Reusing automotive composites production waste

Research continues to improve prospects for the increased reuse of automotive composites production waste. J.P. Snudden, C. Ward, and K. Potter of the Advanced Composites Centre for Innovation and Science (ACCIS) at the University of Bristol in the UK discuss this possible high value solution.

Although advanced fibre reinforced plastics (FRP) have been utilised for over half a century, it is only in recent years they have started to be used in mass market products, such as the high volume automotive sector. Previously the use of advanced composites was limited to high performance markets such as aerospace, defence, high performance automobiles (at low volumes), and racing. This perhaps contributed to a relatively low effort in researching the recycling of composites, especially as R&D mostly sought structural performance gains, but also many of the materials are heterogeneous and so difficult to recycle. In the modern era, with the introduction of legislation which limits the amount of non-recyclable material allowed on new automotive vehicles, levies applied to the disposal of waste by landfill or incineration, combined with the increasing volume of material used; research in this area has begun to become a focal point.

Generally it is up to manufacturers to design their vehicles in such a way that recovery of all materials is possible, i.e. design for recycling. It is likely that if recycling solutions are not made commercially viable in the near future, as composites become more affordable for mass market items, vehicle manufacturers will be forced to use more easily recyclable materials to satisfy their obligations (or invest in highly bespoke and likely costly solutions). This seems illogical since the use of lightweight materials can aid fuel efficiency, which in turn benefits the environment and slows the pollution rate. The point is especially pertinent with the present trend towards hybrid and electric powered vehicles. These vehicles require significant structural weight reductions due to the added mass of the storage cells (in order to have performance similar to traditionally powered vehicles), and composites could provide that solution. Thus a well incorporated recycling process for these materials must be included. Ultimately, the situation is that the introduction

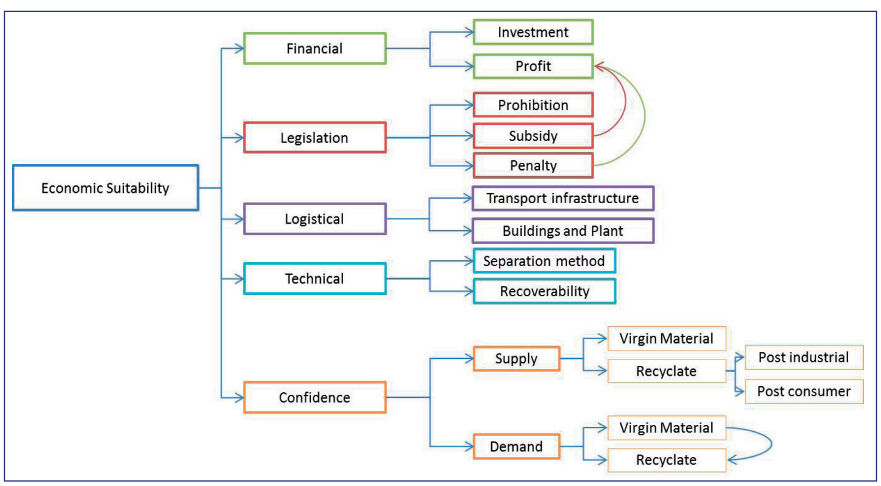

Figure 1: Economic drivers for the suitability of recycling materials.

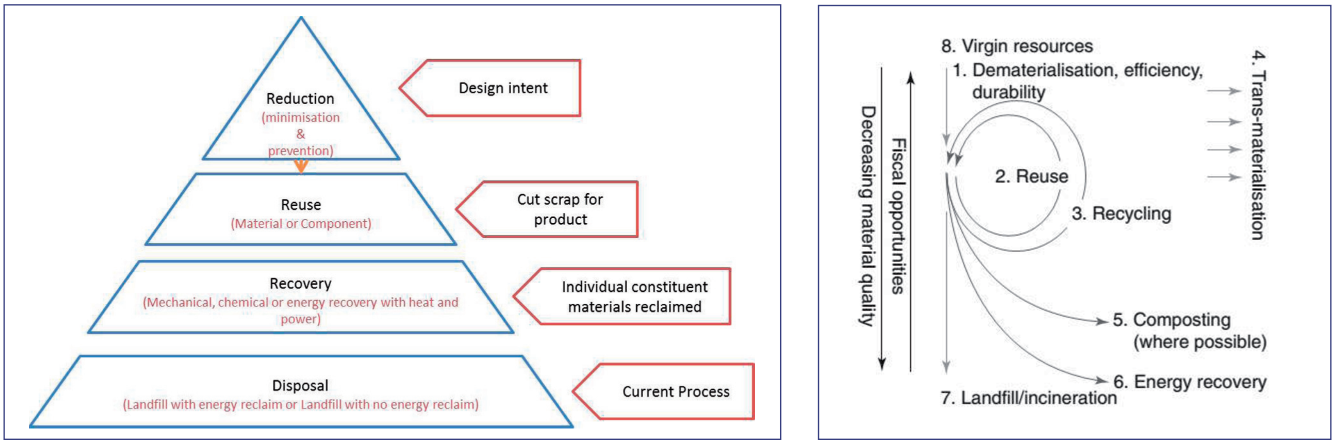

Figure 2: Hierarchal options for waste handling of production scraps: a) The traditional linear organisation for disposal options, and b) The less well used cyclical hierarchy. Other hierarchy formats that could be employed are also available.

of legislation is just a small part of the wider financial driver for composite recycling. But the risk is that needs in terms of End of Life dominate recycling thinking, whereas options for production wastes are also required.

Figure 1 shows the major drivers for economic suitability and how they are interlinked. It also highlights that waste material is produced by the user both during production and at the end of the component's life. In terms of a global outlook on advanced composites waste generation, no reliable hard numbers are known to be openly available; although in 1997 it was suggested that around 853 tonnes of scrap carbon fibre prepreg were produced in industry. It has been suggested that the aerospace industry suffers a historic buy-to-fly ratio of up to 1.7: 1 (i.e. the amount of material purchased versus the material used on the final shipped product), although this may not be representative of modern builds and all sectors. Nevertheless, this ratio highlights scrap as a priority for composites production. Other views have estimated manufacturing waste to be in the region of 10% to 30%, depending on component complexity, etc. These estimates appear reasonable considering other studies.

The advantages of production waste streams over End of Life structures are that some forms of it should be easily reused within an ongoing production process, the history of the material can be easily traced, it is local, and there should be a low level of contamination. It presents a good opportunity to reduce the amount of useable waste going to landfill, and for those appropriate forms, reuse in high value applications. Alongside a brief review of current recycling options for thermoset composite waste, this article summarises opportunities for reuse of production waste; including some research from the University of Bristol, UK.

Options for waste disposal in composites manufacture

Despite quantities being difficult to understand, it is important to develop an understanding of the scrap types possible. Advanced composite waste may be generally divided into five groups of (1) uncured or dry material/liquid resin rolls and scrap, (2) uncured trim, (3) cured trim, (4) cured scrap, and (5) End of Life. From this, it can be found that manufacturing scrap is broadly defined as (1-4). These categories are perhaps an oversimplification, and do not consider consumables or inserts/core materials etc. They also do not consider defunct materials, though the same classifications could be employed to the material producers. Unfortunately such simplifications also fail to identify the diversity of material types available. For example, there are a large volume of types of carbon fibre, ranging in type, weight, tow count etc.; and identification without any form of labelling is very difficult. Similar difficulty is found with the resins (in type and class); although some resins cannot be mixed and so have a further waste reuse aspect.

1. Manufacturing waste

Previously, reviews were undertaken for US users of advanced composites regarding the type, quantity, and disposal methods of the waste streams. It was found that the dominating scrap material was uncured prepreg with approximately 66% of the total scrap generated. Some variation in this figure can also be found by simply reviewing a specific geographical area. It was suggested that up to 68.5% of waste composite material was available for capture or could be saved through source reduction, and the largest contributing factor to waste was seen to be the manufacturing technique employed, with hand lay-up the worst process for waste generation.

Manufacturing scrap is an immediate problem as it requires disposal/treatment at the point of creation, and requires immediate handling. It is often quoted that manual procedures only utilise 40% of the available material. In a given component, the proportion of material wasted post-processing in trimming and machining etc. ranges between 2% and 40%, with around 16.2% on average. But the largest area for concern appears to be in the preparation of plies from the feedstock rolls, as this phase of manufacture is often reported to create scrap anywhere between 25% and 50% of the input material.

2. End of life waste

The end-of-life scenario is complicated by the length of time a component can remain in service. It may only become waste when maintenance costs become excessive, technology upgrades are required, and/or part replacements become scarce. Essentially, they only become waste when it is no longer economical to use them. It is difficult to predict when and more importantly where End of Life components will become available (other than those that are in catastrophic crash events). This is perhaps more true for aerospace than automotive, but the lack of a reliable feedstock is an issue that needs addressing while composites are penetrating new markets; while for those established markets the distribution of product may make component collection economically challenging.

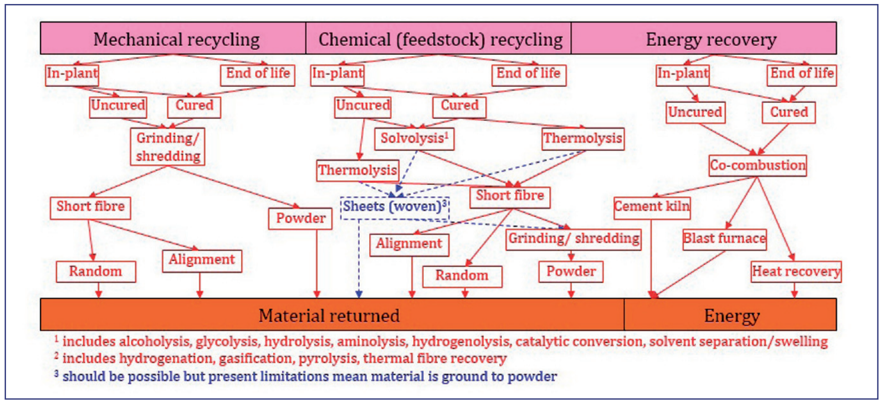

Figure 3: Generally organised recovery routes available for advanced composite materials.

3. Manufacturing scrap material: reduce, reuse, recycle potential

When reviewing waste management strategies the waste hierarchy principle or cyclic hierarchy of materials use, as illustrated in Figure 2, should be considered. Whilst the waste hierarchy principle can validly be applied to composites, it is suggested that the cyclic hierarchy is more appropriate, particularly when considering manufacturing waste. Disposal as landfill or energy recovery have been omitted, but it is recognised these can still offer waste management options.

3.1. Reduce

The prevention or reduction of waste is the most vital point in the waste hierarchy, as it should result in the least environmental and economic costs, and requires none or limited collecting and/or processing of materials. It also produces significant benefits in terms of production efficiencies and resource use. Reduction involves using less material in design and manufacture, trying to keep products for longer, and using less hazardous materials. In composites, it has been shown that manufacturing waste is a current concern despite processes such as ply cutting and nesting that would describe itself as waste minimisation and lean enabling. Thus to identify how this is such a problem, it is necessary to look at design as well as the stages of manufacture. It is increasingly clear that design and manufacture are interrelated in composites; and that waste generation is dependent on design decisions related to internal knowledge bases, as well as the individual designer. The greatest influences on scrap generation (whether manual or automated forming, net shape or not) are by far found in Design for Manufacture (DfM). Amongst others these include: defining the manufacturing plies, drape simulation of the plies to the tool geometry, adding trim allowances for machining, and generating the flat patterns from the ply shapes (according to the roll width of material to be used). It should be noted, however, that DfM as defined in the software products used in composites design does not equate to DfM as it is conventionally defined.

Scrap in manufacturing will always be produced - it is inevitable given the processes available. However, by taking into consideration some generally identified commonalities, interdependencies, and interrelationships in design and manufacture (that will dictate scrap generation), reduction of the volume is possible. This is perhaps especially true if this is undertaken in collaboration with continuous improvement activities. These are:

- Commonalities: material roll width compared to the design geometry.
- Interdependencies: dependency for accurate axis systems is primary; dictating efficiency and designs that are fit for purpose, but for scrap both are dependent on the datum position used.
- Interrelationships: the ability of design and manufacture to communicate the design intent as well as understanding manufacturing capabilities.

3. 2. Reuse

Many materials have defined shelf as well as use-by dates, and in many cases there are risks that these will be exceeded. Materials can be 're-lifed' for a short period otherwise they are regarded as waste for disposal. There is previous history of reuse in composites, albeit confined to unused rolls that exceeded their date specification. These rolls were sold as non-certified materials and permitted for lower technologies use as an exchange basis.

This has now more or less been stopped through liability risk (small quantities can be found on trading forums), and any out of specification material will now simply be disposed of, transferred to partners for use in prototyping trials etc., or used in-house for research needs. Recently there has been interest in categorising the impact of outlife on Out of Autoclave materials, and these works could in the future enable some materials reuse strategy to be employed.

There has been very limited work in reuse of scrap uncured prepreg (and none known of on dry cloth), although the potential reuse of scrap prepreg as a construction tile

Process	Waste stream	Products/waste	Advantages	Disadvantages	Reprocess cost (£/t)
Mechanical grinding	Cured laminates and uncured roll/trim scrap	Particles as filler or short fibres/dust	Recovery of both fibres and resin No use or production of hazardous materials	Significant degradation of mechanical properties Unstructured coarse and non-consistent fibre architecture Limited possibilities for re-manufacturing	~120-350
Solvolysis	Cured laminates and uncured scrap sections	Recovered fibres Suspended organic compounds and acids	Very high retention of mechanical properties and fibre length High potential for material recovery from resin	Common reduced adhesion to polymeric resins Low concentration tolerance Reduced scalability of most methods Possible environmental impact if hazardous solvents are used	Experimental/costs unavailable
Pyrolysis	Cured laminates and uncured scrap sections (in-house or end of life)	Recovered fibres Various gases, oils	High retention of mechanical properties Potential to recover feedstock from resin No use of chemical solvents	Possible deposition of char on fibre surface Sensitivity of properties of recycled fibre to processing parameters Environmentally hazardous off-gases	Experimental/costs unavailable
Thermo-mechanical recovery	Cured and uncured scrap	Recovered fibres Solid and gaseous products	High tolerance to contamination No presence of residual char on fibre surface Well established and documented process	Strength degradation between 25 and 50% Fibre length degradation Unstructured fibre architecture Impossibility for resin recovery	Experimental/costs unavailable
Incineration with energy recovery	All composite waste streams, no quality implications	Energy recovery, cement or iron Solid and gaseous wastes that require disposal	-	-	~20 (cement kiln) ~60-175 (MSW, industrial combustion)
Landfill	All composite waste streams, no quality requirements	N/A	-	-	~70-90 (hazardous landfill)

Table 1: The advantages and disadvantages of some different recycling methods.

has been investigated. The reuse of scrap as press mouldings has also been looked at, with a conclusion that a 'sandwich' structure of overlapping mixed shape and sized scrap sections would return the best material use. Scrap prepreg has been suggested for use for secondary parts as panels by MDA and Bell Helicopters through chopping scrap to squares and processing, and has also investigated prepreg reuse to generate low cost raw material for alternate industries, as well as reduction strategies. Prepreg scrap was identified as a priority waste, while the ply cutter was said to be a prime collection point. The work aimed to recover ply cutter scrap sections through reuse as either continuous pieces or by splicing/overlapping scrap shapes to form laminates.

More recently, research seems to have preferred to chop scrap prepreg to squares or rectangles and employing it as a random orientated strand in press mouldings. These processes do show some potential, although risks degraded properties and manufacturing defects by comparison to processes that maximise the scrap surface area. Moreover, in some cases additional resin has had to be used. It is potentially valid to suggest that the shredding works should be regarded as recycling opportunities more than reuse.

3.3. Recycling

The recycling routes open to composites are generally similar to those viable for thermoplastics, apart from specialist processes such as revitalisation, although the route specification may also differ due to the materials character. Figure 3 attempts to summarise the techniques available for composites recycling. Just as with thermoplastics, the quality of the recovered products greatly depends on the feedstock material. The least mixed the waste source the easier a recycling operation will be, although in composites this is complicated by the heterogeneous nature of the material and its variation in reactivity to recovery techniques between the polymer and fibrous elements. Table 1 summarises the various recycling processes in terms of waste stream, products, and fiscal demands where known compared with landfill. It also attempts to present advantages and disadvantages of each process. It is often argued that recycling is suitable for all waste states (1-5 previously); however it is the authors' opinion that recycling is mostly suited to cured waste than uncured/dry cloth, as in this state the material has a potentially higher value in being able to be formed

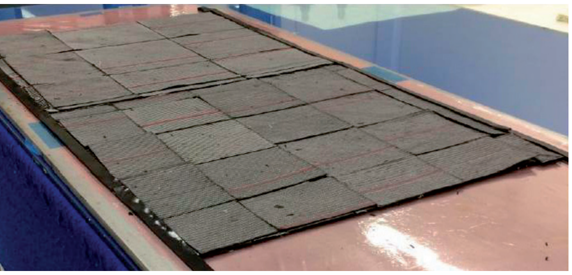

Figure 4: An example of a discontinuous coupon layup, pre-infusion, made up of 100mm square triaxial NCF patches (nearest) and 150mm square triaxial NCF patches (furthest).

to a product as in standard manufacturing. In terms of cured components/trim, often recovery of constituents is the only real value.

The main problem with many of the recovery techniques is the question of what to do with the recovered products. Mechanical grinding recycles near 100% of the feedstock but produces a heavily degraded fibre/resin clump or granules limited in use as filler material, or as additives to other processes such as concrete, but little else. Most solvolysis or thermolysis processes seem to only aim to recover the fibres by priority and wastes the cured matrix. This by-product varies by process, but must be disposed of. Most appear to head to landfill, although use in energy recovery may be feasible, and some processes can recover oil and gas for self-feeding of its process. This is largely restricted to those thermal techniques, which are also the processes that appear to be making some commercial headway. The quality and cleanliness of the recovered products naturally varies by technique. They generally offer more useful products than mechanical grinding, but all of these processes still present fibres with some form of residual contamination (up to a few percent). Both solvolysis and thermolysis are however still reliant on the feedstock being chopped, shredded, or broken up to accommodate gate sizes as they are still batch processes. Thus the fibres in the as-recovered state are short in length, and characterisation of those recovered materials has shown a range of lengths versus the input material. Further, the fibres largely appear matted, or loosely bound in clumps with no structure or order meaning that further processing is required unless it is sold in this format. Broadgood feedstock is suggested to retain fabric structure via the weave pattern, however at present no recovered fabrics are known to be available.

Processed recycled short length fibres have seen several approaches to use it in preforming and/or manufacturing techniques, including demonstration with 3-DEP, DCFP, and very recently incorporation to a selective laser sintering technique. However the main commercialisation route still appears to be to deliver a dry random mat form. Alternatively, it might be distributed along an adhesive sheet as a random mat prepreg or veil. In the future the most high value potential will be to align the material as a short fibre composite sheet, and this is presently an active field of research. Reference may also be able to be taken from examples where selvage waste is collected and reformed into discontinuous tow Non Crimp Fabric (NCF), some including comingled thermoplastic matrices, and which now appear to be successfully penetrating the market.

3.4. Research at University of Bristol

The University of Bristol has in previous years concentrated efforts on the reduction or reuse of composite waste. This includes examples where scrap cloth prepreg was reused as press moulded laminates and compared to continuous plates of cloth and UD tape. Other work has explored in some detail the reduction possibilities in composites manufacture, by examining the waste results possible for a number of parts and the impact of design choices such as materials choice, ply shape, and complexity to nest etc. It showed that simple choices, in areas such as datum location, could have drastic impacts on waste generated. The work also investigated the scrap formed at ply cutting and explored opportunities to reuse it by collecting shapes and fitting them together to produce an irregular pattern discontinuous roll. This was made possible as in this case the scrap was relatively simple, regularly presented, and of sufficient size to make it feasible. However, much of this work was primarily based in the aerospace sector and predominantly of prepreg forms.

More recent research investigates a novel and adaptable/flexible approach to the reforming of dry cloth production waste with a far greater complex ply pattern that is more representative of complex geometry manufacture. Generically, the waste is cut into patches, the size of which depends on the value of the end product, before being laid up (reformed) and resin infused. If the component that the reformed material is used for is high value, the patches will be cut larger so that the fibres are longer, meaning that the amount of waste that can be reused will be reduced. If the reformed material is used in a lower value component (a semi structural unit for example), then the patches can be smaller and more waste used. Reforming is done in a regular pattern, so that structures are produced with regular discontinuities, forming a grid pattern in each layer of the laminate. These grids are offset from each other between the plies, according to design guides, to provide adequate strength in the laminate. This gives a reformed composite with aligned fibres, and providing reasonably predictable strength characteristics. An example of a plate laid up using these patches is shown in Figure 4.

This methodology can also be adopted for waste reduction. As noted, it is possible to optimise the layout of the ply nest to minimise the volume of offcuts produced. If this optimisation scenario was modified to minimise the amount of waste produced after cutting the initial offcut material into patches to be reformed, then the final volume of waste would be further reduced. This would depend on the size of the patches required. A smaller patch size will mean that the ply nest will be altered less from the originally optimised layout since a greater volume of the offcuts will be used. In turn the size of the patch will be a balance between the higher the perceived value of the material, and the cost of the waste that cannot be reused. In other words, if the material is used in a high value application, the material will be of higher value compared with if it was used for a low value application, such as a non-structural body panel. Figure 5 gives an example of a ply nest for a complex part, and the area of waste that can be reused with patches of increasing size. Scrap treatment processes by cutting up waste to coupons exist in many ply cutter packages, however optimising the nest for virgin ply and scrap recovery requires further work to be integrated.

Current issues with composites recycling

At this time there are chiefly four factors restricting the reuse and/or recycling of production wastes into composite products. First, sending waste to landfill is still by far the cheapest option for manufacturers. Second, few reuse and recycling processes are commercially viable. Third, in terms of the overall impact of recycling processes on the environment, there is likely to be not enough improvement on landfill for it to be a viable option. Fourth, there is a general unwillingness to utilise reused or recycled composites since they are perceived to be of lower quality than virgin material, and it is difficult to ensure consistency in the material performance.

The issue of cost is being resolved from two directions. Legislation being applied to landfill management will generally increase the cost of sending waste to landfill, while advances are being made in reducing the costs of recycling processes as they are scaled up, and links to the issue of a lack of commercial scale processes. For example, in the UK ELG Carbon Fibre Ltd. has scaled up its pyrolysis process to recycle 1200 tonnes of scrap per year in a continuous process, while other international recycling operators continue to do the same. But these are recycling options and large scale reuse processes within manufacturing are realistically still required (especially if using dry fibre which does not need recycling per se). Currently expanding capacities are in fact dwarfed by the increasing quantity of scrap in production (or future End of Life) being produced, but it may also make investment in capacity more readily available in the future (which drastically needs to happen to catch up with the waste produced). This is certainly true for production waste where waste locations and quality can be more adequately controlled. For costs and capacities in composites, it is also worth noting that it is far more appropriate to regard waste by volume than weight, and understand the lost value of scrap material. For example and although generalising, 1 tonne of scrap of 250gsm material is around 4000sqm, and if £25sqm equals £100k, but only costs up to £130 to dispose of (plus shipping etc.). Recapturing and reusing just 25% of such a waste volume could see significant returns depending on several factors such as material type, volume, handling requirements, suitability, and the extent of supplementary materials or processes required.

The issue of environmental impact is very interesting. Life Cycle Assessments (LCA) for landfill, pyrolysis, and incineration with energy recovery have been performed for the recycling of both glass and carbon fibre. Results suggested that for glass fibre it was more environmentally sound to send the material to landfill, while recycling of carbon fibre via pyrolysis could be environmentally beneficial if it reduced the production of virgin fibre (and it emissions). To the authors' knowledge no LCA taking in the impact of the reuse of material has been conducted, or is available at this time.

Finally, the apparent reduction in quality of reused or recycled composite is difficult to solve since the material may have inconsistent properties, and depending on the application being targeted may be simply inferior by product. There are two factors chiefly responsible for this. First, there may be a wide variation in the quality of the feedstock material due to different waste management policies within different manufacturers. Second, the reuse or recycling process may add levels of variability and costs, depending on the method(s) used (for example spinning or aligning of recovered UD tape as bundles). Certainly products available show significant variation with traditional knockdowns in properties; and this is also presently represented in the academic literature (where no consistent metric of comparison between reuse/recovery type and product exists). Generally speaking, whether reuse or recycled composite waste will return short fibre material. Due to these issues, manufacturers are unlikely to use recycled composite reinforcement in structural components in the near term. But there is a market for short fibre materials, and since this is the case, perhaps novel applications for recycled material are required instead of viewing it as a replacement for virgin material.

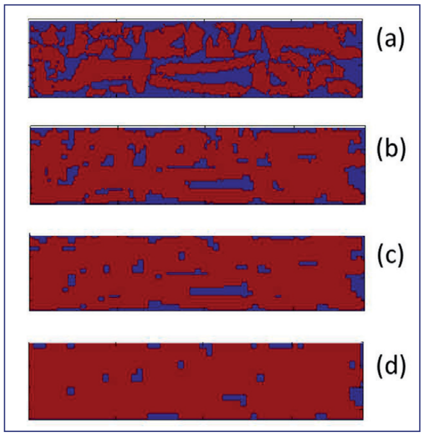

Figure 5: An example of a ply nest for a complex geometry, showing the re-useable waste available by using different sized patches: (a) The original ply nest, and how presently a significant volume of material is lost, (b) Capture and re-use potential by using 50×50mm patches, (c) Capture and re-use potential by using 100×50mm patches, and (d) Capture and re-use potential by using 100×100mm patches. For reference blue is the re-useable waste.

Reforming production waste for high value applications

To demonstrate the reforming approaches investigated at Bristol a material has been produced that can be used in high value applications. Samples have been made up into tubes and crushed in quasi-static conditions at 18mm per second, to simulate in simple set-up scenarios where energy must be absorbed. This application was chosen for two main reasons. Firstly, ultimate strength is not the primary requirement for crash structures as energy absorption performance is more important. Secondly, despite the potential for the automotive sector to grow into one of the largest consumers of composite materials, some structures will always remain metallic unless the costs of a composite equivalent can be made competitive. Similar works can be found that compare the dynamic performance of an in-date, out-of-life, and recovered fabric (infused with the same resin system) for crash structures. They showed that recovered and reused fabrics could be exploitable in this form of application, with comparable properties to virgin material, albeit reduced compared to the works of others.

Tubes were made from off-cuts of triaxial and biaxial carbon fibre NCF, with individual patch dimensions of 100×50mm. As a design feature, the thickness of the 400mm long tubes was increased down the length, and a failed tube is shown in Figure 6. Results showed the reused coupon material absorbed similar amounts of energy to continuous virgin glass fibre reinforced epoxy, and crushed in a stable and predictable manner, but absorbed more energy as the thickness of the tube increased (see Figure 7). From these initial results more recent work has focussed on understanding the failure event, identifying improvements in structural performance (to increase energy absorption in comparison to continuous carbon fibre equivalents), and exploring repeatability in mechanical performance. Since the reformed material was made from waste, the cost of buying material was technically saved. But the manufacturing time was unsatisfactory, meaning that savings on material would be outweighed by production costs. New results suggest there is scope for material performance to be improved, which would reduce this deficit, but in order for the material to be commercialised, an automated manufacturing process would need to be developed.

Evolution of design requirements

The use of reformed composite materials in both aerospace and automotive is currently restricted by generally accepted design requirements, although variation between the two sectors can be found. Aerospace design is largely driven by conservative allowables, while automotive design appears to be principally driven by process

Figure 6: Image of a demonstrator crush tube, after quasi-static testing at 18mm per second.

and manufacturing rate. This is likely to be due to the differences in load cases and design life of the vehicles. New aircraft have a design life of more than 35 years, whilst for automobiles it can be expected to be considerably shorter. The geometric tolerances for assembly in the automotive sector are perhaps tighter overall than for aerospace because the shape of an automobile is more design driven, while the shape of an aircraft is functionality driven. For reformed material this means restrictions in application. If it is difficult to ensure consistency in the material due to the discontinuities, both sectors are likely to be unwilling to adopt it for structural components at the present time.

Another major difference between the two sectors is the value: volume ratio. Despite product size differences, per kilogram aircraft are several times more expensive than automobiles, but the rate of production for automotive is many times higher than that of aerospace (for example, around 120 Airbus A350s per annum compared with around 20,000 BMW i3s per annum). It is said that for composite materials to make headway in automotive a more than 95% reduction in component cost, relative to aerospace, is needed and so collaborations between the sectors is beginning. Examples such as recycling are becoming available, and so convergence in design requirements (such as design for X) may be likely in the future. Such convergence suggests that a period of transition is likely to be needed in industrialising composite material use in both sectors, if they are to become widely accessible to higher volume production. The mass market automotive sector will seek to move to true composite structures (as opposed to composite clad metallic frames), whilst retaining its need for high volume: low value. Aerospace will look towards moving composite production from low volume: high value to medium volume: medium value, as the new generation of narrow body aircraft is designed. It is at this point of transition that there is an opportunity for reformed composites to demonstrate its capabilities and suitability to be used in these markets.

Future direction

The mass market automotive industry has certainly begun to move towards applying composite materials; and this includes the application of recycled materials. An example of this is the roof panel of the BMW i8, manufactured using reformed production waste carbon fibre as a random mat. As a commercial demonstrator this is excellent, but owing to costs it is likely a cheaper material could have been used due to the probable low structural loading on it. As noted previously, there is still some way to go before composites are used in the mass market automotive sector to their full potential in principal structural or sacrificial components. This is important given the Life Cycle Assessment reviews of advanced composites, examples of the performance of recycling options; and its impact on the use in the aerospace, and automotive where recycled material is suggested to be the only competitive material (although reused material will be a further benefit).

The aligned reformed material being investigated at Bristol is an example of potential progress towards this primary structure goal. Although the research is currently at a low Technology Readiness Level (TRL), it has suggested that discontinuous material performs well in energy absorbing load cases. This is hoped to be a more valuable use for reused materials than merely body panels. In order to move on from the laboratory to a commercially robust venture, a suitable manufacturing process needs to be investigated, and examples such as Patch Preforming or Part via Preform are attractive. Generally, manufacture needs to be inexpensive and as quick as possible to be competitive with manufacturing processes for other materials. But this is somewhat hindered by the nature of recovered materials having an initial cost for capture and handling; and so this will firstly need to be reduced for it to become commercially viable. One potential method to reduce this would be to include a waste collection system and a reforming station directly within the manufacturing centre of virgin material components to cut out any logistics costs (thus limiting capital risks, however to date much more emphasis has been placed on recovery processes than on collection, handling and sorting. It is certainly true that a waste management system is needed that considers the full hierarchy and the stages of the materials in terms of value, structure, and capability. If attained, then the future of composite recycling could be very promising.

Final remarks

The use of advanced composites in the early adopting industries has been steadily increasing, but risks plateauing somewhat in the near future. On the other hand, in the mass market automotive industry we are potentially on the verge of seeing a rapid and vast increase in composites use, albeit for relatively low value: high volume components (transport and associated industries may also expand into composites). A driver for this uptake is the need to reduce vehicles structural weight - electric vehicles in particular require light-weighting to account for the added mass of the storage cell(s). This uptake into the automotive sector is possible because of increasing amounts of work in reducing costs associated with design and manufacture, leading to increased material use.

Waste technology research is part of this effort, be it a reduction or reuse of the waste generated, or methods of re-applying materials back into production. Significant research effort has focussed on End of Life, but what work that has been done tends to concentrate on recovery of one product at the expense of the other, use of that recovered material in lower value structures, or employing options such as using it as low value filler. In comparison to the End of Life scene, production waste has not been looked at in any great detail; perhaps as it is seen as an element of the manufacturing process and factory system, rather than a visible waste source. Many production/manufacturing sites are implementing ISO 14000 (environmental) and ISO 9000 (quality) management status. Although not directly influencing waste management, the standards expect efficient and effective management of processes (ISO 9000) and environmental impact reductions (ISO 14000) and this may offer positive change. What work that has been done has researched scrap reduction or lower quality reuse, and not from the point of view that it may be possible to reuse it for high value applications in place of virgin materials. The work at the University of Bristol and some others is a step towards reusing material directly from production for high value use. The research is trying to turn the issue from a negative attitude of "how do we get rid of this waste" to a positive one of "how do we recover as much value out of this material as possible." ■

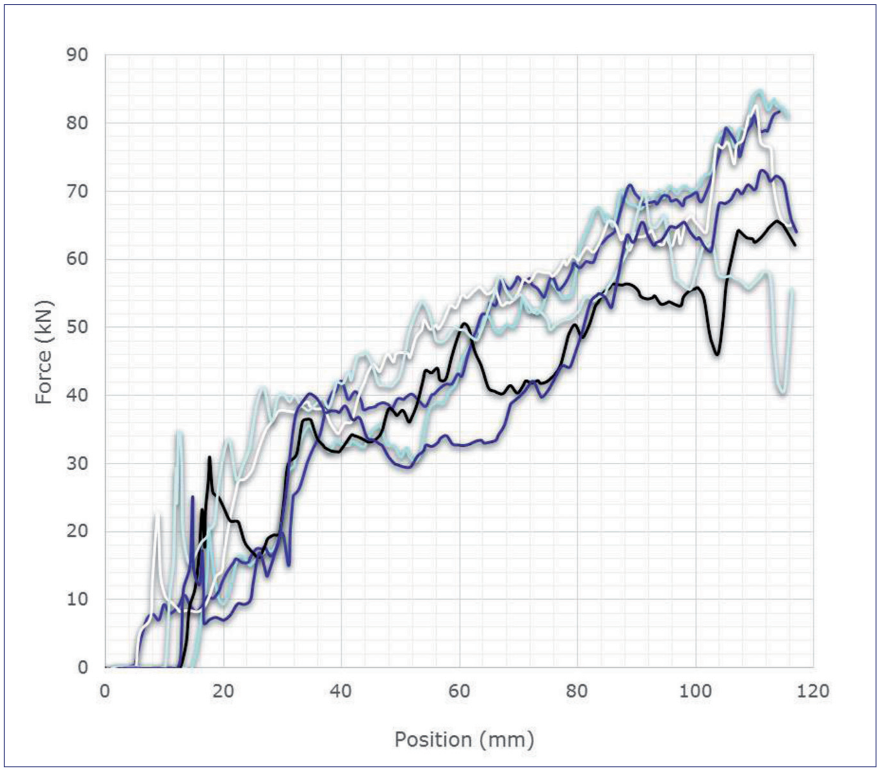

Figure 7: Load/displacement results from the demonstrator tests highlighting the rising force required to crush the increasingly thick tube, and offering performances equivalent to virgin glass fibre materials, despite being discontinuous coupons and scrap materials that are used.

Further information

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