Composite Recycling

Summary of recent research and development

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Photo: Aircraft graveyard in Arizona, by Phillip Cutter

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1 Executive Summary

Fibre reinforced composite materials have enormous potential in the construction, transport and wind energy sectors because of their durability, light weight and ability to be manufactured in complex shapes. The steady increase in the use of composites has brought benefits in many areas. However, most composites use thermosetting resin matrices, which are not easily recycled because they are cross linked and cannot be remoulded, in contrast to thermoplastics which can be remelted. Several research projects have been carried out to develop recycling processes and seek ways of effectively using recycled material in new or existing applications.

The Materials KTN has commissioned this report to summarise work done over the last decade. A list of major research projects is included, preceded by some text to summarise the research which has been undertaken and put it into context.

UK carbon fibre composite production amounts to about 2,130 tonnes. While carbon fibre composites represent about 40% of UK composites production by value, they correspond to only about 2% of UK composites production by volume, the vast majority being glass fibre composites. Recently, much more research has been done in carbon fibre composite recycling. This may be because of the cost differential (virgin carbon fibres are around 10 times the cost of glass fibres) and its effect on the economic viability of processes, combined with the profit margins and political visibility of the industries involved.

Several recycling processes have been developed. Two are commercially functional in the UK: Recycled Carbon Fibre markets milled, chopped and pelletised carbon fibres recovered in a pyrolysis process, mainly for electrostatic applications in polymers. Hambleside Danelaw and Filon have both developed mechanical grinding processes for glass fibre composites, used in limited quantities in their own roofing products. Other processes exist, though are not commercially active. Ongoing research into solvolysis using supercritical fluids, which would recover resin chemicals as well as fibres, is of particular interest.

Research has demonstrated feasibility for using composite recyclate in several other applications. Ground GFRP can be used in concrete and rubber compounds for the construction industry, and in moulding compounds for automotive products and sanitary ware. Random-oriented and aligned veils have been manufactured at lab scale, and other trials to produced aligned recycled carbon fibre products such as tapes, yarns and filament wound products are ongoing. Recycled carbon fibres have also been successfully trialled in automotive moulding compounds and ceramic composites for friction applications.

There is a need to develop supply chains to source, gather and process both end-of-life and manufacturing composite waste. This has been set in motion for CFRP, but capital investment to initiate a GFRP recycling supply chain is required. The economic case for GFRP recycling is less clear than for CFRP, though both Hambleside Danelaw and Filon, after several years of research effort, are claiming that they can now cost-effectively recycle GFRP through mechanical grinding processes.

Alongside supply chain development, appropriate standards for waste categorisation need to be developed, as the reliability of supply is critical to product development. Similarly new products will need to be tested and certified. Further work on life cycle analysis would help to evaluate optimum recycling options for different types of composites.

This report is intended to be used as a resource to identify gathered experience and expertise and see where and how it is strategic to progress research and bring it to market.

2 Introduction

Fibre reinforced composite materials have enormous potential in the construction, transport and wind energy sectors because of their durability, light weight and ability to be manufactured in complex shapes. The steady increase in the use of composites has brought benefits in many areas. However, most composites use thermosetting resin matrices, which are not easily recycled because they are cross linked and cannot be remoulded, in contrast to thermoplastics which can be remelted[1]. Several research projects have been carried out to develop recycling processes and seek ways of effectively using recycled material in new or existing applications.

The Materials KTN has commissioned this report to summarise work done over the last decade. The aim is to use this as a resource to identify gathered experience and expertise and see where it is strategic to progress research and bring it to market.

The report contains a list of publicly funded research projects involving UK partners, with outline details of each. To set this in context, some text is included with summary market information, a brief description of the various recycling processes employed, some information on international activity and a summary of application areas.

2.1 Scope

This report is concerned with composite materials using a thermoset resin matrix and reinforced with glass and carbon fibres. In most cases this will be glass fibre reinforced polyester and carbon fibre reinforced epoxy, and will be referred to as GFRP / CFRP (glass / carbon fibre reinforced polymers). There are also thermoset composites using aramid, natural and other fibres, but volumes are currently small in comparison with glass and carbon and they are not addressed here. The report identifies, as far as possible, all research and development work undertaken in the UK or with UK partners involved in the last ten years. A brief section on international work is included for context.

2.2 Market and economics

UK carbon fibre composite production totals at about 2130 tonnes, predominantly for aerospace and defence (36%) and wind energy (33%), with significant volumes in automotive, marine, other industrial uses and sports goods.[2] GFRP production was about 144,000 tonnes in UK and Ireland in 2007[3], mainly for construction, transport (including boatbuilding and low volume road transport applications) and wind energy.

While carbon fibre composites represent about 40% of UK composites production by value, they correspond to only about 2% of UK composites production by volume, the vast majority being glass fibre composites.

[1] See *1.1. Problems in recycling thermoset composites,* in *Recycling technologies for thermoset composite materials—current status;* S.J. Pickering*;* Composites Part A: Applied Science and Manufacturing, Volume 37, Issue 8, The 2nd International Conference: Advanced Polymer Composites for Structural Applications in Construction, August 2006, Pages 1206-1215

[2] 2008 figures, from The UK Carbon Fibre Composites Industry: Market Profile, BIS, Netcomposites / Connectra 2009

[3] The Composites Market in Europe, AVK report, Sept 2008. http://www.eucia.org/uploads/cf91cb671a72c3a9c26b2e91c6edab57.pdf

Reliable figures for waste composite material volumes are not available, but it has been reported that "an estimated 3000 tonnes.. of CFRP scrap (is) generated annually in the USA and Europe"[4]. This presumably includes both manufacturing and end-of-life waste. Since CFRP is a relatively new material, volumes of end-of-life waste remain fairly small.

A funding proposal in 2009 estimated UK GFRP manufacturing scrap to be 22,750 tonnes p.a. and end-of-life scrap five times that amount. FRP production is increasing, particularly CFRP in aerospace and other industrial applications. End-of-life wind turbine blades are likely to account for hundreds of thousands of tonnes of composite waste within 20-30 years[5]. This would be mostly GFRP, with some CFRP.

Although GFRP production volumes are far greater than CFRP, it is evident that more investment has been put into carbon fibre composite recycling. The main reason for this is because the value of the fibre is an order of magnitude higher, and so an economically viable recycling process is easier to achieve. It is also significant that the market applications for carbon fibre are ones with both higher profit margins and higher political profiles, and so the industries involved, particularly aerospace, have invested in R&D to develop recycling processes. Nevertheless, several companies manufacturing GFRP products have invested in this area.

2.3 Acknowledgements

This report was funded by the Composites Sector Group of the Materials KTN, which in turn is funded by the Technology Strategy Board. The author would like to thank Dr Steve Pickering, University of Nottingham for reviewing the report and numerous others who have contributed information.

[4] from *Launching the carbon fibre recycling industry*, 29th March 2010, at www.reinforcedplastics.com/view/8116/launching-the-carbon-fibre-recycling-industry

[5] See *Recycling wind*, 31st Jan 2009 at http://www.reinforcedplastics.com/view/319/recycling-wind/ where separate estimates are quoted of 225,000 t /yr in 2034 and 380,000 t/yr in 2040 for rotor blade material.

3 Recycling processes[6]

3.1 Mechanical grinding

GFRP recycling has tended to focus on mechanical grinding of the cured composite material. After suitable size reduction, the material is ground in a hammer mill or similar and graded into different fractions. This approach is economically challenging, as it is difficult to produce finely ground recyclate at a cost comparable to currently used fillers such as calcium carbonate.

Two UK roofing product companies, Filon and Hambleside Danelaw, have invested significantly in R&D to develop processes and applications for GFRP grinding. Filon has focussed on improving the energy efficiency of the grinding process, thus reducing cost[7]. Hambleside Danelaw has focussed on retaining fibre length, with a view to maximising the value of the recyclate.

Exeter University analysed glass fibres from ground recyclate which they were supplied for the RECCOMP project. This showed that single fibre strength was reduced by 20-30% though modulus remained comparable, compared to virgin fibres. Fibre matrix bond strength (pull-out) was reduced by about 50%[8]. These values may differ for recyclate from different grinding processes.

ERCOM Composite Recycling GmbH was established in Germany in 1990 to recycle automotive production and post-use waste by shredding and grinding graded parts into powder, to be used in new SMC in proportions up to 20%[9]. ERCOM terminated in 2004 due to economic problems.

The French company, Plastic Omnium, has been using ground recyclate as filler in composite parts such as radiator brackets for some years. This may be due to significant government subsidies to support the economic viability of the process.

3.2 Pyrolysis

Many of the CFRP recycling projects have centred around a partial pyrolysis process, where the resin matrix is burned off with limited oxygen. Carbon fibres processed in this way retain 90% or more of their original mechanical properties. This process has been commercialised by Recycled Carbon Fibre (RCF, formerly Milled Carbon). RCF's facility in the West Midlands has capacity to process 2000 tonnes/yr of carbon fibre waste, and markets recycled carbon fibre in milled, chopped and pelletised forms.[10]

Variants of pyrolysis processes have been trialled in several places around the world for both glass and carbon fibre composites. A pyrolysis process for GFRP recycling was developed at the University of Leeds in a method where the fluid pyrolysis products can be used as fuel. However,

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[6] A more scientific summary of most of these processes, as developed to 2006, can be found in *Recycling technologies for thermoset composite materials—current status;* S.J. Pickering*;* Composites Part A: Applied Science and Manufacturing, Volume 37, Issue 8, The 2nd International Conference: Advanced Polymer Composites for Structural Applications in Construction, August 2006, Pages 1206-1215

[7] See article in Roofscape 8 at http://www.filon.co.uk/pdf-docs/roofscape8.pdf

[8] *Recyclate fibres –matrix interface analysis for reuse in sheet moulding compounds (SMC)*, J. Palmer, O.R. Ghita, L. Savage, K.E. Evans, Proceedings - European Conference on Composite Materials (ECCM13) –3-5th June2008, Stockholm, Sweden

[9] George Marsh, *Facing up to the recycling challenge*, Reinforced Plastics, Volume 45, Issue 6, June 2001, Pages 22-26

[10] see www.recycledcarbonfibre.com

the process significantly reduces mechanical properties of the glass fibres. [11] A Danish company, ReFiber ApS, uses pyrolysis on GFRP waste. The resultant glass fibres are bound with polypropylene into insulation slabs[12].

Microwave pyrolysis processes are also under development in UK (Nottingham University), USA and Germany, with the aim of reducing the energy input in the recycling process. Firebird Advanced Materials Inc. (Raleigh, N.C., USA) has developed a proprietary continuous microwave recycling method and is aiming to begin its commercialisation this year[13].

3.3 Cement kiln route

Projects have been carried out to show that composite materials can be successfully fed into a cement kiln. Approximately two thirds of the material is transferred into raw materials for cement and one third, the organic part, is burnt, generating energy.

The European Plastics Converters (EuPC), the European Composites Industry Association (EuCIA) and the European Composite Recycling Service Company (ECRC) put this forward as a valid recycling route for automotive thermoset composites to comply with the EU End-of-Life of Vehicles Directive (Directive 2000/53/EC)[14].

3.4 Fluidised bed

This process was developed at Nottingham University and involves feeding scrap composite pieces, reduced to about 25mm, into a bed of sand. The sand is fluidised with a stream of hot air at 450-550 ºC. The polymer breaks down and vaporises, releasing the fibres and filler which are carried out in the gas stream. The fibres and filler are separated out, and the resin products are fully oxidised in a combustion chamber, where the heat energy can be recovered.

This process can be used for both carbon and glass fibre composites. Glass fibres lose about 50% of their tensile strength but retain their stiffness if processed at 450 ºC, which is sufficient to remove polyester resin. At higher temperatures more strength is lost. Carbon fibres show strength loss of about 20% when processed at 550 ºC (suitable for epoxy resin), retaining original stiffness.

A particular advantage of the fluidised bed process is that it is very tolerant of mixed and contaminated materials.

3.5 Solvolysis

Several projects are developing solvolysis processes to recycle thermoset composites. Nottingham University has investigated using supercritical propanol to dissolve the resin from carbon fibre epoxy composites[15]. This is being pursued in the AFRECAR project.

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[11] *Pyrolysis of composite plastic waste*, A. M. Cunliffe, N. Jones and P. T. Williams, Environmental Technology, vol. 24. (2003) pp 653-663

[12] See www.refiber.com

[13] see *Carbon fiber reclamation: Going commercial,* March 2010, at http://www.compositesworld.com/articles/carbon-fiber-reclamation-going-commercial

[14] See June 2009 press release *Thermoset Composites are compliant with EU Directive* at http://www.eucia.org/uploads/0d9ec02ab80b3375cd57085924c09688.pdf

[15] *Chemical recycling of carbon fibre composites using alcohols under subcritical and supercritical conditions;* Raul Pinero-Hernanz, Juan Garcia-Serna, Christopher Dodds, Jason Hyde, Martyn Poliakoff, Maria Jose Cocero, Sam Kingman, Stephen Pickering, Edward Lester, The Journal of Supercritical Fluids, Volume 46, Issue 1, August 2008, Pages 83-92

A European project, EURECOMP[16], involving several UK partners is trialling both water and methanol in supercritical state to recycle predominantly glass fibre composites. Water requires a higher temperature and pressure to reach supercritical state but has environmental benefits.

The solvolysis approach allows the chemicals in the resin to be reclaimed. Other international research groups are investigating this approach.

[16] See www.x-at.co.uk/downloads/posters/eurecomp.pdf

4 International

In addition to references mentioned above, other international activity in composites recycling is summarised here.

4.1 ECRC

The European Composites Recycling Service Company (ECRC) was founded in 2003 by a number of key players in the composites industry, including Inoplast, MCI (formerly Menzolit-Fibron), Owens Corning, Vetrotex, Johns Manville, Reichhold, DSM, Polynt (formerly Lonza) and the European Composites Industry Association (EuCIA). Its mission is to provide cost effective recycling solutions that will enable the composites industry to meet its environmental responsibilities and, in doing so, provide a platform for future growth. A particular concern is to meet the demands of the EU End-of-Life of Vehicles Directive (Directive 2000/53/EC).

4.2 AFRA

The Aircraft Fleet Recycling Association (AFRA), founded in 2005, is a global industry association to promote environmental best practice, regulatory excellence and sustainable developments in aircraft disassembly, as well as the salvaging and recycling of aircraft parts and materials. Several of its founder members, including Boeing, have been instrumental in supporting the development of carbon fibre recycling processes.[17] AFRA members in 10 different countries currently scrap an estimated 30% of the world's end-of-life fleet aircraft[18].

4.3 PAMELA

Airbus ran the Process for Advanced Management of End-of-life Aircraft (PAMELA) project with several partners to demonstrate that 85% of the weight of an aircraft could be recycled, and to set a standard for safe and environmentally responsible management of end-of-life aircraft. This has led to the formation of TARMAC (Tarbes Advanced Recycyling and Maintenance Aircraft Company). A report on PAMELA[19] says little about composite recycling, but Airbus is now working with CFK-Valley Stade in Germany to develop a commercial scale pyrolysis based plant for CFRP recycling.

4.4 CleanSky JTI

The Clean Sky Joint Technology Initiative (JTI) is a European Commission funded project to develop breakthrough technologies to reduce environmental impact in the air transport industry[20]. Recycling of composites is being addressed as part of the Eco-Design technology domain in Clean Sky. Advanced Composites Group is a UK partner in the recycling work.

[17] See www.afraassociation.org
[18] from *Launching the carbon fibre recycling industry*, 29th March 2010, at www.reinforcedplastics.com/view/8116/launching-the-carbon-fibre-recycling-industry
[19] See www.airbus.com/fileadmin/media_gallery/files/brochures_publications/AirbusACADEMY-ProcessforAdvancedManagementofEnd-of-LifeAircraft.pdf
[20] See www.cleansky.eu

5 Applications

Research has been undertaken and is ongoing to assess feasibility of applying composite recyclate in a wide variety of applications, but few application routes have been commercialised as yet.

5.1 Currently available products

Recycled Carbon Fibre sell recycled milled, chopped and pelletised carbon fibres in competition with virgin fibre products. Their website[21] lists the following applications:

- Anti-static paints and coatings
- Thermoplastic polymers – conductive, anti-static and reinforced
- EMI shielding
- Epoxy coatings in flotation modules
- Composite tooling
- Non-wovens
- High-temperature insulation

Both Hambleside Danelaw and Filon are using some ground GFRP recyclate in their own roofing products, predominantly as filler with little or no reinforcing benefit[22]. As mentioned above, Plastic Omnium in France uses ground recyclate in moulding compounds for automotive products and Refiber in Denmark uses pyrolysis-recovered glass fibres bound with polypropylene to form insulation slabs.

5.2 Research into aligned fibre applications

Improved mechanical properties can be achieved when fibres are aligned in a composite, thus several research projects are investigating / have investigated production methods to cost-effectively align the short, recycled fibres. These include creating aligned veils, tapes and yarns (which could be re-woven). Fabrics made using short recycled fibres tend to have improved drapability compared to virgin fibre fabrics. Such fabrics could be used to make composite products, e.g. by infusion processes or as prepregs.

Most of this research has been with “clean” carbon fibres from a pyrolysis process or from dry fibre waste (selvedges, offcuts, end-of-reel, etc). Processability of dry waste fibres differs from those recovered by thermal processes from cured composites because the dry fibres retain the size applied to the virgin fibres at manufacture. Glass fibres from a grinding process have small pieces of resin still attached, so may be more challenging to process, particularly in aligned products, though this does not appear to have been tried. The E3COMP project is trialling dry waste glass fibres in filament wound products.

If the current research into solvolysis reclamation techniques is successful and commercially viable, then “clean” glass and carbon fibres would be produced which should be processable in the same way as carbon fibres from a pyrolysis process.

At present the author is not aware of any commercially available products incorporating aligned recycled fibre, though some technologies may be close to market.

[21] www.greencarbonfibre.com/applications-for-green-carbon-fibre.html
[22] Hambleside Danelaw’s WRAP registered products with recycled content can be seen at http://www.hambleside-danelaw.co.uk/WRAP-Products.pdf

5.3 Research in other non-aligned applications

The potential to make random-oriented veils by both wet-laid and air-laid processes has been demonstrated.

The RECCOMP project demonstrated that ground GFRP recyclate could successfully be used in automotive moulding compounds[23]. HIRECAR demonstrated use of recycled carbon fibres in bulk and sheet moulding compounds[24].

Work at Loughborough University through BeAware has demonstrated benefits of adding GFRP recyclate to concrete and rubber. Addition of 5% GFRP waste powder to concrete, with superplasticiser (2% of cement content), increased compressive strength by about 14% compared to a control[25]. Mixing up to 50% GFRP waste in rubber compounds increased hardness and modulus of elasticity, as well as improving damping ability and acoustic properties[26].

Several other applications have been trialled incorporating ground GFRP recyclate including shower trays, wood plastic composites, particleboard and kitchen worktops[27]. The Rebrake project is trialling recycled carbon fibres in ceramic composites for friction applications such as aircraft and automotive brakes[28].

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[23] *Successful closed-loop recycling of thermoset composites,* J. Palmer, O.R. Ghita, L. Savage, K.E. Evans, Composites Part A: Applied Science and Manufacturing, Volume 40, Issue 4, April 2009, Pages 490-498

[24] *Development of high value moulding compounds from recycled carbon fibres*, Turner, T.A.; Warrior, N. A.; Pickering, S. J.; Plastics, Rubber and Composites, (2010) Vol 39, No3/4/5, pp151 to 156

[25] *Improvement of the mechanical properties of glass fibre reinforced plastic waste powder filled concrete,* P. Asokan, Mohamed Osmani, ADF Price, Construction and Building Materials, Volume 24, Issue 4, April 2010, Pages 448-460 and GRP waste in concrete briefing document at www.beaware.org.uk

[26] See GRP waste in rubber briefing document at www.beaware.org.uk

[27] Some examples can be seen in *Composite recycling in the construction industry;* Amanda Conroy, Sue Halliwell, Tim Reynolds, Composites Part A: Applied Science and Manufacturing, Volume 37, Issue 8, The 2nd International Conference: Advanced Polymer Composites for Structural Applications in Construction, August 2006, Pages 1216-1222

[28] See article at www.industrytoday.co.uk/automotive/successful-research-programme-allows-high-performance-brake-discs-to-be-manufactured-at-lower-cost-from-recycled-carbon-composite-material/0262 5th January 2010

6 Conclusion

Substantial amounts of composite end-of-life and manufacturing waste are being landfilled or incinerated and waste volumes are likely to increase significantly in coming years. There is currently much more GFRP waste than CFRP waste. CFRP production is increasing at a faster rate than GFRP, but few CFRP products are reaching end-of-life at present because the material is newer, whereas GFRP has been used, especially in construction and boatbuilding, for 50 years or so. Increasing composite production coupled with reduced landfill availability mean that it is essential to develop efficient and cost-effective recycling routes, with associated supply chains.

Several processes for recycling thermoset composite materials have been developed. There is still potential for improved and new processes and research is ongoing. Many potential applications for using carbon and glass fibre recyclate have been demonstrated but only a few have been commercialised. It may be that the recent economic downturn has slowed the process of commercialisation as several products with recycled composite content appear to be close to market.

There is a need to develop supply chains to source and gather both end-of-life and manufacturing composite waste. Recycled Carbon Fibre's facility in the West Midlands has capacity to take all the UK's cured CFRP waste for several years to come. However there is a need for capital investment in plant to recycle GFRP. This would ideally be more localised in order to keep transport costs down since volumes are greater and the value of the recycled product is lower in comparison to CFRP. The economic case for GFRP recycling is less clear than for CFRP, though both Hambleside Danelaw and Filon, after several years of research effort, are claiming that they can now cost-effectively recycle GFRP through mechanical grinding processes.

Appropriate standards for waste categorisation will need to be developed to facilitate the development of supply chains for products containing composite recyclate, as the reliability of supply is critical to product development. Similarly new products will need to be tested and certified.

There is a lack of information on life cycle analysis and the relative environmental benefits of different recycling processes. Further research in this area would help to evaluate optimum recycling options for different types of composites.

Thermoset Composites Recycling Projects 2000-2010

(ordered by end date)

Title / Dates	Summary	Cost / Funding	Partners	Contact
TRIM Thermoset recycling into high grade products by dual injection moulding Mar 1998 to May 2001	The work focuses on the dual injection molding process in which a skin of virgin material can be molded over a substantial core of recyclate in a single operation. This process has already been developed with thermoplastics, but the completely different behavior of thermosets presents a significant challenge. A unique prototype-molding machine will be used and the initial efforts will be directed towards promoting secondary cross-linking in previously cured thermoset polymers. Subsequent work will concentrate on controlling the thickness of the virgin skin material and the bonding that occurs between the skin and the core. Relationships will be established to optimise the amount of recylate that can be used to achieve specified mechanical properties.	EPSRC £221,000 grant to University of Warwick	**University of Warwick** Aeroquip-Vickers Ltd Battenfeld U K Ltd D S M Rover Group Ltd	Professor G Smith G.F.Smith@warwick.ac.uk Dr T Goodhead University of Warwick

Title / Dates	Summary	Cost / Funding	Partners	Contact
RECOMP Recycling Process for the Recovery of Plastic Composite Materials Jan 2001 to Jan 2003 Carbon & glass	Large pilot scale development and scale up of the pyrolysis of composites was investigated. Detailed compositional analysis of the end products of pyrolysis was determined to aid the evaluation of specific identifiable end-uses for the products, linked to the industrial partners. In particular the use of pyrolysis oil as a fuel or chemical feedstock and the recovery of glass fibre for recycling into applications such as new BMC or SMC composite materials, as a strengthener for concrete, and in other applications such as vehicle exhaust silencers and fibre board.	Grant of £372,000, representing 50% of research costs, of which £134,110 grant to University of Leeds DTI / EPSRC through WMR3 LINK programme (Waste Minimisation through Recycling, Recovery and Re-Use in Industry)	**University of Leeds** PeraTechnology SMMT Shanks Waste Solutions British Plastics Federation Hepworth Composites OSS Group Reichhold Cray Valley Filon Products	Prof Paul Williams University of Leeds 0113 343 2504 p.t.williams@leeds.ac.uk

Title / Dates	Summary	Cost / Funding	Partners	Contact
Improving the future recyclability of composite building products 2001 to 2004	The objective of the project was to make recycling and reuse of composite building products a viable option in the construction industry. It focused on fibre reinforced polymeric materials (FRPs). The project involved reviewing polymer composite recycling initiatives and techniques, and investigating manufacturing processes, materials usage and current practice. Technical, economic and policy issues necessary to improve the future recyclability of composite materials were investigated. Technical difficulties and cost implications of salvage of composites were analysed, and the refurbishment potential and possibility of reuse of polymer composites materials were investigated. Publication at project end: Recycling fibre reinforced polymers in construction: A guide to best practicable environmental options, 2004, Authors: A Conroy, S Halliwell, T Reynolds, A Waterman. ISBN 1 86081 689 4	Construction Directorate (DTI) Framework Programme - New and Improved Technologies and Techniques Theme £162,000	**BRE**	**Amanda Holt** Senior Consultant Resource Efficiency, BRE 01923 664471 holta@bre.co.uk

Title / Dates	**Summary**	**Cost / Funding**	**Partners**	**Contact**
Processing Recycled Carbon Fibre for High Grade Applications July 2002 to Dec 2005	The outcome of the project has been to develop a process to recycle scrap carbon fibre composite materials, based on fluidised bed technology and to demonstrate that the recycled carbon fibres can be used in high value applications to displace virgin carbon fibre. The recycled carbon fibre has been fully characterised and found to have good mechanical properties and a surface chemistry that can provide good bonding to epoxy resins. A validated model of the fluidised bed recycling process has been developed. The recovered carbon fibres are short (typically 5 - 15mm), randomly oriented filaments in a fluffy form and they can easily be dispersed by wet processing techniques and formed into non-woven fabrics. This has been demonstrated on a commercial plant. The non-woven products produced have been shown to be able to replace virgin carbon fibre in providing electromagnetic shielding in polymer composite applications. A technique for producing a mat of aligned fibres from the recycled carbon fibres has been demonstrated and this has the potential to be used to give a fibre product suitable for use as a high grade structural reinforcement.	EPSRC £174,811 grant to U of Nottingham	**University of Nottingham** Advanced Composites Group Aston Martin Lagonda (Gaydon) Cleanaway Ltd BAE Systems	Dr Steve Pickering University of Nottingham stephen.pickering@nottingham.ac.uk

Title / Dates	Summary	Cost / Funding	Partners	Contact
BeAware Built Environment Action on Waste Awareness and Resource Efficiency Nov 2005 to July 2008 (inc GFRP)	BeAware examined 20 construction products to identify resource efficiency improvements. A simplified environmental assessment was carried out using life cycle assessment (LCA) data. The supply chain for each product was also investigated for resource efficiency improvements that could be implemented. The product assessment results and workshop outcomes were used to produce a series of BeAware sector guidance reports that can be downloaded from www.beaware.org.uk and include briefing documents on GRP waste in concrete and GRP waste in rubber.	£1,665,357 (£771,673 from TSB)	**BRE** Construction Products Association Agrifibre Technologies Ltd Biffa Waste Services Ltd British Plastics Federation British Precast Concrete Federation British Woodworking Federation Charnwood Borough Council Loughborough University Modular & Portable Building Association National Federation of Demolition Contractors National House-Building Council NetComposites Ltd Packaging and Industrial Films Association UK Forest Products Association Wood Panel Industries Federation	Gilli Hobbs beaware@bre.co.uk 01923 664471

Title / Dates	Summary	Cost / Funding	Partners	Contact
RECCOMP Recycling composites April 2005 to Oct 2008 Glass (& some carbon)	The project aims are: 1) To develop a viable method of recycling SMC/BMC. 2) To investigate and optimise the beneficial properties of ground thermoset recyclate, leading to the production of new SMC/BMC materials 3) To optimise the benefits provided by recyclate as an active reinforcing agent. 4) To create a market for thermoset recyclate focusing on closed loop recycling (recyclate used in the same application).	£878,764 (£439,382 from TSB)	**SIMS** BPF Brunel Univ European Friction Exeter Univ Menzolit MG Rover Mitras SMMT SP Ltd	Dr Richard Hooper Materials Recovery Technologist SIMS 01789 720431 rhooper@uk.sims-group.com (Or better, Oana Ghita, Exeter Univ, o.ghita@exeter.ac.uk)
HIRECAR HIgh value composite materials from REcycled CARbon fibre July 2005 to March 2009 Carbon	Reclaimed short carbon fibres mixed with novel polymer matrices to produce bulk and sheet moulding compounds and preformed parts suitable for exterior body panels, structural components and for co-moulding with carbon fibre textiles - thus, representing all body in white (BIW) technologies.	£903,282 (£333,043 from TSB)	**University of Nottingham** Advanced Composites Group Ford Motor Co Tenax Fibers TFP (Technical Fibre Products)	Prof Nicholas Warrior Univ of Nottingham 01159 513793 nick.warrior@nottingham.ac.uk

Title / Dates	Summary	Cost / Funding	Partners	Contact
ReBrake Extended Life and Innovative Recycling of Carbon Waste for Friction Applications March 2007 to Sept 2010 Carbon	The aim of this project is the: 1) development of a process to use carbon composite waste for the manufacture of ceramic composites for high temperature, extended life aircraft, automotive and industrial friction applications, to provide rotors that will last the life of a car, extend the use of industrial brakes and clutches and, for aircraft, increase by 50-100% the landings per overhaul, 2) development of friction materials for pads based on carbon composite waste 3) optimised friction couples for applications in transport and industrial sectors.	£1,492,887 (£601,075 from TSB)	**Surface Transforms plc** AP Racing Ltd Meggitt Aircraft Braking Systems (MABS) Federal-Mogul Friction Products Ltd Loughborough University Advanced Composites Group Wichita Company Ltd Faiveney Transport Ltd Surface Transforms Ltd	Dr Geoff Gould Director, Sales and Marketing Surface Transforms plc 01926 336555 gg@surface-transforms.com or Sue Panteny sue.panteny@btinternet.com
E3 Comp Energy efficient and environmentally friendly recycling of composites August 2008 to Aug 2010 Carbon & glass	To develop the machinery to facilitate the clean production of smart and hybrid composites using recycled, waste and aligned short-fibres. (i) a methodology will be developed to enable recycled short-fibres to be deposited in the required orientation and volume fraction to produce hybrid filament wound components. The short-fibres will be hybridised with continuous fibres to give unique properties that cannot be achieved with mono-fibre composites; and (ii) Novel optical fibre sensors will be used for process monitoring and in-situ condition assessment.	£613,660 (£382,883 from TSB)	**University of Birmingham** Bruker Optics Ltd Dispensing Liquids Halyard (M and I) Ltd Huntsman Advanced Materials Luxfer Gas Cylinders Milled Carbon P-D Interglas Technologies Ltd PPG Industries UK (ltd) Pultrex Ltd	Professor Gerard Fernando, University of Birmingham, g.fernando@bham.ac.uk also Colin Leek, Pultrex, colin@pultrex.com

Title / Dates	Summary	Cost / Funding	Partners	Contact
FIBRECYCLE March 2007 initially for 36 months but now extended to end Feb 2011 Carbon	The project develops technology to produce long and discontinuous materials from recycled carbon fibres (CFs) to allow manufacturing of technical fabric for thermoplastic or thermoset applications in the composites industry. Yarns, tapes, non-woven and woven textiles, and composite materials are being produced in sufficient volume to allow assessment of coupons, panels and finally demonstrator structures. It represents a step change in managing CF waste and offers a solution to the low yields in CF composite processing and offer UK companies an alternative source of high quality but lower cost CF textile for semi-structural applications at a time when the world shortage of CF is expected to continue. The project website link is: www.fibrecycleproject.org.uk	£1,492,887 (£601,075 from TSB)	**Advanced Composites Group** Tilsatec Sigmatex UK EXEL Composites UK Netcomposites University of Leeds	Dr Sophie Cozien-Cazuc Collaborative R&T Project Manager Advanced Composites Group Ltd. (Umeco) 01773 766166 07748464344 scazuc@acg.co.uk

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Recycled carbon fibre composites for structural applications October 2008 to September 2011	This project aims to close the loop in the carbon fibre composites life-cycle, by assisting the creation of non-critical structural markets for the recycled composite. The main goals are (i) to understand the mechanical response of recycled composites, (ii) to guide the optimisation of recycling and re-manufacturing processes towards structural materials, and (iii) to develop structural design methods for the recycled composites. These objectives will be achieved through: (a) In-depth experimental analyses of different types of recycled composites, focusing on the relations between recycling and re-manufacturing processes, the architecture and microstructure of the composites, and the micromechanics of their response and failure processes; (b) Developing analytical models to predict the mechanical response of recycled composites, with emphasis on models relating features caused by recycling to the performance of the recyclates; (c) Implementing computation design tools specific for recycled composites, to assist the simulation of structural recycled components. This project will provide engineers with a better understanding and tools to confidently design non-critical structures with recycled composites; it will also assist recyclers and re-manufacturers in the improvement of their processes, by defining application-driven goals.	€ 100K grant from FCT (Portuguese Foundation for Science and Technology)	**Imperial College London**	Dr. Silvestre Pinho, Imperial College London, silvestre.pinho@imperial.ac.uk

Title / Dates	Summary	Cost / Funding	Partners	Contact
AFRECAR Affordable Recycled Carbon Fibres November 2008 to October 2011 Carbon	Two prime objectives: (i) Develop low-cost, high-strength recycled carbon fibre composite materials with higher fibre content than previously achieved. Applications for lightweight structural reinforcement in the aerospace and motor industries in non-critical applications such as seats, overhead lockers and other interior features on aircraft and body panels in cars. (ii) To scale up the use of supercritical fluid processing to produce high grade recycled carbon fibre and also to recover chemicals from the polymer resin. www.nottingham.ac.uk/afrecar	£881k (£451k from TSB)	**University of Nottingham** Advanced Composites Group Boeing Ford Motor Co Toho Tenax TFP (Technical Fibre Products) Milled Carbon Vestas Technology UK	Dr Steve Pickering University of Nottingham stephen.pickering@nottingham.ac.uk Tel: 0115 951 3785

Title / Dates	Summary	Cost / Funding	Partners	Contact
Innovations in Recycled Carbon fibre for Sustainable Manufacturing dates?	This project brings together established research expertise in carbon fibre recycling at the University of Nottingham (UN) and expertise in the use of carbon fibre fabrics for heating and cooling applications at the University of Nottingham Malaysia Campus (UNMC). The collaboration aims to enhance sustainability through developing: - Processing techniques to manufacture flexible, electrically conducting mats for electrical heating and cooling systems from recycled carbon fibre in the form of a non-woven fabric. - Test methodologies to evaluate the performance of recycled carbon fibre from any recycling process (and virgin carbon fibre) in terms of the mechanical and electrical properties that can be achieved when used in a composite material. Lightweight, low cost heating and cooling elements from recycled material will give industrial companies competitive advantage and open up new opportunities for reusing the fibre in the aerospace and automotive industries. Developing test methodologies for recycled carbon fibre will promote its wider acceptance in manufacturing processes. http://www.nottingham.ac.uk/nimrc/research/sustainablemanufacturing/recycledcarbonfibre.aspx	£144k from Nottingham Innovative Manufacturing Research Centre. (EPSRC funded)	**University of Nottingham** Boeing Company Technical Fibre Products Ltd EXA Technology and Development	Dr Steve Pickering University of Nottingham stephen.pickering@nottingham.ac.uk Tel: 0115 951 3785

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EURECOMP Recycling thermoset composites of the SST May 2009 to April 2012	Developing a novel recycling route for thermoset composites through the solvolysis process which allows for reuse of organic components. Key objective is to separate, through a water-based process, the different elements of the composites - chemicals from the matrix, fillers and fibres - to have them then available in a suitable form for reuse in new applications. In addition, the project will collate the necessary information on upstream and downstream markets, economic efficiency and life cycle assessment.	€2.55 million (€1.97 million from EU, FP7)	**Plastic Omnium Auto Exterieur, France** Volvo Technology Corporation, Sweden Xietong Automobile Accessories, China SACMO, France ECRC (European Composites Recycling Services Company), Belgium BPF (British Plastic Federation), UK URIARTE Safybox, Spain ICAM Nantes, France GAIKER, Spain University of Limerick, Ireland University of Exeter, UK University of Bristol, UK COMPOSITEC, France	Marie-Laure Spaak Plastic Omnium Auto Exterieur Services Lyons, France Tel: +33 474 40 65 45 mspaak@plasticomnium.com (Or Isabelle Flaux +33 4744 06291)

Further reference

The book ***Management, Recycling and Reuse of Waste Composites*** (Ed. Vanessa Goodship, Woodhead Publishing, Dec 2009) is a useful source of information on this subject.

A selection of relevant papers and reports is listed here in reverse date order.

Recycling carbon fibre reinforced polymers for structural applications: technology review and market outlook.
Soraia Pimenta, Silvestre T. Pinho. Accepted for publication, Waste Management (2010).

Mechanical analysis and toughening mechanisms of a multiphase recycled CFRP
Soraia Pimenta, Silvestre T. Pinho, Paul Robinson, Kok H. Wong, Stephen J. Pickering, Composites Science and Technology, Volume 70, Issue 12, 31 October 2010, Pages 1713-1725

Development of high value moulding compounds from recycled carbon fibres
Turner, T.A.; Warrior, N. A.; Pickering, S. J.; Plastics, Rubber and Composites, Volume 39, Numbers 3-5, June 2010 , pp. 151-156(6)

Improvement of the mechanical properties of glass fibre reinforced plastic waste powder filled concrete
P. Asokan, Mohamed Osmani, ADF Price, Construction and Building Materials, Volume 24, Issue 4, April 2010, Pages 448-460

Successful closed-loop recycling of thermoset composites
J. Palmer, O.R. Ghita, L. Savage, K.E. Evans, Composites Part A: Applied Science and Manufacturing, Volume 40, Issue 4, April 2009, Pages 490-498

Chemical recycling of carbon fibre composites using alcohols under subcritical and supercritical conditions
Raul Pinero-Hernanz, Juan Garcia-Serna, Christopher Dodds, Jason Hyde, Martyn Poliakoff, Maria Jose Cocero, Sam Kingman, Stephen Pickering, Edward Lester, The Journal of Supercritical Fluids, Volume 46, Issue 1, August 2008, Pages 83-92

Recyclate fibres –matrix interface analysis for reuse in sheet moulding compounds (SMC)
J. Palmer, O.R. Ghita, L. Savage, K.E. Evans, Proceedings - European Conference on Composite Materials (ECCM13) –3-5th June 2008, Stockholm, Sweden

Recycled Carbon Fiber Filled Polyethylene Composites
Tony McNally, Peter Boyd, Caroline McClory, Daniel Bien, Ian Moore, Bronagh Millar, John Davidson, Tony Carroll; Wiley Interscience, Oct 2007

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S.J. Pickering; Composites Part A: Applied Science and Manufacturing, Volume 37, Issue 8, The 2nd International Conference: Advanced Polymer Composites for Structural Applications in Construction, August 2006, Pages 1206-1215

Composite recycling in the construction industry
Amanda Conroy, Sue Halliwell, Tim Reynolds, Composites Part A: Applied Science and Manufacturing, Volume 37, Issue 8, The 2nd International Conference: Advanced Polymer Composites for Structural Applications in Construction, August 2006, Pages 1216-1222

End of Life Options for Composite Waste: Recycle, Reuse or Dispose?
NCN Best Practice Guide, Dr Sue Halliwell, TWI, 2006

Recycling fibre reinforced polymers in construction: a guide to best practicable environmental option
Conroy A, Halliwell S, Reynolds T and Waterman A., BRE Report, BR467, ISBN 1 86081 689 4, 2004

Pyrolysis of composite plastic waste
A. M. Cunliffe, N. Jones and P. T. Williams, Environmental Technology, vol. 24. (2003) pp 653-663

The use of recycled fibre composites as reinforcement for thermosets
A. K. Bledzki and K. Goracy, Mechanics of Composite Materials, Vol. 29, No. 4, pp. 473–477, July–August, 1993