3rd IPPT_TWINN CONFERENCE

Metal replacement and lightweight polymer composites

BOOK OF ABSTRACT

June 2025

FTPO
Faculty of Polymer Technology

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EDITORS
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3rd IPPT_TWINN CONFERENCE

Metal replacement and lightweight polymer composites

Slovenj Gradec | 4-5 June 2025

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Foreword to
3rd IPPT_TWINN Conference

METAL REPLACEMENT AND
LIGHTWEIGHT POLYMER COMPOSITES

We are pleased to welcome you to the 3rd IPPT_TWINN Conference on Lightweight Polymer Composites and Metal Replacement, a key event that brings together researchers, industry professionals, and innovators from across Europe and beyond. Hosted under the Horizon Europe IPPT-TWINN project, this conference continues to serve as a vibrant platform for knowledge exchange, collaboration, and the advancement of cutting-edge materials and technology science.

This year's conference focuses on the potential of lightweight polymer composites in critical sectors, including energy and building, automotive, aerospace, and sports equipment. As the demand for sustainable, high-performance materials grows, the role of polymer composites in replacing traditional metals becomes increasingly vital. The conference aims to foster interdisciplinary dialogue and showcase the latest research, technological developments, and industrial applications in this dynamic field.

The strong international participation (15 different countries) in the conference is proof of its relevance and this is also the guarantee of its success.

The Book of Abstracts you hold in your hands reflects the diversity and depth of the contributions presented at this event. It includes innovative studies on material design, processing technologies, mechanical performance, environmental impact, and real-world applications. Each abstract represents a step forward in our collective effort to develop smarter, lighter, and more sustainable materials, using advanced manufacturing technologies.

We extend our sincere gratitude to all authors, the scientific board, and participants for their valuable contributions. Your engagement and expertise are what make this conference a success.

We also extend our gratitude to our organizing committee for their unwavering support in making this event possible.

Last but not least, we would like to thank the European Commission for funding the IPPT_TWINN project. Without their support, this conference would not have happened.

We hope that this Book of Abstracts will inspire new ideas, foster fruitful collaborations, and contribute to the ongoing evolution of metal replacement and lightweight composite technologies.

Assoc. Prof. Dr. Blaž Nardin
dean of FTPO and IPPT_TWINN project coordinator

First day – 4th June 2025

8:30 - 9:00	**Registration**
9:00 - 9:15	**Opening speech** **Blaž Nardin - project leader and Dean of Faculty of Polymer Technology**
Plenary speakers	
9:15 - 9:40	**The Versatility of Composites** Gion Andrea Barandun | OST University of Applied Sciences of Eastern Switzerland, Switzerland
9:40 - 10:05	**Understanding the difference between “exercises in style” and true "composite recycling”: An overview of the many ways to re-process composite materials** Niccolo Pini | Doroangus Consulting, Switzerland
Session 1: Energy and building sector	
10:05 - 10:20	**Composites in renewable energy - engineering challenges** **Gergely** Lipóczi | eCon Engineering Kft., Hungary
10:20 - 10:35	**Unsaturated polyester resins (USP) for transport, marine and wind applications** Jasmina Turnšek | Helios Resins, Slovenia
10:35 - 10:50	**Use of lightweight composites in various industries and end of life challenges and solutions** Gregor Vedenik | Veplas d.d., Slovenia
10:50 - 11:05	**Pultruded Composites in Building and infrastructure - Slope stabilisation** Milan Stanarević | Exel Composites GmbH, Austria
11:05 - 11:20	Networking coffee
Session 2: Automotive	
11:20 - 11:35	**From Race to Road, natural fiber composites in a serial car application** Marcel Schubiger | Bcomp, Switzerland
11:35 - 11:50	**Caprocast a technology for the manufacturing of lightweight thermoplastic structural components** Cristina Elizetxea Ezeiza | Tecnalia, Spain
11:50 - 12:05	**The Challenges of Materials Engineering in EV Battery Packs** Primož Štefane | Rimac Technology d.o.o., Croatia
12:05 - 12:20	**Innovative approaches in plastic-metal stir welding: Applications and potential in lightweight construction** Andreas Hausberger | royos joining solutions GmbH, Austria
12:20 - 12:35	**Fibre-Reinforced Parts made from HybridFiber** Carsten Kleine | SILTEX Flecht- und Isoliertechnologie GmbH &Co KG, Germany
12:35 - 12:50	**Development and manufacturing lightweight thermoplastic composite products in low&mid** series sectors Boštjan Žagar | Polymer.si Group, Slovenia
12:50 - 13:05	**Long Fiber Thermoplastic Direct-molding (LFT-D) - a cost-efficient process for large thermoplastic** Karl Schnetzinger | Advanced polymer compounds, Austria
13:05 - 13:20	**From Metal to Polymer: Industrial Demonstrators with Lightweight Composites for Automotive Applications** Rui Soares | CENTIMFE, Portugal
13:20 - 14:00	Lunch

Session 3: Aerospace	
14:00 - 14:15	**Design of microsatellites and selection of reliable material combinations** Tomaž Rodič | SPACE-SI, Centre of Excellence for Space Sciences and Technologies, Slovenia
14:15 - 14:30	**Importance of light weight composite materials in designing airplanes** Iztok Šalamon | GOGETAIR, Slovenia
14:30 - 14:45	**From haute couture to high tech composite parts** Jascha Schmied | Bionic Composite Technologies AG, Switzerland
14:45 - 15:00	Networking coffee
Session 4: Sport equipment	
15:00 - 15:15	**Development and Production of UD-Tape enforced Thermoplastic Components in Injection Molding Processing** Martin Rudolph | svismold, Switzerland
15:15 - 15:30	**Development and manufacturing of composite sailing boats at Flaar Performance Sailing** Gergő Zsolt MARTON | Flaar Performance Sailing / Department of Polymer Engineering, Budapest University of Technology and Economics, Hungary
15:30 - 15:45	**Performance vs sustainability in emotional lightweight composite parts like sporting goods** Herfried Lammer | HEAD, Austria
Panel discussion - Opportunities and challenges of the European polymer composites industry	
15:55 - 16:55	**Moderator of the panel session:** Gion Andrea Barandun, Prof. for composites and lightweight design OST - OSTSCHWEIZER FACHHOCHSCHULE, Switzerland **Panelists:** **Niccolo Pini,** Founder and managing director of Doroangus Consulting, Switzerland **Cristina Elizetxea Ezeiza,** PhD, Responsible of Sustainable and Multifunctional Polymers TECNALIA, Spain **Herfried Lammer,** Chief Innovation Officer, HEAD SPORT GMBH, Austria **Rui Soares,** Senior Researcher in Business Innovation at CENTIMFE, Portugal **András Suplicz,** Associate professor, head of the injection molding laboratory, Department of Polymer Engineering, Budapest University of Technology and Economics **Primož Štefane,** Mechanical Integrity Engineer, RIMAC TECHNOLOGY D.O.O., Croatia (TBC) **Gregor Vedenik,** CEO, Veplas d.d., Slovenia
16:55 - 17:00	Closing remarks of the 1st day
17:00 - 17:15	Networking coffee
17:15 - 19:00	**B2B Meetings and/or FTPO Lab tour**
17:15 - 19:00	**Open training on research funding opportunities** AITIIP, Spain
20:00 - 22:00	**Networking dinner at »Hiša Ančka«** (Conference dinner is **optional** and at participants' own expense)

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Second day - 5th June 2025

8:30 - 8:55	**Registration**
8:55 - 9:00	**Recal Day 1** **Blaž Nardin - Project leader and Dean of FTPO**
9:00 - 9:25	**PLENARY LECTURE** A comprehensive and innovative strategy to design and monitor composite structures under in-service loadings Paolo Andrea Carraro, University of Padova
9:25 - 9:50	**PLENARY LECTURE** Dissolution based recycling of plastic composites - Experience from European Research Projects Martin Schlummer, Fraunhofer Institute for Process Engineering and Packaging IVV
SESSION 1: MATERIALS	
9:50 - 10:05	INVITED LECTURE **Properties of carbon fiber-reinforced lightweight polyamide composites produced by in situ polymerization** András Suplicz, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics/MTA-BME Lendület Lightweight Polymer Composites Research Group
10:05 - 10:20	**INVITED LECTURE** **Patient specific PEEK cranial implants produced via material extrusion-based additive manufacturing - A clinical perspective** Florian Arbeiter, Materials Science and Testing of Polymers, Montanuniversität Leoben
10:20 - 10:25	**Investigating electrically conductive polymer composites** Bela Zink, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics/MTA-BME Lendület Lightweight Polymer Composites Research Group
10.25 - 10.30	**Phenol/5-HMF resin and its composites with paper** Miroslav **Huskić**, TECOS/Pomurje Science and Innovation Centre
10.30 - 10.35	**Sustainable polymers in additive manufacturing** Raquel Navarro, AITIIP Centro Technologico
10.35 - 10.40	**Optimisation of Polymer-Based Bipolar Plates Using Numerical Calculation** Szabolcs Hajagos, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics
10.40 - 10.45	**Possibilities and damage mapping of intelligent composites** Fanni Balogh, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics
10:45 - 11:15	Coffee break
SESSION 2: NEW TECHNOLOGIES/PROCESSES	
11.15 - 11.30	INVITED LECTURE **Novel matrix materials for high pressure hydrogen storage composite vessels** Markus Wolfahrt, Polymer Competence Center Leoben
11.30 - 11.45	INVITED LECTURE **UV Curing - The solution for industrial scale production of composite parts** Sathis Kumar Selvarayana, Allnex
11.45 - 11.50	**Comparison of multi-axis edge trimming technology for machining carbon fibre reinforced polymer (CFRP) composites with industrially applied mechanical edge trimming methods in terms of burr formation and surface roughness** Tamás Sándor Tima, Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics

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11.50 - 11.55	**Experimental Analysis of TFP as a Cost-Effective Method for Manufacturing Composite Autoparts** Artur A. Pollet, ISI Engenharia de Polímeros
11.55 - 12.00	**Development of a Coating Process for Continuous Fiber Reinforced Thermoplastic Composites Manufactured with T-RTM Technology** Péter Széplaki, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics
12.00 - 12.05	**Overmoulding Strength of PP and ABS Systems: Influence of Tool and Melt Temperatures** Rebeka Lorber, Faculty of Polymer Technology
12.05 - 12.10	**Drilling of carbon fibre-reinforced vitrimer composites** Dániel István Poór, Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics/ MTA-BME Lendület Lightweight Polymer Composites Research Group
12:10 - 13:00	Lunch break
SESSION 3: CIRCULABILITY SOLUTIONS	
13:00 - 13:15	INVITED LECTURE **Challenges & Opportunities for the End-of-Life Recycling of Wintersport Hardgoods** Zahra Shahroodi, Institute of Polymer Processing, Montanuniversität Leoben
13:15 - 13:30	INVITED LECTURE **Sustainability issues and recycling in carbon fiber composites, state of the art** Peter Santha, Department of Polymer Engineering, Faculty of Mechanical Engineering, Budapest University of Technology and Economics
13:30 - 13:45	INVITED LECTURE **LIT factory - pilot factory for thermoplastic circular composite production value chain** Klaus Straka, Johannes Kepler University Linz, LIT factory
13:45 - 14:00	INVITED LECTURE **Closing the Loop in Rotational Molding: Integrating PIR, PCR into Sustainable Production** Valentina Benkovič, Roto Group
14:00 - 14:05	**Industrial thermoplastic waste as reinforcement and matrix** Marko Verčkovnik, Faculty of Polymer Technology
14:05 - 14:10	**Waste thermoset composite as reinforcement for recycled polypropylene** Sebastjan Zaverla, Faculty of Polymer Technology
14:10 - 14:30	Coffee break
SESSION 4: TESTING AND PREDICTION METHODOLOGIES	
14:30 - 14:45	INVITED LECTURE **Failure mechanisms in polymer composite laminates - testing, quantification, and modeling** Clara Schuecker, Polymer Engineering and Science Department, Montanuniversität Leoben
14.45 - 14.50	**Durability Performance of Additive Manufactured Gears: An Evaluation Study** Matija Hriberšek, Faculty of Polymer Technology
14.50 - 14.55	**Development of volumetric image processing methods to segment reinforcing carbon fibre clusters in chopped carbon fibre reinforced polymer (cCFRP) composite** Gergely Magyar, Department of Manufacturing Science and Engineering, Budapest University of Technology and Economics
14.55 - 15.00	**Inteligent composites/SMH** Urs Zimmermann, Eastern Switzerland University of Applied Sciences
15.00 - 15.15	Closing remarks, Blaž Nardin - Project leader and Dean of FTPO

Understanding the difference between "exercises in style" and true "composite recycling": An overview of the many ways to re-process composite materials

Dr. Niccolo Pini [a]

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It is in the nature of composite materials of being made of two or more different components. While this ensures unique properties hardly achievable by homogeneous materials, the flip side is that their recycling is much more challenging than for e.g. metals or unreinforced plastics. In the past 40+ years thermoplastic composites were celebrated as the revolution of composites to reduce manufacturing costs and to solve the recycling issues, nonetheless they have not lived up to the expectations, because of, among others, the dramatic reduction of their mechanical properties once mechanically recycled. Nowadays, more than 75% of composite materials are still thermoset based, which are intrinsically even more difficult to recycle than thermoplastic ones.

Luckily, supported by both the legislator and by an increased awareness for sustainability in the western society, in the last 5 to 10 years much effort has been put into sustainable handling of composite materials, following the rule "reuse – repair – recycle". Recycling technologies for composite materials are just at the beginning of a new development cycle so that several recycling approaches are being followed, with different levels of success – and of justifiability.

This keynote presentation will show the current trends in re-processing of composite materials, while trying to separate marketing exercises from true sustainable solutions. The presentation will point out the current issues with re-processing of composite materials, let them be technologic, commercial or bureaucratic, and will discuss their implications for a true sustainable utilisation of composite materials in the future.

Keywords: composite reuse; composite repair; composite recycling; sustainability

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Unsaturated polyester resins (UPR) for transport, marine and wind applications

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Unsaturated polyester resins are prepared from glycols and diacids/anhydrides by melt polycondensation reaction. Melted polyesters are dissolved in styrene as a reactive monomer to prepare a relatively low viscous liquid that can be combined with glass fibres, or other fillers, and cured to prepare composite material parts suitable for specific applications like transportation, construction, engineering, marine, utilities. Ease of manufacturing complex parts, low weight and reasonable investment costs are some of the reasons for the widespread use of composites in several industries. Due to properties such as excellent tensile strength, flexural strength, impact strength, heat resistance, resistance to corrosion, chemicals and weathering, electrical insulation, etc., are composite parts used in large quantities as construction materials and in marine and transportation equipment. In collaboration with manufacturers of composite parts for the wind energy, transportation and marine industries R&D team for Synthetic Resins in Preska, Slovenia develop for over 60 years custom made unsaturated polyester resins for vacuum infusion, resin transfer molding (RTM), casting, filament winding, SMC, BMC, etc. and series of coatings with a protective decorative function (gel coat, top coat) in various shades for a wide range of applications.

Keywords: Unsaturated polyester resin, thermoset, composite material, GFR plastic

CAPROCAST: A technology for the manufacturing of lightweight thermoplastic structural components

Cristina Elizetxea[a], Sonia García[a], Amaia de la Calle[a], Olatz Ollo[a]

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The body in white vehicle structure stands for the 34% of total vehicle weight and it is mainly steel. By replacing metals with structural composites, it will be possible to reduce weight vehicle components maintaining functional performance by up to 50% in the years ahead. A 10% weight reduction allows 7% of CO2 reduction in consume and emissions. Continuous fibre reinforced plastic can achieve weight reductions of 60% compare with steel, but recyclability and cost are still a challenge.

The potential of recyclability of thermoplastic versus thermoset material (the more established material nowadays) allows the material chain optimization for end-of-life products.

Since 2006, TECNALIA is involved in the development of a new process for composite continuous fibre composites manufacturing based on the in-situ polymerization process of ε-caprolactam to obtain continuous reinforced APA6 parts (CAPROCAST). In the process, the melted monomer of polyamide 6 (Ɛ-caprolactam) with its catalytic system is injected directly in the mould and polymerize in it obtaining, at the same time, the composite material, and the shaped part. The low viscosity of the melted monomer allows the fibre impregnation to obtain thermoplastic composites with good mechanical properties.

Focused in the automotive structural parts as main target to reach, during this time TECNALIA has been involved in the selection and validation of the most suitable commercial available catalysts systems; selection and study of compatible fibres (aramid, glass and carbon) as reinforcements; design and manufacturing of a laboratory scale casting machine; optimization of process parameters which assures the best composite mechanical performance in the shorter time; realization of a testing campaign (physical, thermal and mechanical) on developed thermoplastic composites and, finally, manufacturing of a laboratory scale prototypes as demonstrators of technology potential.

Keywords: Ɛ-caprolactam, in-situ polymerization, cost effective, APA6 structural composite, recyclable

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[4] EP 3815886 B1 Procedure and device for manufacturing of hybrid (reinforced and nonreinforced) parts. F. TECNALIA R&I (2023)

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Innovative approaches in plastic-metal stir welding: Applications and potential in lightweight construction

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Mobility is currently facing major challenges due to energy prices and the leap to new drive technologies such as electrification and hydrogen technology. In all these approaches, lightweight construction in particular plays a decisive role in achieving the prescribed climate targets and the necessary CO_2 reduction [1]. In addition to the use of new material combinations, especially in plastic-metal, it is also necessary to think ahead in terms of the manufacturing technologies used. The joining technologies currently used, such as gluing, screwing, etc., require production-oriented design thinking, which is often an obstacle in the context of lightweight construction [2]. Non-adhesive material combinations and material systems that are difficult to manufacture often represent a showstopper here. For this reason, alternative joining technologies based on friction stir welding (FSW) will play an important role in the production of function-centered components [3].

The "polymer stir welding" (PSW) process patented by royos is being tested for practical feasibility as part of the development process for the series tool and market launch. A material combination consisting of polycarbonate and aluminum 6082 is selected for this purpose. To find suitable process parameters, rotational speed, feed rate and the immersion depth of the stirring pin are mapped in a partial factorial test plan. The weld seams produced in the welding process are subjected to a microscopic assessment of the joining zone as well as quasi-static shear tensile tests according to ASTM D5868.

Initial results look very promising. The surface and joining zone quality as well as the shear tensile strength of 7.5 MPa with optimized process parameters indicate that the joining technology will be consistently competitive once it is ready for series production. Especially due to the welding speeds of up to 1 m/min that can already be achieved. The process is close to being ready for series production and will be able to weld plastic/wood as well as plastic/steel in addition to the material combination of plastic/aluminum mentioned above, which suggests great potential for use in lightweight construction.

Keywords: polymer stir welding (PSW), joining technology, aluminium, thermoplastic polymers

References

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Hybrid Fiber Braiding Technology – New Approaches in Composite Materials

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Hybrid fiber braiding technology is an innovative manufacturing process that combines different types of fibers—such as carbon, glass, aramid, polyester, and specialized thermoplastic fibers like modified PA6—into a unified braided structure.

Through deliberate hybridization (e.g., carbon/glass, carbon/aramid, carbon/polyester, aramid/polyester, or even triple hybrids like carbon/glass/aramid), tailored material properties can be achieved.

A notable example is modified PA (the bio-based Lexter™ polyamide from MGC), a semi-aromatic polyamide fiber that features extremely low water absorption (~2.5 %) and excellent melting properties. When this modified PA6 is combined with carbon fibers, it melts during thermal consolidation, forming an integrated matrix that stabilizes the composite—all while significantly reducing production times.

Moreover, the inherent braided structure itself offers key advantages: it distributes mechanical stresses evenly, enhances damage tolerance under various loads (tension, compression, bending, torsion), and allows flexible adaptation to complex shapes. This technique enables the production of lightweight, high-strength, and cost-efficient components for demanding applications in aerospace, automotive, and sporting goods industries.

Image 1: Hybrid fiber types

Keywords:
Fiber hybdridization, braiding technology, thermoplastic consolidation, lightweight, modified PA6

References

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Performance vs sustainability in emotional lightweight composite parts like sporting goods

Herfried Lammer[a], Kai Hißbach[a], Christina Neeser[a]

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HEAD Sport GmbH is a global leading brand in the field of racquet and winter sports. Lightweight high performance composite parts like a tennis racket or a ski help professional athletes and amateurs in proceeding the specific sport at highest possible level. The balance between performance and sustainability in emotional lightweight composite parts—such as those used in sporting goods is a nuanced design and materials challenge. These products carry both functional demands (lightweight, high strength/stiffness) and emotional value (aesthetics, brand prestige, tactile feel), making the trade-offs especially critical.

Two parameters to highlight this balance:

- Weight reduction of the product is often key to speed and agility. The use of bio-based natural fibers (e.g., flax, hemp) is an alternative to glass fibers, but not to carbon fibers. Benefits like better damping are contradicted by higher variability in humidity and temperature depending properties.
- The use of recycling material in such products is possible and has been demonstrated already in some parts. Yet the use of such materials in an ideal way delivers maximal the same properties as the use of virgin materials [1].
- In contrast the emotional side: Very often biobased materials are considered as old fashioned, not state of the art. Recycled materials are equalled with the product must be cheaper.

The challenge is to design emotionally appealing, high-performance products that are also sustainable. Success requires not just material innovation, but also consumer education and changes in brand value narratives. With its combination of greater sustainability and high performance, the HEAD RENEW redefines skiing. Thanks to a new technology in ski construction, these skis can be dismantled into their individual parts at the end of their service life. An internal study has proven that the wooden core and the fiberglass can be reused up to five times with the same level of performance. The other components on the RENEW such as the top sheet, tail protector, steel edges and the base layer can be recycled. A product carbon footprint analysis by Green Vision Solutions confirms that up to 26 percent carbon can be saved in the production of recycled RENEW skis compared to a new pair of skis.

Overall, delivering optimal performance, sporting goods with their high emotional value are very important for the change towards a sustainable and circular economy.

Keywords: Recyceld composites, sporting goods

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Dissolution based recycling of plastic composites - Experience from European research projects

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The recycling of polymers fails when the source material consists of composite materials that do not decompose completely under mechanical stress. Composites therefore often hinder the recycling of plastic waste and remove valuable plastic resources from the cycle, regardless of whether they are contained in pre-consumer or post-consumer waste.

A dissolution-based recycling process has been proposed for the separation of polymer composites, as it enables the targeted dissolution of the target polymers and the subsequent separation of the undissolved and co-dissolved components to ultimately obtain a purified recycled polymer. Despite the use of organic solvents, dissolution is a physical process in which the polymer chain is not degraded. In most cases, the recovered polymers are generally considered suitable for recycling in their original application. Only thermoplastic matrix polymers can be dissolved; for thermosetting matrices, depolymerisation technologies may be used, but in this case the non-polymer components are the target.

In the past, the principle has been applied in a number of different national and EU projects to separate matrix plastics from composite components such as carbon fibres, glass fibres, metal inserts and others. The results of the Multicycle (EU), DeCoat (EU), Multimold (EU), Eurecomp (EU) and Gabriela (German BMWK) projects demonstrate the successful use of dissolution and the purity of the separated components, both polymeric and non-polymeric.

Keywords: Plastics, recycling, dissolution, composite, glass fibre

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Properties of carbon fiber-reinforced lightweight polyamide composites produced by in situ polymerization

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Cross-linked matrix polymer composites are widely used structural materials in various industries (e.g., aerospace, wind energy, and sports equipment). However, a significant drawback is their limited recyclability and the complexity of repair processes, which require challenging and labor-intensive procedures. Thermoplastic matrix composites offer a potential solution to these challenges. In addition to traditional short- and long-fiber injection molding, a novel technique called T-RTM (Thermoplastic Resin Transfer Moulding) has emerged in recent years. This method utilizes the anionic ring-opening polymerization of caprolactam to produce continuous fiber-reinforced composites with a polyamide 6 (PA6) matrix. This technological combination can create new possibilities for developing innovative, functionally integrated composites that were previously unachievable or required cross-linked matrix materials [1, 2].

The use of thermoplastic matrix materials is highly beneficial, as composites made with them align well with the principles of the circular economy. Their easy repairability extends their lifespan, while their thermoplastic matrix ensures straightforward recyclability, substantially reducing environmental impact. Although this research area is relatively new, numerous research groups have already started exploring it [3].

In our study, we investigated the polymerization process of caprolactam and produced carbon fabric-reinforced composites using the T-RTM method. First, we analyzed the effects of manufacturing conditions (e.g., mold temperature, polymerization time) on the properties of the resulting PA6. Based on the optimal parameters, we produced carbon fabric-reinforced polyamide composite plates with different layer configurations. Finally, we evaluated the impregnation efficiency and the mechanical properties of the composites.

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Patient specific PEEK cranial implants produced via material extrusion based additive manufacturing – A clinical perspective

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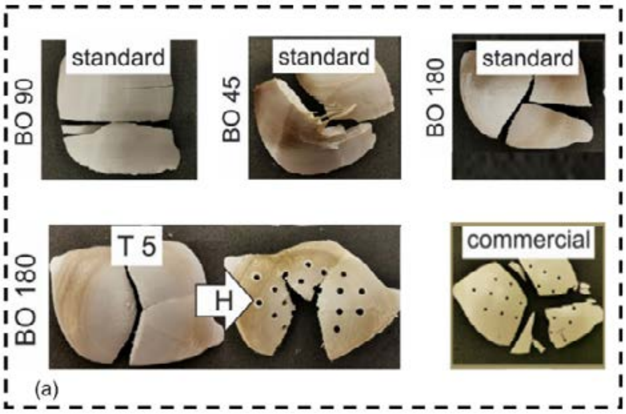

1: Failure types of commercial and additive manufacturing based PEEK PSCIs [1].

Polyetheretherketone (PEEK) has become the gold standard in cranial reconstruction due to its superior mechanical properties and biocompatibility. Conventionally, patient-specific cranial implants (PSCIs) are milled from isotropic PEEK blocks, resulting in smooth, uniformly colored implants with consistent and predictable performance; both qualities that foster surgical confidence and regulatory approval. However, this approach is associated with high production costs and extended lead times. In response, hospitals are investigating in-house fabrication of PSCIs using material extrusion-based additive manufacturing (MEAM) to reduce costs and streamline workflows. While 3D printed PEEK implants have shown clinically acceptable geometric and morphological outcomes, as well as beneficial fracture patterns under impact loading (1), widespread clinical adoption remains limited. To address this, we evaluated the current advantages and limitations of printed PEEK PSCIs, followed by a detailed review of the process parameters influencing implant aesthetics and performance. This analysis aims to identify optimal printing conditions that could bridge the gap between printed and traditionally milled implants, ultimately providing a foundation for standardizing in-hospital production of PEEK PSCIs.

Keywords: Additive Manufacturing, PEEK, Material extrusion-based additive manufacturing, Bone replacement

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Investigating electrically conductive polymer composites

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The increasing global energy demand presents significant challenges, particularly within the constraints of complex economic conditions. As a result, the exploration of innovative energy sources has become a priority. One such advanced energy conversion technology is the fuel cell, whose integration into practical applications is critically important. Among fuel cells, hydrogen fuel cells offer a renewable and efficient energy solution. Currently, these cells are mainly produced from metal alloys, which not only increase production costs but also complicate recyclability and contribute to excessive weight. Polymer composite materials present a promising alternative to address these limitations; however, their application requires further development to meet stringent operational demands. Key material requirements include high thermal and electrical conductivity, adequate mechanical properties, and resistance to electrochemical corrosion.

In this study, we used different types of graphite, carbon black, and carbon fiber fillers with polypropylene matrix to manufacture mono-composite materials. We investigated the thermal, electrical, mechanical, and processing properties of the samples to evaluate the effect of the fillers and their special properties. We selected the best fillers based on the results of the mono-composites, such as the highest electrical and thermal conductivity, lowest percolation threshold, and processibility to produce hybrid composites. We investigated how much the hybridization effect enhances the properties of each compound. The newly developed carbon-filler-based composite material for injection molding offers a lightweight and cost-effective alternative for fuel cell applications.

Keywords: full cell, green energy, injection molding, material development, conductive polymers

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Phenol/5-HMF resin and its composites with paper

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Cellulose can be chemically decomposed and converted, first into sugars and these sugars into various chemicals such as 5-hydroxymethyl furfural (5-HMF), various diols, adipic acid, etc. These chemicals might be used as monomers in the production of polymers such as polyurethanes, polyesters,...

Phenol/5-HMF novolac-type resin (PHMF) has already been synthesized in situ from glucose in the presence of CrCl2/CrCl3 and tetraethylammonium chloride (TEAC) catalysts.[1] After crosslinking, these resins exhibited a high glass transition temperature (Tg) and good mechanical properties. However, the resins were solid and needed to be dissolved before the application. Therefore, the goal of our research was to synthesize liquid resin without using a chromium catalyst.[2]

Several polymerisation methods and reaction conditions were tested (in solution, in bulk, various catalysts and temperatures) to obtain the goal. The resins were thoroughly characterised by NMR and it was confirmed that the structure depends on the reaction conditions. Liquid resin was synthesized only without using a catalyst and with the slightly acid catalyst, mineral montmorillonite (K10). Although prepared in excess phenol, according to the chemical structure, the resin was similar to resol type phenol formaldehyde resin. Therefore, it could have been cured by several methods (heat, acidic catalyst), however, only the use of hexamethylene tetramine (HMTA) was successful and the properties of the cured resin depended on the curing conditions. Increasing the HMTA content and the curing time increased the glass transition temperature.

The composites of PHMF resin with the paper as a reinforcing agent were prepared and tested. The Tg was higher than 180 °C and mechanical properties were better than usually obtained even for epoxy-natural fibre composites. The Young's moduli were approximately 7 GPa, and the tensile strength reached 91.5 MPa. The results suggest that these composites could be used for applications where high strength and high temperatures (up to ≈150 °C) are needed.

Keywords: 5-HMF, composite, paper, NMR, mechanical properties.

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Sustainable polymers in additive manufacturing

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The adoption of bio-based materials as sustainable alternatives to fossil-derived options is becoming increasingly vital across industries. This research focuses on the development and performance characterization of Cellulose Acetate (CA), reinforced with natural fibres. CA, derived from renewable resources, offers good mechanical properties and excellent aesthetic quality, positioning it as a promising alternative to traditional petroleum-based polymers.

This study evaluates the influence of hemp natural fibres on CA composites. Special attention is given to the effect of these fibres on the overall performance of the compounds, including their aesthetic appeal, which is critical for consumer-facing applications. The selection of these reinforcements is driven by their renewable origin, low cost, and ability to enhance specific mechanical characteristics, such as stiffness and strength [1,2].

To enable sustainable efficient and scalable production, the research utilizes advanced additive manufacturing technologies [3]. Fused Granulated Deposition (FGF) technology is used to produce the demonstrators. This AM process allows the use of granulated feedstocks, reducing material costs and waste. Nonetheless, challenges such as layer adhesion and warping of CA during processing are addressed through a comprehensive parameter optimization, ensuring dimensional accuracy and high-quality output. The developed CA composites have been successfully validated through prototypes for construction sector such as green-wall components. These prototypes exhibited improved mechanical performance, aesthetic finishes and durability.

This work highlights a pathway for achieving circular economy goals through the integration of renewable materials and advanced technologies as an alternative to currently used materials and processes. By advancing in the understanding of natural fibre reinforcements and optimizing production processes, this research contributes to reducing the environmental impact of construction products while offering innovative solutions for bio-based composites in high-performance sectors, approaching them to the market.

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Optimisation of Polymer-Based Bipolar Plates Using Numerical Calculation

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Fuel cells have gained significant attention for portable and lightweight energy applications due to their high energy density and environmental benefits. Polymer-based proton exchange membrane fuel cells (PEMFCs) are particularly suitable for drones and portable electronics, where weight reduction and manufacturability are critical factors. Our goal in this study was to optimize the design of polymer-based bipolar plates for small-scale fuel cell applications by improving gas flow distribution and manufacturability. Computational Fluid Dynamics (CFD) simulations were conducted to evaluate different channel geometries, and injection moulding simulations were used to assess manufacturability. The final optimized processing parameters and part design, featuring a counter-flow configuration with semi-circular and U-shaped channels, demonstrated improved gas flow uniformity, reduced pressure drop of the gasses, and minimized part deformation caused by manufacturing. These findings contribute to the advancement of polymer-based fuel cells, enhancing their efficiency and feasibility for lightweight applications in transportation and portable energy solutions.

Keywords: proton exchange membrane fuel cell, computational fluid dynamics, channel design, optimization, injection compression molding

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Possibilities and damage mapping of intelligent composites

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Intelligent composites represent a novel class of materials designed to possess high mechanical performance and integrate self-sensing capabilities, enabling real-time monitoring of their structural health. These advanced materials can detect and respond to external stimuli, making them ideal candidates for applications requiring damage detection and monitoring [1,2].

This research focuses on exploring the internal behaviour and damage mechanisms of intelligent composites, specifically utilizing acoustic emission (AE) techniques to monitor and characterize damage progression. A set of unique tests has been developed to map the acoustic emission signatures corresponding to different failure modes, such as matrix cracking, fibre breakage, and delamination. By identifying the AE characteristics associated with each damage type, a comprehensive evaluation system is being developed to assess the structural integrity of intelligent composites in real time.

The primary aim of this study is to establish a reliable damage assessment framework based on AE data, which will facilitate the early detection of potential failures and provide valuable insights for the design and application of these advanced materials in various engineering fields. The proposed evaluation system promises to enhance the safety and durability of structures utilizing intelligent composite materials.

Acknowledgments

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Keywords: Intelligent Composites, Acoustic Emission, Damage Detection, Structural Health Monitoring, Failure Modes

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Novel matrix materials for high pressure hydrogen storage composite vessels

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In a response to the climate crisis the world is facing, hydrogen receives great attention as a clean energy carrier as well as a feasible and cost-effective renewable energy storage solution. Although different storage technologies for hydrogen are reported in the literature, high pressure vessels represent the most mature technology [1]. In this context, Type III and type IV pressure vessels are state of the art for mobility applications, consisting of a composite overwrap and a metallic (Type III) or thermoplastic (Type IV) liner as gas barrier [2]. Actual developments are directed to liner-less, all composite vessels (Type V), which should reduce the total weight of the vessel by 10 to 30 % and at the same time increase H2 storage capacity by 10 %. [3, 4]. Within the COMET modul “Polymers4Hydrogen” we have investigated ionic liquid-based epoxy resins and evaluated their applicability as matrix material for a linerless all composite construction with improved barrier properties. Imidazolium based ionic liquids with varying anions have been synthesized. Through hardener variation several thermosets have been prepared and characterised to tailor the resulting properties of the cured networks [5-8]. The most promising formulation has shown superior thermal, thermo-mechanical and gas barrier properties compared to the commercially available reference resin. Moreover, the applicability of a carbon fibre reinforced composite impregnated with the developed IL epoxy-system has been critically assessed.

Keywords: hydrogen storage, automotive, type V composite pressure vessel, ionic liquid resin.

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UV Curing - The solution for industrial scale production of composite parts

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Fiber Reinforced Polymers (FRPs) offer lightweight, corrosion-resistant alternatives to metals, enabling weight reduction without sacrificing performance. In vehicles, a 10% weight cut can boost fuel efficiency by 5–7%, reducing emissions and costs. While the composites industry has reduced production costs, long cycle times—ranging from 1 to 10 minutes per part—remain a major barrier to high-volume adoption. In contrast, steel parts can be stamped in seconds. Key challenges include high capital costs, rapid equipment obsolescence, and space limitations at OEM facilities.

UV curing offers a promising solution by significantly accelerating cure times. In addition to faster processing, UV curing enables lower energy consumption, reduced equipment footprint, and improved part quality, making it well-suited for scalable and efficient composite manufacturing. Real-world applications developed by allnex together with its customers highlight the potential of this technology. For example, Glass Fiber Reinforced Polymer (GFRP) LPG tanks offer up to 50% weight reduction compared to traditional steel tanks, resulting in lower transportation costs and improved fuel efficiency in logistics. It has been demosntrated that the UV-assisted curing, enable production cycle times of under 3 minutes per tank, significantly enhancing throughput for high-volume applications.

UV curing not only enables significantly faster curing cycles but also allows for the in-line functionalization of composite parts during manufacturing. While pultrusion of GFRPs is a well-established process in the automotive sector, the integration of UV curing offers substantial advantages in productivity and design flexibility through selective curing. A novel UV-pultrusion process has demonstrated line speeds of approximately 2 m/min for profiles with a cross-sectional area of around 120 mm^2, performance that rivals or exceeds traditional steel part production in terms of efficiency. Additionally, selective UV curing enables the creation of profiles with both cured and uncured segments, allowing for real-time reshaping and integration of functional features directly within the production line.

This presentation will highlight two advanced composite manufacturing technologies—filament winding and pultrusion—with a focus on their enhanced productivity and functionality through UV curing. The presentation will showcase how these processes offer efficient, scalable alternatives to traditional materials like steel, particularly for high-performance and high-volume applications.

Keywords: UV curing, GFRP, pultrusion, filament winding, UV formulations.

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Comparison of multi-axis edge trimming technology for machining carbon fibre reinforced polymer (CFRP) composites with industrially applied mechanical edge trimming methods in terms of burr formation and surface roughness

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The mechanical machining of carbon fibre reinforced polymer (CFRP) composites presents several challenges, including delamination, excessive burr formation, and significant tool wear due to the highly abrasive nature of carbon fibres [1]. To mitigate these issues, the primary objective is to achieve a compression effect that substantially reduces the risk of delamination and burr formation. In industrial practice, this effect is typically achieved using cutting tools with specialized edge-angle designs [2]. However, such tools result in complex and costly tool geometries.

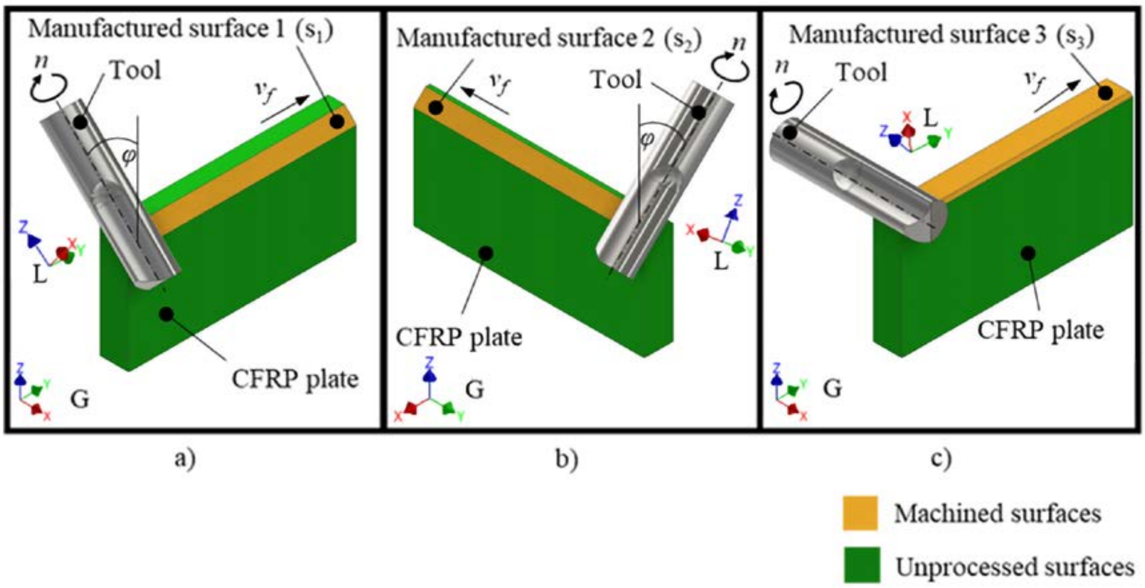

Fig. 1 Illustration of the main steps of the multi-axis edge trimming technology [3]

To enhance the efficiency of CFRP composite machining, we have developed a multi-axis edge trimming technology [3] that enables the desired compression effect without necessitating specialized tool geometries, the illustration of the main steps of the multi-axis edge trimming technology is in Fig. 1. The proposed method achieves the required compression effect by tilting a conventional cutting tool during the machining process. In this study, the developed multi-axis edge trimming technology was evaluated against several industrial cutting tools with specialized edge geometries to validate its effectiveness. Machining experiments were designed and conducted to compare the different approaches. The experimental design was carried out using Minitab software following the Central Composite Design (CCC) method. The experimental factors included the machining technology, cutting speed, and feed rate. The technology factor was analyzed at six levels: four different special-geometry tools commonly used in industrial applications, one conventional edge trimming operation using a standard tool, and one multi-axis edge trimming operation for CFRP composite machining. Both cutting speed and feed rate were examined at five different levels. Following the machining experiments, the workpieces were analyzed using an Olympus SZX16 stereomicroscope, and high-resolution images of the machined edges were captured and evaluated through digital image processing techniques. Additionally, the surface roughness of the machined edges was measured using a Mitutoyo Surftest SJ-401 analogue surface roughness measurement device. The experimental results indicate that the multi-axis edge trimming technology achieves a machining quality that is at least equivalent to, and in many cases superior to, the edge geometries produced using specialized cutting tools currently employed in the industry.

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Keywords: CFRP; Edge trimming; Burr; Tool tilting; Digital image processing

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Experimental Analysis of TFP as a Cost-Effective Method for Manufacturing Composite Autoparts

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The Tailored Fiber Placement (TFP) manufacturing technique presents a distinctive method for the economical use of composites in fabricating intricate, high-performance components [1,2]. This study outlines the successful implementation of TFP in the design of airfoil supports for a Turismo competition vehicle, which are traditionally mettalic. Beginning with the boundary conditions of a conventional support design, we introduced an optimized structure consolidated using carbon fiber TFP preforms. We refined the overall geometry of the supports using a SIMP-based topology optimization approach. EDOstructure [3], a software for modeling complex parts utilizing fiber distribution techniques tailored for TFP, further enhanced this geometry. By strategically distributing the fiber strands along the primary geometry and in regions subject to significant stress, we created a robust component that meets performance requirements while minimizing raw material usage. Figure 1 below illustrates the steps involved in the mechanical design of these components.

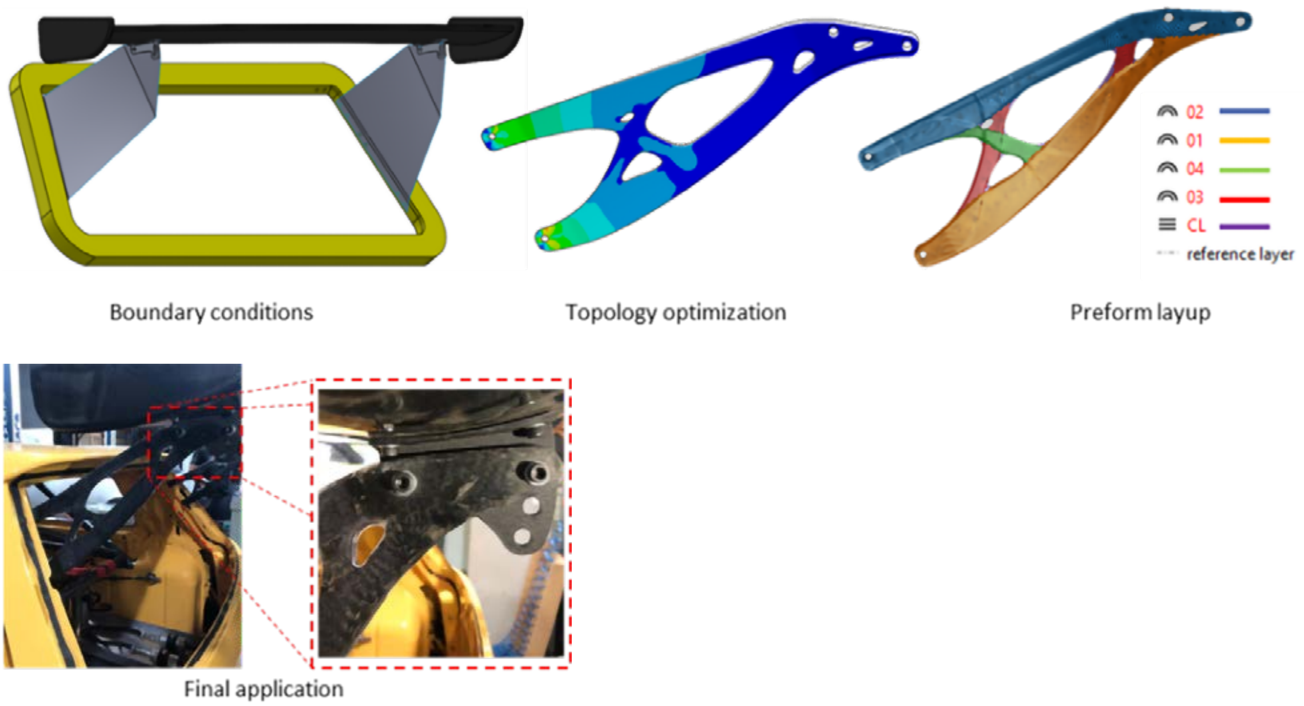

Figure 2 - Steps to achieve mechanical component in its final form.

All numerical models employed material constitutive data that were experimentally determined through comprehensive material characterization (ASTM D3039, D7264, and D7078). We compared the performance of the final optimized component numerically to that of a component constructed from traditional carbon fabric. The methodology presented achieved structural performance equal to that of the conventional solution. Moreover, employing TFP instead of traditional carbon fabric for manufacturing the airfoil supports resulted in an 86% reduction in waste—only 23,39g of residue for the TFP component compared to 167,44g for the conventional method. In terms of cost savings, the advantages are even more pronounced, given the higher costs associated with carbon fabric compared to the carbon fiber strands typically utilized in TFP.

Keywords: TFP; Optimization; FEA; Material characterization.

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Development of a Coating Process for Continuous Fiber Reinforced Thermoplastic Composites Manufactured with T-RTM Technology

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One of the key challenges of the 21st century is recycling and sustainable waste management. A primary objective of the European Union is the establishment of a circular economy and the minimization of waste. Consequently, thermoplastic composites are receiving increasing attention due to their significant advantage over conventional thermoset counterparts: they can be efficiently recycled through material reprocessing (e.g., by grinding followed by short-fiber injection molding). [1]

In the production of continuously reinforced composites, the Thermoplastic Resin Transfer Molding (T-RTM) technology is gaining attention in the last few years. This method enables the in-situ polymerization of monomers within the mold, resulting in high-quality, well-impregnated composite structures [2]. However, a major drawback of the technology comes from the low viscosity of caprolactam (5–10 mPas), which complicates the incorporation of additives. Additives are necessary to improve the properties and resistance of the matrix. Additives tend to either settle at the bottom of the mold or being filtered by the reinforcing fabric in the mold during injection. This leads to inhomogeneous and low-quality products. [3]

A potential solution for this problem is the application of an additive-enriched coating layer that provides desired properties (e.g., UV resistance, wear resistance) that the unmodified matrix material lacks. In this study, I focused on developing such a coating process. Various coating layers were formulated and characterized. Subsequently, coated test specimens were produced, and the adhesion between the coating and the composite structure was evaluated.

Keywords: T-RTM, thermoplastic composite, coating, carbon fiber, polyamide 6

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Overmoulding Strength of PP and ABS Systems: Influence of Tool and Melt Temperatures

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Polymers and polymer composites are increasingly replacing metals in various industry sectors, including automotive, aerospace, and sports equipment, due to their advantageous strength-to-weight ratio and design flexibility. Overmoulding, a multi-material injection moulding process, offers efficient manufacturing of complex parts with tailored properties. This study investigates the overmoulding strength of polypropylene (PP) with PP and acrylonitrile butadiene styrene (ABS) overmoulded with ABS, focusing on the influence of critical processing parameters: tool temperature and melt temperature. Understanding the relationship between these temperatures and the resulting overmould strength is crucial for optimizing the process and ensuring structural integrity in applications. Higher melt and tool temperatures result in improved overmould strength reaching up to 70 % of strength of a specimen produced with single shot.

Keywords: Overmoulding, Tool Temperature, Melt Temperature, Overmould Strength, Injection Moulding.

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Drilling of carbon fibre-reinforced vitrimer composites

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The manufacturing process of fibre-reinforced polymer (FRP) composites usually involves a series of machining operations (e.g. drilling and edge trimming), which are often implemented to ensure strict tolerances for geometrical features and to produce holes for assembly [1]. In the case of these difficult-to-cut FRP composites, the quality of the machined features is highly influenced by many machining parameters [2]. The increasing demand for sustainable solutions for FRP composites has led to the urgent need for the development of novel, fully recyclable materials. In 2010, Leibler and his colleagues [3] published a new class of polymers called vitrimers. Vitrimer materials have a covalent adaptable network (CAN), which means that the primary chemical bonds between the polymer chains can be broken and then reformed at different locations, while the thermosetting network keeps its crosslink density. This mechanism results in multiple special properties (e.g. recyclability of reinforcement and matrix, thermoformability, repairability, shape memory effect, self-healing etc.) [4]. As vitrimers have only recently been discovered, their machinability remains to be investigated; however, in order to support their widespread use in industry and to explore the effect of vitrimer transition temperature, such investigations are indispensable.

In this study, we conducted drilling experiments on polyimine vitrimer carbon fibre-reinforced polymer (CFRP) composites. We applied three drilling tools with different geometries (ie. twist drill, brad&spur drill, fishtail drill) and we analysed the effect of feed (investigated at three levels: 0.1, 0.25 and 0.4 mm/rev) on thrust force (measured with a KISTLER 9257B dynamometer) and circularity of holes (measured with a Mitutoyo Crysta-Plus 574 coordinate measuring machine), while the cutting speed was fixed (100 mm/min). The results of the analysis of variance (ANOVA) demonstrated that the tool geometry exerts a significant effect on the thrust force, while the feed is found to be non-significant. With regard to circularity, the factors did not have a significant effect.

Keywords: polyimine vitrimer CFRP, machinability, drilling, thrust force, circularity.

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Challenges & Opportunities for the End-of-Life Recycling of Wintersport Hardgoods

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The increasing popularity of winter sports has led to a significant rise in the production and disposal of hardgoods such as skis, boots, helmets and poles. According to a Laurent Vanat report published by Forbes [1] 51.7 million skiers are hitting the slopes in Austria alone every year.

The WINTRUST project, funded by FFG and ecoplus, focuses on developing a sustainable recycling system for end-of-life (EoL) winter sports hardgoods, including skis (with bindings), ski boots, ski poles, and ski helmets. These products, primarily made from high-performance plastics and metals, currently undergo thermal recovery rather than recycling, leading to resource loss and environmental impact. By integrating economic, social, and ecological principles of circularity, the project aims to establish efficient separation and processing methods, create new applications for recycled materials. [2-4]

Recycling end-of-life (EoL) winter sports hardgoods presents significant challenges due to their complex multi-material and multi-component nature. These products, composed of high-performance plastics, metals, and composite materials, require advanced separation and processing methods to enable material recovery and reuse. Current recycling efforts face obstacles related to dismantling, sorting, and the economic feasibility of recovering certain materials. This study examines the existing separation and processing routes for five identified use cases in winter sports hardgoods recycling. A particular focus is placed on identifying high-value recoverable materials, such as high-performance plastics and metals, and exploring efficient extraction methods and potential applications for secondary use. However, certain materials remain difficult to recycle due to degradation, composite structures, or the absence of a viable market. Strategies to improve the recyclability of these challenging components are explored, including advancements in processing technologies, alternative applications, and design modifications to enhance circularity. Beyond material recovery, economic, environmental, and logistical barriers must be addressed to establish a sustainable and scalable recycling system. Overcoming challenges in dismantling and sorting, expanding recycling infrastructure, and integrating recovered materials into new product cycles are crucial for developing a circular economy within the winter sports industry. This work highlights the importance of technological innovation, industry collaboration, and policy support in driving sustainable recycling solutions for winter sports equipment.

Keywords: Recycling, Technical Polymers, End of Life Wintersport Hardgoods, WINTRUST

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Sustainability issues and recycling in carbon fiber composites, state-of-the-art

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The increasing use of high-performance carbon fiber reinforced polymers (CFRPs) across sectors such as aerospace, automotive, wind energy, and sports—driven by their superior mechanical properties and design flexibility—has raised pressing concerns about their waste management, especially as global demand reached 181 kt/year with a 12.5% growth rate in 2021 [1]. Recycling CFRPs poses distinct technical and economic challenges due to thermoset matrices like epoxy, which cannot be remelted and require chemical or thermal degradation, unlike easily recyclable thermoplastics. Despite growing interest and notable technological progress, industrial-scale recycling of CFRPs remains limited due to inconsistent material quality, logistical challenges, and the absence of standardized processes. This persists in a gap between laboratory feasibility and market-ready solutions.

State-of-the-art CFRP reclamation technologies are categorized into mechanical, thermal, chemical, and other processes. Pyrolysis, solvolysis, and combined thermolysis have successfully recovered CFs from composite matrices, often retaining up to 90–95% of the original fiber strength [2]. However, the quality of reclaimed fibers (rCF) is highly dependent on processing conditions. Surface damage, shortening of fibers, and changes in sizing can significantly affect performance in secondary applications. This issue is compounded by the limited availability of post-consumer CFRP waste streams with consistent composition and quality, making standardisation and quality control difficult. Recycled fibers are typically short and randomly oriented, limiting their use in high-performance structural components unless further processing or alignment is introduced. Remanufacturing rCF into upcycled products, such as non-woven mats, chopped tapes, or aligned textiles, often lacks sufficient industrial throughput or suffers from high production costs. As a result, rCFs are currently used in non-critical applications, such as automotive interiors, consumer electronics casings, or sports equipment, where cost and performance requirements are more forgiving. Fiber orientation and matrix compatibility must be addressed to move from downcycling to true upcycling. Aligning rCF to highly aligned tapes or hybrid yarns [3] is a key direction, with promising developments and potential for scaling up. With tailored resin systems [4], producing prepregs, unidirectional tapes, or woven fabrics from recycled content expands the scope of high-value reuse.

Industrialisation also demands robust supply chains, economic models, life cycle analysis, and regulatory support. The lack of standardised certification pathways for rCFRP hinders their adoption in safety-critical sectors. Integrating recycling considerations into the initial design of CFRP products could facilitate more efficient recovery and reuse. Recycling CFs is not merely a waste management task but a technological opportunity. Unlocking its full potential requires a systemic approach, combining material innovation, process engineering, and market development. As demand for carbon fiber rises, developing scalable, quality-preserving recycling strategies will be essential to making advanced composites truly sustainable.

Keywords: Recycling, Carbon fiber, Composites, Reclamation, Remanufacturing, Sustainability

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Recycling of Thermoplastic Composites based on Uni-directional Fibre Reinforced Tapes

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Thermoplastic composites (TCs) offer key advantages over thermosets, especially their ability to be remelted and reshaped multiple times. This makes them suitable for mechanical recycling and supports the development of more sustainable, fibre-reinforced lightweight components [1]. A typical recycling process involves three stages: size reduction into flakes, regranulation into pellets, and remanufacturing into new parts [2]. However, despite this potential, many fibre-reinforced TCs are still incinerated at end-of-life, limiting their recyclability [3].

To establish a circular recycling process, strategies are needed to reuse post-industrial composites as high-quality, short-fibre-reinforced materials. A major challenge is maintaining fibre length and mechanical performance during processing steps like shredding, melting, compounding, and molding, all of which can degrade the fibres.

This study introduces an experimental approach to evaluate and optimize the mechanical recycling of continuous fibre-reinforced thermoplastic composites. It begins with fine-tuning the dosing system to ensure consistent feeding of recycled flakes into a twin-screw extruder. Inline ultrasonic sensors were integrated to monitor fibre content, and melt homogeneity in real time. These measurements allow potential real-time process adjustments. After compounding, mechanical properties such as tensile strength and impact resistance were tested, and fibre length distribution was analyzed to assess the effects of processing. Fibre content was quantified through thermogravimetric analysis (TGA), offering accurate data on the final reinforcement fraction.

A simple, low-cost fibre length measurement method was developed and validated against industry-standard equipment. The ultrasonic sensors measured fibre content and showed strong agreement with the offline measurements. Initial dosing experiments revealed a strong correlation between flake size and throughput rate, confirming that dosing settings can be optimized to improve process control.

Overall, the study demonstrates the potential of implementing closed-loop control in mechanical recycling. Real-time ultrasonic data can be used to dynamically adjust feed rates, improving consistency and quality. Coupled with a reliable method for fibre length analysis, this approach supports the sustainable reuse of TCs and advances resource-efficient manufacturing.

Keywords: Thermoplastic composites, Mechanical recycling, Fibre length measurement, Flake size distribution

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Closing the Loop in Rotational Molding: Integrating PIR, PCR into Sustainable Production

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ROTO, a Slovenian manufacturer with decades of experience in polymer processing, has established itself as a leader in sustainable rotational molding and circular economy innovation. As environmental pressures and raw material scarcity intensify, ROTO has strategically committed to closing the loop by incorporating post-industrial recycled (PIR) and post-consumer recycled (PCR) polyethylene into its manufacturing processes. Collaborating with international recycling specialists such as KRM Kunststoff-Recycling-Maschinen GmbH, the company leverages mechanical recycling of in-house scrap and externally collected plastic packaging waste to create high-quality, long-lasting products. These products span multiple sectors—including water management systems, garden infrastructure, and recreational equipment—offering functional, durable alternatives to conventional goods. A flagship example of this closed-loop philosophy is the PeCycled product line, consisting of kayaks and canoes manufactured entirely from 100% recycled polyethylene. Old and end-of-life kayaks are collected from hotels, rental companies, and individual consumers, then sorted, cleaned, shredded, and thermally processed in-house to form new, high-performance outdoor gear.

PeCycled showcases how waste can be transformed into valuable resources without compromising product quality. Employing advanced three-layer rotational molding technology, these kayaks offer exceptional durability, improved buoyancy, and reduced weight—making them ideal for both amateur and professional use. In addition, the company's ecoVoucher take-back scheme incentivizes customers to return old kayaks for recycling, fostering environmental awareness and engagement. Aligned with ISO 14001 standards and grounded in a 'Zero Industrial Waste' strategy, ROTO's operations emphasize full material recovery and process optimization. Digital tools and QR-coded digital product passports ensure full traceability and production control, enhancing transparency, reducing waste, and enabling fast response to market demands. These innovations support ROTO's goal of minimizing carbon footprint and maximizing material efficiency.

PeCycled, endorsed by Olympic gold medalist Benjamin Savšek, represents not just a product innovation but a broader vision for sustainable manufacturing. By demonstrating how rotational molding can be both environmentally responsible and economically viable, ROTO provides a replicable model aligned with EU Green Deal objectives and future policy directions in circular plastics.

Keywords: circular economy, rotational molding, recycled polyethylene, PeCycled, sustainable manufacturing

Industrial thermoplastic waste as reinforcement and matrix

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Composites with recycled polypropylene matrix are most often reinforced with fibers. These are most often glass, but wood, cellulose, flax, hemp, cotton, and many other organic fibers can also be used. For more demanding applications, carbon or aramid fibers can also be used. Fibers obtained from other waste materials, for example from polyester felt [1], can also be added. With the addition of compatibilizers, they can also be added as a reinforcement to other polymer materials [2]. Polypropylene and polyester fibers account for a large proportion of plastic waste. Using both materials together in a thermoplastic composite with improved properties would be another step towards a cleaner environment with less waste. When using polypropylene reinforced with polyester fibers, we obtain a thermoplastic composite with very low density and excellent specific stiffness and strength, which are ideal for use in lightweight applications.

The aim of this study is to enhance the strength and stiffness of recycled polypropylene (rPP) through the modification of the matrix with waste polyester fibers. The proportion of added recycled polyester fibers in the rPP matrix was increased from 5 to 30 wt.% in steps of 5 wt.%. The mechanical, thermal, and rheological properties of these composites were studied in detail and compared with those of rPP. By increasing the proportion of added polyester fibers in the rPP matrix, stiffness, strength, dynamic stiffness, and temperature stability were increased. Toughness and flexibility in thermoplastic composites were found to decrease proportionally with increasing fiber content. From the microscopic images of the fractures after the tensile test, a homogeneous distribution of polyester fibers in the rPP matrix was observed. The fiber surface was also partially covered by the rPP matrix, indicating good surface interactions between the matrix and the fiber surface, which was attributed to the use of the proper compatibilizer.

Keywords: thermoplastic, thermoset composites, recycling, compatibilizer, properties.

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Waste thermoset composite as reinforcement for recycled polypropylene

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Industrial waste is generally better separated than municipal waste, which is why municipal waste is sorted much more frequently than industrial waste. The same applies to washing, as municipal waste is usually found to be much more contaminated. As a result, industrial waste can be recycled more easily. Consequently, recycled materials of significantly higher quality and with better—or, above all, more homogeneous—properties (mechanical, chemical, optical) are produced from this waste [1]. The main advantage of thermoset composites is that excellent properties are achieved while production costs are kept low when the thermoset matrix is combined with reinforcing fibers. A larger fraction of thermoset composite waste can be utilized as reinforcement for a thermoplastic recycled polypropylene matrix [2].

The differences in properties between differently modified samples of thermoset waste in a thermoplastic matrix were investigated. It was found that higher proportions of thermoset waste, which in this case contained only about 40 wt.% glass fibers, improved the stiffness, strength, and thermal resistance of the composite when combined with suitable compatibilizers and the rPP matrix, but drastically reduced elongation at break and toughness. For the rPP matrix, PP-g-MA and a modified TPU copolymer were identified as the best combination of compatibilizers, with PP-g-MA ensuring good interfacial interactions between glass fibers and the rPP matrix, while the modified TPU copolymer improved interactions between thermoset matrix particles and the rPP matrix. These results are considered a good basis for further research into the mechanical recycling of thermoset waste as a reinforcement for thermoplastic matrices.

Keywords: thermoplastic, thermoset composites, recycling, compatibilizer, properties.

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Failure mechanisms in polymer composite laminates – testing, quantification, and modelling

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In contrast to other materials, laminated fiber reinforced composites show multiple failure mechanisms prior to ultimate failure which may occur already at relatively low loads (see Figure 1). Those failure modes usually do not lead to immediate failure but contribute to a gradual progression of damage resulting in a change in the load response and by that affect the triggering of final failure. In order to predict ultimate failure of components, these failure mechanisms and their effect therefore need to be captured and predicted accurately.

This talk shows some results of an extensive research project concerning the complex, multi-scale damage behavior of composite laminates. Specially designed test and evaluation procedures have been developed to monitor and quantify the progression of damage in carbon and glass fiber laminates based, among others, on optical crack detection methods [1]. From the data obtained, a damage model for fatigue life prediction of composite laminates has been developed which also predicts the stiffness degradation due to damage [2].

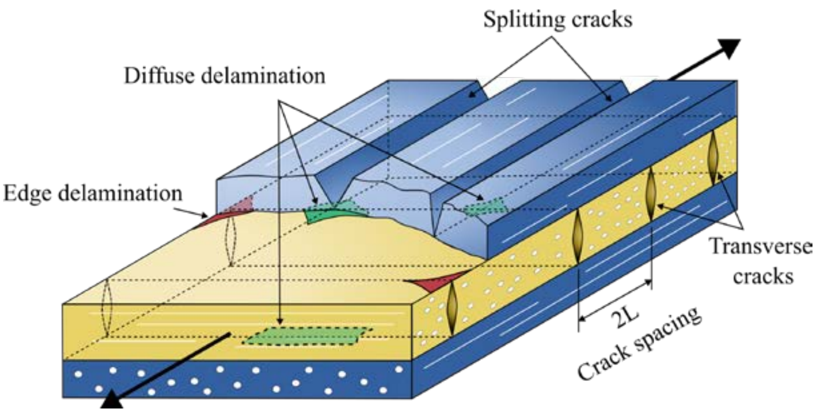

Figure 1: Damage mechanisms in fiber reinforced laminated composites.

Keywords: Composite Laminates, optical crack detection, delamination, damage model.

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Durability Performance of Additive Manufactured Gears: An Evaluation Study

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With the ability to rapidly prototype and manufacture complex geometries, additive manufacturing (AM) offers significant advantages in terms of design flexibility and production time [1]. One of the key applications of AM in gears is design concept validation and ensuring the suitability of selected materials for power transmission contacts. Engineers can quickly produce functional gear prototypes to test and evaluate their performance under real operating load conditions. The ability to iterate designs and test various material combinations enables engineers to make informed decisions about material selection, optimizing for factors such as strength and wear resistance [2, 3]. The study presents the durability characterization of additively manufactured gears from polyamide 6 which was reinforced with short carbon fibers, named Onyx. The gears were produced by Fused Filament Fabrication Technology (FFF). AM gears durability data were compared to conventional produced composite gears (PA66 reinforced 20% wt of short carbon fibers). Steel pinion was engaged with the proposed plastic composite gear. Composite gears were tested under three different load levels to define how lifetime changes with load conditions. When comparing the failure life of AM gears to conventionally produced gears, AM gears demonstrate a comparable failure life at all three load levels. Findings highlight the significant potential of AM gears as a material for innovative prototyping in gear design.

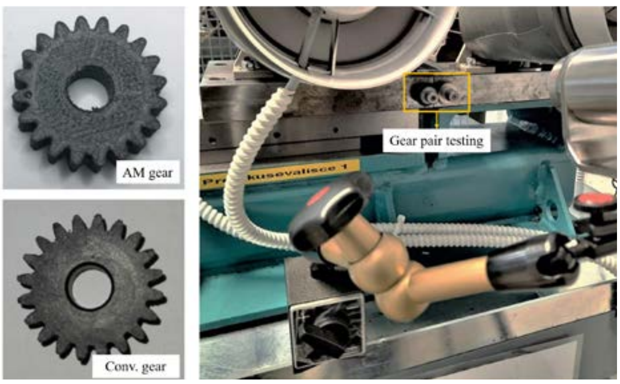

Figure 1: Gears and experimental arrangement.

Figure 2: Root failure of AM gear.

Keywords: Polyamide, carbon fibers, additive manufacturing, gears, testing.

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Development of volumetric image processing methods to segment reinforcing carbon fibre clusters in chopped carbon fibre reinforced polymer (cCFRP) composite

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Chopped carbon fibre reinforced polymer (cCFRP) composites are used in various industrial applications, from automotive to sports equipment and energy, mainly due to their excellent mechanical properties, thermal and corrosion resistance [1]. Among their many advantages, it should be highlighted that they can be produced in complex geometries, even in a nearly ready-to-assemble state, but their machining is often an essential operation [2]. During the machining of cCFRP composites, the formation of machining-induced geometric defects (e.g. burrs, delamination) can pose a significant challenge, which, in addition to being an aesthetic issue, also degrade the mechanical properties of the structure and entail additional costly manufacturing steps [3]. In previous research, we have developed a system for image processing and toolpath optimisation to support machining, whereby the position and orientation of the near-surface reinforcement fibres can be determined with high accuracy from 2D images, and this information can be used to reduce the occurrence of machining-induced burrs [4]. However, in order to not only reduce the amount of near-surface geometric defects and to further improve the accuracy of the existing solution, 3D image creation and processing is necessary. The volumetric images were created using computer tomography (CT) and then processed using custom software developed in Python. Using our in-house developed labelling software, the segmentation of the reinforcing fibre groups and the polymer matrix material was performed manually. Since manual processing is not a sustainable process for the further stages of the research, we developed automatic segmentation algorithms to separate the fibre groups with high accuracy. The algorithms were based on simple threshold separation and digital image processing techniques (e.g. Gaussian filtering, K-means clustering etc.). In order to evaluate the algorithms, quantitative measures of segmentation quality (e.g. F1-score, intersection over union, etc.) were determined. Our results allow further improvements in the machining process of cCFRP materials, which will allow us to develop algorithms to support not only the near-surface but also the entire material volume toolpath creation and machining process in the future.

Keywords: cCFRP, digital image processing, optimization, computer tomograph.

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Intelligent Composites – Structural Health Monitoring

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Current composite designs often exhibit excess weight due to conservatively high safety factors against fatigue—standards that have remained largely unchanged for over 50 years, primarily due to the limited understanding of fatigue behaviour in such materials [1,2]. To contribute to the global effort of reducing emissions and conserving resources, optimising material usage by reducing structural weight is a key objective. A promising strategy to achieve this is the integration of sensor technologies, enabling improved insight into fatigue processes and remaining service life. This approach allows for a reduction in safety factors without compromising structural integrity. Consequently, the development and implementation of at least partially integrated structural health monitoring (SHM) systems represent a critical step forward in advancing lightweight composite structures.

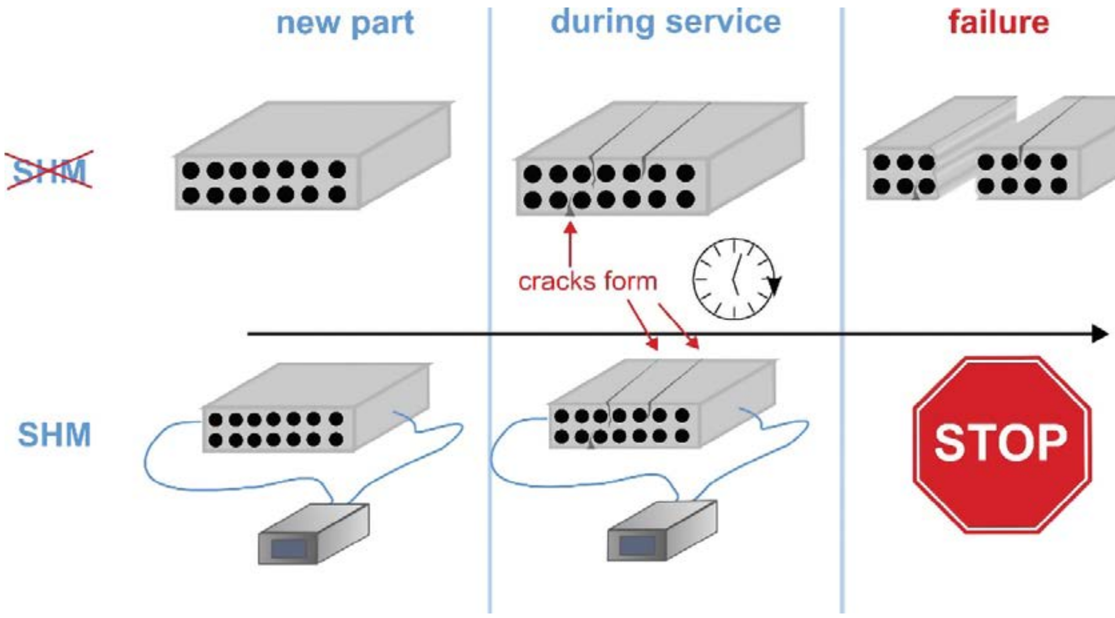

Figure 3 Comparison between a composite structure without an SHM system (top) and with an SHM system (bottom).

The integration of SHM systems enables a reduction in safety margins by providing reliable, real-time data on the remaining service life of components. This facilitates a shift from time-based to condition-based maintenance strategies, allowing for predictive maintenance rather than routine replacement of critical parts. As a result, downtime of essential systems—such as trains, aircraft, or heavy machinery—can be significantly reduced. This not only enhances operational efficiency and safety but also contributes to improved sustainability through more efficient resource utilisation.

Keywords: shm, sensor, fatigue, sustainability

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Metal replacement and lightweight polymer composites

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