Composites Group

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Composites Sustainability Digest

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Industry News

Swancor makes progress with EzCiclo recycleable resins

Swancor Holding Co Ltd (headquartered in Hankou, Taiwan) are making significant progress with the commercialisation of their recyclable EzCiclo resin systems. The epoxy system can be broken down as post-consumer waste at end of life by using the company's "Cleaver" chemicals that are designed to break (cleave) the polymer backbone to leave a byproduct that can be re-used to produce new resins.

A major focus of Swancor is the wind turbine blade market and a significant development was announced in January with Swancor partnering with Adani New Industries of India to jointly build the first Indian recyclable wind farm. Wind energy in India is set to be a big market with the Global Wind Energy Council of India setting a target of 140GW of installed power capacity by 2030. Swancor and Adani aim to certify blades produced using the EzCiclo resins by the summer of 2025 with manufacturing commencing at the end of the year.

This announcement was quickly followed by the company revealing that it has been cooperating with Spanish Automotive start-up Liux who have developed a protype electric vehicle the Geko which makes extensive use of Swancor's EzCiclo RH512 resin, which contains more than 10% bio based raw materials. The resin is used in combination with linen fibres to create fenders, bumpers, doors and tailgate. The Geko claims to reduce the Co_2 footprint of a car by 40% compared to other efficient electric vehicles and by up to 80% compared to internal combustion vehicles.

https://www.swancor.com/en/

Biesterfeld and Infinici Team up

German distribution company Biesterfeld Spezialchemie GmbH has teamed up with Infinici AG (both based in Hamburg), to market and distribute products based on recycled glass fibres.

Infinici which was founded in 2021, works in the field of circular materials and is developing products based on recycled glass and carbon fibres. The company claims that their material forms can be a cost-effective alternative to virgin materials producing parts of both high quality and with a low carbon footprint. Biesterfeld will exclusively distribute the Infinici products in Europe and Turkey. The first product to be covered by the joint agreement will be a non-woven fabric (NWF-650) made completely from recycled glass. The CO2 footprint is claimed to be reduced by 90% compared to comparable materials based on virgin fibres. The non-woven is tailored for use in high volume production operations such as RTM, Vacuum Infusion, GMT and SMC and meets high quality standards required for IATF certification (International Automotive Task Force).

A unique feature of this collaboration is the introduction of 'reverse logistics': Biesterfeld will not only distribute Infinici products but also collect glass and carbon fibre waste from customers. These residual materials will be processed by Infinici into new, high-performance glass and carbon fibre materials – a significant move towards closed material loops.

Biesterfeld appears to be putting greater emphasis on its composites business recently and exhibited at the Paris JEC show in March 2025 for the first time.

https://www.biesterfeld.com/en/ru/industries/composites-tooling-l1/

https://www.infinici.de/

Hera Group unveils FIB3R, a pyro-gasification plant to recover carbon fibre

The Hera group has inaugurated a new plant to recover carbon fibres from composite waste. The facility is based at Imola in Italy and is referred to as FIB3R, reflecting the meme 'recover, reduce and reuse'.

The throughput of the plant is currently planned to be 160 tonnes/year, and the technology is a pyro-gasification process. Pyro-gasification differs from conventional pyrolysis in that the temperature of the process is raised after the initial pyrolysis to convert more of the organic materials to a usable gas. This should produce cleaner fibre and a higher calorific value from the gaseous products which are burnt to provide heat input to the process, thereby minimising the overall energy required.

It is claimed that fibres recovered in this way have a 75% lower embedded energy than virgin fibres.

The total investment in the new plant is put at 8 million euros with the project benefitting from EU funding of 2.2 million euros.

An industrial partnership has been created with the Leonardo Group agreeing to supply Hera with production waste from its aerostructures division (e.g. waste from producing parts for the ATR stabiliser, fuselage and stabiliser of the Boeing 787 and tail sections of the Airbus A220). The company intends to keep a tight control of the input materials to the recycling process with waste arriving in containers equipped with QR codes to always ensure traceability. It is unclear at this time what post-processing of the recovered fibres is planned and how the fibres will enter the supply chain for new composite parts.

https://eng.gruppohera.it/-/hera-group-unveils-fib3r-a-pioneering-plant-that-regenerates-carbon-fibre

Cosmic Aerospace makes flight progress

Cosmic Aerospace has made significant progress with flight testing of its all-composite aircraft the CX-2. The maidan flight took place on 8 Feb 2025 and by 22 Feb, a total of nine flights had been completed.

The CX-2 is a significant aircraft, not just because of its extensive use of composite materials, but because it is a serious attempt to demonstrate the use of electrification in a viable commercial aircraft. The lightweight airframe features ultra efficient long span wings and a high-speed propulsion system known as Skylark which features 32 embedded electric engines, designed for efficiency, redundancy and quiet operation. The battery systems employed are current production units and do not require any breakthroughs in battery technology to make the plane viable.

The speed of development is impressive, a four-month design to first flight has been achieved for the CX-2 which will be used to showcase the technologies intended for full scaled protypes which are projected to fly in 2026. The full-scale prototype is expected to achieve a range of 1000 km with 24 passengers and with 50% lower operating costs comparted to an equivalent jet aircraft.

https://www.cosmicaerospace.com/

Anemoi completes installation of Rotor Sails onboard Vale VLOC in largest wind-propulsion project to date and follows this with U-Ming deal

Anemoi Marine Technologies completed the installation of five composite Rotor Sails onboard the 400,000 dwt Very Large Ore Carrier (VLOC), Sohar Max, making it the largest vessel to receive wind propulsion technology to date. Sohar Max is a first generation Valemax, built in 2012 in China's Rongsheng shipyard.

The project showcased global collaboration between Brazilian mining giant Vale S.A., Omani shipowner Asyad and UK-based Rotor Sail provider Anemoi.

The five 35m tall, 5m diameter Rotor Sails were retrofitted onboard Sohar Max at the COSCO Zhoushan shipyard in China, in October 2024. In addition, Anemoi has installed its bespoke folding deployment system, which will enable to sails to be folded from vertical to mitigate any impacts on the vessel's cargo handling operations.

With the installation of the Rotor Sails, it is expected that Sohar Max will now be able to reduce its fuel consumption by up to 6% and cut carbon emissions by up to 3,000 tonnes annually. Sohar Max has just completed a voyage to Tubarao, during which the rotor sail test period began, and testing will continue future voyages.

In October 2024, Vale announced it is also set to install Anemoi's Rotor Sails onboard the 400,000 dwt VLOC NSU Tubarao, which is owned by NS United Kaiun Kaisha. The project, which is due for completion in September 2025, is expected to achieve significant reduction of fuel consumption and carbon emissions.

In November 2024 Anemoi and U-Ming Marine Transport Ltd.'s ('U-Ming') signed an agreement to install four Rotor Sails on one of U-Ming's 325,000 DWT Very Large Ore Carriers (VLOC).

The installation work is expected to be completed at the end of 2025, with fuel and emission savings of approximately 10-12% anticipated on deep-sea routes between China and Brazil, South Africa, and Australia.

The vessel will be retrofitted with four of Anemoi's 35 m tall, 5m in diameter, cylindrical sails. The Rotor Sails will also be installed with Anemoi's bespoke folding deployment system, whereby the sails can be folded from vertical to mitigate impact on air draught and cargo handling operations.

These projects are the latest in a series of ongoing installation projects Anemoi has with some of the world's biggest shipowners and operators, which are looking to harness wind energy to increase the efficiency of their vessels by reducing fuel consumption and carbon emissions.

Rotor Sails are being increasingly embraced by shipowners who are aiming to achieve net-zero emissions and enhance the energy performance of vessels. Rotor Sails are a compact technology that offer a large thrust force to propel ships, helping them comply with pivotal international emission reduction benchmarks such as CII and EEDI/EEXI.

Anemoi currently offer sails up to 35m high and 5 m in diameter. The outer skins of the rotating sails are produced from glass fibre/epoxy composites combining pultruded sections wrapped using a filament winding process with the top disc, an aerodynamic end plate that enhances the Magnus effect, manufactured using a vacuum infusion process.

(Notes on rotor sails from Anemoi web site: - Although first developed 100 years ago, Rotor Sails had been discounted in commercial shipping at the time, mostly due to the low cost and plentiful supply of fuel. However, with shipowners and managers looking to wean their way off traditional bunker fuels while maintaining full operations, these tall cylinders have picked up steam in recent years to provide auxiliary propulsion and reduce fuel consumption.

The whole principal of Rotor Sails relies on an aerodynamic phenomenon known as the 'Magnus Effect'. As the cylinder rotates within an airflow, a forward thrust force perpendicular to the apparent wind direction is created, which delivers additional thrust to the vessel. The thrust generated can either provide additional vessel speed or maintain vessel speed by reducing power from the main engine. Either way, a vessel's fuel consumption can be minimised and, crucially, its emissions output drastically cut.

Data from modern Rotor Sail systems has shown that the technology can achieve fuel savings of up to 30%. This means Rotor Sails are one of the most effective and sustainable solutions for today's shipping industry, as well as being cost effective.)

https://anemoimarine.com/rotor-sail-technology/

CCIC produces natural fibre breather

The Yangtze River Delta Carbon composites innovation Centre (CCIC, Changzhou, China) has developed a breather material for use in composite manufacture such as vacuum forming, which is made from plant based natural fibres as an alternative to conventional breathers which are produced from fossil fuel derived polyester or polyamide fibres.

The critical function of a breather is to be able to provide a good airflow and allow volatiles to escape during processing, and to provide continuous and uniform pressure on the composite laminate being processed during consolidation and curing. The new Eco-Breather from CCIC performs these tasks to the standards of conventional materials and is compatible with processing temperatures up to 200°C. They do not soften at the elevated temperatures, preserving the structure of the fabric, maximising permeability and allowing them to be re-used in multiple moulding cycles.

A range of non-woven breather fabrics have been developed with areal weights ranging from 340 to 200 g/m^2. The fibres used include jute in combination with lignin for all-natural products or others where the jute is combined with polyester or PLA fibres as hybrid materials.

To date good feedback has been received from trial products supplied to end users over a range of industries including aerospace (Avic Composites, Boeing, Airbus, DLR) and rail operators in China.

The materials are generating quite a bit of interest and was feature on the Airtech stand at the recent JEC show in Paris where it was displayed alongside a biobased vacuum bag. It is likely that the materials will be offered commercially as a 'green' processing ancillary in the very near future.

http://www.ccicyd.com/

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Research News

Carbon Footprint Reduction by Repurposing Fibre-reinforced Plastic (FRP) Composite Waste for Marine Renewable Energy

An interesting twist of the idea of reusing end-of-life wind turbines has been proposed as the basis of the NERC-funded PhD study by QUADRAT, Queen's University Belfast and the University of Aberdeen. https://www.quadrat.ac.uk/ While many ideas are being explored related to recycling wind turbine blades (see REcomp report and papers featured in this digest), an alternative approach has been to use sections of old blades for urban furniture such as bus shelters and bridge supports. The project at Queens, to be supervised by Dr Madjid Karimirad and his colleagues Dr Daniel McPolin from Queen's and Prof Astley Hastings from Aberdeen will take a similar approach but targets renewable energy structures. More specifically, the idea is to use offshore wind turbine blades and other marine structures to construct unique floating solar platforms for nearshore and offshore applications, a very circular approach to the end-of-life problem.

According to Karimirad, 2050, global annual blade waste will reach 2.9 Mt, with 43 Mt of cumulative blade waste. Also, the problem of end-of-life FRP boat disposal and management has taken global proportions with an increasing number of vessels needing management. In the next decade, there will be a considerable number of wind farms reaching their End-of-Service-Life (EoSL) with thousands of tonnes of waste being created and needing to be managed. To mitigate climate change and enhance the decarbonisation agenda, the reuse of marine industries' composite waste can be reused to further develop the marine renewable energy industries, in line with governmental policies and global research objectives.

https://pure.qub.ac.uk/en/persons/madjid-karimirad

Scale-Up new APC funded research programme for sustainable composites in the automotive industry.

October 2024 saw the start of a significant (£6.3 million) project supported by the UK government agency the Advanced Propulsion Centre. The project, SCALE-UP, aims to support the use of composites to achieve lightweighting for battery electric vehicles. The targets are to develop high volume circular manufacturing via four innovations, namely:

- A lighter, sustainable/lower-CO2e, affordable door, as alternative to aluminium benchmark, anticipating future legislation and decarbonisation of aluminium.
- A high-volume, affordable, sustainable carbon fibre wheel breaking the ceiling of state-of-art production volume through deployment of innovative design and manufacturing process.
- Production scale-up of high-performance recycled carbon fibre materials to allow mass production of recycled carbon fibre composite retaining up to 90% of the original performance.
- Digital tools using new modelling methods predicting the feasibility, performance and quality of the final products.

The lead partner for the project is automotive prime, Jaguar Land Rover (JLR) with a number of composites-focused SME's including: -

Carbon ThreeSixty (CTS)- a high-growth, established SME focused on challenging structural composite products. The company is a full design, development and manufacturing partner, with a focus on innovation and technology, taking composite products from initial concept through to volume manufacture in the U.K

Lineat Composites – a start-up/spin out company from the University of Bristol who specialise in converting random, short fibres (including recycled fibres) into aligned product forms, with its patented AFFT technology

iCOMAT – another University of Bristol spin out that is developing tow-sheering technology to allow fibre steering during lay-up allowing non liner pathways and curved component to be produced.

Engenuity Ltd, is a specialist composite engineering company focused on using CAE and material testing to drive design optimization with 30 years' composite engineering experience.

Helicoid Industries brings its patented approach to ply layup optimization called Helicoid, which is a bio-inspired technology for enhanced composite toughness and damage tolerance.

Also involved in the programme is the Bristol Composites Institute, part of the University of Bristol and the largest academic group studying composites in the UK.

The SCALE-UP project will run until the end of September 2027.

For more information, contact Frederic Sicard (fsicard@jaguarlandrover.com)

NCC develop Sustainability Maturity Level (SML) framework within ASCEND project

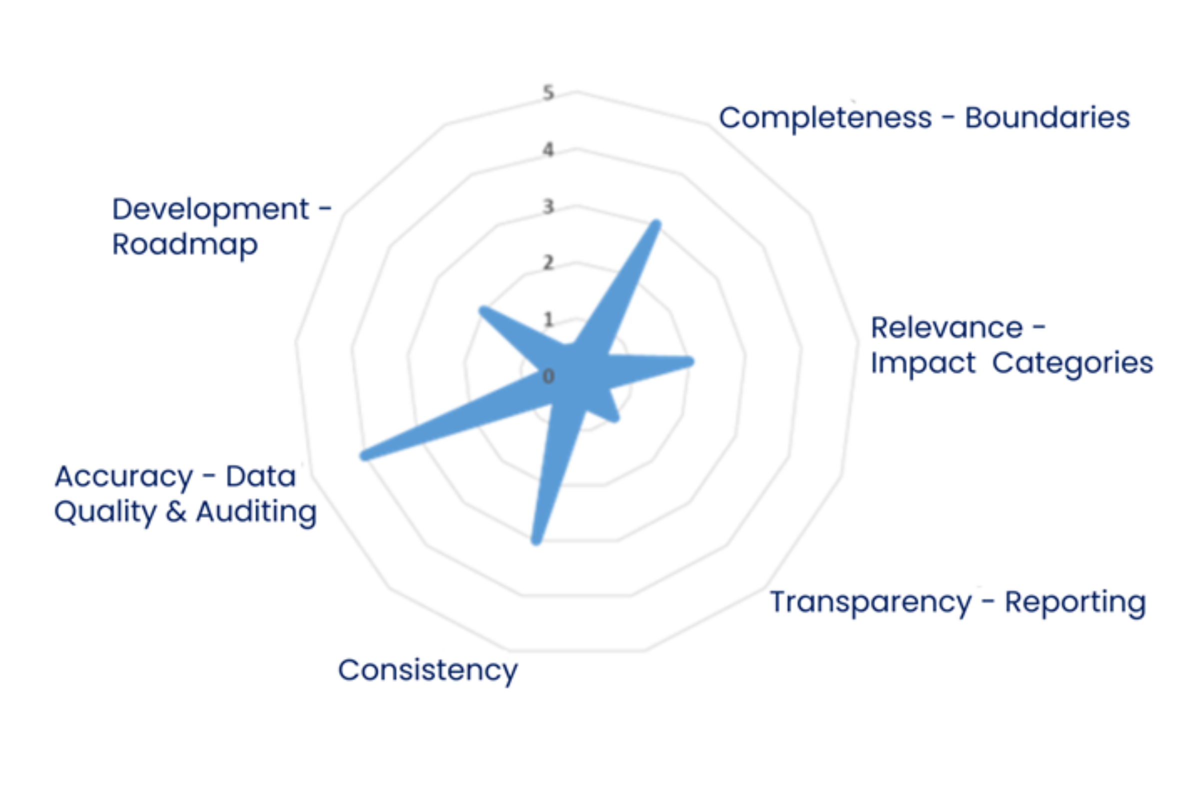
March 2025 saw the closure of the 4 years ASCEND programme in the UK – an ambitious fusion of aerospace and automotive companies looking to develop automated manufacturing technologies that crossed traditional sector boundaries, and which embodied sustainability as a major driver.

The £39.6 million programme, which included 19.6 millions of Government funding brought together a diverse group of companies with complementary capabilities. The programme was led by GKN Aerospace and McLaren Automotive, providing the aerospace and automotive inputs and was coordinated and project manged by Axillium Research who assembled the supporting consortium: Assyst Bullmer (Wakefield) and Loop Technology (Dorchester) in automation systems; Cygnet Texkimp (Cheshire) and Sigmatex (Cheshire) in material processing; Hexcel Composites (Cambridge), Syensqo Composite Materials (Heanor) and Hive Composites (Leicestershire) in advanced materials development; LMAT (Bristol) and FAR-UK (Nottingham) in tooling and manufacturing processes; Des Composites (Sheffield) in design, testing and simulation; Rafinex (London) in optimization software; Airborne (Lambourn) in automated manufacturing cells; and the National Composites Centre (NCC, Bristol) providing research and sustainability framework development.

Much of the programme was focused on developing high-rate deposition technology and rapid curing which is fundamental to the aerospace sector meeting challenging production rates and allows composites potentially to compete with aluminium in a broader range of parts. Efficient self-heated tool, automation of materials handling, rapid curing resin systems all contributed. This has a sustainability benefit by implication in reducing the energy involved in manufacturing. A comprehensive summary of the achievements of the Ascend programme has been recently published by Composites World should readers wish to check up on the details. (https://www.compositesworld.com/articles/ascend-program-completion-transforming-the-uks-high-rate-composite-manufacturing-capability)

A very interesting aspect from a sustainability perspective was the development, by the National Composites Centre, of a standardized framework for environmental assessment in composites manufacturing. Its Sustainability Maturity Level (SML) framework is claimed to transcend existing standards, providing a common language for evaluating environmental impact assessments across the supply chain.

SML addresses six key aspects aligned with the Greenhouse Gas Protocol, including completeness, relevance and transparency, enabling manufacturers to quantify and improve their environmental performance systematically. The framework is intended to move beyond simplified global warming potential metrics to address the complexities of composites manufacturing data sensitivity. The framework implements a comprehensive scoring system that evaluates sustainability across multiple parameters while protecting proprietary processes. NCC believe that their work in the ASCEND programme has demonstrated how empirical assumptions can be integrated into life cycle assessments when direct supply chain data is unavailable. A starburst-style diagram provides decision-makers with a multidimensional view of sustainability performance, rather than reducing environmental impact to a single metric - an approach that may be particularly valuable in contexts where thermal process data and energy consumption metrics require careful handling due to their commercially sensitive nature.



This Starburst Diagram is a representation of the maturity of a product's sustainability data enabling companies to understand the fidelity of sustainability data without the need for sharing sensitive commercial data.

For further information contact James Graham, Chief Engineer - Emerging Markets at National Composites Centre, UK, https://www.nccuk.com/

Conference report

RECOMP 2024 – Reuse and Recycling of Composites

Composites UK ran its regular REComp meeting on the recycling of composites in November 2024. This report highlights many of the presentations from the meeting

The conference started with an overview talk from Jaap van der Woude Chaiman of EUCia's Sustainability Committee. Jaap made the point that composite waste was increasing rapidly across Europe with an estimated 885 ktonnes of thermosetting composites needing disposal in 2025. It is noteworthy that consumption of thermosetting composite materials in the EU exceeded 1700 ktonnes in 2024. Jaap pointed to several barriers currently to recycling.

- The collection, sorting and standardisation of waste
- The absence of waste codes – inhibiting the transfer of waste across borders
- The lack of end-use markets for waste products

- A lack of facilities for end-of-life processing across Europe.

Scale is a key issue coupled with the need to finds ways of making money out of waste. The cement kiln disposal route for glass fibre composites is potentially a good solution, but a cement facility will require a guaranteed supply of a minimum of 10,000 tonnes/year with known and consistent composition to be economic. EUCia have undertaken a full life cycle assessment of the recycling of glass fibre composites in cement kilns which is available on request from EUCia (contact@eucia.eu) while a summary report is available to download from the organisations knowledge hub https://eucia.eu/knowledge-hub

Dr van der Woude also pointed to the Basel convention which establishes standards for the movement of hazardous waste, solid waste and incinerator ash as being a potential problem in addressing composite waste solutions.

Sara Hawi outlined how Airbourne's is exploring routes to minimising scrap and increasing efficiencies in the use of prepreg materials by improving nesting processes and upcycling the skeleton prepreg that remains after an efficient nesting cutting operation. The company is looking to reduce waste by between 50 and 85% by upcycling the skeleton into new products while 100% waste reduction can be achieved if the material is shredded in an online process. The process is at a preliminary stage, but the company predict a reduction in processing costs due to the improved utilisation of materials of just under 40%.

Guy Lawrence from Composites Braiding, https://compositebraiding.com/) proposed an alternative strategy to reducing waste – switching to braiding as a production process. Braided preforms are net shape and do not include waste from trimming and offcuts. Composites Braiding make parts using a thermoplastic/structural fibre commingled yarn with a total scrap rate of 1.2% which is mainly the result of excess yarn left on bobbins, tie-offs and materials pull through (at the start of the braiding process) and minor post consolidation trimming. Attempts to reduce this small waste generation is focusing on avoiding excess yarn left on bobbins by winding in-house and accurate estimating length of yarns required, maximising the number of parts from each braid run (to minimise tie-offs) and improving tool design to reduce the need for trimming post consolidation. The company is also using what little scrap it does produce to make plates by a 3D hot pressing process to consolidate the comingled scrap into products (inserts, spigots, connection nodes and flanges) which are being used in structures alongside the primary parts that generate the scrap. The company is now looking to improve joining techniques for its thermoplastic matrix products using a spin-welding process with the University of Derby.

Guillaume Cledat from Arkema presented an update on the company's Elium resin systems (https://www.arkema.com/global/en/products/product-finder/product-range/incubator/elium_resins/) and their use in the ongoing EU project ZEBRA. Elium resins are a novel new route to thermoplastic composites with attractive manufacturing characteristics and potentially excellent environmental credentials. The material is supplied as a resin system consisting of a liquid polymer diluted in a reactive monomer blend. This low viscosity system can be infused and cured like a conventional thermosetting system but the final product is a thermoplastic. The company produce a range of Elium resin systems that differ in their viscosity, processing temperature and reactivity allowing users to select a product that matches their application and processing needs. The environmental benefits of using Elium are claimed through the ability to recycle and re-use the product at end-of-life, either by melting or remoulding the materials, or by recovering the raw materials via a de-polymerisation processing using thermolysis which can then be re-used in a closed-loop recycling process.

An Elium resin system has been the key component of the EU funded project ZEBRA (Zero wastE Blade ResеArch project) which is studying the potential for circular economy fore wind turbine blades. The ZEBRA project has a broad-based consortium covering the entire circular supply chain including raw materials suppliers (Arkema for the resins and Owens Corning for the glass fibres), CANOE who have developed recycling technologies for acrylic composites by a dissolution process, ENGIE, a wind farm operator, LM Wind Power who make turbine blades, and finally, and critically, SUEZ a multinational waste management company. The project involves producing two full size (>60m) blades and attempting to prove the feasibility of recycling both production waste and end-of-life materials. LM Wind Power and SUEZ have been studying the processes for recycling production waste which consists of consumables, such as vacuum foils, peel-ply, release films, infusion nets, and tubes, which are all thermoplastic (PE/PP, PA) and Elium resin, glass fibres and cut off materials. This waste stream is significant and in a later talk by Tom P Andrews from the NCC, it was estimated to be 29% of the total mass of the manufactured blade. The industry could be dealing with a manufacturing waste stream 23% greater than the end-of-life waste up until 2045 based on current projections. Meanwhile SUEZ has been evaluating the end-of-life options and process stages including cutting up the blades, loading and transport to treatment (recycling) centres and subsequent transport of recycled products. Here the materials include not just the composites (both glass and carbon fibre reinforced Elium) but methacrylate adhesives, balsawood and PET foam cores and paints. For the treatment phase, chemical and mechanical recycling are being considered. The blades are cut into 4m lengths pieces using circular saws and then shredded to 250mm chips. Flotation is used to separate different materials, and the composite fragments are then subjected to secondary shredding to 15 mm chips. The thermolysis of the Elium resins is being explored in a pilot reactor capable of handling 50kg/h. Owens Corning has been re-melting the recovered glass fibres and producing new, high quality, glass fibres from the recovered materials. An overall life cycle assessment for the circular process is being undertaken by ENGIE. The technology all looks feasible, but it is perhaps too early to comment definitively on the economics.

Another company developing a resin system that can be recycled easily is Swancor (https://www.swancor.com/en/). Swancor is a Chinese resin company with a history of producing vinyl ester and epoxy resins. They have produced a new epoxy system which they call EziCiclo. The innovation that the company is promoting is the use of a specially designed liquid chemical mix which they call Cleaver which can be used to break down their epoxy in a chemical reaction/solvolysis at the end-of-life recycling phase. It appears that Cleaver works by creating a scission in the epoxy chain and does not attempt to reverse the original cure reaction of the resin. The process conditions for the degradation are claimed to be relatively mild (3-5 hours at 140°C). It is claimed that the process will allow full recovery of the fibres, the oligomers from the degraded epoxy can be reused, either to make more epoxy or for use in other resin formulations, and that the Cleaver mix can be recovered. The company gave no indication of the composition of Cleaver, nor on how it can be separated from the resin degradation products. Currently Swancor have built a pilot plant for this resin system in Taiwan and are trialling the EzCiclo resin in a number of application areas. It was stated that the resin would not be suitable for use in aggressive chemical environments and is probably not suited for use in aerospace. Nevertheless, this might be a technology worth keeping an eye on in the coming years.

Chemical recycling is also the technology on offer from Uplift 360 (https://www.uplift360.tech/). This is a start-up company with links to Imperial College in London. The company has two sustainable technology areas it is developing. One CemR is a chemical process for removing polymer resins from all reinforcing fibres, including glass, carbon, aramid and UHMWPE. The company is very careful not to give away any details of its proprietary process, but it claims to be able to remove resin at room temperature at low cost and with a low CO_2 equivalence. A focus of the company has been to provide solutions for the recycling of military grade materials, especially body armour and the low temperature process is particularly useful for reclaiming UHMWPE (e.g. Spectra/Dyneema) fibres from old body armour as any process temperature above 90°C destroys the ballistic protection properties. While the process is currently lab-based, they estimate that it could provide a low energy fibre reclamation process competitive with pyrolysis and microwave processing. A pilot line to demonstrate the process is planned for late 2025.

The second technology is identified as RENEW and is a process to regenerate high quality aramid fibres from waste streams. The process is designed to take fibres such as Kevlar that have been recovered from the original composite application in whatever from (intact fabrics, chopped fibres etc), and dissolve those fibres in a proprietary solution. The fibres are not cleaved at all in this process, but the polymer chains are separated. The concentration of this solution is increased to a critical level at which it is feasible to spin new highly orientated continuous fibres. It should be noted that this process does not use the concentrated sulphuric acid that is the standard solvent used in the original process for making Kevlar. The Uplift 360 predictions indicate that the RENEW process will reduce carbon (equivalent) emissions to produce new fibres by up to 66% relative to virgin fibre production. A pilot line for this process is expected to up and running in-house in early 2025.

John Evans from Warwick Manufacturing Group, (https://warwick.ac.uk/fac/sci/wmg/) talked about some of the practical considerations in using recycled carbon fibres obtained via a range of recycling processes. WMG is part of a research consortium ERGO-R (Emissions Reduction via Generative Optimization and Recycling) which also consists of auto makers Jaguar Land Rover, BM Longworth who have developed the pressolysis recycling method, auto parts producer Gestamp, automation and tooling company, Expert Technologies and Icomat, a spin out from Bristol University who specialise in producing orientated fibre forms from discontinuous fibres.

The ERGO-R consortium is looking at three development streams to reduce the overall carbon footprint and create a circular economy for composites in the auto sector.

One steam is looking at recovering continuous carbon fibre from wound components, rewinding the fibres and making UD rCF tape. Another stream is looking at recovering chopped carbon fibres from end-of-life components and using these materials in an rCF -SMC product. A third stream is looking at recovering fibres from waste prepreg, again taking the fibres to an SMC product.

The role of WMG is to evaluate the performance of the recycled fibres and their potential for re-use. Considerable effort is being placed on studying the surface condition of fibres from different sources and after different recovery processes. A major issue with recycled short fibres is not just the surface properties but the physical nature of the materials which tend to be fluffy with a high loft and very difficult to process in a conventional SMC machine. Indeed, a bespoke fibre distribution system has been incorporated into the WMG SMC compounding line using a fish tail arrangement to encourage lateral flow of fibres and a variable speed picker roller to break up clumps of fibres. Next steps in the project for WMG are to fully characterise the candidate material properties for virgin and recovered materials, improve the carbon fibre delivery line of the compounding stage and to develop an LCA model to quantify energy requirements across the entire process.

Gen2Plank (https://gen2plank.com/) is a relatively new UK business that is trying to develop a market for recycled glass fibre and glass fibre composites. The company is actively trying to source glass fibre waste for composite manufacturing companies- (scrap fabrics, edge trims, creel waste, nesting waste, end of roll fibres) and it converts with material into chopped fibres 3-12mm in length for use in extrusions and moulding compounds. The second range of products are extrusions based on PP or HDPE thermoplastics filled with regrind produced from waste composite parts. The extrusion process has been adapted somewhat to cope with the abrasive nature of the reground GRP. The target market for these materials are mainly wood based products and existing composite wood replacements. Examples would be gravelling boards, scaffolding boards, acoustic fencing, kickboard, fence posts and pontoons and decking. The material works well in these applications as the reground composite still exhibits good stiffness and strength. The company hopes to buy scrap material form producers, convert into usable components and where possible sell these back to the original producers to use alongside their products. The key limitation on the business of Gen2Plank seems to be the availability of sufficient waste material. Currently their output is about 50 tonnes/month, so they are looking for an increased supply in order to grow.

Sustainable Extricko (https://extricko.com/) is another new company with interesting ideas on reusing recycled materials in their case the company has developed a biotech upgrade route for Terephthalic acid products which they reclaim for recycling marine products such as PET sails. They are using the Deecom (pressolysis) process developed by BM Longworth to break down sail materials and legacy composites from the marine industry and generate TPA. Old boats made from legacy composites are an increasing problem and with landfill costs of £15/kg for composite waste, a significant number of old boats are simply dumped and abandoned on our coasts and waterways. The TPA material recovered is also not particularly valuable at approx. £0.5/kg (with E glass waste at about £0.75/kg). However Sustainable Extricko have pioneered a process to upvalue the TPA waste stream using metabolic processes (fermentation) to produce vanillin which is used as the backbone materials for recyclable epoxies. The market for vanillin is predicted to grow to 200,000 tonnes/year suggesting a good market for plastic materials recycled in this way.

An update on progress of the Deecom process, referenced in the Sustainable Extricko report was provided in a presentation written by Jen Hills of BM Longworth (https://www.bmlongworth.com/). This also referred to the generation of resin by products when the process is used to break down scrap composites. The high pressure and steam-based process converts plastics such as nylon into caprolactam, polyesters in terephthalic acid and epoxy systems into bisphenol-A. Scott Bader in the UK have been using TPA generated via the Deecom process from waste polyester resin-based composites and using it to generate new unsaturated polyester resins. The company's workhorse resin, Crystic 272 was produced using various fractions (up to 34%) of recycled/recovered TPA with virgin materials. Mechanical properties of the resins seemed very similar to the virgin materials (perhaps a slight drop in strain to failure) but the resins made with recovered TPA were discoloured with a brown tinge. However, when used for making real parts which typically are equipped with a surface gelcoat, this made no difference to the appearance of the final product (tested using a white gel coat).

The Deecom process is gaining a lot of traction particularly with the automotive industry and BM Longworth are gradually increasing the batch size of their reactors to move from 1kg to 100kg batches and are looking for commercialisation partners to got to the next step of of 1 tonne/day.

While there are increasing numbers of technical solutions to breaking down composites into fibres and resins as part of a recycling process, the overall recycling operation has many other component operations. Suez Group (https://www.suez.com/en/uk)are a major international company that specialises in refuse, and recycling and recovery. Thomas Merry from Suez UK outlined the various stages that they are involved with and have experience in following five years of dealing with scrap wind turbines. In 2023 for example the company was responsible for dismantling the Treilles wind farm with 16 wind turbines and requiring disposal of 96 wind turbine blades. Suez operate across the entire spectrum of materials and components in the wind farm including towers generators, foundations as well as the composite turbine blades. Overall, they achieved recycling and recovery up to 98% with 2% disposed of (land fill).

The Suez approach focused on mechanical recycling of the composite components rather than on any process to separate fibres and resins. This involved an initial stage on site of cutting up blades using circular saws into 4-5 m sections. This required dust suppression, with water jetting and ground protection. The sectioned parts are then transported (large trucks) to a processing facility where a twin shaft slow-speed shredder is used to take the sections usually 4-10 m long fed by a grab feeder. The low-speed shaft pulls materials though with minimal dust and shreds the composite into small pieces 25-30 cm in length. The second processing stage involves a hammer mill to break down the composite into even smaller pieces between 5-20 mm with filtration systems and closed bagging again to minimise exposure to dust.

The resulting reground materials is then suitable for use as fillers in BMC production and results in very levels of recycling. The moulding compounds are often used for products such as parking pavements and railway pavements. Suez points to unknown composition of end-of-life composites is a challenge and new input materials need to be tested.

Interestingly, Merry re-iterated that the use of Cement Kilns as a route for disposal of turbine blades requires a tonnage of 10,000 tonnes/year with a fixed composition to be economic.

Gen2 Carbon (https://www.gen2carbon.com/) gave an update on their efforts to recycle carbon fibre in the UK. The company is scaling up its UK facilities to allow it to supply 2000 tonnes/year of recycled carbon fibre products.

It has also demonstrated improvements to its pyrolysis technology (improved gas treatment) which reduces the carbon footprint associated with the recycling to 1.1kgCo2e/Kg. The optimised pyrolysis process also allows for thick CFRP laminates to be use directly without shredding. A full-scale plant embodying these improvements and capable of handling 1000 tonnes/year will be operational in the UK this year (2025). Gen 2 converts recovered carbon fibres into new intermediatory product forms such as needle punched non-wovens for producing new composites parts as well as supplying the demand for short fibres in moulding compounds. They predict that the market for recycled carbon fibres which is currently dominated by compounding the fibres (>95%) will change and progressively involve more use in clean energy applications and composites (laminates not moulding compounds) with these sectors taking about 20% of the market by 2032. The company predicts that global demand for carbon fibres is predicted to exceed 400,000 tonnes/annum by 2032, with at least 300,000 tonnes in the form of continuous virgin fibre. The demand for the remaining 100,000 tonnes is largely made up of short fibre applications with both virgin and recycled fibres competing. The needle punched non-wovens from Gen 2 (G-Tex M) are made from 100% recycled fibres and can be used as dry fabrics, or prepregs and a range G-Tex TM uses recycled fibres with thermoplastic fibres. The products can also be combined with natural fibres if required.

A different approach to utilising recycled carbon fibres to make new composite parts is offered by UK start-up Lineat (https://lineat.co.uk/). The company is a spin out from Bristol University and has developed a carding process that signs short fibres as produced by various reclamation processes into highly aligned tape products. When these tapes are infused with resin it is possible to achieve volume fractions of 40% and normalised data compared with virgin fibre laminates shows excellent modulus retention (over 90%) and respectable strength properties (54% in tension). The company has been working with SHD Composites (https://shdcomposites.com/) who have produced prepregs from the materials. Currently Lineat are prodcuing100mm wide tapes with 35-50 gsm areal weight and by 2026 they are looking to manufacture aligned tow materials 2-4 mm wide with a binder to protect and retain orientation. The company is also increasing its production capacity with expansion of its pilot line due in 2025 to raise production to 1 tonne/year with gradual expansion such that by 2028 they are projecting 100 tonnes of product based on recycled fibres. The advantages of the fibre tapes is not just their low carbon footprint with the recycled fibres, but the formability of the tapes is significantly improved relative to continuous fibre materials and it is now possible to commingle the carbon fibres with polyamide to create thermoplastic precursor tapes.

PRF Composites (https://www.prfcomposites.com/) reported on its recently launched prepreg product REEPREP that uses carbon fibre waste obtained from kit cutting and trimming which would otherwise has gone to landfill to create a random fibre prepreg system suitable for use in aircraft interiors. The materials have an extended out-life to reduce freezer needs and the resin is the company's RP570eXpress cure systems for rapid processing. The company can supply the material in 4mm thick sheets and believes that one thick sheet of REEPREG can replace 4 standard fabric prepreg layers in aircraft interior applications.

Recycling of continuous fibres is extremely challenging from most composite parts, but it has been shown to be feasible if the source part is a filament wound vessel. Some estimates suggest that wound pressure vessels could constitute 15% of the global market for carbon fibre in 2025 making this a significant resource for recycling in the coming years. In 2022 A consortium of the National Composites Centre (NCC https://www.nccuk.com/), BM Longworth (https://www.bmlongworth.com/) and Cygnet Texkimp (https://cygnet-texkimp.com/) demonstrated that continuous carbon fibre could be recovered from filament would pressure vessels using the Deecom process and subsequently used to re-wind a new vessel. This study did not seek to demonstrate or quantify the performance of such a pressure vessel made from continuous rCF . The NCC along with Bristol University is however continuing to explore this area in order to understand what is required to convert reclaimed continuous fibre into prepreg, how to manufacture that prepreg and what the properties would be in the final composite. One of their observations to date is that the generation of 'clean' recycled carbon fibres is not necessarily idea for the unwinding process and the material is easier to deal with when there is heavy char and residual resin on the fibres. Recognising this allows less energy to be used in the reclamation stage and makes handling easier. It does however present some difficulties in a tow to preform conversion stage and at that point char removal and resizing of the tows may be needed to facilitate tow spreading during prepreg production. The work is ongoing and measurements of composites properties with optimised surface treatments are awaited. NCC is looking for further collaborators to work on this programme.

As mentioned at the early part of this report, Tom P Andrews from NCC reported on studies of the overall waste issues associated with wind turbine blade manufacture. The analysis by NCC of the waste generated during the manufacturing process suggests that this is equivalent to 29% of the total weight of the blades which will create a bigger waste problem than end of life blades themselves until 2045. The manufacturing waste is complex and made up of off-cuts, packaging, infusion consumables, core materials, backing materials, some cured materials some uncured. NCC has been examining how this complex waste stream can be converted back into new products following various processes with glass fibre regrind being used as fillers, infusion consumables being transformed into mixed plastic granules for compression moulding. The problem envisaged however is not a technical issue with the recycling processes, but a logistical and economic barrier. The waste stream is not big enough to support a dedicated recycling supply chain meaning that multiple waste processors with differing specialities would need to incorporate this waste stream alongside waste from other (composites) sources.

The complexity of the local infrastructure involved in general waste recycling in the UK was a topic of the final talk from SUEZ. The cross sectorial nature of the business (i.e. the sources of the waste material) becomes apparent when areas such as construction and demolition, municipal, automotive are considered. Achieving circularity within composites is challenging. It is evident that the advantages that composites offer in terms of bespoke tailoring of a composite for specific uses becomes a problem at end of life as the variability within the materials is enormous. It is a concern that at present there are on effective drivers for using recycled materials and that the cost of processing is often higher than purchasing virgin material. While the industry is swell stocked with design engineers and academics, it is light on end users on recycled materials and has very few waste managers.

SUEZ suggests that materials passports would help in the end-of-life stage of a component or part as the waste companies would know what they are handling. Legislation such as the Emission Trading Scheme (ETS) and Extended Producer Responsibility (EPR) will change behaviour although in many cases raising costs if the quantity of waste cannot be reduced. Ultimately however the view of Suez is that cross value chain collaboration is key to solving these complex problems.

Recent journal articles

A selection of recent articles published in the open literature that related to the theme of sustainability and composite materials. In this issue of the Digest, we have focused on the themes of life cycle assessment, recycling technology and bio composites and fibres.

Life cycle assessment

A new multi-objective optimisation model for an integrated energy system based on life-cycle composite technical, economic and environmental indices

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Energy Conversion and Management
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Abstract
Integrated energy systems offer higher energy, environmental, and economic benefits than conventional separate systems. To comprehensively assess the performance of the integrated energy systems, applying life cycle assessment methods, the life-cycle primary energy saving ratio, renewable energy supply ratio, and electricity supply ratio are aggregated into a composite technical index, the life-cycle carbon dioxide emissions reduction ratio and life-cycle sulphur dioxide emissions reduction ratio are aggregated into a composite environmental index, and the life-cycle annual total costs and life-cycle annual costs saving ratio are aggregated into a composite economic index to fully assess the economic, technical, and environmental performances of the system. A new multi-objective optimization model is constructed with composite technical, economic, and environmental indices as objective functions. Optimization results indicate that under the optimal configuration, the composite technical, economic, and environmental indices of the system reach 0.894, 0.909, and 0.915. Compared to the reference system, the highest life-cycle primary energy saving ratio, life-cycle annual costs saving ratio, life-cycle carbon dioxide emissions reduction ratio, and life-cycle sulphur dioxide emissions reduction ratio are 31.20 %, 22.13 %, 52.70 %, and 88.90 %, respectively. The lowest life-cycle annual total costs are 67750.47 $, and the highest renewable energy supply ratio and electricity supply ratio are 59.22 % and 91.70 %, respectively. The multi-objective optimization model presented in this work offers a different viewpoint for comprehensively evaluating the technical, economic, and environmental performances of the integrated energy systems, which is predicted to guide the design of the integrated energy systems.

Data quality and uncertainty assessment of life cycle inventory data for composites

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Composites Part B 292 (2025) 112021
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Abstract
Life Cycle Assessment (LCA) is an increasingly common method for assessing the environmental impact of products. For both novel and established composite materials, the quality and uncertainty of LCA data varies across sources, and there is a particular paucity of data for novel materials which can inhibit their adoption in favour of more established materials. After reviewing available LCA datasets for the

constituent materials of composites, this study analyses life cycle greenhouse gas emissions datasets for a sample of materials – glass fibre, carbon fibre, and epoxide resin – and assesses the data quality and uncertainty across their sources. The results revealed major discrepancies in the datasets to produce composites are summarised and presented via a colour-coded visual to aid interpretation and transparently select the most appropriate dataset for the LCA. The study highlights the importance of giving more attention to composite datasets in the future and advises that the process of selecting the most representative values should be approached with caution

End-of-life wind turbine blade management across energy transition: A life cycle analysis

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Resources, Conservation & Recycling 213 (2025) 108008
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Abstract
The growing demand for renewable energy has led to a significant increase in the deployment of wind turbines globally. As these turbines reach the end of their operational lives, managing the waste generated from their composite blades presents environmental challenges. By employing life cycle analysis (LCA), the research assesses the environmental impacts of four major disposal scenarios - landfilling, mechanical recycling, pyrolysis, and solvolysis – in the context of Australia's ongoing energy transition from fossil fuels to renewables. This innovation provides a deeper insight into how shifting energy sources soon influence the environmental performance of recycling and disposal methods, offering guidance for more sustainable waste management strategies. According to the results, solvolysis shows the most positive impacts on the environment (single score factor ≈ -500 MPt) owing to the potential to produce recovered carbon fibre. Pyrolysis is the next environmentally friendly method, with a slight difference. Mechanical recycling appears to have comparable results to these methods; however the quality of recycled fibres has significant differences. Sensitivity analysis also underscores the critical role of electricity usage in the environmental impacts by 65 % and 86 % share of human health damage assessment in solvolysis and pyrolysis, advocating for its reduction or transition to renewable sources. Finally, the study shows that transitioning to renewable electricity in recycling processes revealed a potential reduction in the environmental impact by around 33–85 %, depending on the end-of-life treatment scenarios. There is also an opportunity to utilise both pyrolysis and solvolysis methods, as their environmental impacts are comparable when renewable resources are used. As we delve into innovative recycling approaches for wind turbine blades, there arises a hopeful prospect for a more sustainable future where conscientious material management contributes to environmental well-being.

Environmental and economic assessment of mechanical recycling of end-of-life wind turbine blades into rebars and comparison with conventional disposal routes

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Composites: PartA190(2025)108711
https://10.1016/j.compositesa2025.108711

Abstract
As the decommissioning of wind turbine blades begins, managing thermoset glass fibre-reinforced polymer (GFRP) waste from end-of-life blades presents a critical challenge. This study evaluates four disposal methods for blade waste—landfill, incineration, co-processing, and mechanical recycling—using life cycle assessments to identify the most sustainable option. Unlike conventional GFRP grinding into short fibres and fine powders, the recycling method in this study repurposes blade waste into high-aspect-ratio recyclates to substitute virgin GFRP rebars, thereby preserving the composite integrity and simultaneously adding value to GFRP mechanical recycling. Results reveal that mechanical recycling could offer notable technical, environmental, and economic advantages upon industrialization. Specifically, 1 kg of recycled GFRP rebars can effectively replace 0.98 kg of virgin GFRP rebars. At a processing scale of 100 kg/h, recycling 1 kg of GFRP waste could notably avoid about 2.4 kg of CO_2 emissions, and if considering revenues from the sale of recycled rebar (priced at 2 €/kg), the recycling fee could drop to 0.15 €/kg. This cost is lower than gates fees for landfilling, incineration, and cement kiln routes (~0.2 €/kg), which would incentivize a shift from landfilling or incineration toward repurposing, thus fostering sustainable resource utilization and advancing the circular economy potential of decommissioned turbine blades.

Material Selection of Tanks for Storage and Transport of Liquid Organic Hydrogen Carriers: A Lightweight and Lifecycle Assessment Comparative Study of Metal, Polymer, and Composite Alternatives

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Energy Technology2025, 13, 2401297
https://doi:10.1002/ente.202401297

Abstract
Liquid organic hydrogen carriers (LOHCs) are a key technology for a decarbonized industrial production. A comparative study on the material selection of tanks for the storage and transport of LOHC is

presented. Three material classes are compared: metals (steel), polymers (thermoplastic), and composites (glass fibre-reinforced plastic). Considering existing standards, two sizes of tanks (150 and 700m3) are dimensioned based on scenario requirements of loading and environmental conditions specific to the transport of the LOHC benzyl toluene. Thermoplastic tanks fulfilling the requirements are significantly heavier even than steel tanks, while the lowest tank mass can be achieved using glass fibre-reinforced plastics (GFRP). Concerning GFRP: 1) a resin with suitable chemical resistance is preferable over a thermoplastic lining; 2) a construction geometry with a flat bottom and curved roof improves lightweight; and 3) woven roving yields lighter tanks than chopped strand mats. Lifecycle assessment for mobile and stationary tanks indicates that GFRP offers the smallest CO2 emissions for mobile tanks due to fuel savings, while steel is preferable for stationary tanks. In this regard, advancements in circularity and bio-based raw materials for composites can improve GFRP's ecological balance for LOHC applications.

Recycling technology

A novel green mechanical recycling strategy for carbon fibre-reinforced polymer laminates based on the glass transition principle

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Composites Science and Technology 260 (2025) 110983
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Abstract
A novel glass transition-assisted mechanical delamination process was developed for the environmentally friendly and high-value recovery of carbon fibre reinforced polymer (CFRP) laminates. When heated to 250–350 °C for 5–15 min in an air atmosphere, the resin matrix quickly transitioned from a rigid glassy state to a flexible rubbery state, making the CFRP laminates soft and bendable. Simultaneously, the shear strength of the resin in the rubbery state decreased significantly to 0.35%–4.58 % of its original value. The softened CFRP laminates could be easily bent by a bending machine. Excessive bending deformation caused the resin between adjacent carbon fibre (CF) sheets to tear and de-bond, resulting in delamination of the laminates into individual CF sheets. Upon cooling to the glassy state, the shear strength of the resin was restored to 87.59%–98.55 % of its original value. This mild glass transition treatment did not significantly affect the mechanical properties of the CF. The resulting monolayer CF sheets could be easily cut into thin slices or filaments of uniform size and hot- pressed into new CFRP plates. The flexural and tensile strengths of the refabricated CFRP plates were approximately 58.98%–82.71 % and 54.55%–87.79 % of those of the original laminates, respectively.

Effects of constituent materials on resin separation from CFRP by electrical treatment

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Materials letters 381(2025)137786
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Abstract
Carbon fibre-reinforced plastics (CFRP) waste is typically recycled through feedstock recycling, which recovers carbon fibres from CFRP by employing an aggressive thermal process to break down the resin matrix. However, this process faces challenges, as oxygen gas during heating has difficulty penetrating dense composites, resulting in low-quality recovered carbon fibres (rCFs). It was demonstrated that high-grade rCFs could be obtained by combining the thermal process with a short period of electrical treatment (ET). In this study, we investigated the effects of fibre orientation and matrix type on the separation efficiency (SE) by ET using uni-directional (UD-) and plain-weave (PW-) CFRPs, as well as twill-weave CFRTP. The results indicated that the SE value of UD-CFRP was nearly equal to that of PW-CFRP, suggesting that fibre orientation did not significantly affect resin removal. In contrast, the SE value of CFRTP was four times higher than that of CFRPs at a low constant voltage, as the separation resistance of the matrix decreased owing to thermal-oxidative degradation caused by moderate temperatures resulting from Joule heat and oxygen generated on the anode side.

Efficient degradation and recycling of carbon fibre reinforced epoxy composite wastes under mild conditions by constructing dual dynamic covalent networks

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Polymer Degradation and Stability, 2025 111102
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Abstract
The recycling of high-value cores from epoxy composite wastes is critical for environmental protection and sustainable development. However, the efficient degradation of epoxy resin under mild conditions remains a significant challenge due to its stable 3D crosslinked network structure. Herein, we propose an innovative strategy utilizing dual dynamic covalent bonds to achieve efficient, safe, and controlled degradation of epoxy resins in solvents. Specifically, a series of epoxy resins D_xBV_y/NMA containing dual dynamic covalent bonds (imine and ester bonds) were prepared by combining the bio-based epoxy

monomer BV-EP, which contains imine bonds, with the commercial epoxy monomer DGEBA, followed by curing with nadic methyl anhydride (NMA). The results demonstrate that the incorporation of BV-EP maintains excellent thermomechanical properties and thermal stability in D_xBV_y/NMA systems. Remarkably, D_5BV_5/NMA achieved 100 % degradation in aminoethanol at 160 °C within just 25 min, indicating an extraordinarily high degradation efficiency. The degradation mechanism was elucidated using FTIR and ^{1}H NMR, revealing that both imine and ester bonds in the crosslinked structure can undergo exchange reactions with amino groups in aminoethanol. Importantly, the carbon fibre reinforced epoxy composite CF-D_5BV_5/NMA was also efficiently degraded in this system, allowing for recycling through a straightforward post-processing step, yielding virtually non-destructive carbon fibres (CF) and high-purity monomer 9,9-bis(4-aminophenyl) fluorene (BAPF). This work introduces a novel approach for the efficient and lossless recycling of CF from the carbon fibre reinforced epoxy composite wastes, thereby contributing to the sustainable development of the epoxy resin field.

Structural upcycling of thermoplastic composite recyclates through continuous fibre printed preforms

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Polymer Composites 2025, 1-13
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Abstract
To enhance the structural characteristics of recycled composites, this paper demonstrates a process that incorporates additively manufactured continuous fibre preforms in a geometry that is compression moulded with recyclates. The continuous fibre preform is designed to serve as the primary structural reinforcement whereas the recycled material serves as a secondary reinforcement in the composite part. Continuous fibre preforms were manufactured with 60% by volume of carbon fibre-reinforced Polyether Ether Ketone (PEEK) using Additive Fusion Technology (AFT) with account for reshaping during the moulding process and ensure the continuous fibre is located where required. The performance of the upcycled composite pin bracket was evaluated by analysing the onset of failure and the ultimate load under tensile loading of the bracket. The results demonstrated the potential of this upcycling method to enhance the structural characteristics of recycled composite materials and compensate for the loss of structural characteristics associated with fibre attrition.

Recycling carbon fibres by solvolysis: Effects of porosity and process parameters

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Composites Part A: Applied Science and Manufacturing, Volume 190, March 2025, 108667
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Abstract
Chemical recycling, also known as solvolysis, is one of the most promising strategies for recycling fibre-reinforced thermosetting composite materials, due to its ability to recover nearly undamaged fibres for reuse. This approach is particularly appealing for carbon fibres, which have a high environmental production cost. However, there is a lack of understanding of the modelling and optimization of reaction conditions that would be required for the widespread use of this technology. This study explores how different solvolysis conditions and manufacturing-induced porosity influence the efficiency of the solvolysis process in epoxy-based carbon fibre composites. The goal is to enhance understanding of the process to enable more efficient material recovery. A comprehensive series of experiments was conducted, varying solvolysis process parameters, fibre volume fractions in the composites, and solvent concentrations. The effects of voids within the composite materials on solvolysis efficiency were investigated through numerical analysis, incorporating an anisotropic diffusion coefficient into the model. The results reveal that the quality of the material significantly affects the overall rate of solvolysis. The findings suggest that understanding the role of voids and the relationship between composite quality and solvolysis can improve the efficiency of composite recycling, contributing to more sustainable lifecycle management of these materials.

Biocomposites and fibres

Lignin-derived carbon fibres: A green path from biomass to advanced materials

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Abstract
Carbon fibres (CFs) with notable comprehensive properties, such as light weight, high specific strength, and stiffness, have garnered considerable interest in both academic and industrial fields due to their diverse and advanced applications. However, the commonly utilized precursors, such as polyacrylonitrile

and pitch, exhibit a lack of environmental sustainability, and their costs are heavily reliant on fluctuating petroleum prices. To meet the substantial market demand for CFs, significant efforts have been made to develop cost-effective and sustainable CFs derived from biomass. Lignin, the most abundant polyphenolic compound in nature, is emerging as a promising precursor which is well-suited to produce CFs due to its renewable nature, low cost, high carbon content, and aromatic structures. Nevertheless, most lignin raw materials are currently derived from pulping and biorefining industrial by-products, which are diverse and heterogeneous in nature, restricting the industrialization of lignin-derived CFs. This review classifies fossil-derived and biomass-derived CFs, starting from the sources and chemical structures of raw lignin, and outlines the preparation methods linked to the performance of lignin-derived CFs. A comprehensive discussion is presented on the relationship between the structural characteristics of lignin, spinning preparation, and structure-morphology-property of lignin derived CFs. Additionally, the potential applications of these materials in various domains, including energy, catalysis, composites, and other advanced products, are also described with the objective of spotlighting the unique merits of lignin. Finally, the current challenges faced and prospects for the advancement of lignin-derived CFs are proposed.

Decreasing the environmental impact of carbon fibre production via microwave carbonisation enabled by self-assembled nanostructured coatings

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Advanced Composites and Hybrid Materials (2024) 7:39
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Abstract
The use of carbon fibre (CF)-based composites is of growing global importance due to their application in high-end sectors such as aerospace, automotive, construction, sports and leisure amongst others. However, their current high production cost, high carbon footprint and reduced production capability limit their use to high-performance and luxury applications. Approximately 50% of the total cost of CF production is due to the thermal conversion of polyacrylonitrile (PAN) precursor fibre (PF) to CF as it involves the use of high energy consumption and low heating efficiency in large furnaces. Looking at this scenario, this study proposes in the present study to use microwave (MW) heating to convert PF to CF. This is scientifically and technologically challenging since PF does not absorb microwave energy. While MW plasma has been utilised to carbonise fibres, it is the high temperature from the plasma that does the carbonisation and not the MW absorption of the fibres. Therefore, for the first time, this research shows how carbonisation temperatures of >1000 °C can be reached in a matter of seconds

using a novel microwave (MW) susceptor nanocoating methodology developed via a layer-by-layer assembly of multiwall carbon nanotubes (MWCNTs) on the PF surface. Remarkably, these CFs can be produced in an inexpensive domestic microwave and exhibit mechanical performance equivalent to CF produced using conventional heating. Additionally, this study provides a life cycle and environmental impact analysis which shows that MW heating reduces the energy demand and environmental impact of lignin-based CF production by up to 66.8% and 69.5%, respectively.

Comparing flax fibre/biopolymer woven composites with carbon fibre enhanced, partially green alternatives: Mechanical performance versus sustainability

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Abstract
Natural fibre/biopolymer matrix, known as green/fully sustainable, composites are emerging as alternatives to non-sustainable or partially sustainable composites, while ideally targeting similar material properties. This study first characterizes and compares thermo-mechanical performance of novel green composites made of Flax Fibre (FF) reinforced in thermosetting bio resin options, fabricated via two different manufacturing techniques. Namely, flax fibre-reinforced bio epoxy (Bio epoxy/35 %FF) woven bio composite was fabricated via vacuum infusion, while FF-reinforced (bio) Polyfurfuryl Alcohol (PFA) woven prepreg was consolidated through vacuum bagging (PFA/45 %FF) as the second option. Additionally, for design comparisons, Carbon Fibre (CF)-PFA (PFA/ 60 %CF), as well as hybrid FF-CF-based PFA (PFA/45 %FF-15 %CF) samples were fabricated to understand the performance difference between the green composite options versus the latter partially sustainable or hybrid design alternatives. Results demonstrated that, despite their required different manufacturing techniques, Bio epoxy/ 35 %FF and PFA/60 %FF provided very comparable density, tensile strength, and impact properties. Both bio composites outperformed the CF-added designs under damping property (by 150 %) at low frequency and specific energy absorption property (by 37 %), thanks to the unique micro-architecture of flax fibre that enhances deformation energy dissipation through inter- and intra-cell walls friction and internal failure mechanisms. However, incorporating 15 % of CF into PFA/FF (i.e. hybrid PFA/45 %FF-15 %CF) increased the tensile strength by 130 % and the tensile modulus by 90 %, while keeping a similar impact energy absorption as the fully flax based bio composite options. The fully CF-based PFA (as a least sustainable option among the tested samples)
revealed the highest tensile properties, hardness, and thermal stability, clearly highlighting the necessity for formal trade-off analyses during design.

Mechanical performance of rattan cane wood fibre–reinforced polymer at high temperatures

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Abstract
The growing applications of natural fibres and green composites in manufacturing various products have expanded the search for more functional and sustainable fibres. Due to availability, cost, and environmental concerns, there is a continued effort to seek more natural fibres that can effectively substitute synthetic ones. The high resilience quality observed in cane wood sticks spurred interest in their potential for fibre production and use in composites. However, one drawback of using natural fibre in composites is its poor temperature tolerance. This article seeks to study the thermal behaviour of rattan cane wood fibre–reinforced plastic under elevated temperatures. The high-temperature analysis was conducted by heating the produced cane wood fibre/polyester composite sample from 50°C to 400°C and taking weight measurements at 50°C intervals. At 200°C, the composite began degrading, with evidence of a 4% mass reduction. A further increase to 250°C resulted in a mass reduction of 9.1%. Additionally, a mass reduction of 10.5% was observed when the temperature was increased to 300°C. Subsequently, as the temperature was increased to 350°C and 400°C, mass reductions of 31.6% and 67.6%, respectively, were observed. The structural integrity of the material was also compromised, as evidenced by the presence of cracks, charring, and loss of strength. This implies that the composite is thermally unstable at such high temperatures

Mechanical properties of hemp fibre-reinforced thermoset and thermoplastic polymer composites: A comprehensive review

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Abstract
Hemp fibres have mechanical characteristics like those of synthetic fibres, which makes them an attractive material for producing environmentally friendly composites. Hemp fibres have excellent mechanical properties and a unique hydrophilicity, requiring for extra attention in composite formulations. Hemp fibres are a very versatile vegetable fibre that is frequently utilized in structural composites. In addition, hemp has shown potential in a variety of other fields, including as sports goods, building, and lighter materials. The present article aims to give a comprehensive summary of the status

of sophisticated studies in hemp fibre reinforced composites at present time. The most important research on thermoset and thermoplastic materials reinforced with hemp fibre is compiled and discussed in this publication. This document also provides an overview of the primary attributes of hemp fibres, talks about how to develop these attributes chemically, explains how to create and describe hemp fibre composites, and identifies areas that need more research. In summary, this study ends with several important recommendations and future approaches that draw attention to the issues that require further investigation and potential industrialisation of composites.

A review on effect of nanoparticle addition on thermal behavior of natural fibre–reinforced composites

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Abstract
Always, the environment in which humans live needs to be saved from various calamities, and one such calamity is usage of petroleum-based products. Petroleum-based products are derived from various synthetic processes that adversely affect the environment. It may not reflect immediately, but it affects soon. They are non-environmentally friendly and cannot progress toward the sustainability factor. The alternative to metallic or synthetic fibres is natural fibres that are derived from plant sources. The demerit of using natural fibre is its less strength; however, this strength can be enhanced by incorporating it as a strengthening component in polymer matrix composite (PMC) materials. Still, the major advantage of using metal is its ability to withstand higher temperatures, whereas PMCs fail in these characteristics. The use of nanoparticles as fillers in the natural fibre–reinforced PMCs is a probable solution to the above problem. This review assesses the thermal characteristics of various nanoparticle-filled natural fibre–based polymer composites. It can be seen from most of the research that the filled polymer composites exhibit better thermal behaviour compared with non-filled polymer composites. This consolidation would be useful for researchers to further accelerate their research in this domain.

Cleavable Bio-Based Epoxy Matrix for More Eco-Sustainable Thermoset Composite Components

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Abstract
Cleavable bio-based epoxy resin systems are emerging, eco-friendly, and promising alternatives to the common thermoset ones, providing quite comparable thermo-mechanical properties while enabling a circular and green end-of-life scenario of the composite materials. In addition to being designed to incorporate a bio-based resin greener than the conventional fully fossil-based epoxies, these formulations involve cleaving hardeners that enable, under mild thermo-chemical conditions, the total recycling of the composite material through the recovery of the fibre and matrix as a thermoplastic. This research addressed the characterization, processability, and recyclability of a new commercial cleavable bio-resin formulation (designed by the R-Concept company) that can be used in the fabrication of fully recyclable polymer composites. The resin was first studied to investigate the influence of the different post-curing regimes (room temperature, 100 °C, and 140 °C) on its thermal stability and glass transition temperature. According to the results obtained, the non-post-cured resin displayed the highest T_g (i.e., 76.6 °C). The same post-curing treatments were also probed on the composite laminates (glass and carbon) produced via a lab-scale vacuum-assisted resin transfer moulding system, evaluating flexural behaviour, microstructure, and dynamic-mechanical characteristics. The post-curing at 100 °C would enhance the crosslinking of polymer chains, improving the mechanical strength of composites. With respect to the non-post-cured laminates, the flexural strength improved by 3% and 12% in carbon and glass-based composites, respectively. The post-curing at 140 °C was instead detrimental to the mechanical performance. Finally, on the laminates produced, a chemical recycling procedure was implemented, demonstrating the feasibility of recovering both thermoplastic-based resin and fibres.