UNIVERSITAT POLITÈCNICA DE VALÈNCIA

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Trabajo de Fin de Grado

"Estudio Del Envejecimiento Natural De Los Materiales En Un Entorno Riguroso: Aplicación Al Pic Du Midi De Bigorre A 2877m Sobre El Nivel Del Mar"

Grado en Ingeniería Aeroespacial

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INP TOULOUSE ÈNIT ÉCOLE NATIONALE D'INGÉNIEURS DE TARBES

Technacol

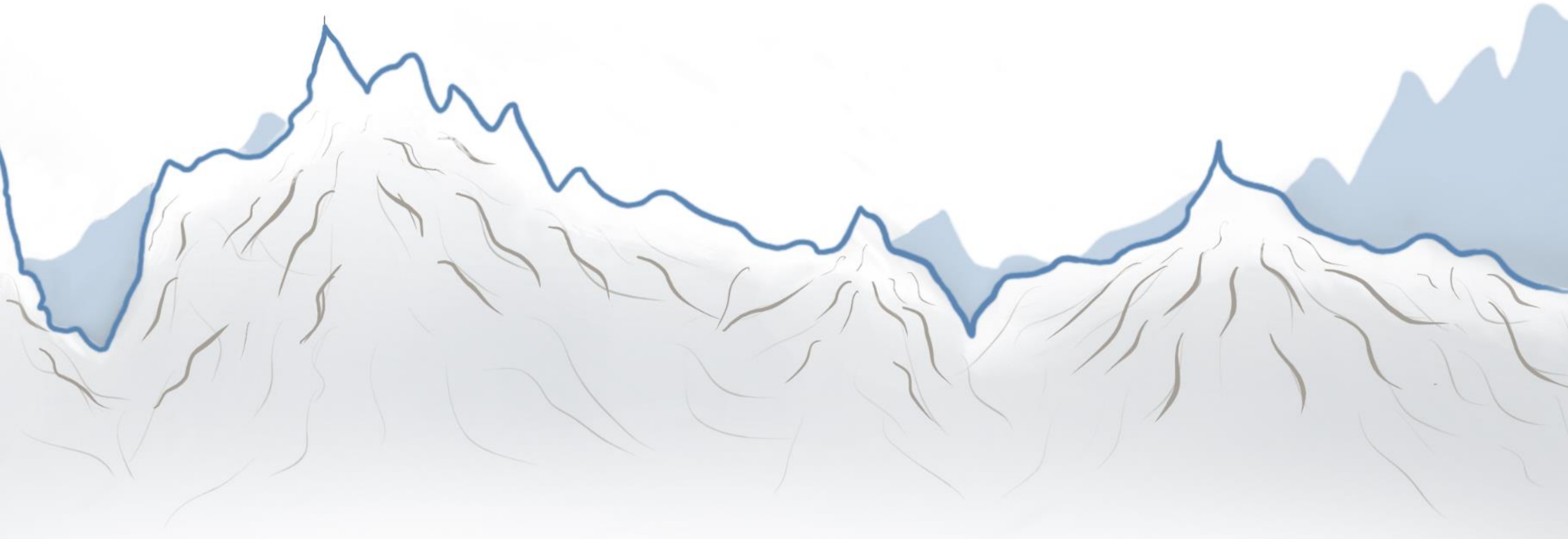
PAPic

| Poly Ageing Pic

Final Report

Study of Material Natural Ageing in a Harsh Environment

European Project Semester Spring 2023



Hugo Pamies Moreno

Supervisors

Mathieu Charlas

Philippe Fillatreau

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1. Introduction

1.1 EPS Context

Figure 1: EPS icon

The EPS Semester in spring 2023 started on 6th of March and ends on 29th of June. During this time interval the project teams must present their results to a jury twice.

The European Project Semester (EPS) is about teamwork between students from various parts of the world working on a real-life project, facing challenges such as cultural differences, or lack of skills. This program is found all around Europe and only offered by European Higher Education Institutions keeping English as the language of communication. PAPic team is participant on the European Project Semester in spring 2023 at the Ecole Nationale d´Ingénieurs de Tarbes (ENIT) in France. The members of PAPic are Hugo Pamies, Ika Chandra, and Sofia Moya.

The team must attend to courses about Project Management, Communication Skills and French Language. This program is a chance for train students to emphasize real life situations, they will have to demonstrate the ability to plan, delegate, communicate and co-operate as a team to achieve the same objective.

1.2 The ENIT

École Nationale d'Ingénieurs de Tarbes or ENIT is a school for mechanical and industrial engineering. It is located in Tarbes, France. ENIT offers the students a qualified education for 5 years of 10 semesters. They have 160 teachers, more than 3000 partner companies, 3 million euros for a budget of research per year, and research laboratories. The mission of the ENIT is to develop a publicly responsible, creative, competitive individual who is open to research, innovative technologies, and cultural values, as well as to promote scientific development, and social and economic well-being.

Figure 2: ENIT building

Being a prominent institution of higher education, with scientific and educational levels comparable to the greatest European technical schools, is the vision of ENIT. This school is appealing to both French and foreign students and scientists, which is capable of any challenge and has a significant social impact.

ENIT also made several programs for foreigners, such as FITEC Programmer, European Project Semester, Master Industry 4.0, Research Initiation Project (SPIR), and some courses taught in French.

1.3 PAPic Team

PAPic team consists of 3 EPS students. One from Spain, one from Indonesia and one from México. This multicultural team with different skills created and carried out the PAPic project.

PAPic, which stands for Polymer Ageing at the Pic du Midi, was chosen since the team will be testing polymer materials, that usually take the initials of its components as a name. Its logo represents the Pyrénées, and it was made based on the infrared spectroscopy of one of the materials chosen, which is the PA12. Those colors are chosen because they represent the appearance of the mountain in winter. The Pandion Haliaetus or in French, Balbuzard pêcheur, was chosen to symbolize "the only living being that can go up there" emphasizing the harsh environment of Pic du Midi, at 2877m.

Figure 3: PAPic Team Members

1.4 Technacol

Technacol Company was created in 1990 as a part of Adhesion team of the "Ecole Nationale d'Ingénieur de Tarbes" laboratory. Technacol's main objective was to transfer academic research to industry to create new innovations. Technacol has been working by researching the endurance of polymers in harsh conditions. Technacol is currently working at the intersection of industry and academic research, so it allows to form scientific relationships to bring innovation to the final client.

Technacol
Experts Adhésion & Durabilité

Figure 4: Technacol logo and slogan

1.5 The Pic du Midi

Pic du Midi is one of the highest peaks of the Pyrenees, with 2,877 meters of altitude and it is located in the south of France, at one hour and a half from Tarbes. A unique panorama of the entire Pyrenees can be seen from the top of the Pic du Midi. It offers a cable car for those who want to go to the summit. They provide stargazing with a professional entertainer at the summit at night. Besides the research, it is also a popular destination for extreme sports such as trail running, mountain biking, and hiking.

Inside the Pic du Midi, there is a planetarium with interactive research founded by scientists from the Pic du Midi observatory. It presents knowledge of the Sun, cosmic rays, stars, and meteorites.

2. Acknowledgements

PAPic would like to thank everyone who supports the European Project Semester in the spring 2023, especially Ecole Nationale D'Ingénieurs De Tarbes. We would like to thank Karen Sautet, Leonor Carrillo, and the whole staff from the International Office at ENIT who were always helping us since the application process to the end of the project.

Furthermore, we are very thankful to our technical supervisor Mathieu Charlas for his invaluable advice, continuous support and guidance for the project. We are also grateful to him for explaining the material behavior in an easy way. Likewise, he has been our client and we are extremely grateful for his patience and for trusting us.

Also, we would like to thank our management supervisor Philippe Fillatreau. We benefited enormously from his excellence as a teacher and as a researcher, for sharing his experience and guiding us to manage our project properly by giving some very valuable advice. We are very grateful to him for being very patient and for all the time that he spent in discussing the various subjects of this project.

Moreover, we would like to thank our teachers. Again, Philippe Fillatreau who gave the valuable lessons in Project Management and taught how to use Microsoft Project, which is one of the most important tools used to organize our project. Andrew Ghio who taught communication and language skills during this semester, helped improve our presentation and communication in English. We also thank Manuelle Denisse for giving lessons in French.

In addition, we would like to thank Technacol for providing access to their facilities and resources. Also, a huge thanks to Jeremy Fraisseix for supporting in the laboratory with his technical expertise and Guillaume Morel for joining the trip to Pic du Midi and helping with developing the new test vehicle.

Finally, to our home universities for providing the opportunity to have a life changing experience like this one.

3. Planning

3.2 Scope of the Project

3.2.1 Context

Technacol has been working for many years on polymer durability, following the latest trends in the industry, where a fast evolution is taking place, and new materials are beginning to be understood and used for special applications. Polymers are versatile, they can be found in a wide variety of day-to-day products, in the shape of plastic bottles, boxes or even the fabric of our robes. This type of material takes numerous forms and can be used in an infinity of engineering cases: from

Figure 5: Carbon fiber composite winglet

electrical isolation with PTFE to medical instruments with PMMA, or in combination with special fibers in order to make high strength composites, like epoxy or polyester.

At the same time, sectors like aerospace are racing towards a more sustainable future where material selection is key for achieving light structures, and durable parts. Polymers offer great resistance and a relatively low weight, helping to reduce emissions in commercial aircraft and extending the life expectancy of the products. A greener future of aviation relies partly on the development of components that need less maintenance and less resources to be manufactured.

Figure 6: View from Pic du Midi in a sunny day

But the harsh conditions of the atmospheric flight environment make these polymers face several challenges. The low temperature, high UV radiation, high humidity ambience that airplanes fly in, favor a decrease in the performance of the materials. The combination of these natural parameters determines the expiration date of the product, and the prediction of this natural ageing is on its own a great challenge for material scientists and engineers. (Selikhov & Ushakov, 1991) [XVII]

3.2.2 Objectives

The harsh conditions of atmospheric flight can be similarly found in a regional icon of the Pyrenees: The Pic du Midi. Its proximity to Tarbes and the mentioned conditions makes it the perfect place for Technacol facilities and for the development of this project, with two clear objectives:

- Understand natural ageing, how the real conditions make an impact on the properties of the materials and their behavior, and how they can be reproduced in a lab to help to improve their performance during the developing phases in the industry.
- Then, the team will develop a material analysis and ageing report including a model that will serve for comparing and establishing the effects of natural ageing between in the Pic du Midi and in a lab, on the mechanical properties of certain polymers chosen for the study, according to their exposure to the natural elements.

3.2.3 Approach

The team will set up an experimental strategy by selecting, designing, and performing tests and ageing on at least 5 polymer materials. First in the laboratory and then in a harsh natural environment, the Pic du Midi. The parameters that must be considered are temperature, humidity and UV Radiation.

The selected polymer materials are PA12, PA6, PEEK, RYTON PPS, PC, PS, CF Prepreg and Araldite Epoxy; chosen according to characteristics like chemical resistance, melting points, and the application that they have in the industry, as it will be detailed later in the report.

Figure 7: Catalogue of resin polymers available at Technacol

Figure 8: Team members set up a sample kit at Pic du Midi

3.2.4 Time and budget constraints

Intermediate Presentation 20th April 2023. Final Presentation 29th June 2023. The reports must be submitted one week before the presentation to give the jury members the opportunity of preparation. No specific budget is agreed on. The team will work with the means already available to Technacol. If there is a certain need, the team can contact the technical supervisor.

3.2.5 Stakeholders and Clients

The stakeholders are the people involved in the project in one way or another. The team has direct contact with the client Mathieu Charlas who is also the Technical Supervisor. In this case the Management Supervisor is Philippe Fillatreau that brings support to the team.

Role	People involved
Team members	Karen Sofia Moya Muñoz *Business Management Engineering* Ika Chandra *Material Engineering* Hugo Pamies Moreno *Aerospace Engineering*
Technical supervisor	Mathieu Charlas *Research engineer at Technacol*
Management supervisor	Philippe Fillatreau *Project management teacher for the local EPS*
Clients	Technacol Company represented by Mathieu Charlas
Organization	École Nationale d'Ingénieurs de Tarbes
Person in charge of the EPS program at ENI Tarbes	Mathieu Charlas

Table 1:Stakeholders and clients

3.2.6 Deliverables

The main deliverables represent all the things that are needed to satisfy the customer.

Deliverables	**Sub deliverables**
D.1 Material Analysis & Ageing Report	D.1.1 Operational Guide of the Lab Equipment D.1.2 Experiment Setup D.1.3 Result Interpretation D.1.4 Correlation Model
D.2 Aged samples kits	
D.3 New solution for attaching samples	D.3.1 Physical Prototype of Attaching Device
D.4[1] New test vehicles[2]	D.4.2 Physical Prototype of The New Test Vehicle
D.5 Management Documents	D.5.1 Planning Documents D.5.2 Monitoring Documents
D.6 EPS Documents	D6.1 Intermediate Report. D6.2 Intermediate Presentation. D6.3 Intermediate Commercial Video. D6.4 Final Report. D6.5 Final Presentation D6.6 Final Video.

Table 2: Deliverables

3.2.7 Milestones

Milestones represent critical points in the project and acts as a performance control point. That helps to provide an initial estimate of duration, cost, and resources.

Code	**Subject**	**Deliverables**	**Date**
M.1	Obtain baseline in the laboratory with non-aged samples		30/03/2023
M.2	Kick-off meeting (Project requirements document)		04/04/2023
M.3	D.2 Aged Sample Kits	D.2	04/04/2023
M.4	D.3 New solution for attaching samples	D.3	04/04/2023
M.5	Trip to The Pic du Midi: set backup samples		05/04/2023
M.6	Start ageing in the laboratory		07/04/2023
M.7	D.6.1 Intermediate Report	D.6.1	13/04/2023
M.8	D.6.2 Intermediate Presentation	D.6.2	20/04/2023
M.9	Test laboratory samples		22/05/2023
M.10	D.4 Physical Prototype of the New Test Vehicle.	D.4	24/05/2023
M.11	Test naturally aged samples		13/06/2023
M.12	Study results and extract partial conclusions		15/06/2023

M.13	Second trip to Pic du Midi: field tests, retrieve samples, set new test vehicle.		17/06/2023
M.14	Final Report	D.6.5	22/06/2023
M.15	Material Analysis & Ageing Report: study results, compare and obtain final conclusions	D.1	29/06/2023
M.16	Final Presentation PAPic	D.6.4	29/06/2023

Table 3: Milestones

3.2.8 Exclusions

This project work does not include the following tasks:

- Test more than the specified materials in this document (PA12, PA6, PEEK, RYTON PPS, PC, PS, Carbon Fiber prepreg, EPOXY).
- Test on equipment that is not available to Technacol.

3.2.9 Limitations

The limitations of this project are defined as follows:

- Time, only two months to do the natural aging testing in Pic du Midi.
- Limited material samples: the team is unable to produce more.
- The trip to Pic du Midi will be canceled if the wind speed is above 40 km/h.
- The trip to Pic du Midi also relies on external administrative work.
- The design of a new test vehicle depends on other factors and the capability of the client to provide the resources.
- The main parameters that are going to be used are humidity, temperature and UV. The wind speed will not be considered.

3.2.10 Project Requirements

As stated in the deliverables, we intend to develop a technical procedure that helps to compare and establish the effects of natural ageing in the mechanical properties of certain polymers.

PLAN A	Test and do ageing on the materials selected, then design and manufacture a new test vehicle that should include studying aspects of adhesive bonding and surface treatment.
PLAN B	Solely focus on the first part and try to obtain more in-depth conclusions if the repeating process with the new test vehicles is not possible for logistic reasons.

Table 4: Plan A and Plan B

Code	Project Requirements
PR1	Select a minimum of 5 polymer materials.
PR2	Minimum of 2 months of ageing at the laboratory.
PR3	Minimum of 2 months of ageing at Pic du Midi
PR4	Account for variations in the environmental conditions (different exposure to UV and humidity)
PR5	Study at least five of the most significant material properties: hardness, glass transition temperature and/or melting temperature, storage modulus and loss modulus[1].
PR6	Every material tested should have at least one valid result in: calorimeter, rheometer, and spectrometer[2].
PR7	The solution for attaching the samples must comply with the already existing configuration of M8 holes.
PR8	Interpret the result of the study and compare it to real use cases of industrial applications, such as aerospace.

Table 5: Project Requirements list

3.2.11 Risks

It is necessary to identify the risks to define the possible events that could have an impact on the project. Depending on the probability and the impact of the risks, preventive and corrective actions should be taken. For this project, the risks were classified with the standard tool 5M´s (Man, Media, Machine, Management and Mission).

Improving risk analysis on the project helps to reduce and anticipate the harmful effects in the project. The risk matrix is a tool used to analyze the risks by evaluating the impact and the probability of the event. The 5x5 risk matrix contains 5 levels of probability and 5 levels of impact. (*5x5 Risk Matrix: Importance and Examples | SafetyCulture*, 2005.) [I]

- **Impact:** It is the severity of the damage that the risks may cause to the project if it occurs. Can be negligible, minor, moderate, major, or catastrophic.
- **Likelihood:** Is the probability that the risks may happen, in this case rated as frequent, occasional, remote, improbable or extremely improbable.

[1] The properties of interest will be detailed in section 4.7

[2] The functions of the equipment will be detailed in section 4.4

Impact and likelihood of the risks:

Rating	Description	Value
Catastrophic	The risk can result in a loss of the project, take preventive actions	5
Major	Can cause irreversible problems or mistakes that require constant attention	4
Moderate	Can cause injuries or mistakes	3
Minor	Can cause little mistakes	2
Negligible	Will not cause serious problems	1

Table 6: Impact of the risks

Rating	Description	Value
Frequent	Likely to occur many times (at least monthly)	5
Occasional	Likely to occur sometimes	4
Remote	Unlikely to occur, but possible	3
Improbable	Highly likely to occur (not known to have occurred)	2
Extremely improbable	Almost inconceivable that this event will occur	1

Table 7 Likelihood of the risks

The Risk Rating Matrix can be consulted in Appendix I – Risk Rating Matrix.

The first step is to assign a number from 1 to 5 on the categories of probability and impact to each risk, then by multiplying a hazard's likelihood and impact values, the acceptability level of the risk can thus be calculated ($IxP = R$).

Low:	This means that the risk has minimum or no impact on the project activities.
Low/Medium:	Risks that can impact on a small scale.
Medium:	Events that can cause impact but not too serious.
Medium/High:	Risks that are below a risk rated as high; this can cause issues in the project.
High:	Risks that we must pay close attention to. Critical importance.

Table 8: Level of the risk

The Risk Table (Appendix II – Risk Table) shows the biggest risks, which are summed up by the team and presents the Preventive and Corrective actions that the team must take to prevent them. Or, if it occurs, what actions should be taken. It shows the complete analysis of each risk.

3.2.12 Risk conclusions

Once the project starts, PAPic realized there were more risks than expected. However, the team figured out how to face each risk and found a solution for every problem. Resulting in a good job at correcting them and taking preventive actions for avoiding repeating the same mistakes again.

3.3 Work Breakdown Structure

The Work Breakdown Structure (WBS) is a scheme that classifies each deliverable of the project into sub-deliverables followed by specific tasks which can be managed by one identified person. The objective is to convert the deliverables into a list of tasks. The WBS facilitates the measurement of the progress, and it is appliable to every project no matter their size or field. The following Figure shows a general view of the WBS. Please find the detailed WBS in Appendix III - WBS.

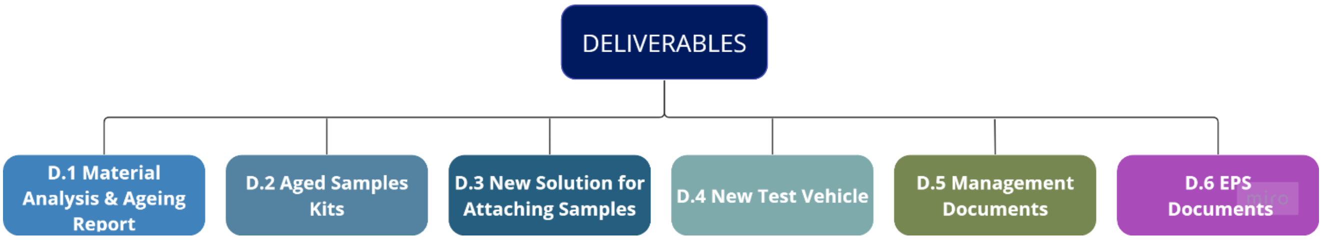


Figure 9:Deliverables WBS (D= Deliverable, T= Task)

3.4 Workload Estimation

An estimate of the workload can be made based on the work breakdown structure by dividing several main tasks and estimating how many hours each team member would spend on them. The workload estimation is about 295 work hours per member which means a total of 885 hours. The following diagram shows the percentual distribution of the estimated workload. The work was split following the skills of each member. It was decided to start from the top, that are the milestones and then the deliverables, to the bottom: the specific tasks to finally get one responsible per task.

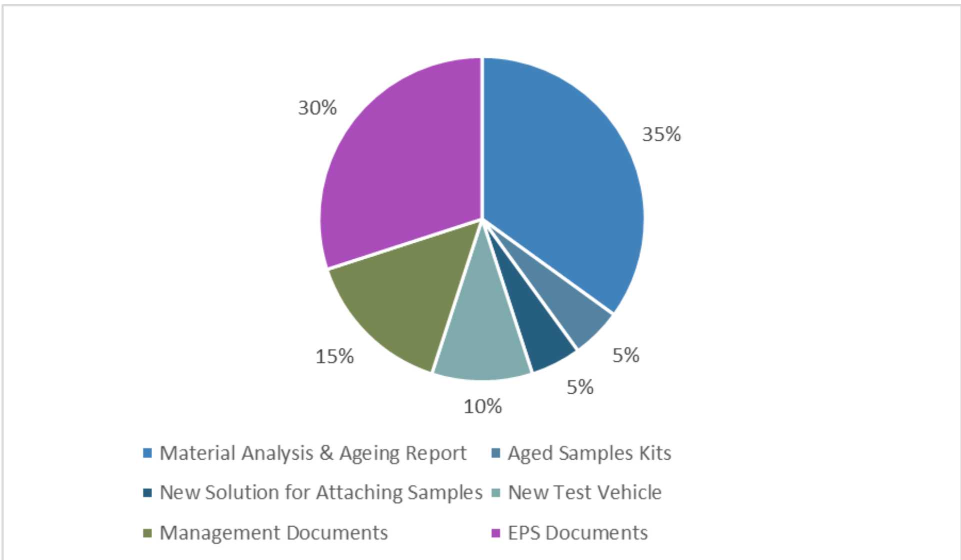


Figure 10: Pie chart of the estimated deliverable workload distribution

The team made an estimate of the task distribution for each member. Hugo is more concerned with technical work; he has more experience with materials and machines because of his skills in aerospace engineering. As a material engineer, Ika is more involved in the test of the materials and the experimental setup. Sofia, with her business management skills is caring more about the Management Documents and EPS Documents but still wants to know more about technical work. Team members decided on this workload estimation to enjoy doing the task, and give the best in each one. A detailed table with the workload estimation can be found in Appendix IV – Workload Estimation Table.

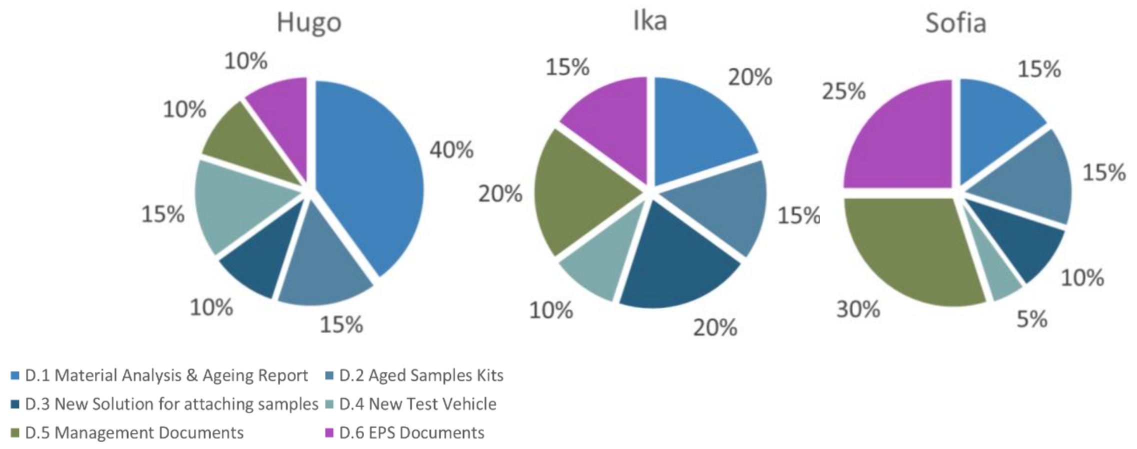


Figure 11: Estimated deliverable workload distribution within the team members

3.5 Actual Workload

The team evaluated the workload estimation and compared it with the actual workload. In the following figure it can be seen that the team underestimated the Material Analysis & Ageing Report. The team spent more time because there were many samples to test. PAPic also underestimated the D.2, they did not realize that going to the Pic du Midi, would take them a lot of time, at least 8 hours each trip. On the other hand, the team overestimated the Management Documents. At the end these deviations were cancelled out so the team rescheduled and redistributed the work during the project.

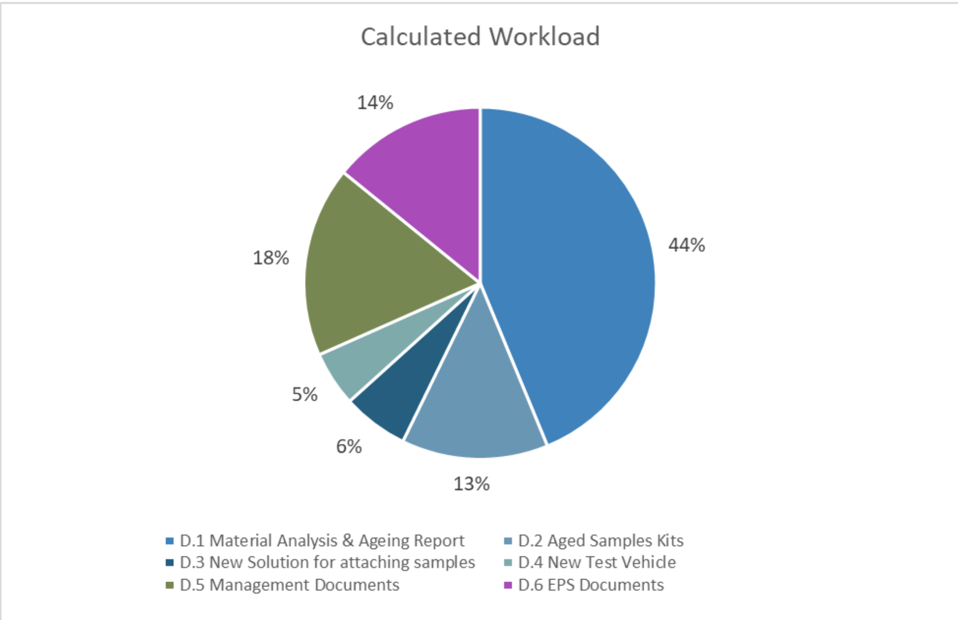


Figure 12: Pie chart of the calculated deliverable workload distribution

	D.1	D.2	D.3	D.4	D.5	D.6	Total (hours)
Estimated	127	40	9	15	57	47	**295**
Actual	135	55	9	7	59	30	**295**

Table 9: Comparison between estimated and calculated workload

The team calculated the real workload for each team member, so they could realize the differences with the estimations.

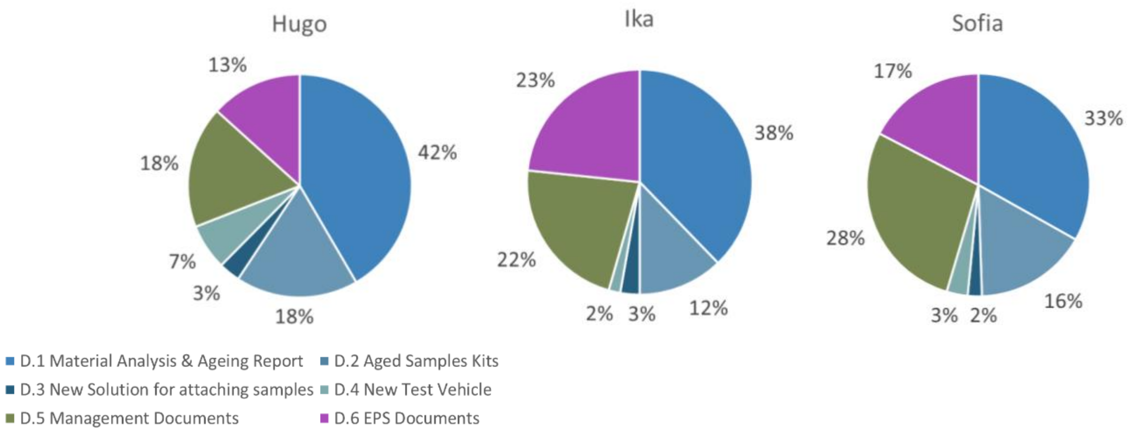


Figure 13: Calculated deliverable workload distribution within the team members

Hugo's main tasks were testing and analyzing the results. The D.2 became longer because of the time spent on going to the Pic du Midi. Moreover, it can be observed that the work in the EPS documents increases because he participated in editing the video.

Ika remained doing more technical work. Unfortunately, she could not join the team on the second trip to the Pic du Midi so she stayed doing more about management and EPS documents.

Sofia's main task remained writing the management and EPS documents. This part becomes shorter because the team had a lot of work to do in the lab, such as testing and ageing the samples, so she helped with other tasks that took more time.

3.6 Gantt Chart

PAPic has decided to implement this visual tool to have a clear overview of the project. This is related to the tasks and deliverables of the WBS with an estimated workload for the set of tasks. Please find the detailed Gantt Chart in Appendix V – Gantt Chart.

3.7 Communication Plan

PAPic has created a communication plan for the project, to determine who will receive the information, how and when they are going to receive it. In the next table, the detailed information about the stakeholders, the frequency and the way that each stakeholder would like to receive the deliverables is presented.

Stakeholder	Deliverables	Role	Frequency	Priority	Way to deliver	Notes and attachments
Philippe Fillatreau	Minutes of meetings/ Intermediate Report/ Final Report	Management Supervisor	Weekly with pre-appointment	Project Managements Documents / EPS Document	Email/ in-person	Can teach, guide, and support with the Management and EPS Documents.
Mathieu Charlas	Test results/ Intermediate Report/ Final Report	Technical Supervisor	Once a week with pre appointment	Technical / EPS Document	Email/ in-person	Can help with technical issues
Technacol company Mathieu Charlas	Laboratory Document/ Aged samples	Client	Monthly	Laboratory Document/ Project Results	E-mail/ in-person	Can explain the use of the machines.
Jeremy Fraisseix	Experimental results	Technical Expert	Once a week	Experimental Results	E-mail/ in-person	Go to the laboratory company to do some tests.

Table 10: Parts of the Communication Plan

3.8 Planning of the monitoring

Project monitoring is necessary to organize all aspects of project management and ensure that all project activities are on the right track. From Monday to Friday, the team decides to meet and complete a task in every "*EPS Project Work*" schedule listed on Hyperplanning. Also, to keep track of how each task has progressed every week.

4. Material Analysis and Ageing

4.1 Key concepts

Throughout this project the word polymer appears on many occasions. It is then interesting to define this concept with more precision. Scientists name this type of material after their molecular composition. A single molecule that can be composed of many different elements, but mainly oxygen, hydrogen, carbon and nitrogen, is called a monomer. And so, the link of many of these molecules forming a chain (that can be pure or a mix of monomers) is called a polymer. The wide range of combinations lead to an enormous variety of materials, each with its own properties, advantages and use cases. The name of the polymer is often self-descriptive and gives information about the

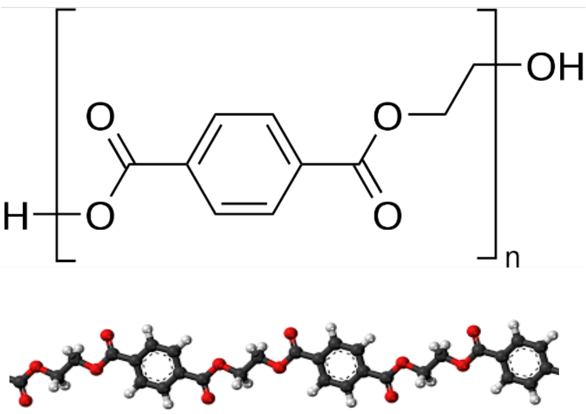


Figure 14: Molecular composition of PET and structure of the chain

molecular structure of the material. For example, PET, or polyethylene terephthalate, commonly used for manufacturing bottles and food packaging, has the following composition: ($C_{10}H_8O_4$) forming a chain of molecules.

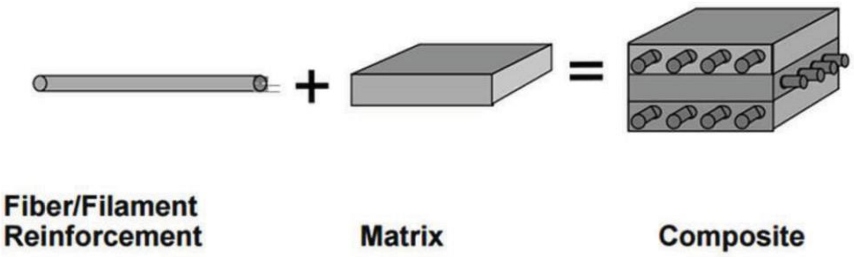


Figure 15: Simplified drawings of the components of a composite material. The matrix represents the polymer resin.

Some polymers are used in combination with other materials to produce what are known as composite materials, those that combine the properties of all their constituents to obtain a new product. In general, this combination aims to enhance the resistance, for example glass fiber reinforced Nylon, commonly used in plastic casings, home appliances and tools. Another example of composite material that has grown in popularity over the last decades is a resin-fiber combination with outstanding lightness and mechanical properties. The use of carbon fiber fabric along with resin polymers achieves a high-performance material that can be extensively found in the most demanding applications like aircraft and space vehicles or sports and competition equipment. (Chawla, 2019)[II]

4.2 Materials of interest

As it has already been mentioned, polymers take lots and very different forms depending on their chemical composition. Technacol has a permanent storage of different polymer material samples at the disposal of the team. Among them, the following interesting proposals were investigated as possible candidates for the study.

- PA12: The Polyamide 12 is a grease resistant, low-density polymer with relatively good wear properties, and low moisture absorption. It is commonly used in the food industry and in aircraft technology. It has the advantage of being 3D printable and comparable lightness at just 1.02g. (*PA 12 - TECAMID 12 Natural / Ensinger*, n.d., 2022) [XI]
- PEEK: The_polyetherethercetone can sustain a working temperature of up to 250ºC and has a high resistance to chemicals. It is often used to substitute metals where the weight is a decisive factor. Commercial PEEK can also be found with carbon or glass fiber reinforcement of up to 30%. (MCAM | Ketron® PEEK |Plastiques Usinables, n.d., 2023) [IX]
- Ryton PPS: The Polyphenylen Sulfide is a rigid and opaque semi-crystalline engineering thermoplastic. The properties of this material are the high temperature, good chemical and inherent flame resistance, dimensional stability, and exceptional mechanical strength. It has a high melting point (280°C). It also has good flammability ratings without flame retardant additives. (Polyphenylene Sulfide (PPS) Plastic: Properties & Applications, n.d., 2023) [XV]
- PC: Polycarbonate is a tough, transparent plastic material with outstanding strength, stiffness, unbreakable, amorphous, light weight, and heat resistance. PCs are commonly used as plastic lenses in eyewear, medical devices, automotive components, protective gear, exterior lighting

fixtures. Its density is 1.2 - 1.22 g/cm3 and tough up to 140°C and down to -20°C. (*Polycarbonate (PC) - Properties, Uses, & Structure - Guide*, n.d., 2019) [XIII]

- PS: Polyestyrene is commonly used for food service industry which is food container It is also found in some electrical components and used as a sort-of living hinge material. It has tensile strength of 53 MPa and melting temperature of 210-249 °C. (*Everything You Need To Know About Polystyrene (PS)*, n.d., 2015) [VII]

Ranking from most to least priority: PEEK, PEI ULTEM, PS, PA12, PTFE, Ryton PPS, PC, EPDM, PVC.

It was decided to discard PVC because it does not have a strong connection with the aerospace industry which is the main interest. EPDM and PTFE are used indeed in the construction of aircraft but mostly for electronics, wiring, isolation and sealings in the hydraulic systems, that are not as exposed to the same harsh conditions of cold, wind and radiation. PEI ULTEM has many characteristics close to those of the other high resistance and high working temperature plastics and thus will be excluded from the experiments to avoid redundance.

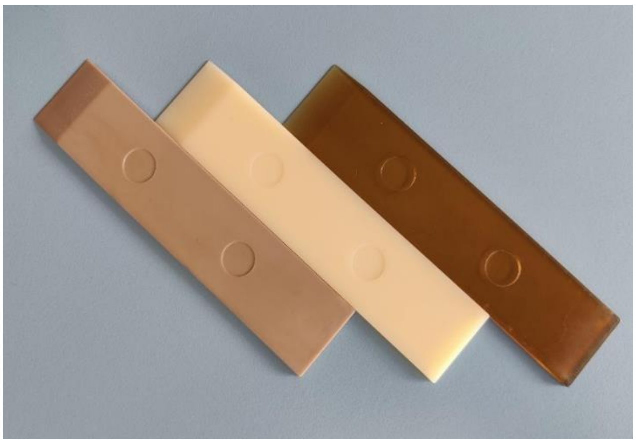


Figure 16: Left to right: PEEK, PA12 and PEI ULTEM samples at Technacol's lab

The materials that will be tested are PA12, PA6, PEEK, RYTON PPS, PC and PS, taking into consideration some characteristics such as the working temperature and chemical resistance, the melting points, and the application industry that they already have. Choosing PS will help the study to be more accurate because a faster degrading material can help to better quantify the amount and intensity of the ageing.

Figure 17: Manufacturing of the 2014-2 epoxy samples at the lab

Additionally to these polymers the team will also test a composite material and a structural adhesive to have include representation of the latest trends in industry. The composite is a carbon fiber prepreg[3] and the adhesive is a bicomponent epoxy resin manufactured by Araldite with the reference 2014-2.

[3] A type of fiber fabric with resin already applied that only needs heat to cure (solidify).

4.3 New Solution for Attaching Samples

The making of sample kits started with choosing the materials available. PA12, PA6, PEEK, RYTON PPS, PC, PS, Carbon Fiber, and Araldite Epoxy. Those were chosen according to characteristics like chemical resistance, melting points, and the application that they have in the industry.

Figure 19: Araldite Epoxy samples

Figure 18: Sample kits

To assemble the kits, 5mm steel cable, bolts, nuts, washers, and some pieces of wood are prepared. The Araldite Epoxy samples were made with a mixture of Araldite resin and hardener. The mixture is poured into a mold and flattened to all sides of the mold using a spatula. The mixture needs at least 24 hours to be perfectly cured. While the epoxy cured, the remaining samples and some pieces of wood were drilled in the center of the surface to create a hole for the steel cable.

4.4 Testing equipment

As introduced before, the testing equipment is listed in this subsection to summarize the laboratory means available to the team for the study. A brief description of the instrument and an example of their usage is also given.(*What Are Rheometry and Rheology? - TA Instruments*, n.d., 2022) [XXI]

4.4.1 Rheometer

The most common applications of rheometers are material testing for polymers and soft matter. The rheometer can perform vastly different tests depending on the material, for example if it is a solid or a viscous fluid. But the basic principle of the machine is applying forces to a sample of material and register the response in time of the piece.

All of this while altering the temperature of the sample from room temperature up to the melting point of the plastic.

PAPic can calculate rheological parameters from the measured values of torque, deflection, angle, and speed using conversion factors. (*Discovery HR 30 - TA Instruments*, n.d., 2021) [IV]

Figure 20: Discovery HR-30 Rheometer at Technacol facilities

The Rheometer will give values for the storage modulus and the loss modulus of the samples. Properties that will evolve and change during the ageing process and that give information about the rigidity and plasticity of the material.

4.4.2 Calorimeter DSC 4000

At Technacol the team will use the DSC 4000, a model manufactured by Perkin Elmers, with a reasonable sensitivity for the purpose of the study.

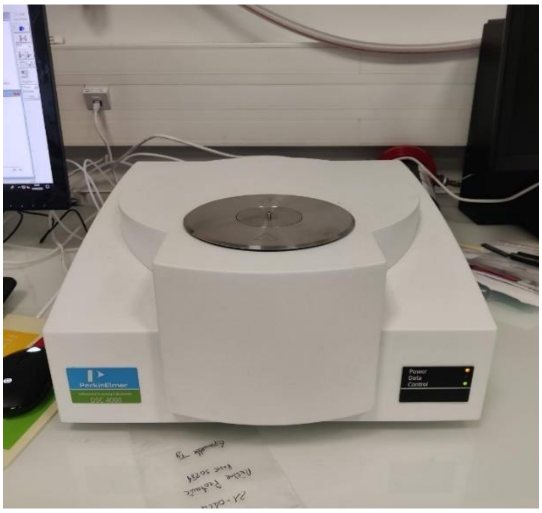


Figure 21: DSC 4000 equipment at Technacol facilities

The calorimeter at Technacol's lab will help PAPic to determine reference temperatures from the materials to test. The glass transition temperature (TG) and the melting temperature (TM), considered to be good indicators of ageing.

The method to determine TG is by Differential Scanning Calorimetry (DSC) which measures the differential in heat flow between a capsule with the sample and an empty reference capsule over time or at different temperatures. Then it determines the change in temperature of the sample in a certain atmosphere. Peaks of heat exchange reveal the location of TG and TM as the energy is absorbed by the material to change state and not to raise its temperature.

The calorimeter measures differential temperature and reports the heat flow to the sample as it is heated, cooled, or held isothermally. Proper selection of heating rate will increase the efficiency of the analysis at the desired sensitivity. (*DSC 4000 | Single-Furnace Heat Flux DSC | PerkinElmer*, n.d., 2013) [V]

4.4.3 Spectrometer

Spectroscopy is a technique used to measure light intensity in the ultraviolet, visible, near infrared, and infrared (IR) wavelength ranges. It examines the absorption and emission of light and other radiation by matter. It also studies interactions between particles such as ions, electrons, and protons.

Spectroscopic measurements are used in many applications, for example color measurements, concentration determination of chemical components, or electromagnetic radiation analyses. "Spectrometers measure the frequency emitted by the substance being analyzed." ("What Does a Spectrometer Measure? - Verichek Technical Services", 2016) [XXII]

Figure 22: Spectrometer at Technacol facilities

In the case of PAPic's study, The IR spectrum of the dissimilar materials will reveal crucial information about their chemical composition. Allowing to discuss possible differences at a molecular level between the artificially and the naturally aged samples.

4.4.4 UV Chamber

Inside the SUNTEST, the product suffers changes such as fading, embrittlement and yellowing that can be compared to the natural UV radiation from the Sun, with the possibility to increase the power in order to accelerate the process. (*SUNTEST CPS+ | Xenon Weathering Instruments for Products & Materials | Xenon Test for Pharmaceuticals and Cosmetics - Atlas*, n.d., 2021) [XVIII]

Figure 23: ATLAS UV Chamber at Technacol facilities

4.5 Natural ageing

Another term that needs to be defined is ageing. In this case the ageing of a material is attributed to a variation in its properties throughout time. It can present itself in various ways, some visible like loss of color, cracks or erosion, and some others invisible like changes in chemical composition or embrittlement. Particularly, natural ageing is referred to as the deterioration of the materials caused by their exposure to the environment.

To end this contextualization, the use of the term "testing equipment" should also be mentioned. PAPic used several machines and specialized measuring equipment to extract information from the material samples. These will be all grouped and called testing equipment for simplicity and will include mechanical and electronic tools able to measure hardness, temperatures, strains, and other parameters of interest. The actual equipment used will be described in the next pages.

4.5.1 Time distribution of the ageing process

To obtain a material sample that has degraded enough to retrieve meaningful results, the maximum amount of artificial ageing time should be achieved. By estimating the necessary workload of testing the different properties the duration of the ageing can be maximized. A whole week has been left for finishing the report and presentation at the end of June, a week and a half is necessary to test the retrieved samples from Pic du Midi, and an approximately three weeks are left to perform laboratory tests on the artificially aged samples. Therefore, the laboratory ageing ends on the 17th of May 2023.

4.5.2 Environmental conditions during the natural ageing process

The conditions in the lab should be relatable to those at Pic du Midi in order to establish a reasonable link between samples and obtain an accurate comparison. These are the average parameters during the period between the months of April and June:

- **UV Radiation:** 600 W. Minimum 0, maximum around 1200 W. Solar radiation at the Pic is three times that at sea level.
- **Temperature:** Between -14°C and 15°C.
- **Pressure:** 714 mBar on average, minimum of 680 mBar maximum of 740 mBar.

- **Humidity:** 40% to 98%

The samples are put in Pic du Midi for two months and ten days. During the first month, the samples experience thermocycle ageing (temperatures above and under 0ºC in the same day) for eight days from 6th until 13th of April and eight days from 19th until 26th of April.

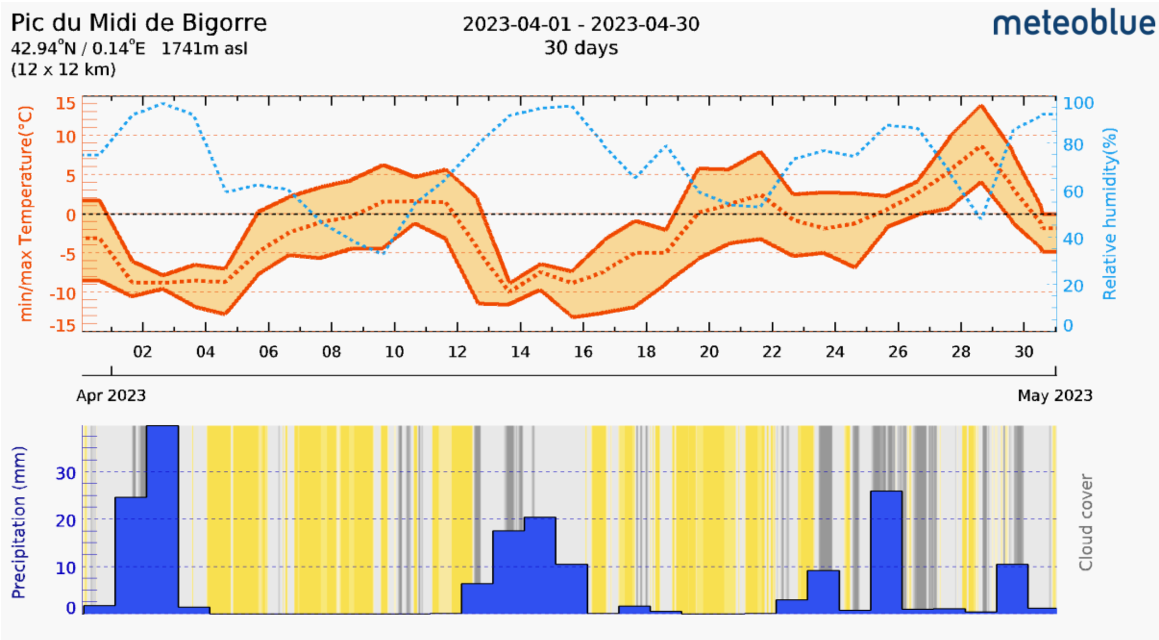


Figure 24: Weather conditions at Pic du Midi during the natural ageing process in April. (Source: Meteoblue)

The UV radiation also affects the ageing process of the samples, the warmest days are usually those with the most UV exposure (in yellow in the following figure). The rest of April is mostly cold because of the high precipitation and overcast conditions.

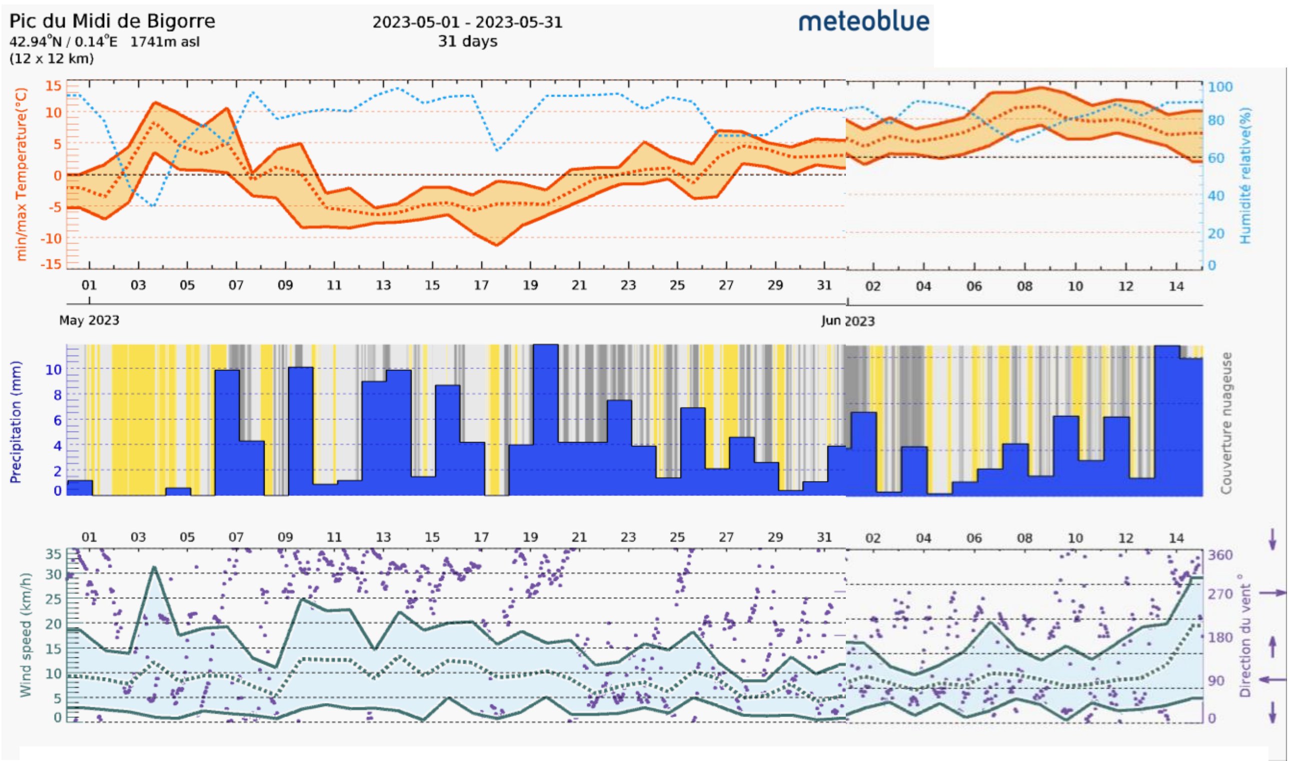


Figure 25:Weather conditions at Pic du Midi during the natural ageing process in May and June. (Source: Meteoblue)

In May, the samples had thermocycle ageing for 12 days. The first three weeks of May are colder because of the high precipitation than that happened in April, followed by higher temperatures in the last week of May until the first two weeks of June, setting the arrival of the summer. The temperature was kept above 0ºC until 13th of June (the day when the sample was taken out). In general, it can be said that the material experienced 28 days of thermal cycling, high humidity (rain) for 64 days, and UV exposure for 45 days.

4.6 Laboratory Ageing

The following processes are the ageing cycles defined by the team as the best candidates for mimicking the aggressive conditions of the mountain. After asking for advice and consulting ISO-9142, PAPic decided on the following cycles, that will later on give the name to the test samples.

4.6.1 Oven ageing

The ageing in the oven is performed in 3 weeks (hence the name of the cycle, O3W) with a temperature of 70ºC during the whole cycle. That temperature is used because it is an aggressive way to affect the ageing process faster than the natural ageing. The following chart represents the exposure to temperature and humidity over time.

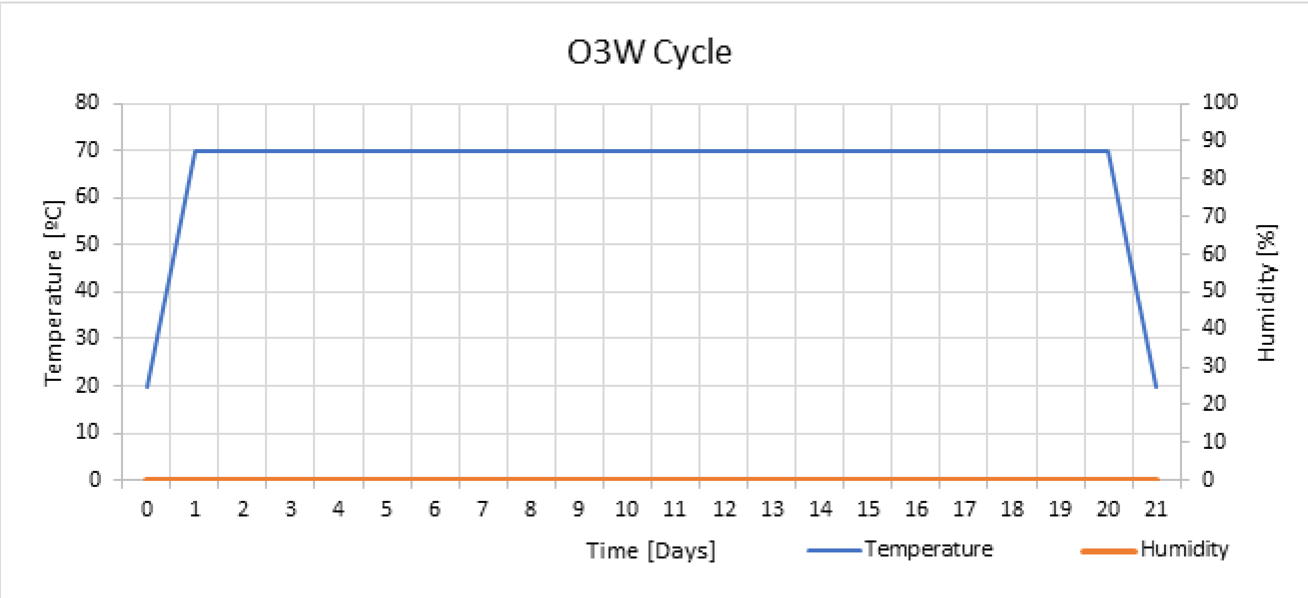


Figure 26: Temperature and humidity in the O3W Cycle

4.6.2 UV ageing

To get a similar result as the naturally aged samples in Pic du Midi, exposed to UV radiation, artificial aging in the UV chamber is performed. This aging process takes 3 weeks and uses 62457 kJ/m^2 of UV light exposure, a temperature of 30ºC, and 0% humidity. In the middle of the ageing process, the samples are flipped once to get all the surfaces aged. The following chart represents the data of the temperature, UV exposure, percentage of humidity, and time used.

Unfortunately, the machine stopped working from day 3 until day 5 because of a technical issue. For this reason, the interruption was included. Restarting the process was not an option due to schedule constraints.

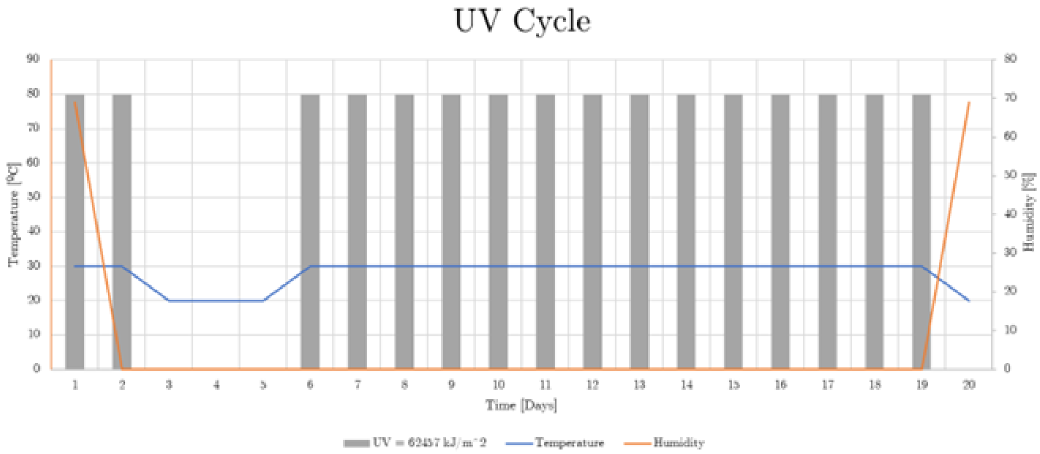


Figure 27: Temperature, humidity and radiation in UV Cycle

4.6.3 Full Cycle

Figure 28: Cold conditions of the full cycle

This artificial ageing is performed to simulate the ageing with the real environment conditions that happens in Pic du Midi. The samples were put in the UV chamber for 2 days with 62457 kJ/m2 of UV light exposure, but then the machine suddenly stopped for 3 days with the samples inside because of an error (as with the previous cycle).

Then the samples were moved to the oven for 5 days at a temperature of 70ºC, then moved to the UV chamber for a day and again to the oven for the next day. On day 13, the samples were moved to the freezer at a temperature of -24,9ºC for an entire day.

The following chart represents the data of the temperature, UV exposure, percentage of humidity, and time used.

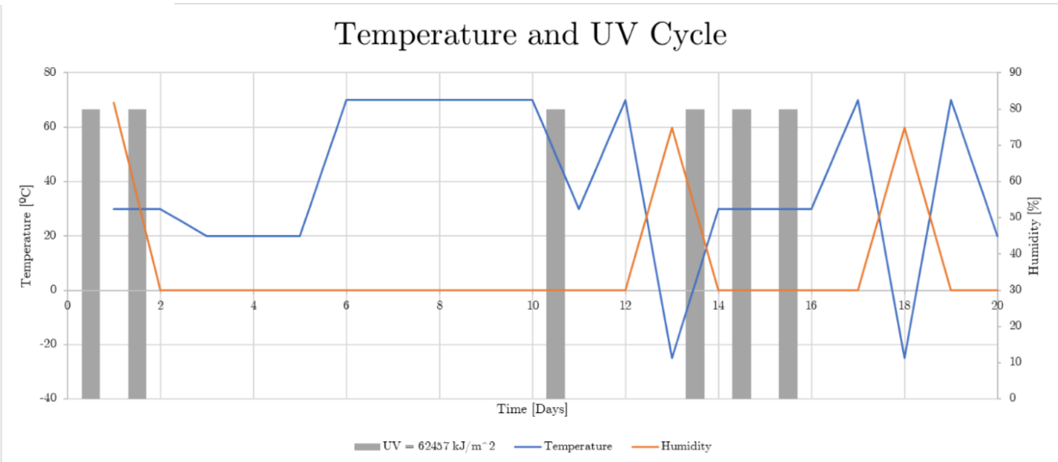


Figure 29: Temperature, humidity and UV radiation during the Full Cycle.

4.6.4 Humid Cycle

This cycle uses an oven with a temperature of 70ºC and a fridge that has a temperature of -24,9ºC as an alternative for a climate chamber. The samples were put in the vacuum plastic with wet cotton inside (with 100% humidity) and placed in the oven for 5 hours. Afterwards, the samples were aged for the next three days by following the cycle, and then were placed in the fridge for 3 hours and stayed overnight in the oven (20 hours).

For the last three days, the cycle spends 3 hours in the fridge, and then 21h in the oven. The following chart represents the data of the temperature, UV exposure, percentage of humidity, and time used.

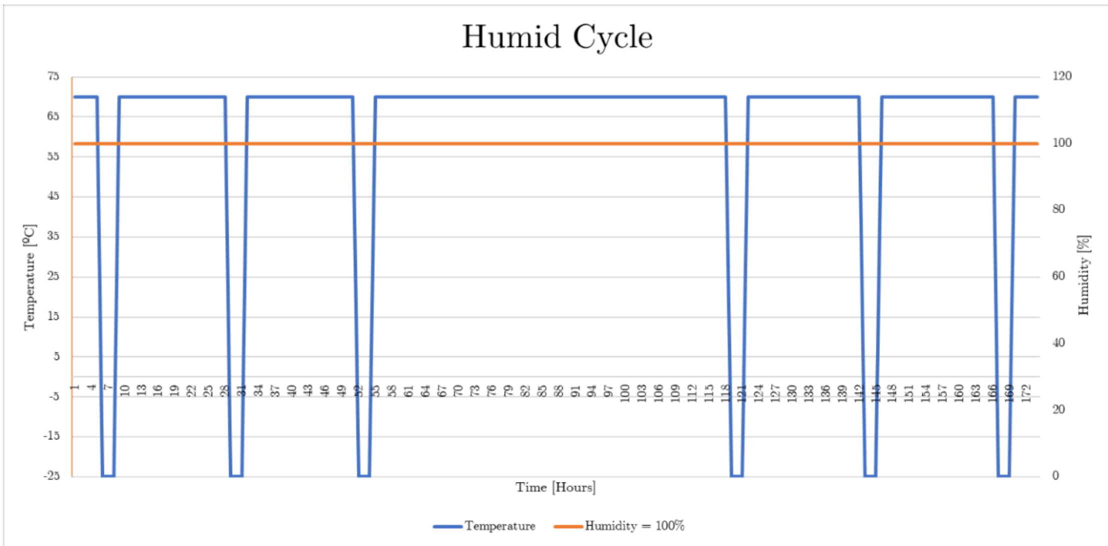


Figure 30: Temperature and humidity during the Humid Cycle.

4.7 Material properties of interest

4.7.1 Hardness

Hardness is the ability of a material to resist localized plastic deformation, such as a small dent or a scratch. Formed on that basis, hardness testing techniques have been developed where a small indenter is forced into the surface of the material to be tested. The purpose is to determine the depth or size of the resulting indentation. This can be used to determine the hardness number. The lower the hardness value, the greater and deeper the indentation, indicating the softer material. (*Low Temperature Properties of Polymers*, n.d., 2020) [VIII]

Figure 31: Hardness measurement tool

The samples are measured for hardness using the Shore Scale or an analog equivalent, as defined by ASTM D2240. This is a portable hardness tester that is pressed smoothly on the specimen with the required contact force until the presser foot is securely inserted and the hardness value can be read once the needle is stable.

4.7.2 Melting temperature

The melting temperature of the polymer (TM) is the temperature at which polymers convert from a solid crystalline state into solid amorphous state. All the crystalline and semi crystalline polymers have TM. Thermoset polymers do not have a melting point, which means chains of thermoset polymer have highly cross-linked molecules. When the temperature is gradually raised, thermoset polymers decompose before melting. As a result, after curing, thermoset polymers cannot be reshaped. Melting temperature can be measured by using Differential Scanning Calorimetry (DSC). ((*Thermoset Vs Thermoplastic (What Is the Difference?)*, n.d.-b, 2019) [XIXX]

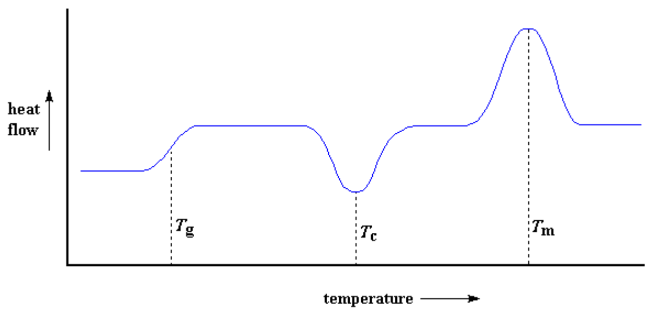


Figure 32: Graph presenting evolution of heat flow as a sample gains temperature.

4.7.3 Glass Transition Temperature

The temperature at which a glassy state transforms to a rubbery state is known as glass transition or TG. The polymer changes from solid to semi-solid or rubbery phase and marks a region of changes in physical and mechanical properties. It is also used to define changes in volume, and Young's modulus of solids. Above the Tg, the polymer is in a rubbery state (less rigid and brittle). Some polymers have a low TG, for example, PA6 has a TG lower than room temperature. (*Differential Scanning Calorimetry*, n.d., 2018) [III]

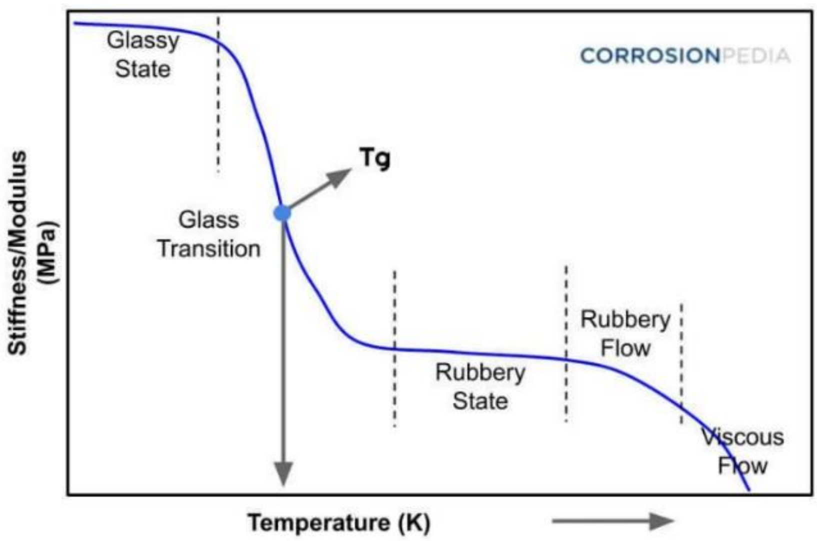


Figure 33: Evolution of the stiffnes of a sample as it gains temperature. (What Is a Glass Transition Temperature? - Definition from Corrosionpedia, n.d., 2021) [XX]

5. Results of the study

5.1 Trends

Figure 34: Samples after 2 months of natural ageing

In general, the 8 polymers of study show similar patterns of behavior to the different environmental conditions that they have been exposed to. It is evident for example, that the UV radiation alone is not enough to make a significant impact on the performance of most materials. PAPic believed this parameter to be more aggressive than humidity for instance, and the results have proven this theory to be inaccurate.

Another trend that can be stablished is the increase of the Tg in most of the cases where heat was applied in some degree. The longer the exposure to the hot environment of the oven at 70ºC, the higher the increase. In the case of the resins, it can be attributed to post-curing, in the case of the other polymers will depend on the composition, but the basic principle for it is the allowance of mobility for the molecules of the plastic within its inner structure. The molecules rearrange to form stronger connections that can improve the heat resistance. In some cases, like the epoxy resin, this Tg improvement comes with serious embrittlement. In other cases, like with the PPS, certain cycles make the plastic less rigid, increasing its flexibility at operational temperatures.

Finally, Hardness was chosen as a variable of interest for the study but it turned out to have a very small change. Only PA6, Epoxy and PPS have deviations in hardness higher than 10%, and it's usually the UV ageing that induces it as it is the most surface aggressive and hardness is measured in the outer layers of the piece.

5.2 Ageing Model

In this chapter, the results of al tests will be shown and explained briefly, to give an idea of the main concepts that take place during the different ageing processes. The plots correspond to the data collected by the rheometer, and they will help to identify the loss of rigidity with the increase of temperature, the Tg and also the Tm in some cases. Then a chart will be discussed, comparing the rheometric characteristics with the data from the DSC and showing the differences between types of ageing.

At this point it is also important to mention that each polymer sample has its own code for easy identification. First the name of the polymer itself, for example EPOXY. Then the type of ageing to which it has been exposed:

- R for Reference.
- UV for UV radiation cycle.
- O3W for Oven Cycle at 70ºC.
- CY for the full cycle.

- HC for the humid cycle with thermal shocks (-25ºC to 70ºC).
- N for natural ageing (2 months and 10 days at Pic du Midi).

Finally, an extra number will be added at the end to account for the different samples that can be extracted from the same master sample (the bigger sample that the test samples are cut out from). For example, EPOXY-R-2 is the second piece of a master sample of epoxy that has not been aged.

In general, a model includes an equation or a correlation plot where the user can introduce one or various parameters and obtain a value for the desired variable. In this case the ideal model would be the one that provides the deviation in Tg, G' or H, with a single input in units of time aged. For this it is compulsory to have at least two points to connect, but the more points (measurements in time) the model includes, the more accurate it will be.

This is why instead of including one correlation plot for each material and each type of ageing -which would not give useful information- PAPic has decided to explain which is the artificial ageing that better simulates the changes in each material in the natural environment. This will allow future PAPic studies to try new artificial ageing cycles accordingly. Adding more information to the evolution of the natural ageing will also be a great contribution, and a correlation study will start to make sense after having data from reference, 2 months old and 4+ months old samples.

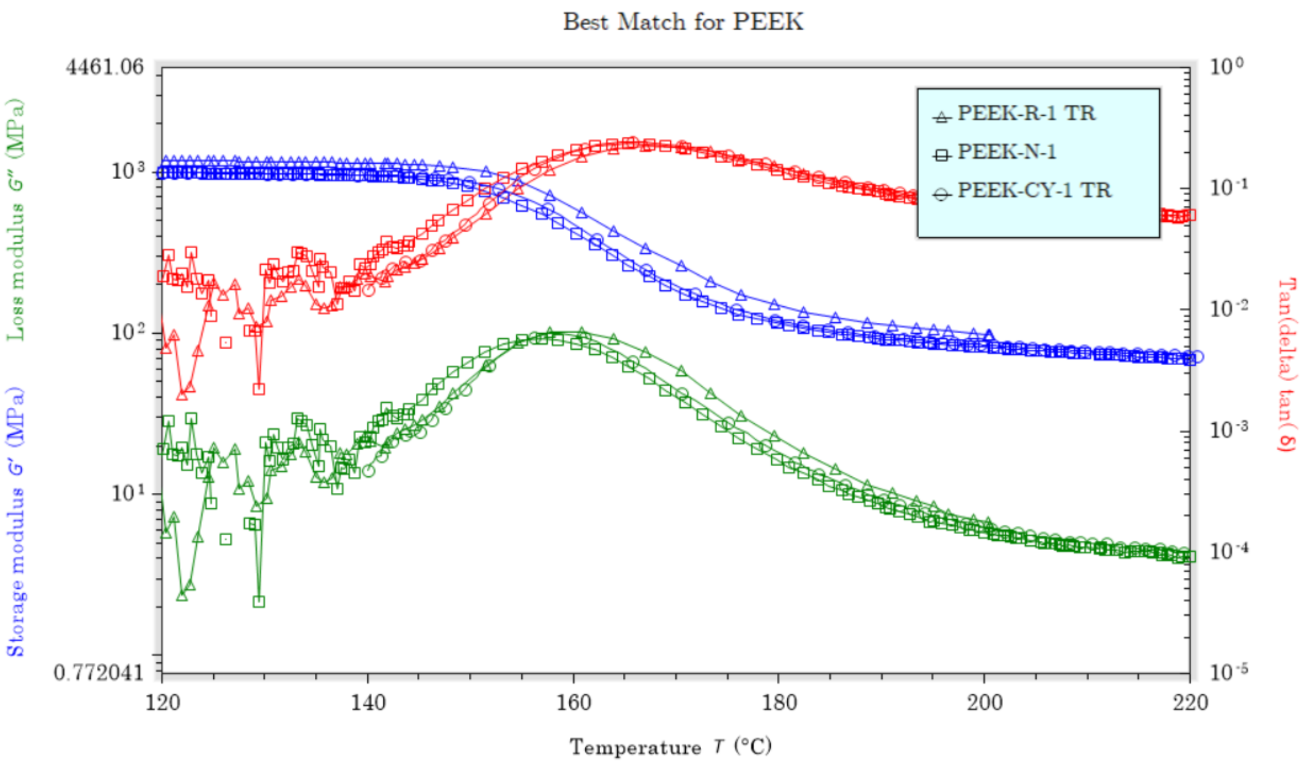


Figure 35: Rheometric overlay for the best match for PEEK

In this case the best coincidence for an artificial ageing is the Full Cycle that was applied to the PEEK, comparing with the naturally aged sample and the reference. The results do not have big differences because of the resistance of this material but the Tg for the PEEK aged in the cycle is very close to 164ºC of the reference, a couple of tenths colder for the N and CY samples.

But it is evident that the CY lines in the rheometric test are the much closer to the N lines than to the R lines. PAPic suggests a review of the CY procedure to reduce the oven temperature and promote more thermal shocks with less hours in each chamber. This should give results even closer to the natural ageing.

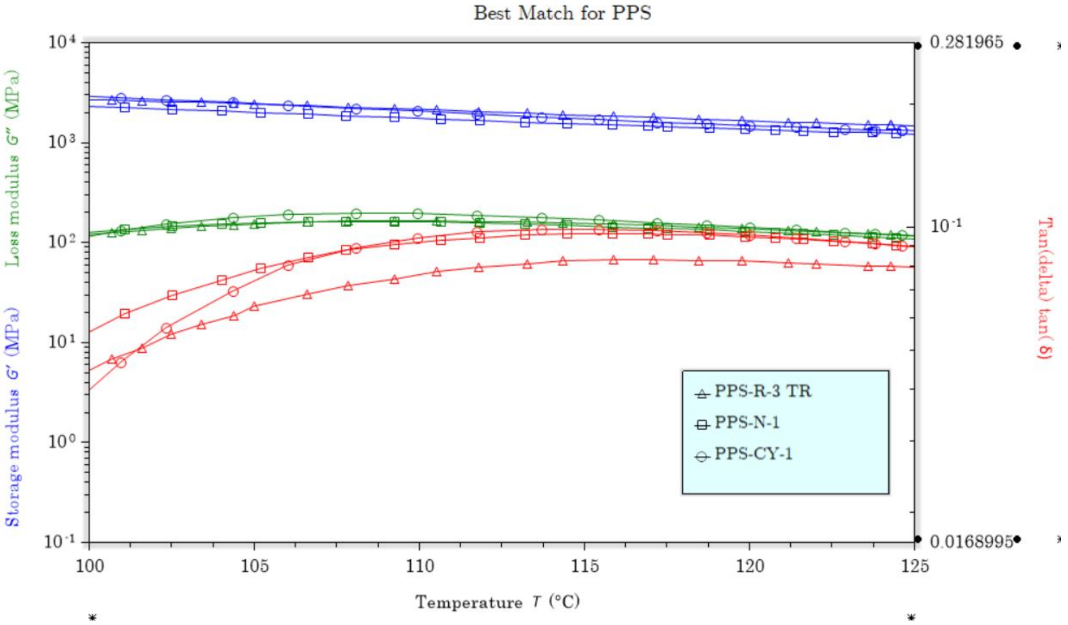


Figure 36: Rheometric overlay for the best match for PPS

The case of PPS is less evident than the previous one. Most of the artificial ageing procedures increased the Tg and the G' curve. But again, the CY procedure, even if it's not perfect, seems to better follow the overall behavior ($Tan(\delta)$) of the naturally aged sample as shown in the figure and with the values of *ΔTg DSC*.

Material	*Age*	*Tg DSC[ºC]*	*ΔTg DSC*
PPS	Reference	135	-
	Only Oven	103,3	-23,48%
	Only UV	122	-9,63%
	Full Cycle	**125**	**-7,41%**
	Humid Cycle	124	-8,15%
	Natural	**127**	**-5,93%**

Table 11: DSC results for PPS

To make it an even closer fit, it would be interesting to change the parameters of the CY procedure. Lowering the temperature at the oven would likely result in a lower G' curve, which is desirable.

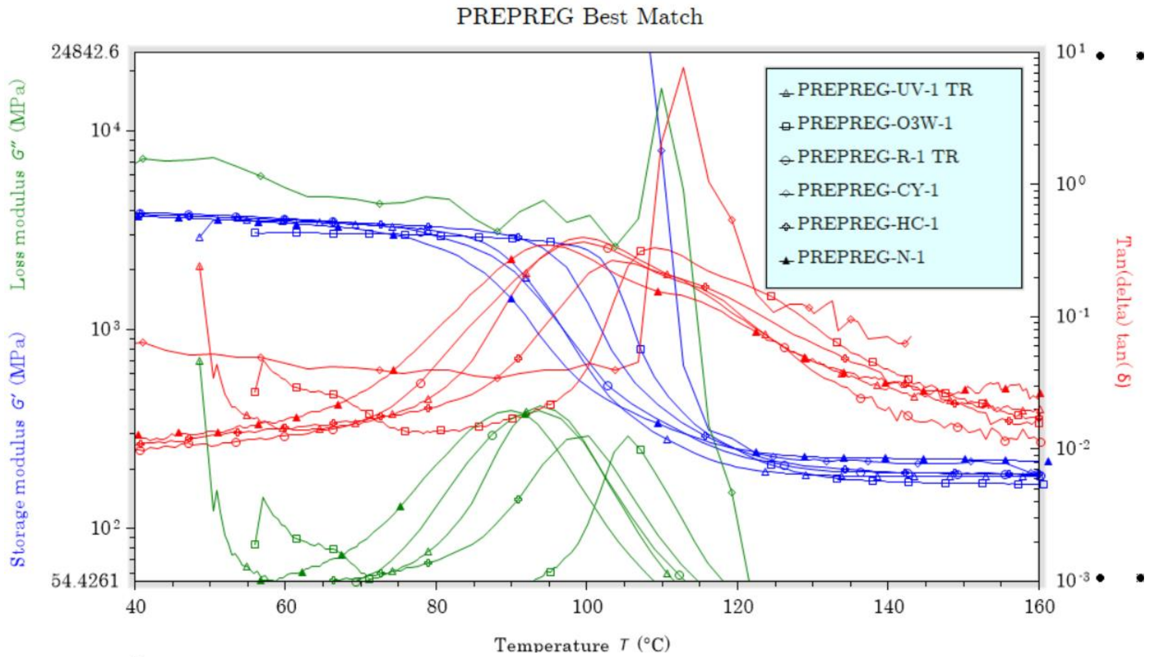


Figure 37:Rheometric overlay for the best match for PREPREG

Carbon fiber Prepreg is a material with a very unpredictable behavior. It is very affected by spending time in the oven, as its Tg gradually increases with the time exposed to 70ºC, being the O3W cycle the one with the highest Tg. This trend is confirmed by the DSC. In general, high temperature will have an opposite effect on resin polymers because of the effect of post-curing. The UV cycle has a stronger impact after crossing the Tg and G' drops to the levels of the naturally aged. For a future test with Carbon Fiber, PAPic suggests to completely avoid time in the oven, and modify the Humid Cycle to change the oven sectors for UV sectors.

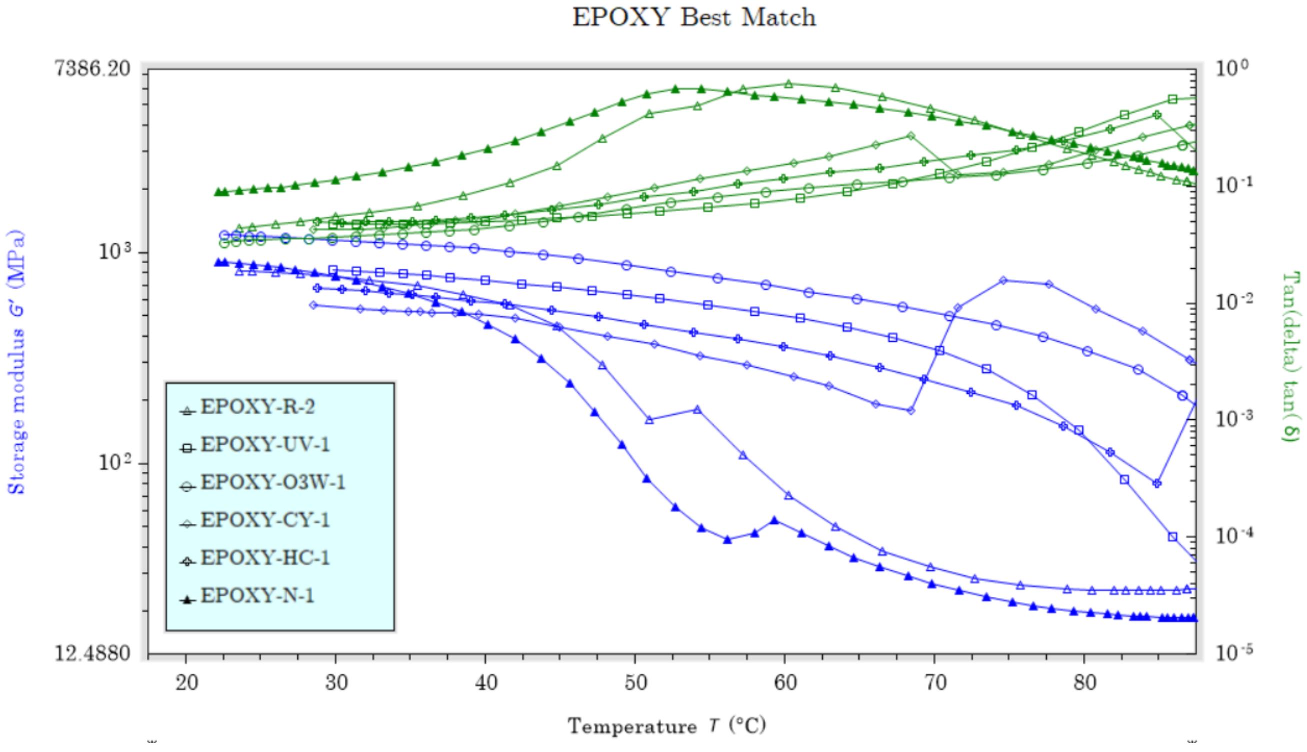


Figure 38: Rheometric overlay for the best match for EPOXY

The case of the EPOXY was expected to be similar to the Carbon Fiber prepreg results, the closest match to the N sample is the reference one. It is absolutely necessary to remove the high temperature from the processes. The DSC confirms this behavior, where the N sample is the only one decreasing its Tg, which was the expected change from the beginning of the project.

Material	*Age*	*Tg DSC[ºC]*	*ΔTg DSC*
EPOXY	Reference	51	-
	Only Oven	70	37,25%
	Only UV	67	31,37%
	Full Cycle	68	33,33%
	Humid Cycle	79	54,90%
	Natural	**46**	**-9,80%**

Table 12: DSC results for EPOXY

A significant amount of embrittlement can also be observed in the naturally aged sample:

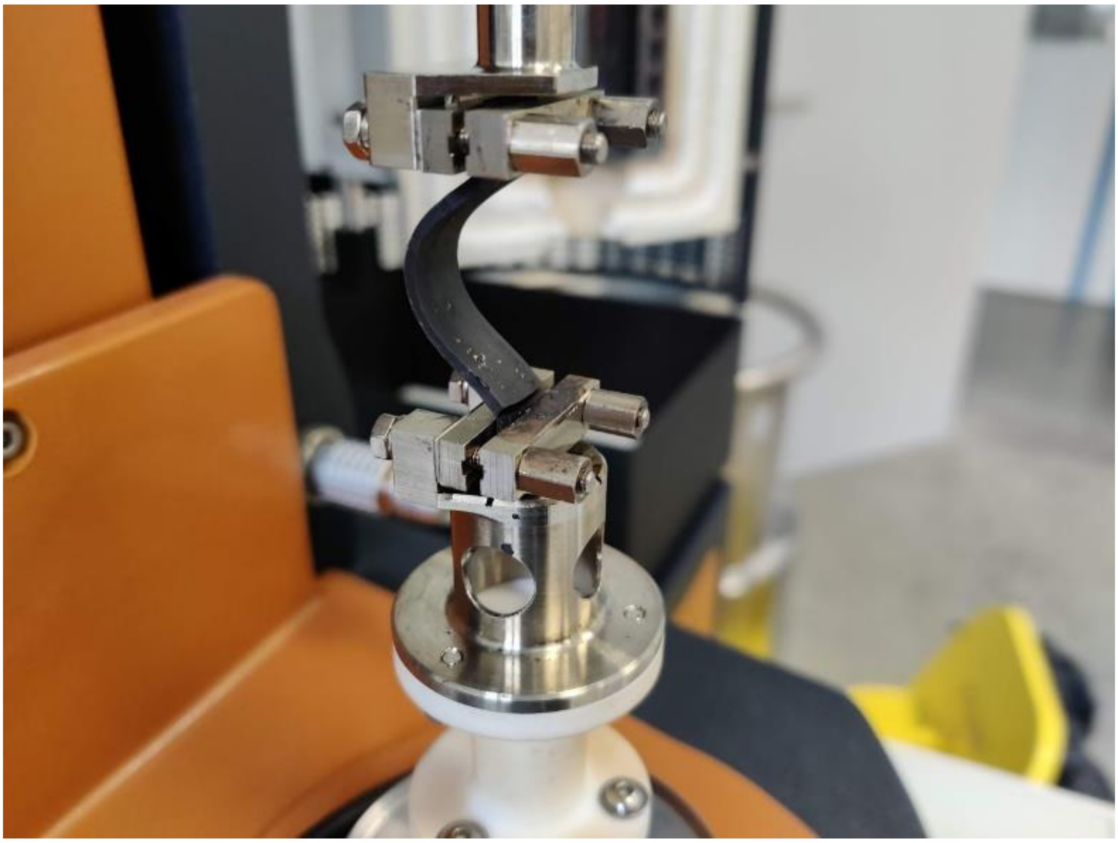


Figure 39: Embrittlement causes the EPOXY-N-1 sample to break during tests

PA6 was a big surprise. Its Tg dropped by a huge 30% according to the DSC after two months at Pic du Midi. And this case is especially sensitive to high temperatures because the original Tg is very close to room temperature.

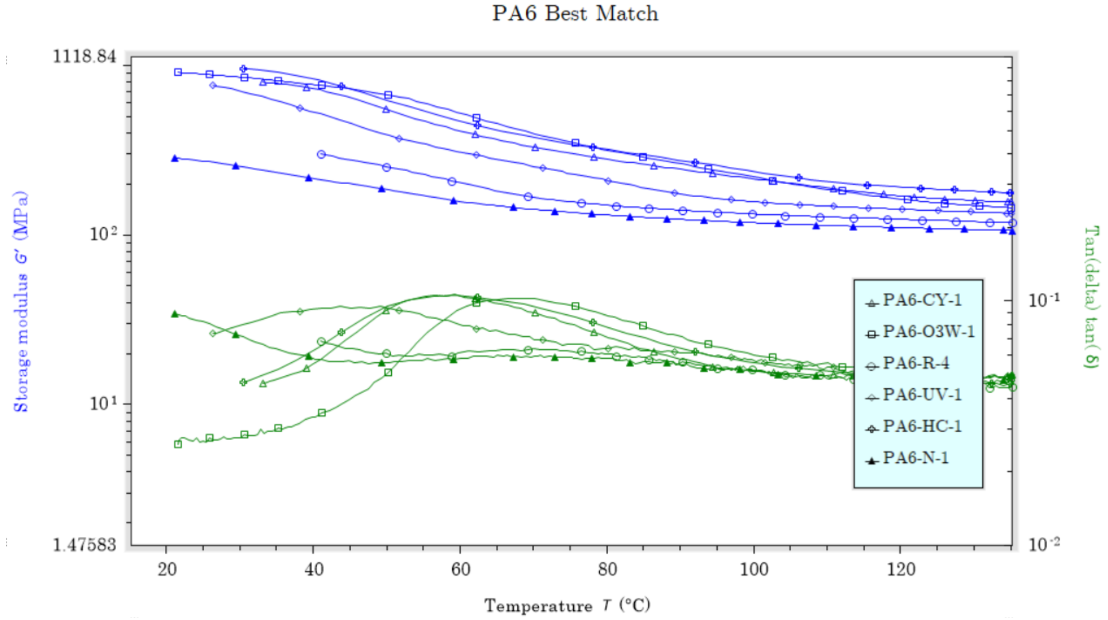


Figure 40: Rheometric overlay for the best match for PA6

Even the UV cycle was able to increase it. Both CY and HC treatments are very similar which means that humidity is not really affecting too much. For this particular material, a totally new approach will be necessary, and perhaps a climate chamber ranging -30 to 20ºC is the only viable way to achieve anything similar to the natural ageing.

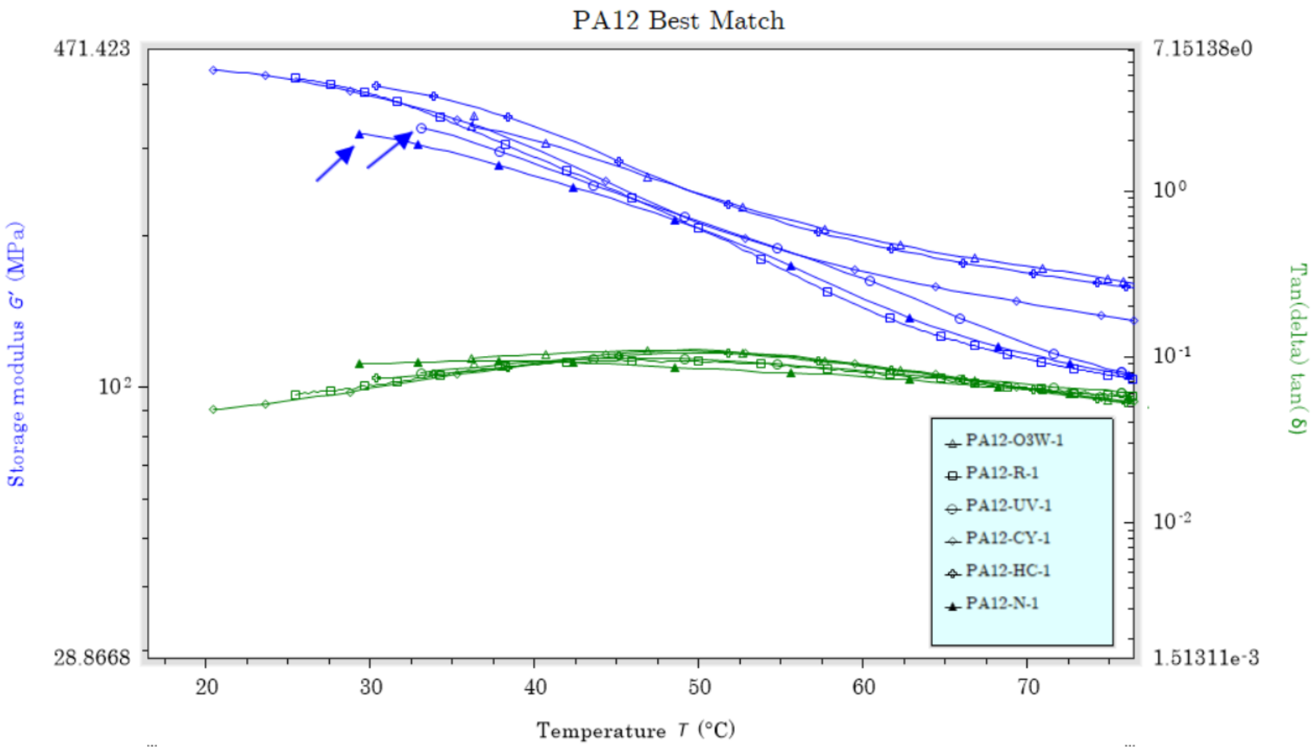


Figure 41: Rheometric overlay for the best match for PA12

PA12 shows its similarities with PA6. It is a stronger material with a higher Tg (this time easier to measure) and also more stable. It also has great humidity resistance as CY and HC have approximately the same effect on it. It looks however that the UV could be the main culprit of the loss of Tg in the naturally aged sample, as the values for rigidity are relatively close together. PAPic believes that the heat in the UV chamber has prevented the Tg from dropping all the way through, but the best model for predicting PA12 natural ageing might be a colder UV cycle.

Material	*Age*	*Tg Rheo [ºC]*	*ΔTg Rheo*
PA12	Reference	45,95	-
	Only Oven	48,29	5,09%
	Only UV	**41,01**	**-10,75%**
	Full Cycle	48	4,46%
	Humid Cycle	41,9	-8,81%
	Natural	**40**	**-12,95%**

Table 13: Rheometer results for PA12

It would be interesting to try different ways to keep a low temperature in the UV chamber in the future, for example reducing the power setting, or running a cooling system through its interior.

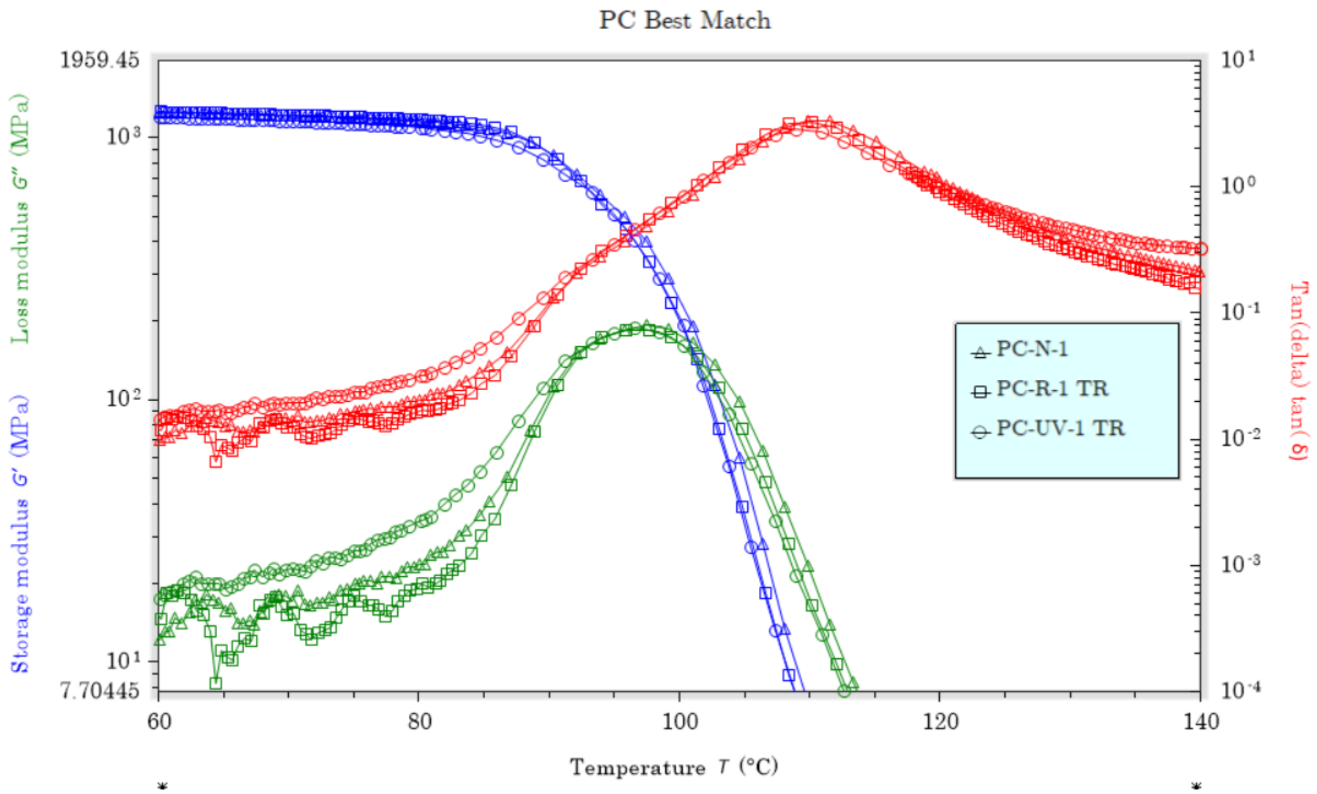


Figure 42: Rheometric overlay for the best match for PC

The degradation of the PC is surprisingly low considering that it's not the best one for outdoor conditions, at least in theory. In the Best Match figure, the rheometric curves of the N sample barely differ from the reference, however, taking a look at the G' and H, maybe the UV cycle is the best model if those were to be the variables of interest, as the following data reflects:

Material	*Age*	*G' at 20ºC [Pa]*	*ΔG' at 20ºC*	*H*	*ΔH*
PC	Reference	1341,39	-	85	-
	Only Oven	1370,53	2,17%	86	1,18%
	Only UV	**1303,63**	**-2,81%**	**84**	**-1,18%**
	Full Cycle	1220,76	-8,99%	83	-2,35%
	Humid Cycle	1379,69	2,86%	84	-1,18%
	Natural Ageing	**1311,12**	**-2,26%**	**84**	**-1,18%**

Table 14: Mechanical properties evolution for PC

Future tests with PC should follow a similar philosophy to the ones proposed for the other low-Tg polymers, this means less temperature and more thermal shock.

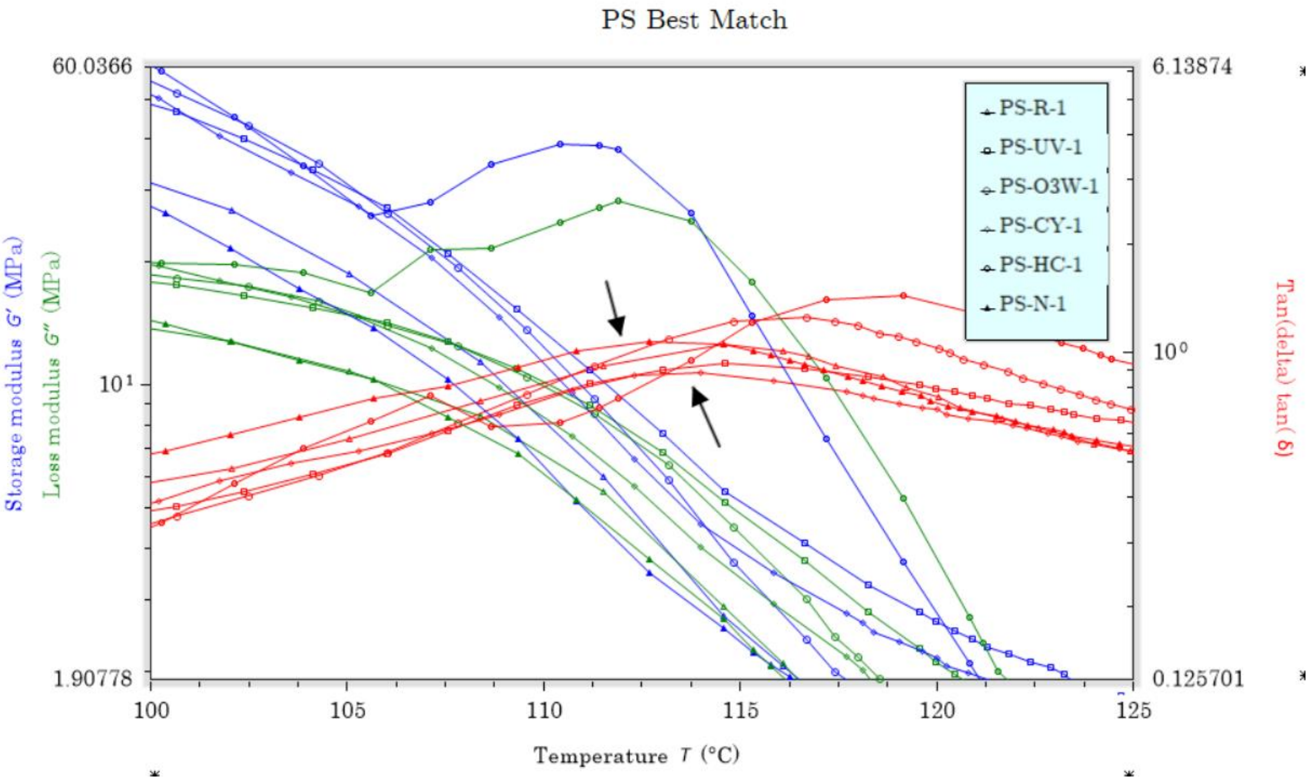


Figure 43: Rheometric overlay for the best match for PS

The PS, is maybe one of the hardest to analyze. From a Tg perspective, as shown in the previous figure, the Full Cycle is the model that better mimics the decrease that comes with the natural ageing. Also confirmed by the data from the DSC:

Material	Age	Tg DSC [ºC]	ΔTg DSC
PS	Reference	85	-
	Only Oven	97,74	14,99%
	Only UV	80,59	-5,19%
	Full Cycle	**76,21**	**-10.35%**
	Humid Cycle	96,66	13,72%
	Natural	**75**	**-11,76%**

Table 15: DSC Data of the PS

However, if the parameters of interest were to be rigidity and hardness, there is another procedure that constitutes a better model, and it is the Humid Cycle. PAPic has observed the appearance of water vapor bubbles forming inside the HC and N samples during the temperature ramp of the rheometry test, both in PS and PC. Although it may happen with more materials, here it is easier to appreciate due to the transparency of both polymers.

Figure 44: Bubbles inside PS-HC-1 sample

Figure 45: Bubbles inside PC-N-1

Among other future suggestions, several tests should be repeated due to some anomalous results that make interpreting more difficult. For example, the Epoxy-HC-1 sample should be tested again in the rheometer because it broke while the test was running. PA6 and PA12 samples should be tested again in the rheometer at less temperature with liquid nitrogen because in some cases the Tg can be below room temperature. PS samples from all aging processes should be tested again in a rheometer because the results are very similar. PPS-HC samples should be tested again because the results obtained cannot be interpreted with ease. The ageing affects the chemical composition of the materials and IR tests can give more information in this regard. PAPic has done IR analysis for all 48 samples but only used them for confirming the presence of water. In the theoretical side, Tm, plasticization, recrystallization, and thermal shock should be studied more deeply because these phenomena are very present in the results.

6. Composite Bonding Demonstrator and New test Vehicle

As interesting as the results for the Carbon Fiber and Epoxy have been, it will also be to apply these materials to their real use in the industry: for structural and aerodynamic parts in aircraft for instance. Prepreg parts are commonly assembled with structural adhesive such as the Araldite from the tests. So PAPic has decided to include in this research an analysis of the performance of this epoxy as a bonding agent for the studied prepreg, and also to apply the technique through a demonstrator.

Figure 47: Location of the devices on the engine nacelle

Figure 46: Typical appearance of the Strake

The basic idea is to manufacture a part that simulates a typical aircraft component, an engine strake, out carbon fiber plates bonded with structural adhesive (Pantelakis & Tserpes, 2014) [XII].

6.1 Conception of the composite bonding demonstrator

To manufacture this test vehicle, the necessary materials are a raw board of the desired polymer for the study and a small quantity of the structural adhesive that wants to be tested. The manufacturing process can be summarized in the following steps:

- Design of the geometry and dimensions in CAD.
- Sketch measurements on the sheet of material.
- Cut the pieces to their final shape, either with manual tools or with a CNC machine, depending on the availability.
- Sand the parts to remove sharp edges.
- Prepare the surfaces for the adhesive.
- Apply structural adhesive and bond the parts, ensuring good distribution along the surfaces.

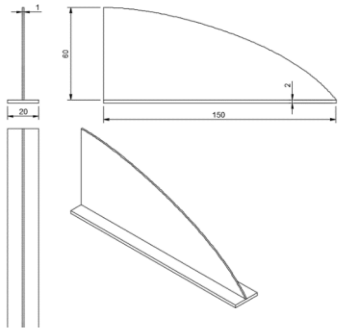


Figure 48: CAD drawings of the demonstrator strake

The results of the manufacture of this demonstrator can be seen in this picture of the final product at the Pic du Midi:

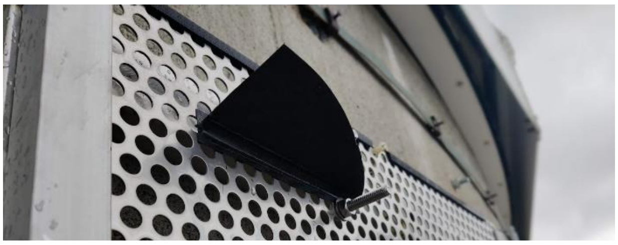


Figure 49: Engine Strake demonstrator at Pic du Midi

6.2 New test vehicle for composite bonding

To measure if the adhesive bond between the carbon fiber and the epoxy weakens with natural ageing, and to see if the surface treatment applied can counter this degradation, PAPic manufactured new test vehicles that can be essayed in the traction test machine to evaluate adhesion. Two carbon fiber strips are bonded following the standard CSN EN 1465 (1997). The epoxy Araldite 2014-2 with 2 mg of glass micro balloons was applied on the shadowed area in the following figure:

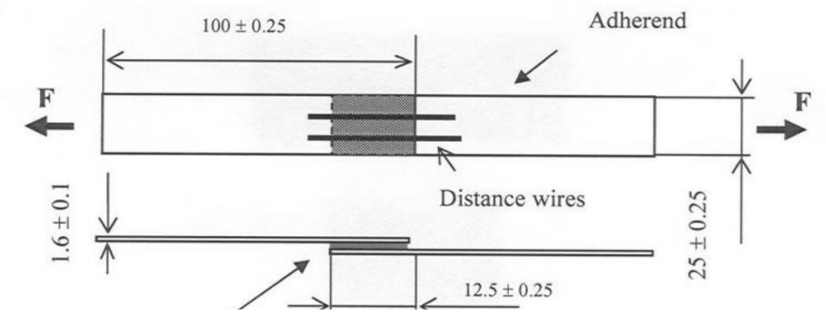


Figure 50: Dimensions of the stripe according to CSN EN 1465 (1997)

The micro-balloons help to maintain a constant thickness layer of epoxy along the surface.

Before bonding, the surfaces of the carbon fiber strips receive a plasma treatment that can help to improve the adhesion. (Tiwari & Bijwe, 2014) [XX]

Each test vehicle received a different amount of treatment. With a constant speed of 10 mm/s for the platform, PAPic decided to go through 1,2,8,16 and 32 passes. After curing for 24h, traction tests were performed, obtaining fruitful results.

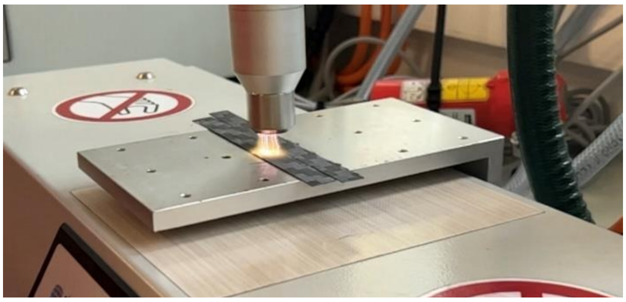


Figure 51: Plasma surface treatment for the new test vehicle

To interpret the results, it is important to explain the ways in which an adhesive bond can fail:

- **Adhesive failure:** The adhesive material (the epoxy) separates from the substrate (the carbon fiber) along the interface.
- **Cohesive failure of the epoxy**: the adhesive material breaks but the remains stay attached to the substrate.
- **Cohesive failure of the substrate**: The carbon fiber breaks and the bond stays intact.

It is safe to assure that the use of plasma treatment to the surface of this new test vehicles was successful in improving the performance of the bond. In the sample without treatment, the failure was entirely adhesive, as big traces of the grey colored epoxy can be seen on the surface. This means there is a lot of room for improvement in the adhesion.

The sample with one pass of treatment shows smaller patches of epoxy which indicates some degree of cohesive failure of the adhesive, apart from the evident adhesive failure. From the sample with two passes to the one with 32, there is a gradual decrease of the adhesive failure and a significant increase of the cohesive failure in the substrate. Which means that the full potential of the bond has been reached, as it is not the epoxy that fails but the material of the structure. This can be seen in the following figure:

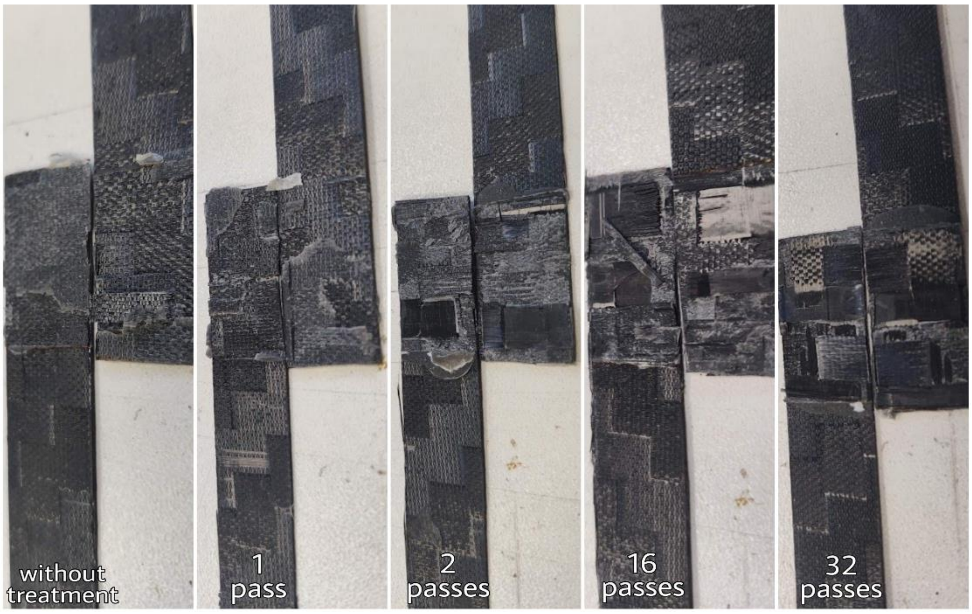


Figure 52: Results of the traction tests for each treatment.

After these great results, PAPic installed a sample kit of this new test vehicle together with the demonstrator in the Pic du Midi, so that future studies can explore the natural ageing of the bond itself, with the help of the rheometric tests that have been provided in this document for the prepreg and epoxy used.

7. Acceptance & Quality

To provide a clear and objective way to measure if the goals of the project were met the team has written the expected results and the results obtained of each requirement the client asked. The following table shows a guidance on the needs that had been done successfully.

Code	Project Requirements	Test Description	Expected Results	Results Obtained
PR 1	Select a minimum of 5 polymer materials.	Look the different materials that Technacol has and research on the most interesting materials.	Select 8 different materials.	The team selected PPS, PEEK, PS, PC, PA12, PA6, EPOXY, PREPREG
PR 2	Minimum of 2 months of ageing at the laboratory.	Implement a way to simulate ageing in the laboratory using the oven, frige and the UV chamber.	Start ageing in the lab 7th of April. Have the results for 29th of May.	PAPic started the ageing on 20th of April, we ended on 15th of May. The parameters were increased (uv, cold temperature and high temperature) to simulate 2 months of ageing.

PR 3	Minimum of 2 months of ageing at Pic du Midi	Take the selected samples to the mountain, attach them in a metal fence and leave it for 2 months.	Take the samples to the Pic du Midi on April 5th, pick up the samples on July 7th	The team took the samples to the Pic du Midi on April 5th, and were picked it up on 13th of July.
PR 4	Account for variations in the environmental conditions (different exposure to UV and humidity)	Established different cycles to simulate ageing. Put the samples in the oven, fridge or UV chamber for 2 weeks, simulating the parameters at the Pic du Midi.	Create a cycle using the uv chamber, oven, and fridge to age the samples.	There were applied 4 types of ageing. In each type of ageing, were test 8 different materials. • Oven for 3 weeks. (temperature exposure 70°C) • Uv chamber for 3 weeks. (uv exposure) • A cycle using uv chamber, fridge and oven. (uv exposure, temperature exposure from −24,9°C to 70°C) • A cycle using the fridge and the oven with 100% of humidity. (temperature exposure from −24,9°C to 70°C and humidity 100%)
PR 5	Study at least five of the most significant material properties: hardness, glass transition temperature and/or melting temperature, storage modulus and loss modulus[4].	When the samples are aged, they are going to be tested one by one in the rheometer, in the dsc and the infrared.	Obtain hardness results from each sample aged in the laboratory, in the Pic du Midi and each reference. Obtain the graphics of the calorimeter and rheometer to observe the properties.	The team had 48 tests of hardness of each material. The team had 48 graphics of the rheometer tests of each material, where it can be observed the glass transition, the rigidity and the melting temperature for the ones that had.
PR 6	Every material tested should have at least one valid result in: calorimeter, rheometer, and spectrometer[5].	The reference of each sample and the aged samples are tested by the rheometer, the	Test the 8 materials selected and the same materials aged the lab and in	48 tests were made of each material in: calorimeter dsc, rheometer and spectrometer.

		dsc, and the infrared.	the Pic du Midi.	
PR 7	The solution for attaching the samples must comply with the already existing configuration of M8 holes.	Manufacture a solution to keep the samples together and attached to a metal fence.	Create a new solution for attaching samples with a fence and screws.	3 Sample kits were made with 8 different materials. A sample kit of epoxy was made. A metal fence was used to attach the sample kits.
PR 8	Interpret the result of the study and compare it to real use cases of industrial applications, such as aerospace.	Download the graphics and analyze them with the help of our technical supervisor. Explain the correlation between natural ageing and lab ageing.	Have the graphics of the rheometer of each material. Have the graphics of the spectrometer. Have graphics of the calorimeter.	The team made a description of the comparison between the samples aged in the Pic du Midi, the samples aged in the laboratory and their reference. For each material the team has 48 graphics of the rheometer plus one comparing the reference with the 5 types of ageing and one of the spectrum tests comparing the reference with the 5 types of ageing.

Table 16: Project requirements and the results

The priorities of the project were summarized on Plan A and Plan B, the approaches of both plans were very similar but at the end the Plan A was successfully achieved.

	Plan Description	Expected Results	Results Obtained
PLAN A	Test and do ageing on the materials selected, then design and manufacture with a new test vehicle that should include studying aspects of adhesive bonding and surface treatment.	Present a document with a technical procedure of how do simulate ageing in the lab, showing graphics and explaining the behavior of each material, and create a demonstrator using the materials we have been studied to understand the real industrial applications.	PAPic wrote the Material Analysis & Ageing Report, presenting the graphics of the rheometer and the spectrometer tests of each material. It is explained how the ageing is simulated in the lab, describing the 5 types of ageing the team implemented. The team manufactured a demonstrator with carbon fiber and epoxy and took it to the Pic du Midi so later another team could test it.

Table 17: Plan and results

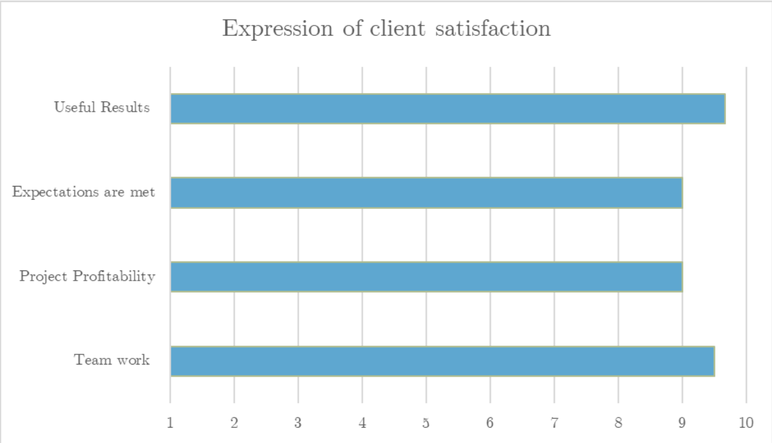


Figure 53: Expression of client satisfaction

Since the beginning of the project, the objective of the team was to deliver high-quality work. The team decided to implement a survey for the client so he could express of his level of satisfaction. In the survey the project procedures, activities, and outputs to verify if PAPic meets quality requirements have been evaluated. This is beneficial for both the client and the team. The scale is from 1 (not agree) to 10 (totally agree). The following chart represents a general expression of the client satisfaction.

Based on the results, the client believes that the team has been working cohesively and united, showing interest in the project, and working in a professional and organized way. Moreover, the client is completely sure that the team has expanded its knowledge.

He also agrees that the terms for the milestones met the expectations, however, he is not fully convinced about the definition of the needs in the scope of the project, but he is sure that the work developed is coherent with the objectives.

The Material Analysis and Ageing Report is going to be very useful for the company, and Technacol reports that they would be counting with PAPic in future projects. The team made an estimated cost of 10,000€ according to the actual workload, and the client confirms that it is profitable for the company.

Therefore, the satisfaction level of the client reaches 90%, which means he is happy with the results of the project. Client feedback helps PAPic members to improve for the next projects as they also help Technacol back to increase productivity, improve future project outcomes and expand their rheometry archives.

7.1 Added values to stakeholders

First, the team has successfully provided the client with valuable information about the different materials that they work with. This information is useful for Technacol, because they will have a wider panorama of how to simulate ageing in the lab and they will be able to provide their clients with more accurate data about certain polymers. The team understood the behavior of ageing at the Pic du Midi, and showed the client new ways, and guidance to simulate ageing in the laboratory. Also, the team was able to share with the client their knowledge, their abilities, and their experience in the engineering field. PAPic put their skills at the service of the client bringing the best attitude and effort to successfully achieve the goals.

Another added value is the innovation and creativity of what the team can do with the new information that was obtained, and how it is possible to explore industrial applications, in fields like aerospace. Taking this into account, the team manufactured a demonstrator with carbon fiber and epoxy adhesive, leaving it to age in the Pic du Midi, together with three kits of 8 different materials and one kit of carbon fiber strips to enable a continuation of the research or new future studies. The files of the results of each material were handed to Technacol so they can make use of them. Including more than 100 tests in the rheometer, DSC and traction machine.

Fortunately for the next generation of researchers, the team has provided a wide range of results that remain to be studied, like 48 high quality IR spectroscopy analysis performed right after the correspondent ageing. They will have the opportunity to pick up the samples and the demonstrator in the Pic du Midi and test them in the laboratory. This means they will have a broader vision of the ageing in those materials because by then they will have spent more time in natural ageing conditions.

Through the Material Analysis & Ageing Report provided by PAPic, they will be able to look at how to simulate ageing in the lab, and decide on repeating the same method or implementing a new one.

Finally, they will have access to the files in the rheometer, the calorimeter, and the spectrometer to check the last results. They will be able to use every given test to compare with the one they perform and get new conclusions.

8. Conclusions

8.1 General conclusion

In this project, PAPic had the opportunity to understand the behavior of certain polymers in harsh environments like Pic du Midi, and then simulate the ageing in the lab. PAPic had the amazing opportunity to make a visit to the Pic du Midi as a part of the project. The team members trained on how to use the machines in the laboratory and did research to find the best way to simulate ageing.

From the beginning, the team decided how to going to organize, divide tasks, and how to guide the whole project. Today PAPic knows the importance of the scope and has learned a lot about project management with the WBS and Gantt Chart being very useful tools for giving a good overview of the project.

Despite the difficulties, problems, and risks, the team continued to work. In the end, the team was struggling because there was a lot of information to analyze, but with the help of the technical supervisor and Technacol´s staff, PAPic succeeded. As a result, the team is satisfied with the results of the project despite the challenges and obstacles that have been faced.

It has been a pleasure for PAPic to work with Technacol and to enjoy working in their facilities. Believing in the success of the project from the beginning, the team members worked every day giving their best. They are grateful for all the acquired knowledge and the opportunity they had of getting out of their comfort zone.

8.2 Technical conclusions

From a technical perspective, it is very convenient to have had this diversity of polymers to see that the ageing in each one can be reproduced in different ways according to the needs of the experiment. Besides the evident room for improvement, PAPic believes that the amount of compiled information is sufficient to enable multiple future studies and to simulate natural ageing in some specific cases with the reduced time expense and increased convenience that was the main goal of the project.

With polymers like PEEK or PA12, the model fits almost perfectly and the artificial ageing cuts the necessary test period to just 30% of the natural ageing time. Regarding the aeronautical application, the extreme resiliency of the prepreg is great news for the demonstrator product implementation, but the epoxy adhesive that is usually applied in combination with the prepreg has turned out to weaken very fast and in an unpredictable way. It would be very interesting to try different types of structural adhesive to see which one performs best in harsh conditions.

All in all, PAPic is very proud of the results obtained in such a short study, and for being able to provide the client with the desired information, considering that this field of science was completely new for all the team members.

9. Bibliography

(I) *5x5 Risk Matrix: Importance and Examples | SafetyCulture*. (n.d.). Retrieved April 11, 2023, from https://safetyculture.com/topics/risk-assessment/5x5-risk-matrix/

(II) Chawla, K. K. (2019). Composite Materials. *Composite Materials: Science and Engineering*, 1–560. https://doi.org/10.1007/978-3-030-28983-6/COVER

(III) *Differential Scanning Calorimetry*. (n.d.). Retrieved April 13, 2023, from https://www.pslc.ws/macrog/dsc.htm

(IV) *Discovery HR 30 - TA Instruments*. (n.d.). Retrieved March 15, 2023, from https://www.tainstruments.com/hr-30/

(V) *DSC 4000 | Single-Furnace Heat Flux DSC | PerkinElmer*. (n.d.). Retrieved March 15, 2023, from https://www.perkinelmer.com/es/product/dsc-4000-system-100-240v-50-60hz-n5370212

(VI) *Ebnesajjad, S., & Landrock, A. H. (2015). Introduction and Adhesion Theories. In Elsevier eBooks (pp. 1–18).* https://doi.org/10.1016/b978-0-323-35595-7.00001-2

(VII) *Everything You Need To Know About Polystyrene (PS)*. (n.d.). Retrieved March 17, 2023, from https://www.creativemechanisms.com/blog/polystyrene-ps-plastic

(VIII) ISO 9142:2003 – *Conditions atmosphériques pour vieillissement cyclique*

(IX) *MCAM | Ketron® PEEK |Plastiques usinables*. (n.d.). Retrieved March 17, 2023, from https://www.mcam.com/fr/produits/plastiques-usinables/materiaux-avances-160-220-c/ketronr-peek/

(X) Müller, M. J., Hrabě, P., Chotěborský, R., & Herak, D. (2006). *Evaluation of factors influencing adhesive bond strength. Research in Agricultural Engineering,* 52(1), 30–37. https://doi.org/10.17221/4877-rae

(XI) *PA 12 - TECAMID 12 natural | Ensinger*. (n.d.). Retrieved March 17, 2023, from https://www.ensingerplastics.com/en/shapes/products/pa12-tecamid-12-natural

(XII) Pantelakis, S., & Tserpes, K. I. (2014). Adhesive bonding of composite aircraft structures: Challenges and recent developments. *Science China: Physics, Mechanics and Astronomy*, *57*(1), 2–11. https://doi.org/10.1007/S11433-013-5274-3/METRICS

(XIII) *Polycarbonate (PC) - Properties, Uses, & Structure - Guide*. (n.d.). Retrieved March 17, 2023, from https://omnexus.specialchem.com/selection-guide/polycarbonate-pc-plastic

(XIV) Polymers, M. C. (n.d.). *Amorphous vs. Crystalline Polymers*. Mallard Creek Polymers. https://www.mcpolymers.com/library/amorphous-vs-crystalline-polymers

(XV) *Polyphenylene Sulfide (PPS) Plastic: Properties & Applications*. (n.d.). Retrieved March 17, 2023, from https://omnexus.specialchem.com/selection-guide/polyphenylene-sulfide-pps-plastic-guide

(XVI) Schijve, J. (2009). Fatigue of structures and materials. *Fatigue of Structures and Materials*, 1–622. https://doi.org/10.1007/978-1-4020-6808-9/COVER

(XVII) Selikhov, A. F., & Ushakov, A. E. (1991). Special features in ensuring strength and service life of aircraft structures made of polymer composite materials, with damage taken into account - 2. Probabilistic model of failure. *Mechanics of Composite Materials*, *26*(4), 513–522. https://doi.org/10.1007/BF00612626/METRICS

(XVIII) *SUNTEST CPS+ | Xenon Weathering Instruments for Products & Materials | Xenon Test for Pharmaceuticals and Cosmetics - Atlas.* (n.d.). Retrieved March 15, 2023, from https://www.atlas-mts.com/products/standard-instruments/xenon-arc-weathering-test/suntest/cps?ytvid=Z5IQhY3ejW4

(XIX) Thermoset vs Thermoplastic (What is the Difference?). (n.d.). https://www.twi-global.com/technical-knowledge/faqs/thermoset-vs-thermoplastic

(XX) Tiwari, S., & Bijwe, J. (2014). Surface Treatment of Carbon Fibers - A Review. *Procedia Technology*, *14*, 505–512. *Procedia Technology*, *14*, 505–512.

(XXI) *What are Rheometry and Rheology? - TA Instruments.* (n.d.). Retrieved March 15, 2023, from https://www.tainstruments.com/what-are-rheometry-and-rheology/?lang=ja

(XXII) What Does a Spectrometer Measure? - Verichek Technical Services https://verichek.net/spectrometerunits.html#:~:text=Spectrometers%20measure%20the%20frequency%20emitted%20by%20the%20substance%20being%20analyzed

(XXIII) *What is a Glass Transition Temperature? - Definition from Corrosionpedia.* (n.d.). Retrieved April 13, 2023,https://www.corrosionpedia.com/definition/593/glass-transition-temperature-tg

(XXIV) *What is Plasma Surface Treatment?* (n.d.-b). https://www.thomasnet.com/articles/machinery-tools-supplies/plasma-surface-treatment/

10. Appendix I – Risk Rating Matrix

			Risk Rating				
			Standard Risk Matrix				
Impact	**Catastrophic**	5	Medium/High	Medium/ High	High	High	High
	Major	4	Low/ Medium	Medium/ High	Medium/ High	High	High
	Moderate	3	Low/ Medium	Low/ Medium	Medium/ High	Medium/ High	High
	Minor	2	Low	Low	Low/ Medium	Low/ Medium	Medium/ High
	Negligible	1	Low	Low	Low	Low/ Medium	Low/ Medium
			1	2	3	4	5
			Extremely Improbable	**Improbable**	**Remote**	**Occasional**	**Frequent**
			Likelihood				

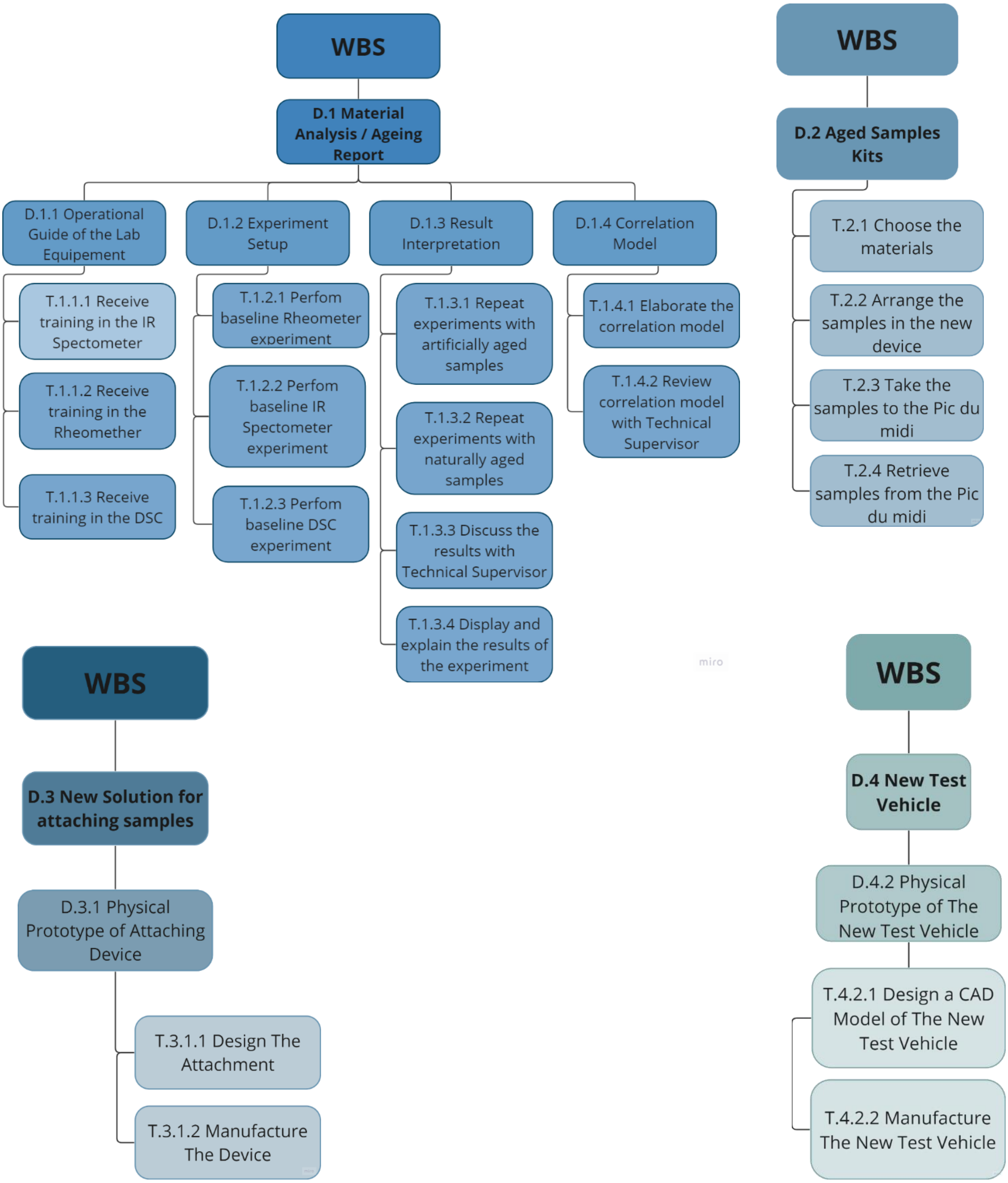
11. Appendix II – Risk Table

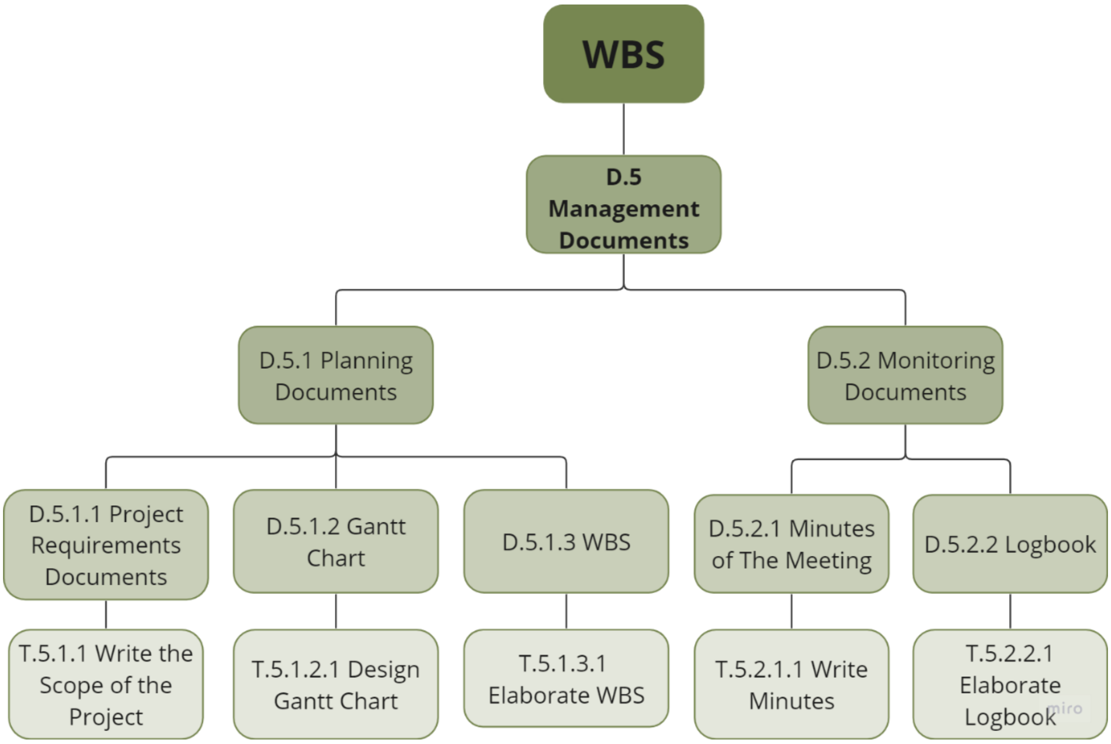
Kind of risk	Risk summary	Impact	Probability	Risk factor	Preventive action	Corrective action
	Team cannot communicate with supervisors/stakeholders because they are not available.	4	5	20 High	Establish meetings according to their schedules	Reschedule the meetings and establish zoom calls with the client and stakeholders in advance.
	Language barriers.	2	2	4 Low	Improve English skills.	Be patient and be sure everybody on the team understands your ideas.
	Lack of technical skills of team-members. Ex: how to use the machines. The machine can be damaged.	5	3	15 Medium/ High	Research how to use the machine and learn new skills.	Ask an expert for help and guidance. Talk with the supervisors
	Friction and communication problems with the members.	4	3	12 Medium/ High	Working on team building.	Talk between members. Ask for help from the EPS supervisor.
	Work accidents happen to team members. Ex. Get hurt with the machines	5	3	15 Medium/ High	Search on the internet for how to use the machines. Ask an expert for help and some guidance.	Call emergency. Take security measures. Try to be careful next time.
	Team member gets sick and cannot be available.	5	3	15 Low/ Medium	Protect ourselves, take health preventive measures. Distribute the tasks equally.	Keep the team informed about the illness. Make up time to complete their tasks.
	Bad climate conditions to go to the Pic du Midi. The wind speed must be less than 40km/h.	4	4	16 High .	Start to check weather conditions at Pic du Midi one week before we have the trip.	Change the trip to the Pic du Midi when the weather conditions get better.
	Samples get lost	5	1	5 Medium/ High	Keep the samples safe in a box and put a label of the material on it.	Ask Technacol for more samples of the materials.

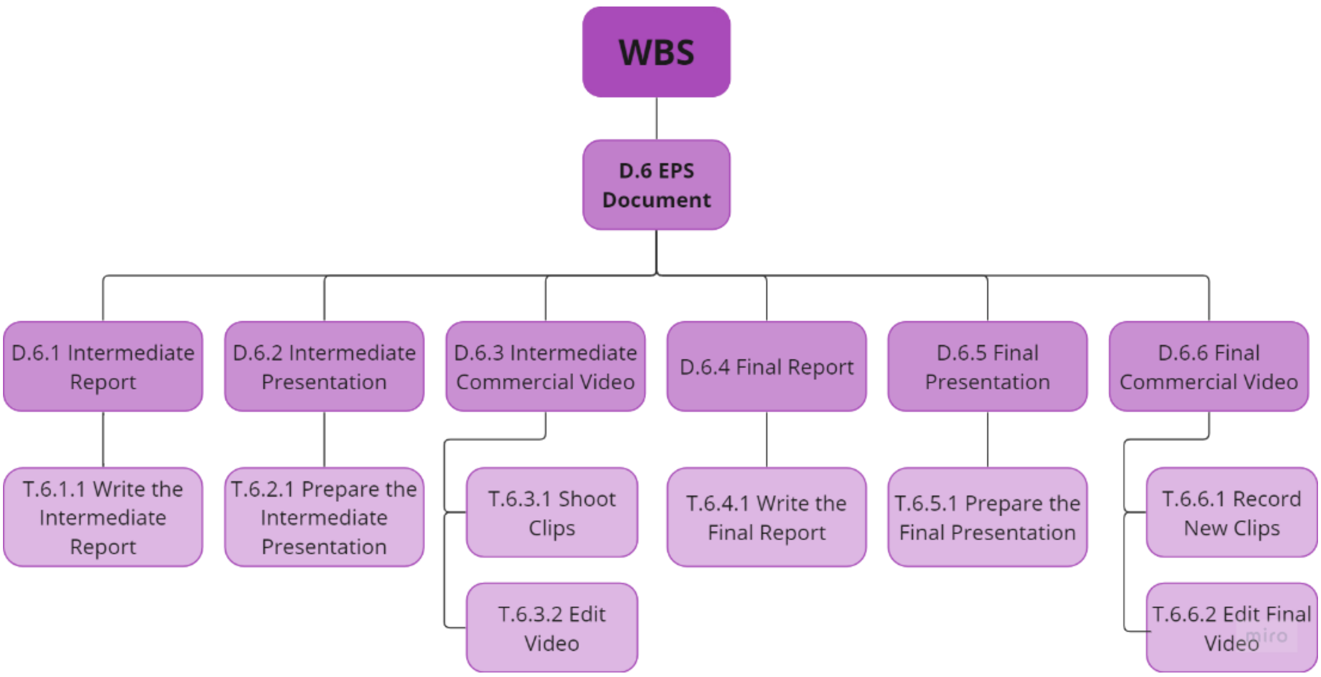
	Laboratory machines and equipment are not available.	4	3	12 Medium/ High	Check the availability of the machines and schedule the use with anticipation	Ask for ENIT's climate chamber. Reschedule the use of the machines.
	Sample breaks during the test	3	4	12 Medium/ High	Attached at least two samples of each material carefully.	Explain why the sample was broken. Try to do another test.
	Samples have irregular ageing that we cannot define.	3	2	6 Low/ Medium	Start the ageing as soon as possible.	Explain what happened with the irregular ageing that the samples had.
	The test failed because of some errors in the software and machines	2	4	8 Low/ Medium	Be sure the software of the machine is prepared, calibrated and ready to do a successful test.	Check and review the conditions of the software, remake the test.
	Not enough material provided.	2	3	6 Low/ Medium	Check the availability of materials. Make a list of the materials that we want.	Test and aged only with the material provided.
	Goals are not achieved.	5	3	15 Medium/ High	Be sure to complete each task of the WBS.	Adjust the goal in relation to time.
	Deadlines or milestones are not respected	4	3	12 Medium/ High	Follow the time schedule.	Reschedule the milestones.
	Lack of organization.	4	3	12 Medium/ High	Make a list that divides the task into some sections and sort it by priority level.	Try to make a new list that is easier to do.

Man *Media* *Machine* *Management* *Mission*

12. Appendix III - WBS




WBS
D.5 Management Documents
D.5.1 Planning Documents
D.5.2 Monitoring Documents
D.5.1.1 Project Requirements Documents
D.5.1.2 Gantt Chart
D.5.1.3 WBS
D.5.2.1 Minutes of The Meeting
D.5.2.2 Logbook
T.5.1.1 Write the Scope of the Project
T.5.1.2.1 Design Gantt Chart
T.5.1.3.1 Elaborate WBS
T.5.2.1.1 Write Minutes
T.5.2.2.1 Elaborate Logbook


WBS
D.6 EPS Document
D.6.1 Intermediate Report
D.6.2 Intermediate Presentation
D.6.3 Intermediate Commercial Video
D.6.4 Final Report
D.6.5 Final Presentation
D.6.6 Final Commercial Video
T.6.1.1 Write the Intermediate Report
T.6.2.1 Prepare the Intermediate Presentation
T.6.3.1 Shoot Clips
T.6.3.2 Edit Video
T.6.4.1 Write the Final Report
T.6.5.1 Prepare the Final Presentation
T.6.6.1 Record New Clips
T.6.6.2 Edit Final Video

13. Appendix IV – Workload Estimation Table

WBS	Task Name	Start	Finish	Resources Name	Workload (hours)
1.1.1	Research about polymer materials	Mon 3/13/23	Fri 3/17/23	HP,**IC**,SM	5
1.1.2	Research about material ageing	Wed 3/15/23	Tue 3/21/23	**HP**,IC,SM	5
1.1.3	Write theoretical context	Tue 5/9/23	Fri 5/12/23	**HP**	3
1.2.1	Receive training in the IR Spectrometer	Fri 3/24/23	Mon 4/3/23	**HP**,IC,SM	7
1.2.2	Receive training in the Rheometer	Wed 3/22/23	Thu 3/30/23	**HP**,IC,SM	7
1.2.3	Receive training in DSC	Mon 3/20/23	Tue 3/28/23	**HP,**IC,SM	7
1.3.1	Perform baseline Rheometer tests with all 8 materials	Thu 3/30/23	Mon 4/17/23	**HP**	12
1.3.2	Perform baseline IR Spectrometer tests with all 8 materials	Mon 4/3/23	Fri 4/7/23	**HP**,IC,SM	6
1.3.3	Perform baseline DSC tests with all 8 materials	Mon 3/27/23	Fri 4/7/23	**HP**,IC,SM	12
1.3.4	Write experiment setup	Tue 5/16/23	Tue 5/23/23	HP,**IC**,SM	4
1.4.1	Repeat experiments with artificially aged samples	Tue 5/23/23	Fri 6/9/23	**SM**	32
1.4.2	Repeat experiments with naturally aged samples	Thu 6/8/23	Mon 6/19/23	**HP**	8
1.4.3	Discuss the results with the Technical Supervisor	Mon 6/12/23	Thu 6/15/23	HP,**IC**,SM	7

1.4.4	Display and explain the results of the experiments	Wed 6/14/23	Thu 6/22/23	**IC**,SM	4
1.5.1	Elaborate the correlation model	Mon 6/19/23	Mon 6/26/23	**HP**	6
1.5.2	Review correlation model with the Technical Supervisor	Thu 6/22/23	Fri 6/23/23	HP,**IC**,SM	2
2.1.1	Choose the sample materials	Mon 3/13/23	Tue 3/21/23	**HP**,IC,SM	7
2.1.2	Arrange the samples in the new device	Fri 3/31/23	Wed 4/5/23	HP,**IC**,SM	4
2.1.3	Take the samples to Pic du Midi	Wed 4/5/23	Wed 4/5/23	HP,IC,**SM**	10
2.1.4	Age the samples in the lab	Wed 4/19/23	Mon 5/22/23	**HP**,IC,SM	11
2.1.5	Retrieve samples from Pic du Midi	Wed 6/7/23	Wed 6/7/23	HP,IC,**SM**	8
3.1.1	Write the document for the new attachment	Tue 5/9/23	Wed 5/10/23	**SM**	2
3.2.1	Design the attachment	Tue 3/28/23	Fri 3/31/23	**HP**	4
3.2.2	Manufacture the device	Fri 3/31/23	Tue 4/4/23	HP,IC,SM	3
4.1.1	Write the document for the new test vehicle	Thu 5/11/23	Wed 5/17/23	**HP**	5
4.2.1	Design a CAD model of the new test vehicle	Mon 3/13/23	Thu 3/16/23	**HP**	4

4.2.2	Manufacture the new test vehicle	Tue 5/23/23	Tue 5/30/23	**HP**,IC,SM	6
5.1.1	WBS	Tue 4/11/23	Tue 4/11/23	IC,**SM**	1
5.1.1.1	Elaborate WBS	Tue 4/11/23	Tue 4/11/23	IC,**SM**	1
5.1.2	Gantt Chart	Tue 4/11/23	Tue 4/11/23	**HP**	1
5.1.2.1	Design Gantt Chart	Tue 4/11/23	Tue 4/11/23	**HP**	1
5.1.3	Project Requirements Document	Fri 3/10/23	Tue 4/11/23	HP,IC,**SM**	22
5.1.3.1	Define the scope of the project	Fri 3/10/23	Tue 4/11/23	HP,IC,**SM**	22
5.2.1	Minutes of the meeting	Fri 4/7/23	Fri 4/7/23	**SM**	1
5.2.1.1	Write Minutes	Fri 4/7/23	Fri 4/7/23	**SM**	1
5.2.2	Logbook	Thu 4/6/23	Thu 4/6/23	**SM**	1
5.2.2.1	Elaborate Logbook	Thu 4/6/23	Thu 4/6/23	**SM**	1
6.1.1	Write Intermediate Report	Tue 3/28/23	Wed 4/12/23	**HP**,IC,SM	11
6.2.1	Prepare Intermediate Presentation	Fri 4/14/23	Wed 4/19/23	HP,IC,**SM**	4
6.3.1	Shoot clips	Mon 4/3/23	Fri 4/7/23	HP,**IC**,SM	5
6.3.2	Edit video	Fri 4/14/23	Mon 4/17/23	HP,**IC**,SM	2

6.4.1	Write Final Report	Fri 6/16/23	Thu 6/22/23	HP,IC,**SM**	5
6.5.1	Prepare Final Presentation	Mon 6/26/23	Wed 6/28/23	HP,IC,**SM**	3
6.6.3	Record new clips	Thu 6/8/23	Mon 6/19/23	**IC**	8
6.6.4	Edit final Video	Tue 6/20/23	Fri 6/23/23	**SM**	4

14. Appendix V – Gantt Chart

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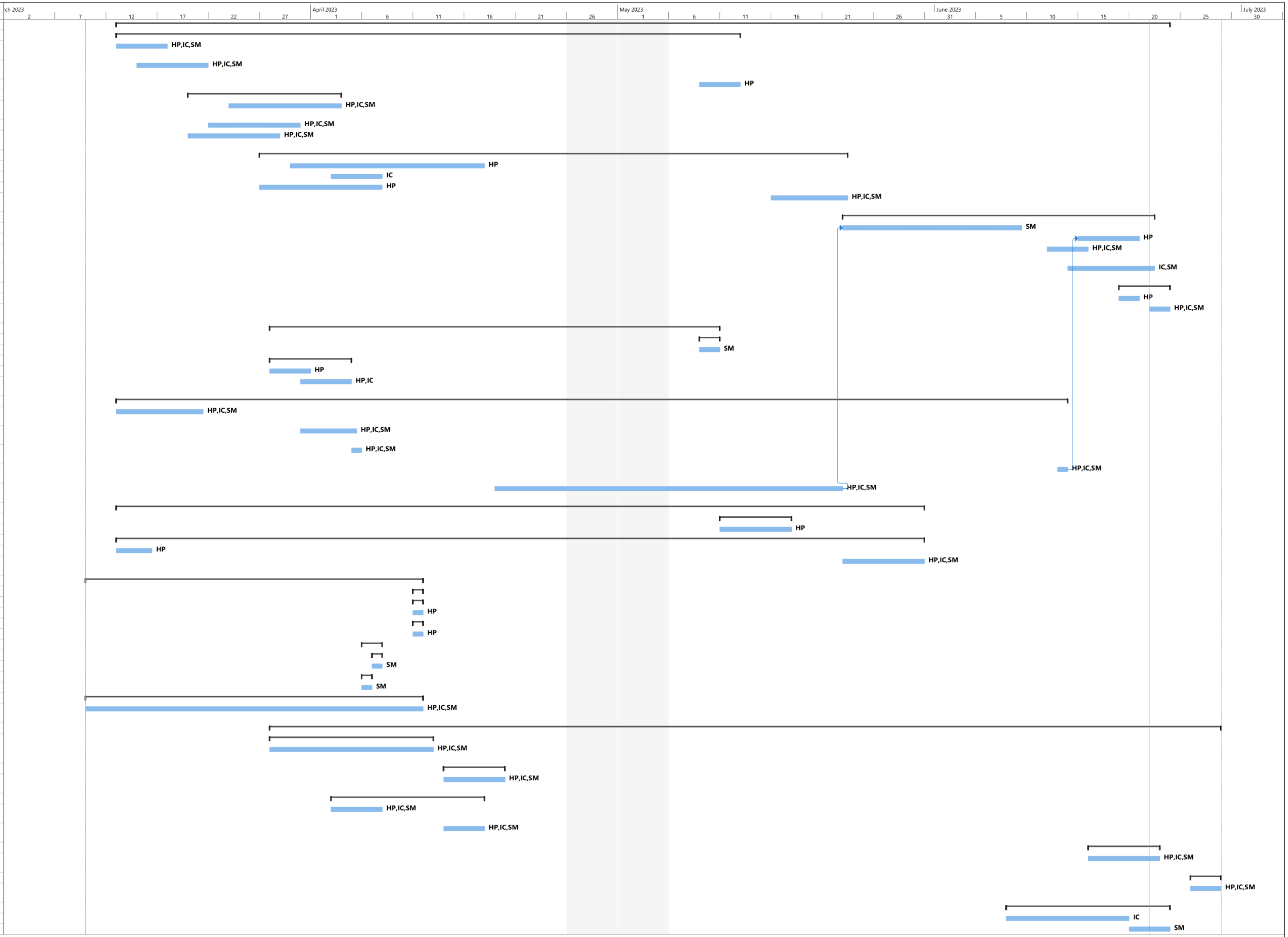
ID	Task Mode	WBS	Task Name
1		1	**Material Analysis and Ageing Report**
2		1.1	**Theoretical context**
3		1.1.1	Research about polymer materials
4		1.1.2	Research about material ageing
5		1.1.3	Write theoretical context
6		1.2	**Operational guide of the lab equipment**
7		1.2.1	Receive training in the IR Spectrometer
8		1.2.2	Receive training in the Rheometer
9		1.2.3	Receive training in DSC
10		1.3	**Experiment setup**
11		1.3.1	Perform baseline Rheometer tests with all 8 materials
12		1.3.2	Perform baseline IR Spectrometer tests with all 8 materials
13		1.3.3	Perform baseline DSC tests with all 8 materials
14		1.3.4	Write experiment setup
15		1.4	**Result interpretation**
16		1.4.1	Repeat experiments with artificially aged samples
17		1.4.2	Repeat experiments with naturally aged samples
18		1.4.3	Discuss the results with the Technical Supervisor
19		1.4.4	Display and explain the results of the experiments
20		1.5	**Correlation model**
21		1.5.1	Elaborate the correlation model
22		1.5.2	Review correlation model with the Technical Supervisor
23		2	**New solution for attaching the samples**
24		2.1	**Technical information document**
25		2.1.1	Write the document for the new attachment
26		2.2	**Physical prototype of the attaching device**
27		2.2.1	Design the attachment
28		2.2.2	Manufacture the device
29		3	**Aged Sample Kits**
30		3.1	Choose the sample materials
31		3.2	Arrange the samples in the new device
32		3.3	Take the samples to Pic du Midi
34		3.4	Retrieve samples from Pic du Midi
33		3.5	Age the samples in the lab
35		4	**New test vehicles**
36		4.1	**Technical information document**
37		4.1.1	Write the document for the new test vehicle
38		4.2	**Physical prototype of the test vehicle**
39		4.2.1	Design a CAD model of the new test vehicle
40		4.2.2	Manufacture the new test vehicle
41		5	**Management Documents**
42		5.1	**Planning documents**
43		5.1.1	**WBS**
44		5.1.1.1	Elaborate WBS
45		5.1.2	**Gantt Chart**
46		5.1.2.1	Design Gantt Chart
47		5.2	**Monitoring Documents**
48		5.2.1	**Minutes of the meeting**
49		5.2.1.1	Write Minutes
50		5.2.2	**Logbook**
51		5.2.2.1	Elaborate Logbook
52		5.3	**Project Requirements Document**
53		5.3.1	Define the scope of the project
54		6	**EPS Documents**
55		6.1	**Intermediate Report**
56		6.1.1	Write Intermediate Report
57		6.2	**Intermediate Presentation**
58		6.2.1	Prepare Intermediate Presentation
59		6.3	**Intermediate Commercial Video**
60		6.3.1	Shoot clips
61		6.3.2	Edit video
62		6.4	**Final Report**
63		6.4.1	Write Final Report
64		6.5	**Final Presentation**
65		6.5.1	Prepare Final Presentation
66		6.6	**Final Commercial Video**
67		6.6.3	Record new clips
68		6.6.4	Edit final Video



Project: PAPicWBS
Date: Thu 6/22/23

Task	Summary	Inactive Milestone	Duration-only	Start-only	External Milestone	Path Driven Successor Summary Task	Manual Progress
Split	Project Summary	Inactive Summary	Manual Summary Rollup	Finish-only	Deadline	Path Driven Successor Normal Task	
Milestone	Inactive Task	Manual Task	Manual Summary	External Tasks	Path Driven Successor Milestone Task	Progress	