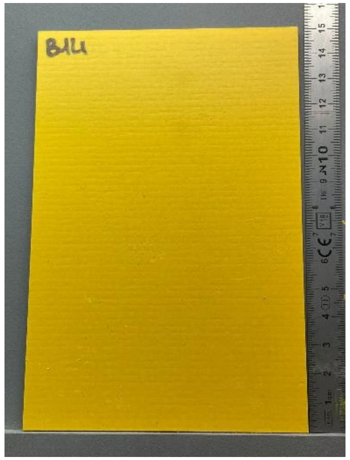
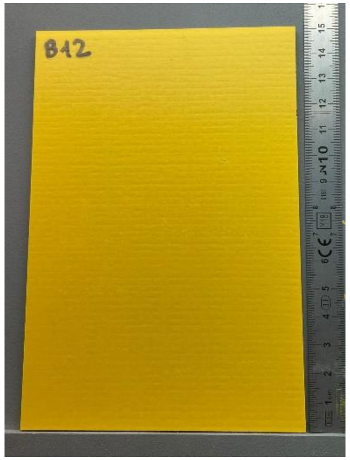
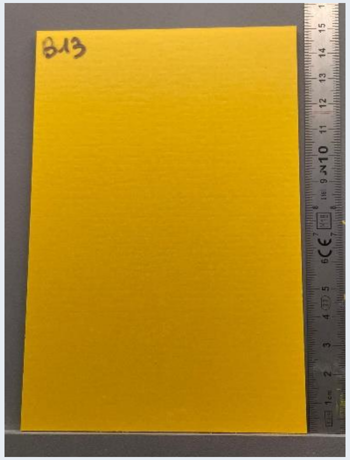
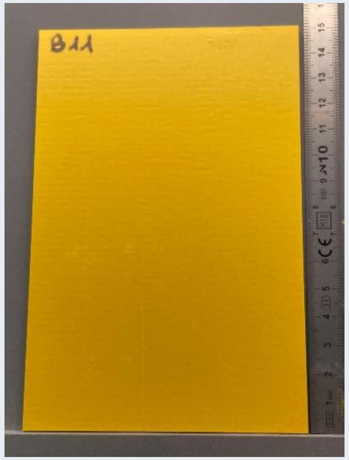
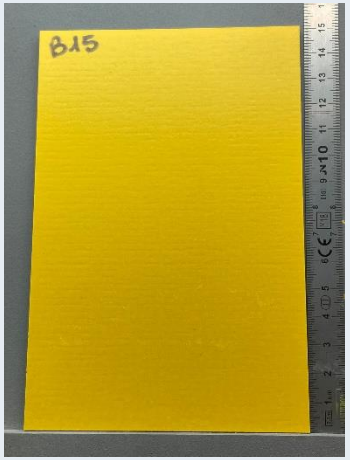
Annex 2 - Dry coating Alexit 471/Elium samples pictures before aging

Dedicated to	Pictures		
Exposure to humidity			

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

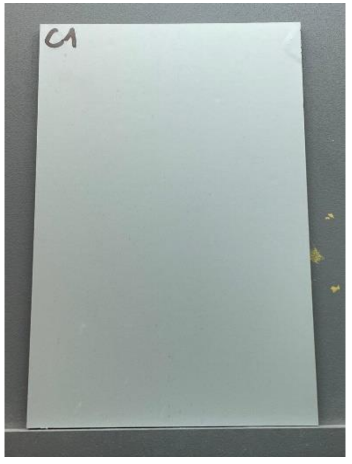
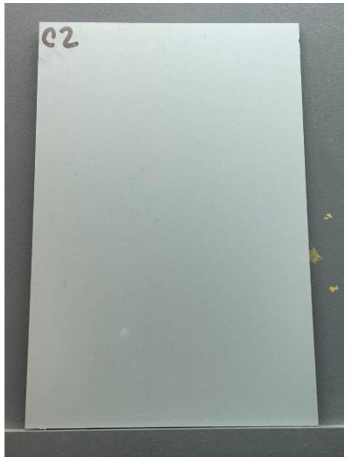
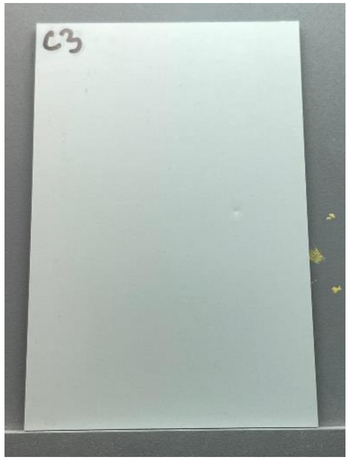
Dedicated to	Pictures		
Neutral salt spray test			
Exposure to UV			

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

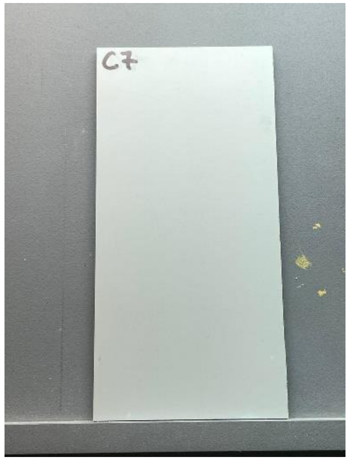
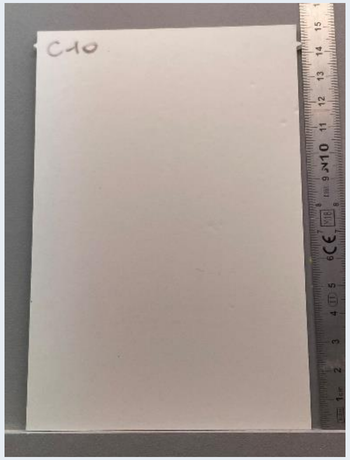
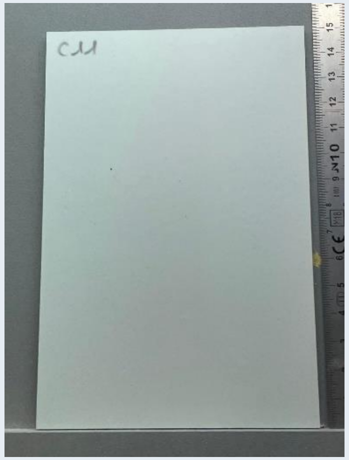
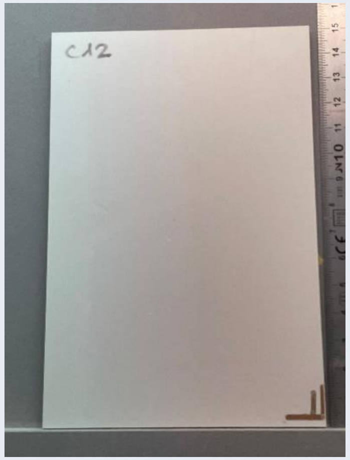
Dedicated to	Pictures		
Salt water immersion			
Adhesion			

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

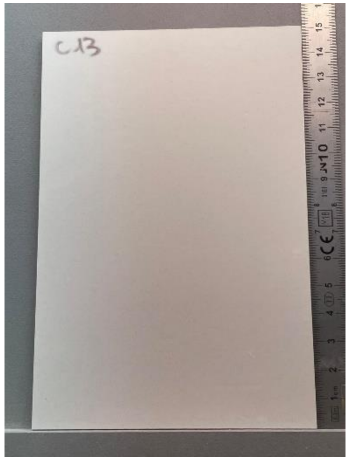
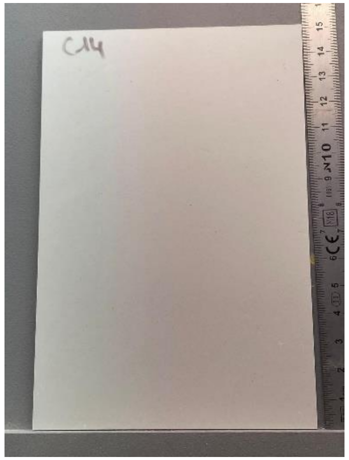
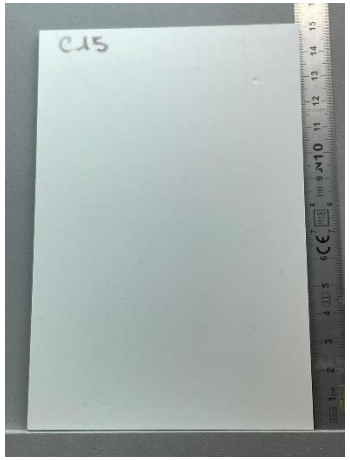
Annex 3 - Dry coating Alexit 411-77/Infugreen samples pictures before aging

Dedicated to	Pictures		
Exposure to humidity			
Neutral salt spray test			

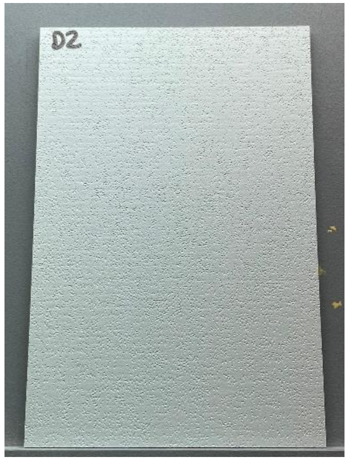
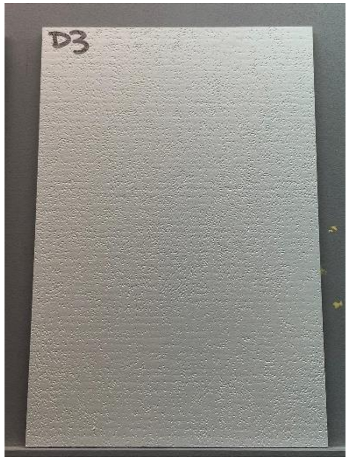
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952966.

Dedicated to	Pictures		
Exposure to UV			
Salt water immersion			

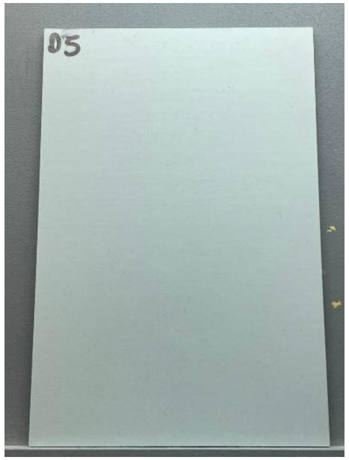
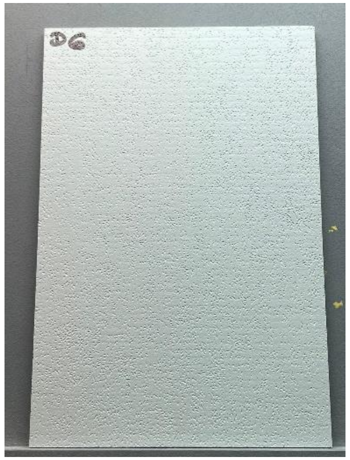
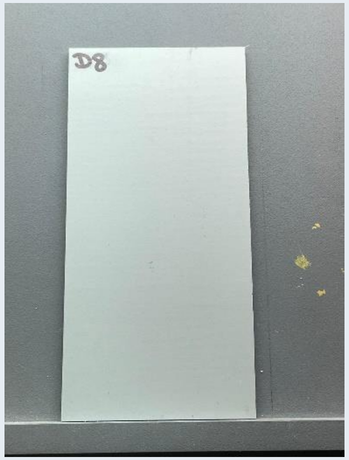
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952966.

Dedicated to	Pictures		
Adhesion			

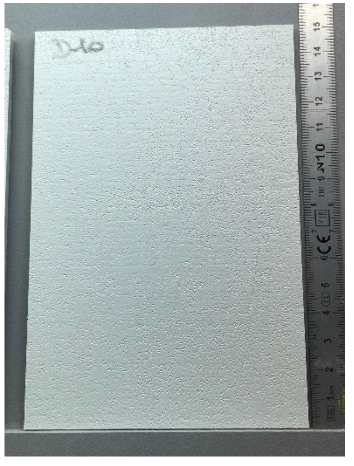
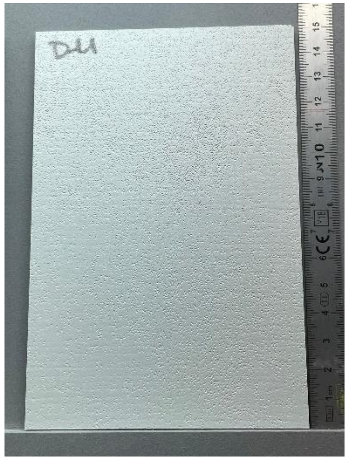
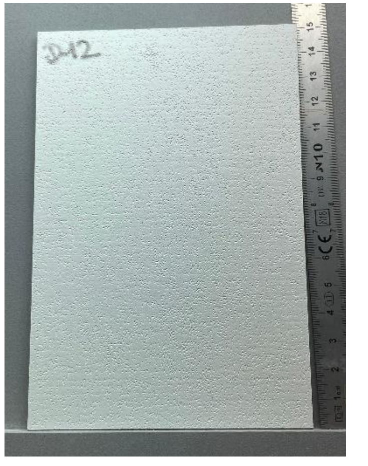
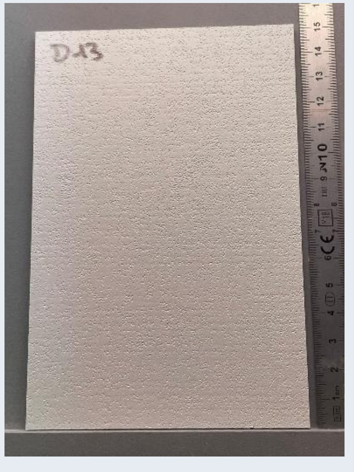
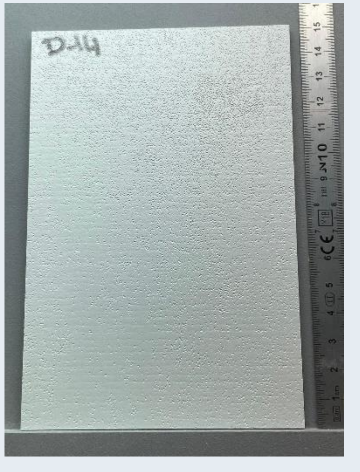
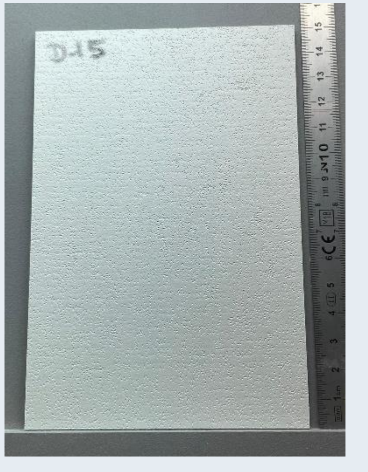
Annex 4 - Dry coating Alexit 411-77/Elium samples pictures before aging

Dedicated to	Pictures		
Exposure to humidity			

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

Dedicated to	Pictures		
Neutral salt spray test	 6		
Exposure to UV			

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

Dedicated to	Pictures		
Salt water immersion			
Adhesion			

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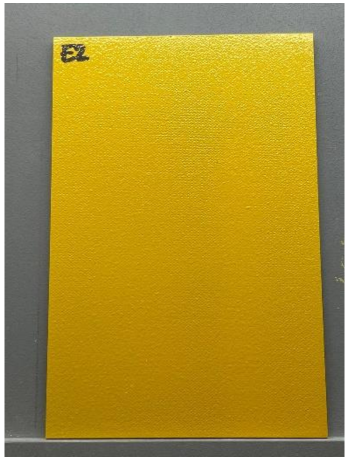
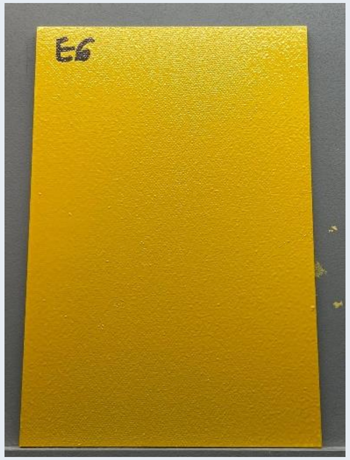
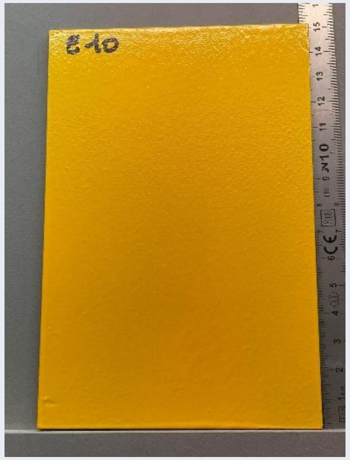
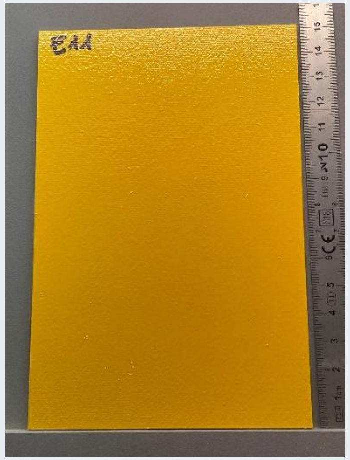
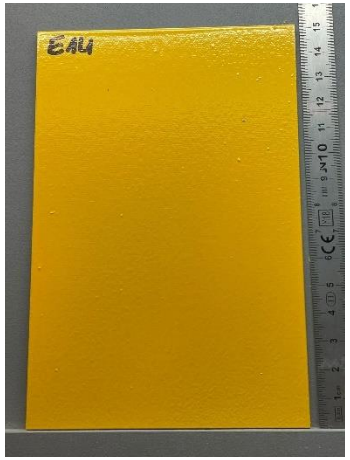
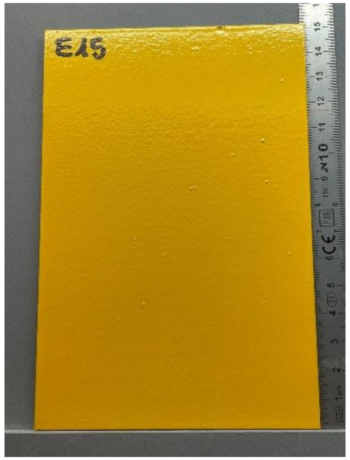
Annex 5 - Liquid Hempathane 55210/Infugreen samples pictures before aging

Dedicated to	Pictures		
Exposure to humidity			
Neutral salt spray test			

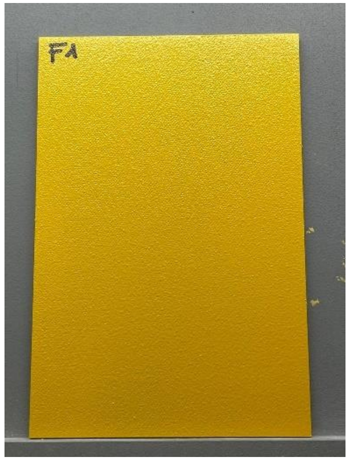
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952966.

Dedicated to	Pictures		
Exposure to UV			
Salt water immersion			

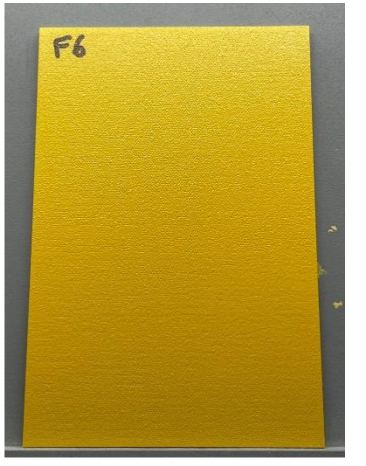
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952966.

Dedicated to	Pictures
Adhesion	  

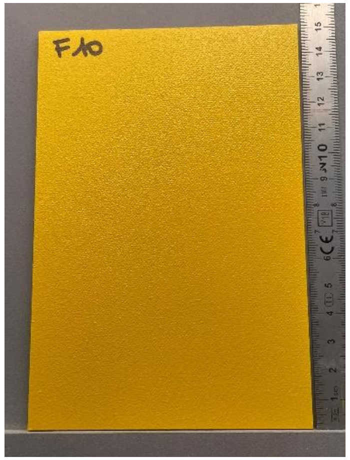
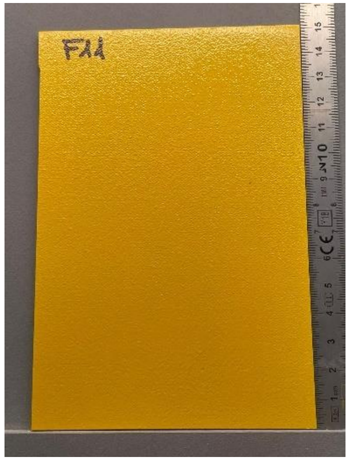
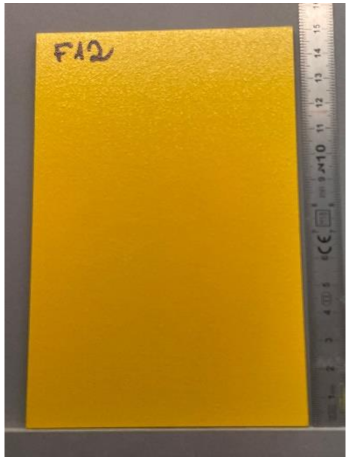
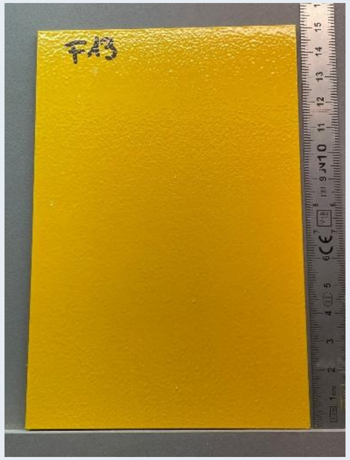
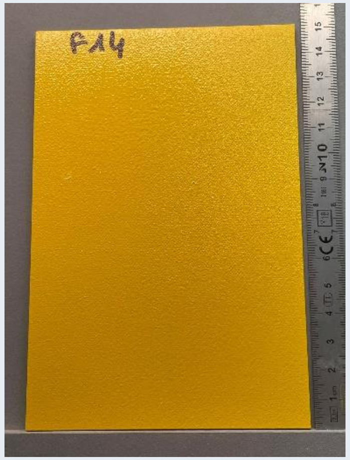
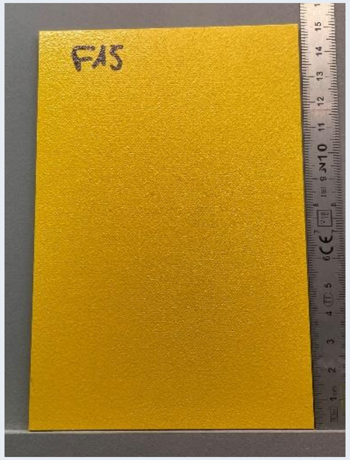
Annex 6 - Liquid Hempathane 55210/Elium samples pictures before aging

Dedicated to	Pictures
Exposure to humidity	  

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

Dedicated to	Pictures		
Neutral salt spray test			
Exposure to UV			

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

Dedicated to	Pictures		
Salt water immersion			
Adhesion			

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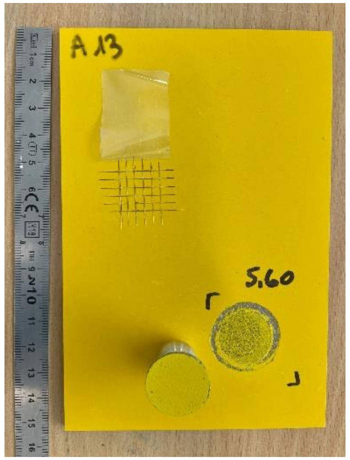
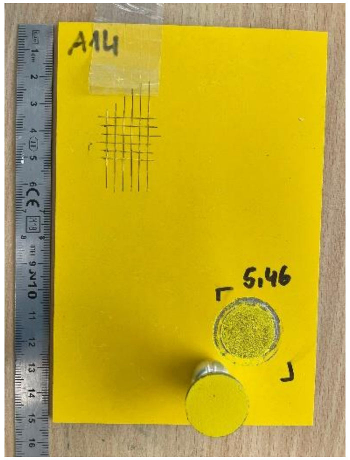
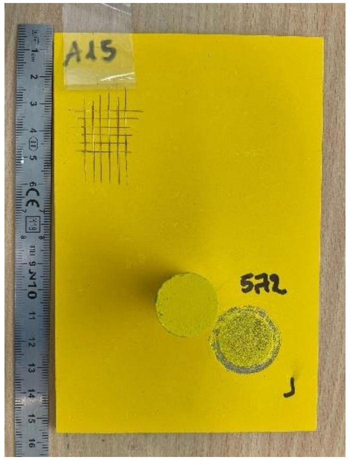
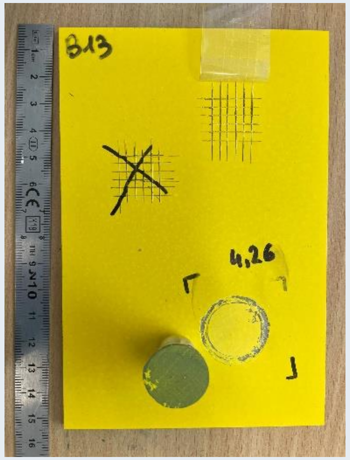
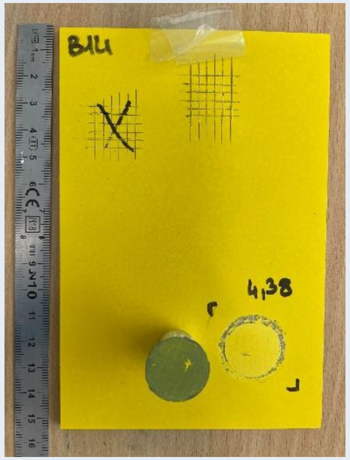
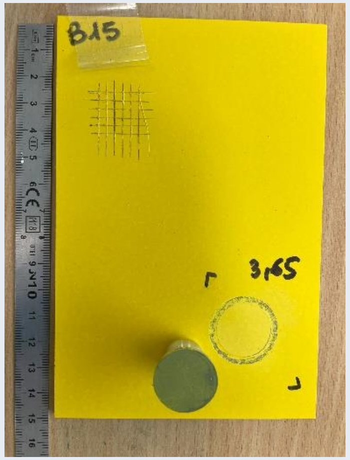
Annex 7 - Pictures after adhesion test

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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

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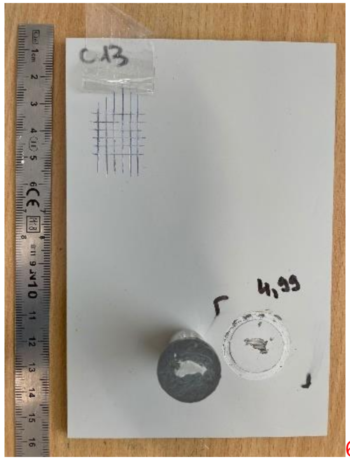
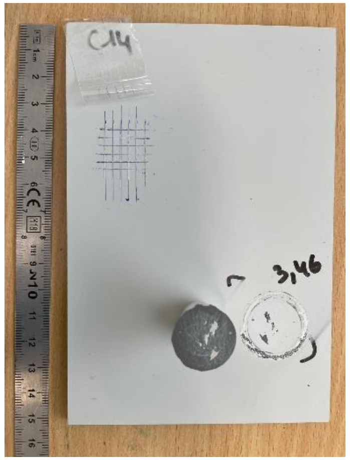
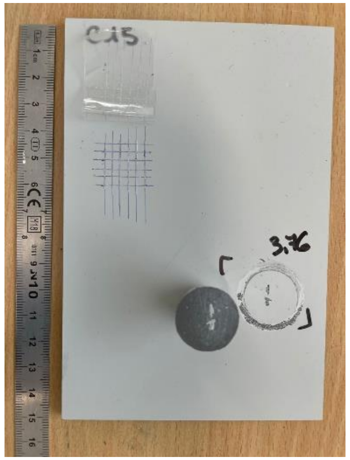
<tr><td rowspan="2">Dry coating Alexit 411-77</td><td>Infugreen</td><td>

6</td><td>
</td><td>
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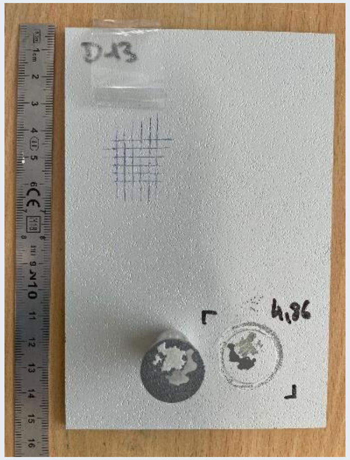
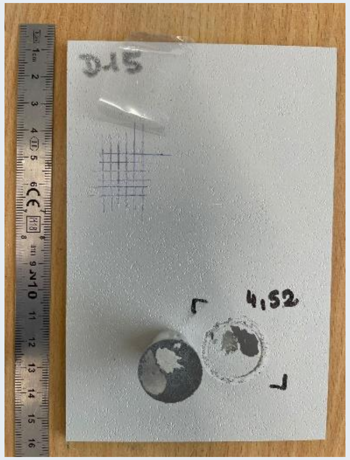
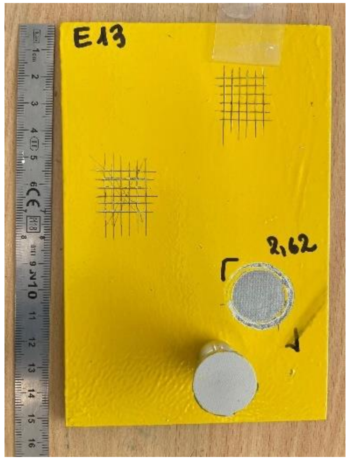
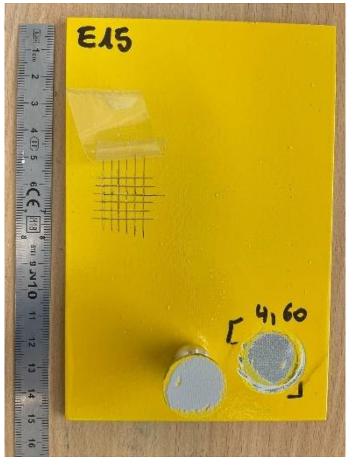
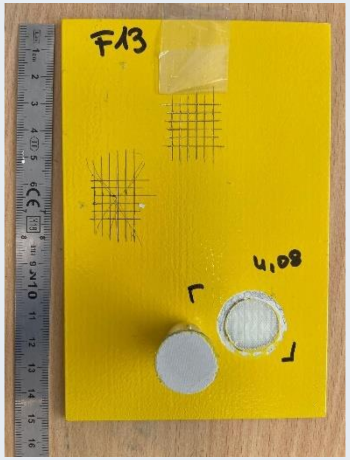
<tr><td>Elium</td><td>
</td><td>
</td><td>
</td></tr>
</table>

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

Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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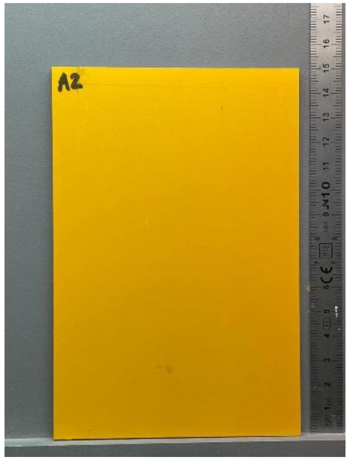
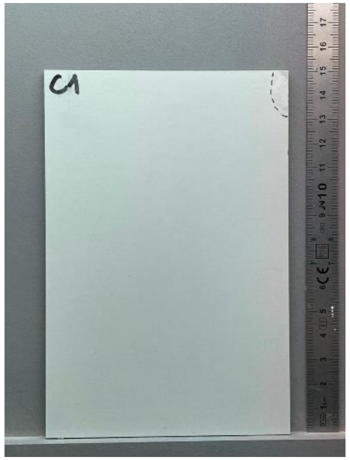
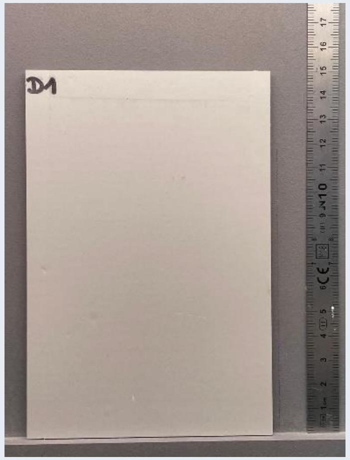
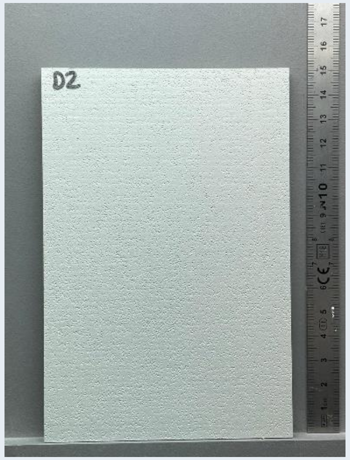
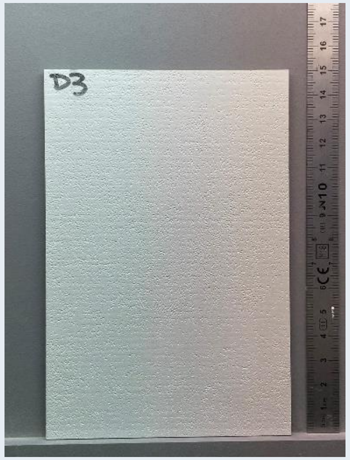
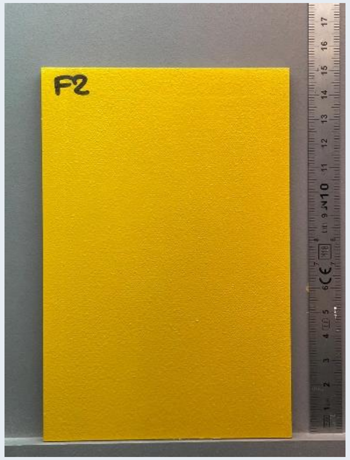
Annex 8 - Pictures after exposure to humidity

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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

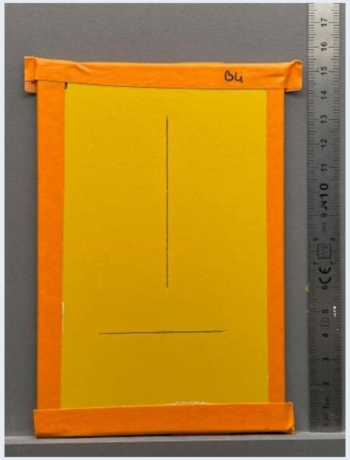
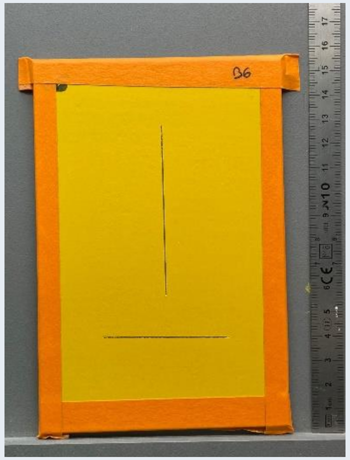
Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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

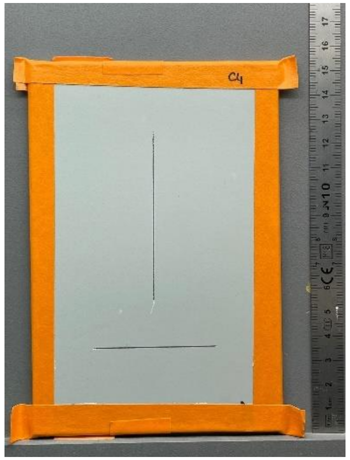
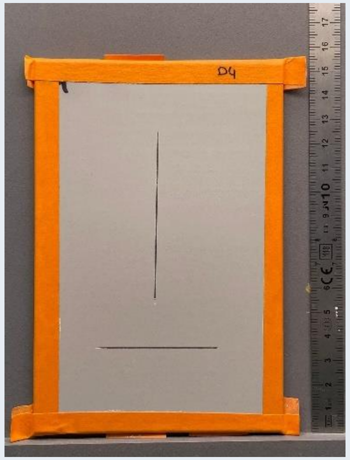
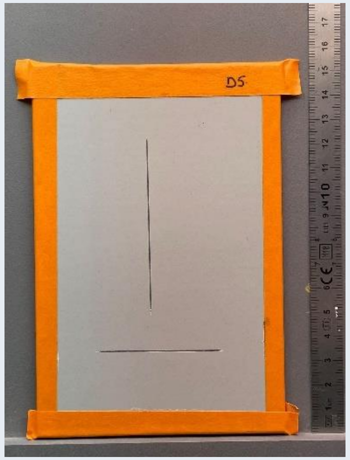
Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

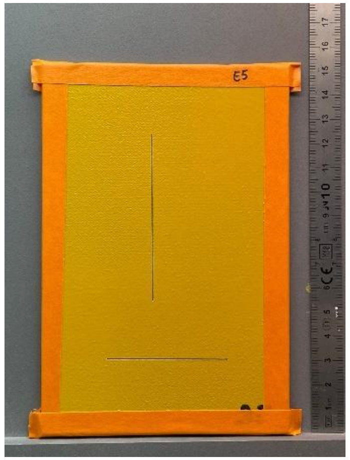
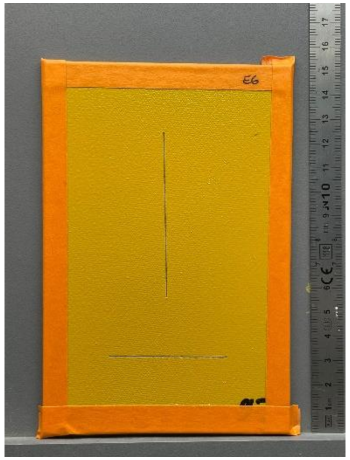
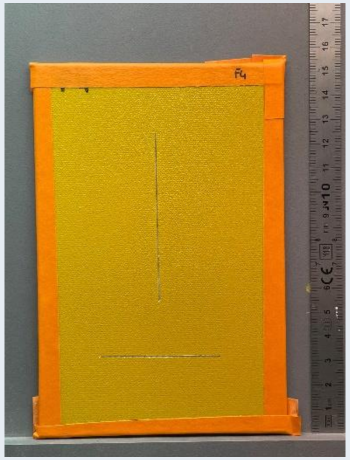
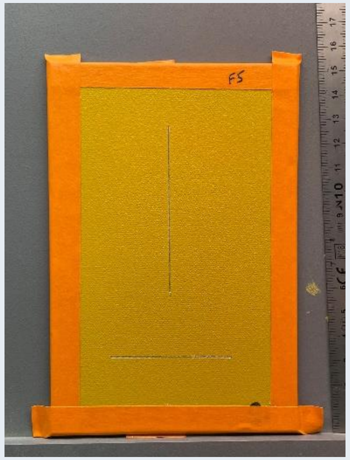
Annex 9 - Pictures after neutral salt spray test

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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

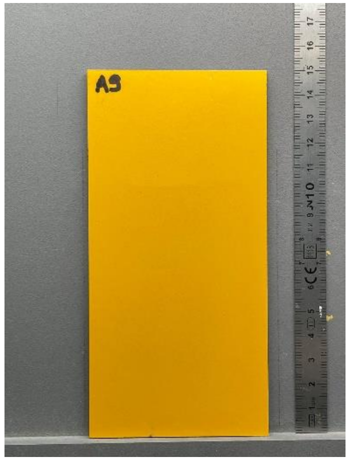
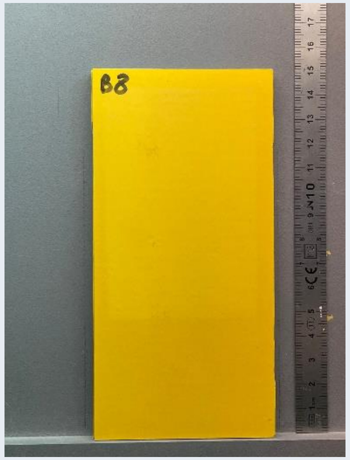
Coating	Composite resin	Pictures
Dry coating Alexit 411-77	Infugreen	  
	Elium	  

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

Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

Annex 10 - Pictures after exposure to UV

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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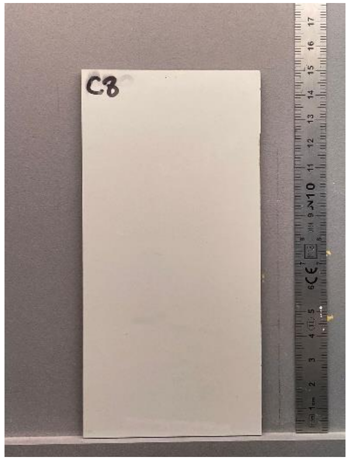
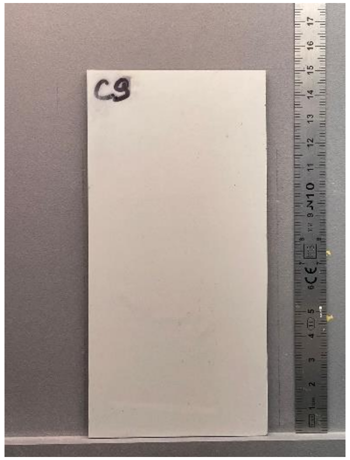
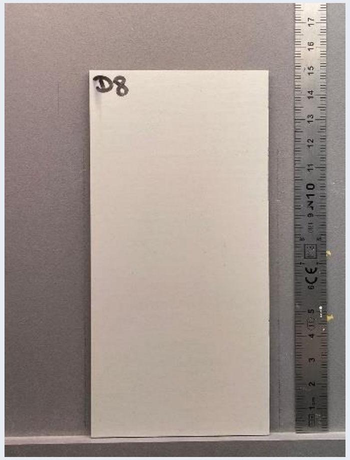
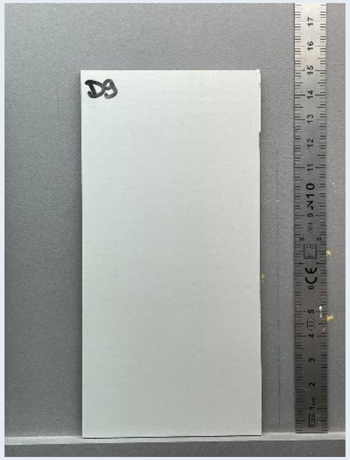
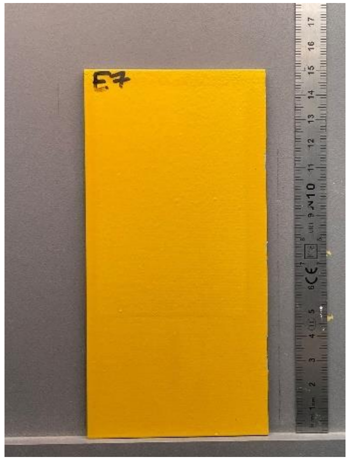
Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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

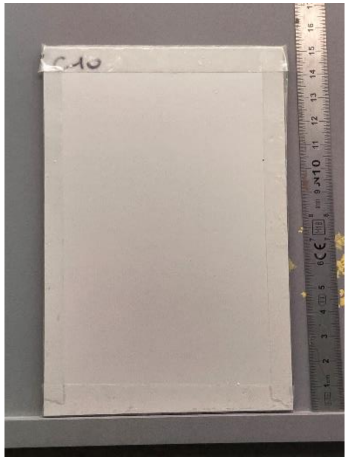
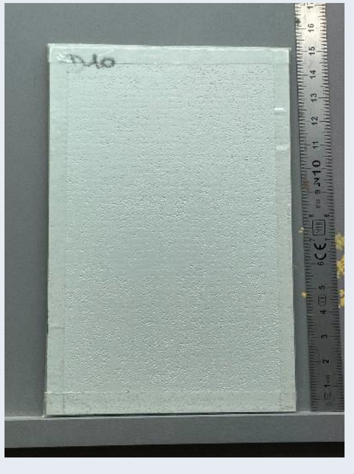
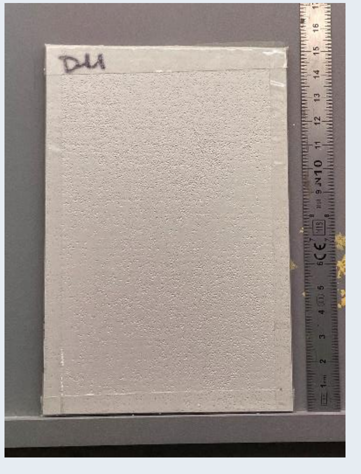
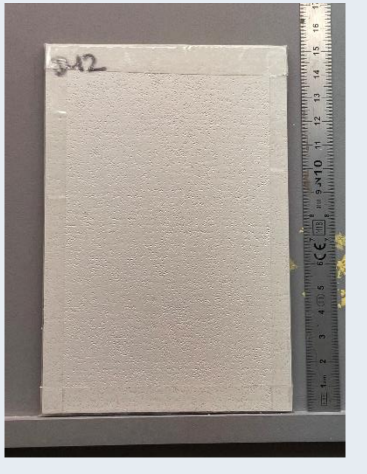
Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

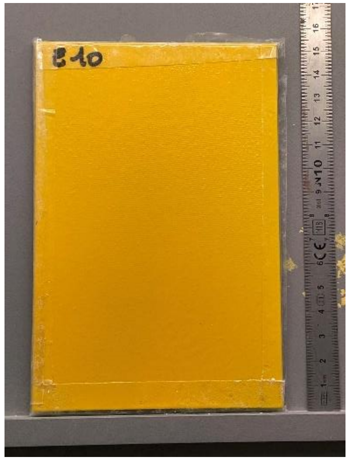
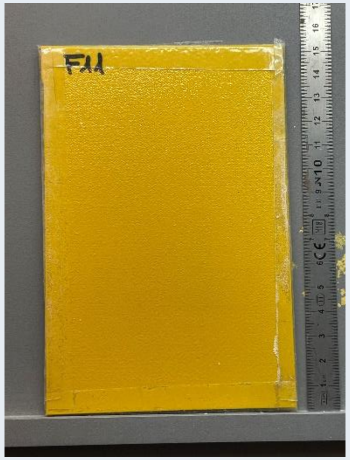
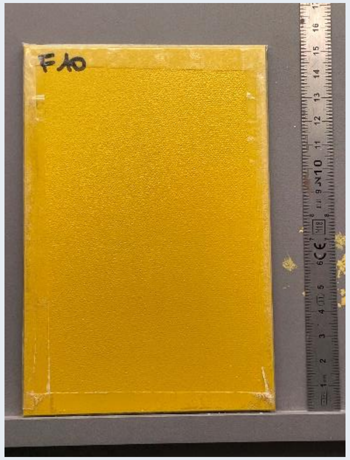
Annex 11 - Pictures after salt water immersion

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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

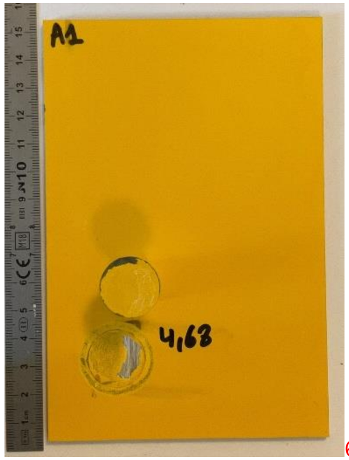
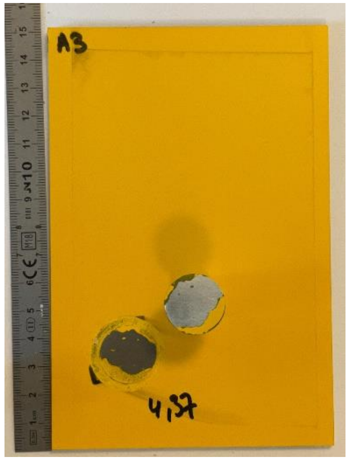
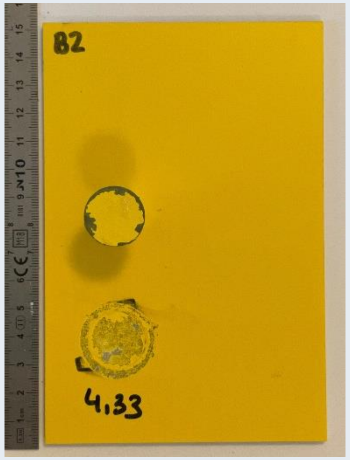
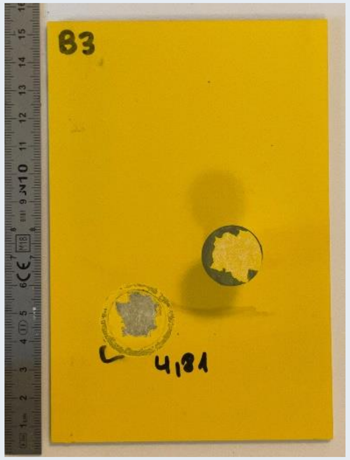
Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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

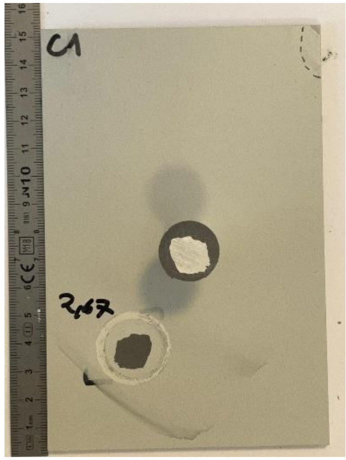
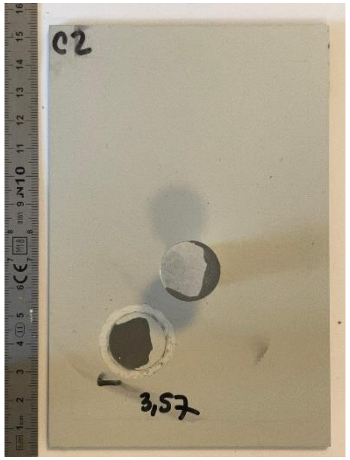
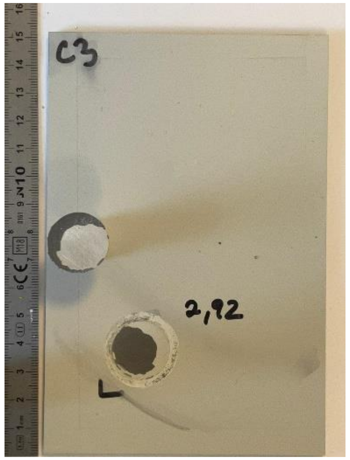
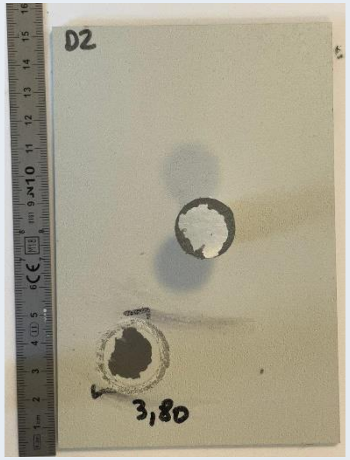
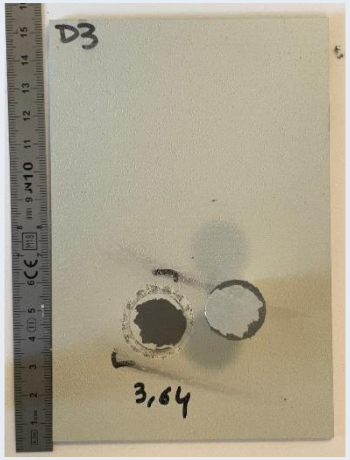
Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

Annex 12 - Adhesion pictures after exposure to humidity

Coating	Composite resin	Pictures
Dry coating Hempathane 55210	Infugreen	 6  
Dry coating Alexit 471	Elium	  

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

Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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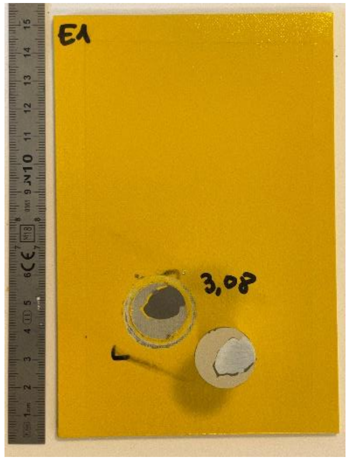
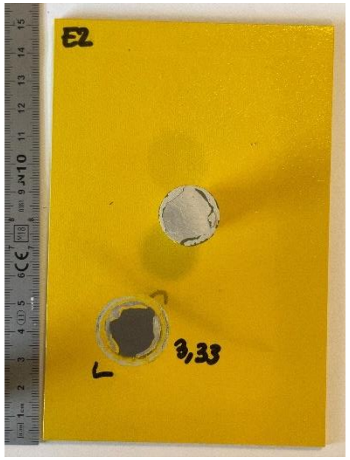
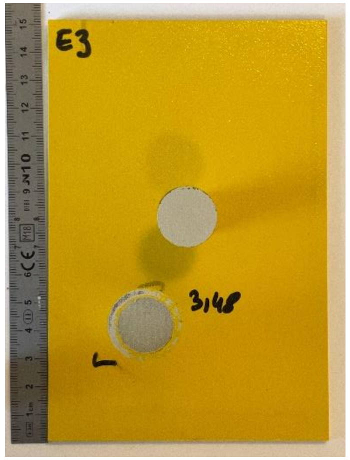
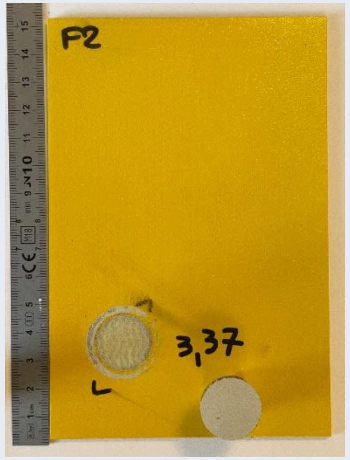
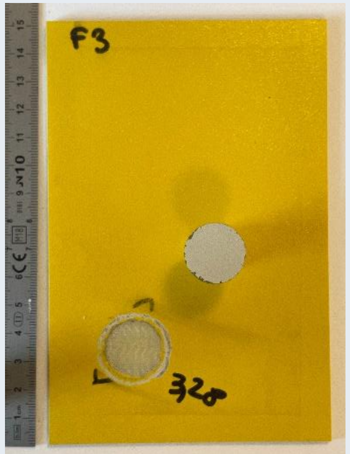
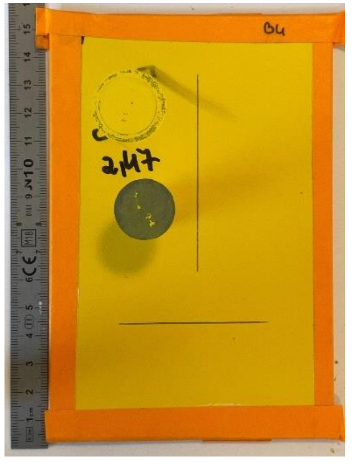
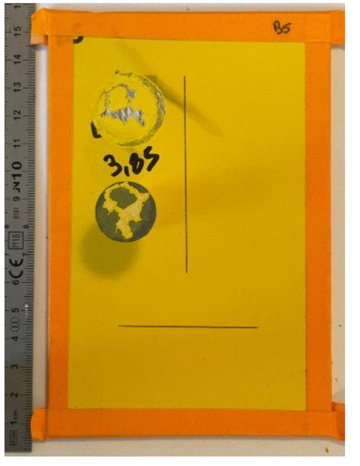
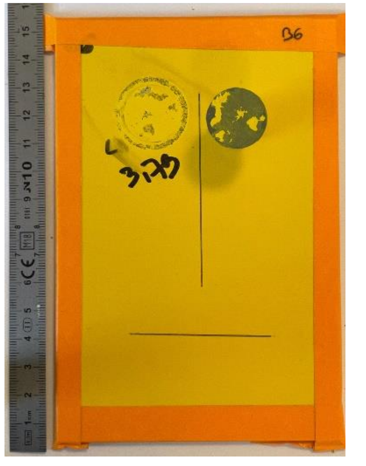
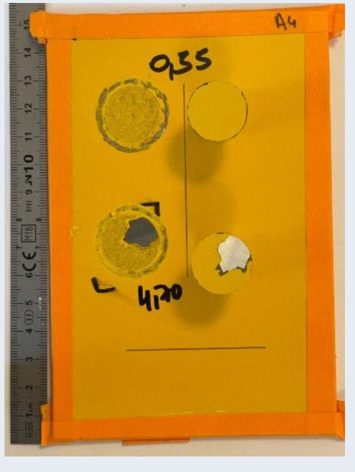
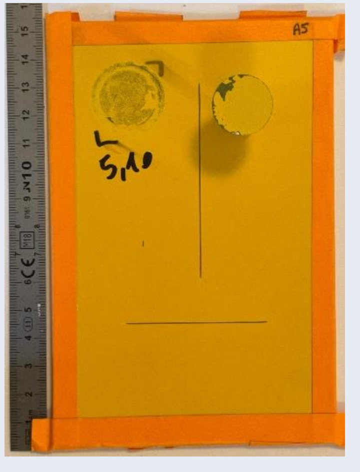
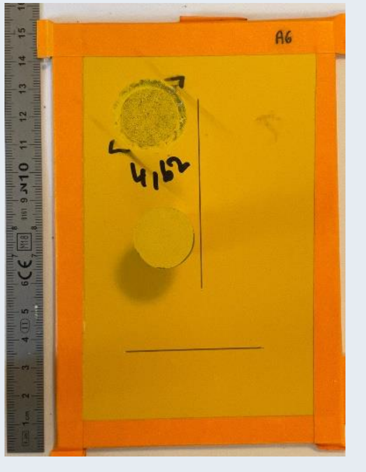
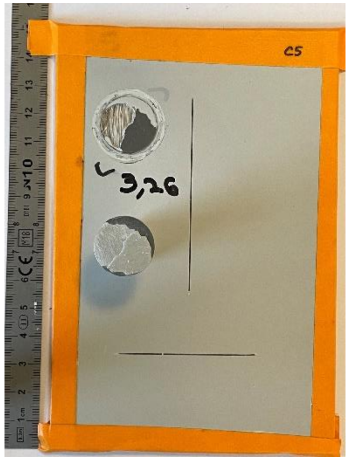
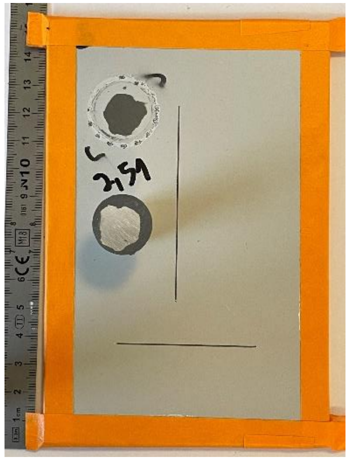
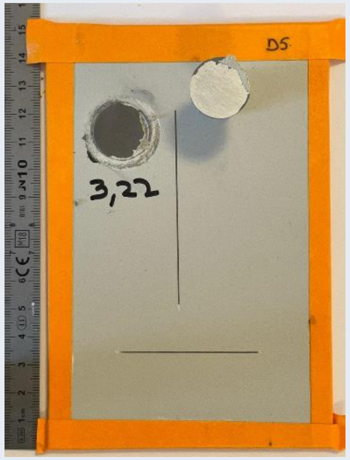
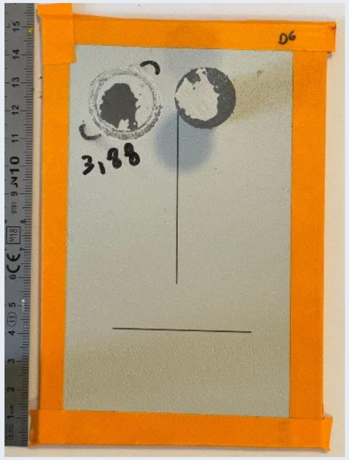
Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

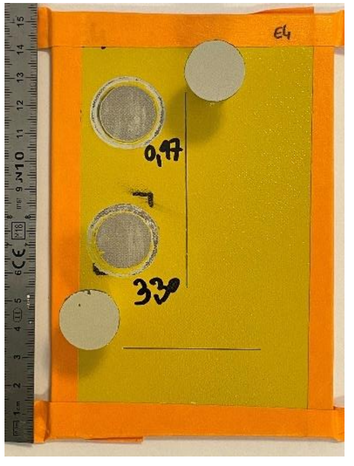
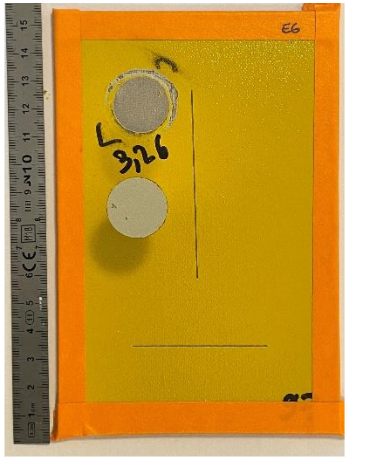
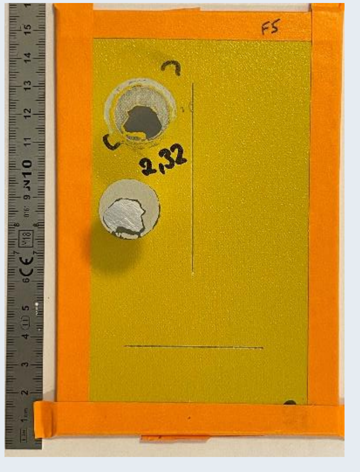
Annex 13 - Adhesion pictures after neutral salt spray test

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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

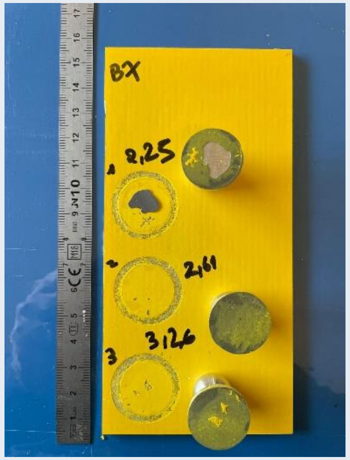
Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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

Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

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

Annex 14 - Adhesion pictures after exposure to UV

Coating	Composite resin	Pictures
Dry coating Hempathane 55210	Infugreen	
Dry coating Alexit 471	Elium	

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

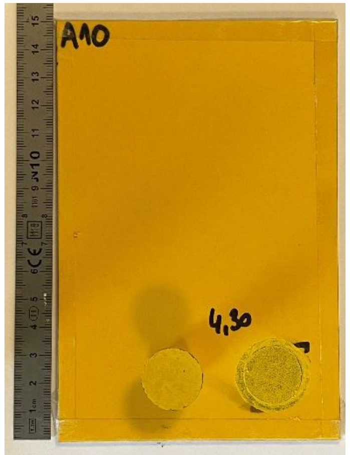
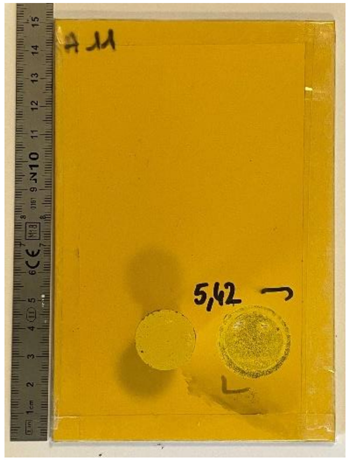
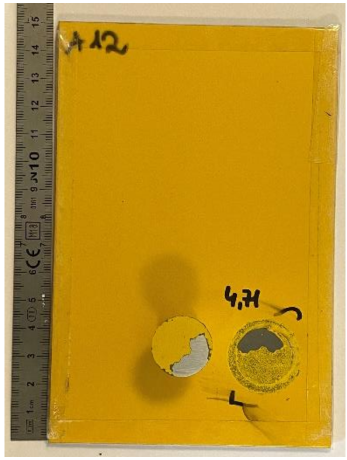
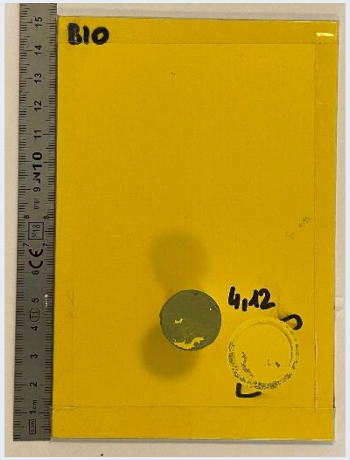
Coating	Composite resin	Pictures
Dry coating Alexit 411-77	Infugreen	
	Elium	

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

Coating	Composite resin	Pictures
Liquid paint Hempathane 55210	Infugreen	
	Elium	

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

Annex 15 - Adhesion pictures after salt water immersion

Coating	Composite resin	Pictures		
Dry coating Hempathane 55210	Infugreen			
Dry coating Alexit 471	Elium			

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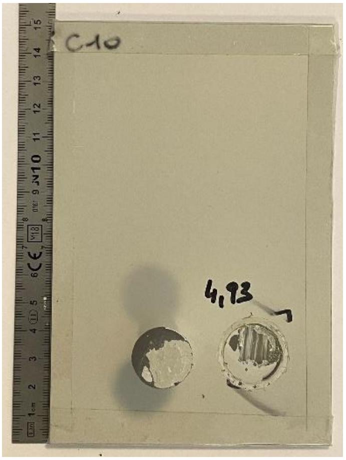
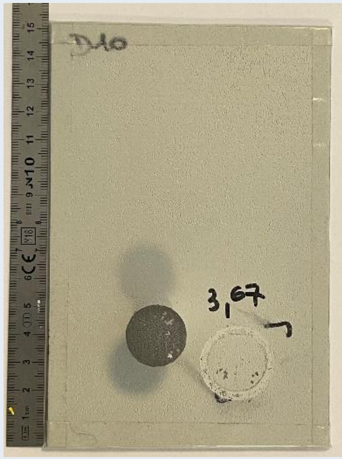
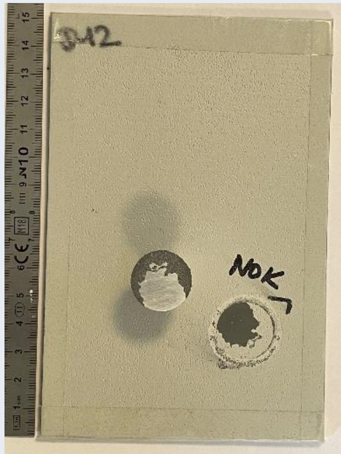
Coating	Composite resin	Pictures		
Dry coating Alexit 411-77	Infugreen			
	Elium			

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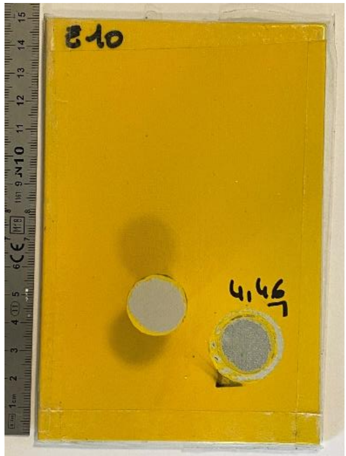
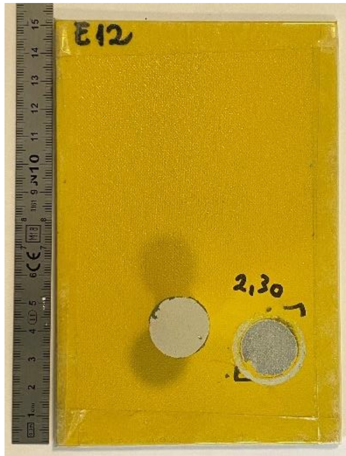
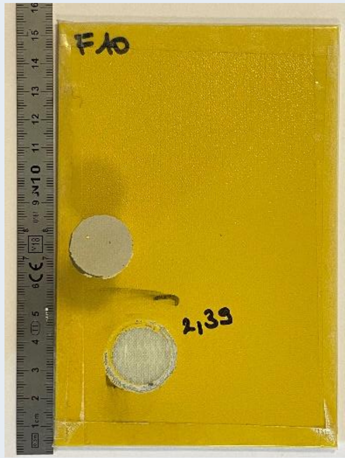
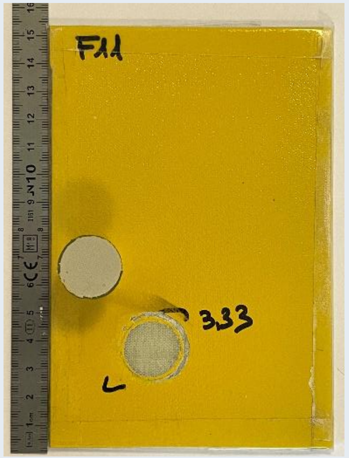
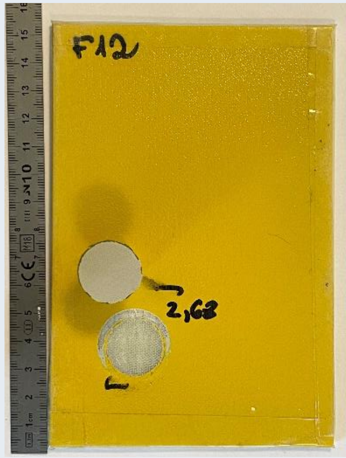
Coating	Composite resin	Pictures		
Liquid paint Hempathane 55210	Infugreen			
	Elium			

Annex 16 - Data of water uptake after aging

Coating	Form	Composite resin	Water uptake					
			Salt water immersion		Exposure to high humidity		Neutral salt spray test	
			%	Deviation	%	Deviation	%	Deviation
Hempathane 55210	Dry coating	Infugreen	0,18	0,05	0,67	0,11	0,57	0,01
Alexit 471		Elium	0,15	0,03	0,74	0,07	0,45	0,01
Alexit 411-77		Infugreen	0,18	0,01	0,61	0,04	0,54	0,01
		Elium	0,13	0,01	0,51	0,11	0,41	0,04
Hempathane 55210	Liquid paint	Infugreen	0,21	0,04	0,44	0,06	0,44	0,07
		Elium	0,27	0,06	0,38	0,03	0,37	0,04

Mean on 3 repetitions

Annex 17 - Data of colour after aging

Coating	Form	Composite resin	Colour							
			Salt water immersion		Exposure to high humidity		Neutral salt spray test		Exposure to UV	
			ΔE	Deviation	ΔE	Deviation	ΔE	Deviation	ΔE	Deviation
Hempathane 55210	Dry coating	Infugreen	0,42	0,12	1,36	0,55	0,63	0,08	5,35	0,47
Alexit 471		Elium	0,71	0,41	0,76	0,11	0,41	0,09	7,32	0,56
Alexit 411-77		Infugreen	0,09	0,04	0,38	0,02	0,37	0,38	0,19	0,46
		Elium	0,15	0,03	0,50	0,22	0,73	0,87	0,27	0,46
Hempathane 55210	Liquid paint	Infugreen	1,15	0,54	2,11	0,17	1,57	0,76	3,81	0,64
		Elium	0,58	0,12	1,30	0,48	1,31	0,41	5,60	1,12

Mean on 3 repetitions

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Annex 18 - Data of adhesion before and after aging

Coating	Form	Composite resin	Before exposure	After exposure							
				Salt water immersion (35g/L)		Exposure to high humidity (100%)		Neutral salt spray test		Exposure to UV	
			Mpa	Mpa	Deviation	Mpa	Deviation	Mpa	Deviation	Mpa	Deviation
Hempathane 55210	Dry coating	Infugreen	5,59	4,81	0,57	4,44	0,22	4,81	0,26	4,07	0,36
Alexit 471		Elium	4,10	3,55	0,56	3,96	1,08	3,37	0,78	2,71	0,51
Alexit 411-77		Infugreen	4,07	4,64	0,84	3,05	0,47	2,79	0,41	4,41	2,07
		Elium	4,69	4,89	1,72	3,70	0,09	4,33	1,40	5,55	1,27
Hempathane 55210	Liquid paint	Infugreen	3,95	3,51	1,10	3,30	0,20	3,37	0,16	2,90	0,37
		Elium	3,60	2,80	0,48	3,27	0,11	2,62	0,26	2,98	0,12

Mean on 3 repetitions

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Annex 19 - Detailed Tabular Summary of results of all the tests conducted - Flexural 0°

Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60						
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain at Failure (%)	Span/ Thickness
Hempathane 55210	Dry coating	Infugreen	0°	F1	15.02	3.458	1.845	924.6	26.8	3.22%	17.35
				F2	14.96	3.503	1.941	951.4	23.7	3.54%	17.13
				F3	14.85	3.468	1.717	865.3	27.3	3.25%	17.30
				F4	15.11	3.577	1.606	747.6	25.8	3.06%	16.77
				AVERAGE	**14.98**	**3.50**	**1.777**	**872.2**	**25.9**	**3.27%**	**17.14**
				ST DEV	0.11	0.05	0.146	90.5	1.6	0.20%	0.26
				CV (%)	0.73	1.53	8.24	10.38	6.14	6.20	1.52

Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60						
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain at Failure (%)	Span/ Thickness
Alexit 471	Dry coating	Elium	0°	F1	14.94	3.235	1.771	1019.5	28.3	3.34%	18.55
				F2	14.77	3.193	1.812	1083.1	30.8	3.49%	18.79
				F3	15.06	3.261	1.960	1101.5	31.5	3.51%	18.40
				F4	15.04	3.292	2.013	1111.9	27.3	3.92%	18.23
				AVERAGE	14.95	3.245	1.889	1079.0	29.5	3.61%	18.49
				ST DEV	0.13	0.042	0.116	41.4	2.0	0.25%	0.24
				CV (%)	0.88	1.29	6.13	3.84	6.8	6.90	1.29

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Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60						
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain at Failure (%)	Span/ Thickness
Hempathane 55210	Liquid	Infugreen	0°	F1	14.55	3.330	1.549	864.1	28.6	2.82%	18.02
				F2	14.89	3.288	1.703	952.3	30.1	2.97%	18.25
				F3	15.19	3.330	1.734	926.8	30.0	2.98%	18.02
				F4	14.73	3.287	1.724	974.8	26.6	3.10%	18.25
				AVERAGE	**14.84**	**3.31**	**1.678**	**929.5**	**28.8**	**2.97%**	**18.13**
				ST DEV	0.27	0.02	0.087	47.8	1.6	0.11%	0.13
				CV (%)	1.81	0.74	5.16	5.14	5.72	3.80	0.74

Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60						
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain at Failure (%)	Span/ Thickness
Hempathane 55210	Liquid	Elium	0°	F1	14.78	3.134	1.764	1093.4	34.3	3.13%	19.14
				F2	14.88	3.162	1.884	1139.5	31.3	3.49%	18.98
				F3	14.85	3.152	1.936	1181.0	32.3	3.65%	19.03
				F4	15.01	3.153	1.916	1155.3	31.1	3.75%	19.03
				AVERAGE	**14.88**	**3.15**	**1.875**	**1142.3**	**32.2**	**3.51%**	**19.05**
				ST DEV	0.10	0.01	0.077	36.8	1.5	0.27%	0.07
				CV (%)	0.65	0.37	4.11	3.22	4.57	7.66	0.37

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Annex 20 - Detailed Tabular Summary of results of all the tests conducted - Flexural 90°

Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60									
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain @ Failure	Span/ Thickness	Max Load(kN)	σ_{max} (MPa)	Strain at Max Load (%)
Hempathane 55210	Dry coating	Infugreen	90°	F1	15.16	3.403	0.120	61.5	9.9	0.76%	17.63	0.134	68.7	1.19%
				F2	15.30	3.508	0.122	58.3	9.4	0.63%	17.10	0.133	63.6	1.46%
				F3	15.06	3.496	0.110	53.8	8.9	0.58%	17.16	0.135	66.0	1.84%
				F4	15.28	3.533	0.107	50.5	8.8	0.55%	16.98	0.144	67.9	1.89%
				F5	15.30	3.504	0.120	57.5	8.9	0.62%	17.12	0.123	58.9	1.06%
				AVERAGE	**15.22**	**3.489**	**0.116**	**56.3**	**9.2**	**0.63%**	**17.20**	**0.134**	**65.0**	**1.49%**
				ST DEV	0.11	0.050	0.007	4.3	0.5	0.08%	0.25	0.007	3.9	0.38%
				CV (%)	0.70	1.44	5.87	7.58	4.94	12.67	1.46	5.58	6.07	25.29

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Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60									
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain @ Failure	Span/ Thickness	Max Load(kN)	σ_{max} (MPa)	Strain at Max Load (%)
Alexit 471	Dry coating	Elium	90°	F1	15.31	3.219	0.066	37.5	10.3	0.36%	18.64	0.124	70.3	1.94%
				F2	15.26	3.249	0.066	37.1	10.0	0.39%	18.47	0.127	70.9	2.08%
				F3	15.33	3.253	0.073	40.5	9.6	0.45%	18.44	0.130	72.1	1.88%
				F4	15.29	3.279	0.068	37.2	9.3	0.39%	18.30	0.116	63.5	1.68%
				F5	15.35	3.302	0.070	37.4	9.0	0.41%	18.17	0.130	69.9	2.24%
				AVERAGE	**15.31**	**3.26**	**0.069**	**38.0**	**9.6**	**0.40%**	**18.40**	**0.125**	**69.4**	**1.96%**
				ST DEV	0.03	0.03	0.003	1.4	0.5	0.03%	0.18	0.006	3.4	0.21%
				CV (%)	0.21	0.96	4.08	3.77	5.54	7.62	0.96	4.64	4.87	10.81

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Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60									
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain @ Failure	Span/ Thick ness	Max Load(kN)	σ_{max} (MPa)	Strain at Max Load (%)
Hempathane 55210	Liquid	Infugreen	90°	F1	15.07	3.228	0.098	56.3	10.0	0.52%	18.59	0.114	65.3	0.75%
				F2	15.29	3.264	0.115	63.5	10.3	0.65%	18.38	0.115	63.5	0.65%
				F3	15.24	3.266	0.119	65.9	10.3	0.65%	18.37	0.119	65.9	0.65%
				F4	15.25	3.247	0.112	62.7	10.0	0.64%	18.48	0.112	62.7	0.64%
				F5	15.27	3.260	0.111	61.6	10.0	0.60%	18.40	0.116	64.3	0.77%
				AVERAGE	**15.22**	**3.25**	**0.111**	**62.0**	**10.1**	**0.61%**	**18.45**	**0.115**	**64.4**	**0.69%**
				ST DEV	0.09	0.02	0.008	3.5	0.2	0.06%	0.09	0.003	1.3	0.06%
				CV (%)	0.58	0.49	7.01	5.71	1.61	9.44	0.49	2.25	2.02	8.52

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Coating	Form	Composite resin	Flexural	L - SPAN (mm)	60									
				SAMPLE	b - WIDTH (mm)	h - THICKNESS (mm)	LOAD (kN) @ Failure	σ_f (MPa)	E_f (GPa)	Strain @ Failure	Span/ Thickness	Max Load(kN)	σ_{max} (MPa)	Strain at Max Load (%)
Hempathane 55210	Liquid	Elium	90°	F1	15.27	3.150	0.056	33.0	9.6	0.39%	19.05	0.100	59.4	1.72%
				F2	15.31	3.148	0.065	38.4	9.5	0.45%	19.06	0.102	60.5	1.79%
				F3	15.33	3.174	0.075	43.9	9.2	0.56%	18.91	0.128	74.6	2.09%
				F4	15.31	3.095	0.071	43.3	10.1	0.53%	19.39	0.115	70.6	1.86%
				F5	15.26	3.162	0.071	41.8	9.7	0.45%	18.98	0.121	71.4	2.16%
				AVERAGE	**15.30**	**3.15**	**0.067**	**40.1**	**9.6**	**0.48%**	**19.08**	**0.113**	**67.3**	**1.92%**
				ST DEV	0.03	0.03	0.008	4.5	0.3	0.07%	0.19	0.012	6.9	0.19%
				CV (%)	0.19	0.96	11.27	11.19	3.43	14.15	0.97	10.66	10.22	10.07