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ADDRESSING METROLOGICAL CHALLENGES IN THE RECYCLING OF POLYMER MATRIX COMPOSITES: A ROADMAP

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Addressing Metrological Challenges in the Recycling of Polymer Matrix Composites: a Roadmap

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ABSTRACT

This report focuses on the measurement challenges associated with the recycling of polymer matrix composites, the constituent materials recovered from the recycling process, and the second life products made from these recycled materials. It covers a brief survey of the industry, the need for and state-of-the-art in composites recycling, and a roadmap of the measurement challenges which need to be addressed as a priority by 2030.

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Approved on behalf of NPLML by
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EXECUTIVE SUMMARY

With the steady growth of the UK composites sector as a key player in enabling net zero technologies, the need to recycle materials from fibre-reinforced polymer (FRP) composite applications at their end-of-life is rapidly increasing. The unique engineered properties of FRPs facilitate carbon-neutral solutions through their crucial role in the manufacture of renewable energy technologies, lighter weight (and therefore lower emission) transportation and more durable, longer lasting infrastructure. Once these products are removed from service, recycling of the FRPs from which they are made is essential to the realisation of the goal of a circular economy.

At present, whilst technologies for recycling FRP composites are available, they have not been rolled out at scale. This is due, in part, to a number of barriers that exist in both the upscaling of recycling technologies and the uptake of the recycled materials. Firstly, the lack of provenance of the waste feedstock adds complexity to the recycling process and introduces variability in the quality and material properties of the recovered materials. Traceability of this feedstock will, in addition, be essential in carrying out the desired lifecycle assessment (LCA) of composite materials and products. Further, there exists a lack of data to demonstrate the quality and properties of recycled materials, which is linked to a measurement infrastructure that is potentially lacking and unvalidated. These data are critical in providing the confidence required for manufacturers to adopt FRP recyclates.

Following consultation with stakeholders through an open survey and in-person workshop, a roadmap for the short, medium and long-term priorities in metrology research to support this area has been developed and is presented at the end of this report.

1 INTRODUCTION

Composite materials are widely recognised as a key enabling class of materials in the realisation of sustainable technologies such as greener aviation and renewable energy, with a current estimated UK market value of £4 billion[1]. However, in the drive towards a circular economy, solutions for end-of-life of composite products are essential. While an important intermediate step is to keep materials in use for as long as possible (e.g. through improved durability), it is eventually necessary to take these products out of service, and many first-generation products have already, or are soon to reach their end-of-life. At present, many of these products are disposed of through landfill or incineration. Moving towards recycling will not only ensure a more sustainable industry but recover energy to get the maximum value out of these materials. However, large-scale composites recycling has not yet been achieved. It is worth noting that, in addition to end-of-life products, waste composite material will also be generated during the manufacturing process, e.g. in the form of out-of-life unprocessed materials, unprocessed offcuts, machining (e.g. trim) of processed materials, etc.

The development of more a sustainable composites industry, including recycling of materials, was named as one of the Innovation Priorities in the National Materials Innovation Strategy published by the Henry Royce Institute in January 2025[1]. This attitude is mirrored by several organisations, including Innovate UK, which set out goals for low-carbon manufacturing in its UK Materials and Manufacturing vision for 2050 report[2], and the Aerospace Technology Institute (ATI) which highlighted the importance of processing composites at their end-of-life in their 2022 Destination Zero report.[3]

While the appetite for recycling composites at end-of-life is strong, recovering material requires complex processes to separate the reinforcement from the matrix, and is further complicated by the presence of additives such as binders which are widely used in several manufacturing processes and composite material formats. A number of recycling techniques are currently available, but the choice of which technique to use is dependent on the type of reinforcement (e.g. glass, carbon) and matrix (e.g. thermoset, thermoplastic). The different recycling methods can be categorised as follows:

- Reformatting
- Mechanical process (e.g. grinding)
- Electrochemical
- Chemical / thermochemical processes (e.g. solvolysis)
- Thermal (e.g. pyrolysis, fluidised bed, microwave irradiation, gasification, pressolysis)

One of the issues encountered in the recycling of composites is the relative energy demand for recycling compared to that of manufacturing with virgin material, which is significantly disproportionate in the case of glass fibre materials. At present, the most economically viable and only method currently used on the commercial market for glass fibre based composite recycling is grinding. Conversely, in the case of carbon fibre based composite materials, most means of recycling outweigh the energetic cost of producing virgin materials. The most common method for recycling carbon fibre composites is currently pyrolysis, however

[1] National materials strategy, Henry Royce Institute, https://www.royce.ac.uk/content/uploads/2025/01/National_Materials_Innovation_Strategy_FINAL_WEBSITE.pdf
[2] Materials and manufacturing vision 2050, Innovate UK, https://www.ukri.org/wp-content/uploads/2023/03/IUK-06032023-Innovate-UK-Materials-and-Manufacturing-Vision-2050.pdf
[3] ATI Technology Strategy 2022 – Destination Zero, https://www.ati.org.uk/wp-content/uploads/2022/04/ATI-Tech-Strategy-2022-Destination-Zero.pdf

composite recycling technologies are continuously advancing and while little composite waste is recycled in the UK[4], trials are being carried out to establish a pressolysis-based recycling line using the DEECOM® system developed by Longworth (UK). A list of other composite recycling organisations can be found on the EuCIA website[5]. New forms of matrix and reinforcement and approaches to composite product design for recycling will continue to shift this landscape in addition to the existing recycling technologies.

Most composite recycling processes separate the reinforcement from the polymer matrix in such a way that only the reinforcement is recovered. The assessment of the value of a recycling process and the potential second life of the recovered material will depend on the material properties retained by the reinforcement, which can be classified as:

- Full retention of properties
- Partial retention of properties
- Total loss of properties

To identify the potential second life applications of these recycled constituent materials and reach the correct markets, a validated measurement infrastructure will be necessary to determine the “new” material properties, qualify these materials and enable innovation.

Further to the economic viability and technological maturity of composites recycling processes, development of this area will ultimately face a need for Life-cycle Assessment (LCA) to ensure the reclamation process does not cause greater waste, e.g. in the form of solvent waste, higher energy use, or greater emissions than would otherwise be caused by feedstock. As with characterisation of the material properties, metrology at each step of the composite life-cycle is required to ensure traceable, validated data inputs into LCA.

This report follows on from the work presented in NPL Report MAT 123, where more background information on the recycling of composite materials can be found[6]. In the next sections, data gathered from stakeholders on metrology challenges and priorities in the recycling of composites are presented, followed by a roadmap for the next steps required to support this emerging area.

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[4] The sustainability of fibre-reinforced polymer composites, A Good Practice Guide, Composites UK

[5] https://eucia.eu/wp-content/uploads/2025/01/EUROPEAN-COMPOSITES-CIRCULARITY-SOLUTIONS-EuCIA-JANUARY-2025.pdf

[6] Review of Recycling and Traceability Methods for Carbon Fibres, NPL Report MAT 123, https://doi.org/10.47120/npl.MAT123

2 INDUSTRY PERSPECTIVES ON COMPOSITES RECYCLING

Industry views and requirements were collected through a comprehensive international survey carried out in 2024. Responses to the survey were received from 38 participants from across more than ten countries and more than seven major industry sectors as listed in Figure 1. Full details of the individual questions and responses are presented in Appendix A: Responses to the industry survey.

In addition to the survey, members of the UK composites industry were invited to attend an in-person Composites and Polymers (CAP) Industry Advisory Group (IAG) meeting organised by NPL in November 2024, which featured a workshop on composites recycling. Fifteen attendees from across multiple industry sectors discussed ways in which the National Measurement System (NMS) research programme could be used to support and problem-solve in recycled composites. The responses obtained from this workshop are presented in Appendix B: Responses from the IAG workshop.

These two information-gathering exercises were carried out to provide an opportunity for industry to describe first-hand the needs and issues surrounding the recycling of composites, specifically focusing on needs for metrology and standardisation with a view to shaping the roadmap presented in this report. The following sections provide an overview of the main themes and issues found through industry responses.

2.1 RESULTS OF THE INDUSTRY SURVEY

A survey of industry views on composites recycling was made openly available online and distributed through several platforms, including Composites UK. Of the 38 respondents, the industry sectors represented are shown in Figure 1.

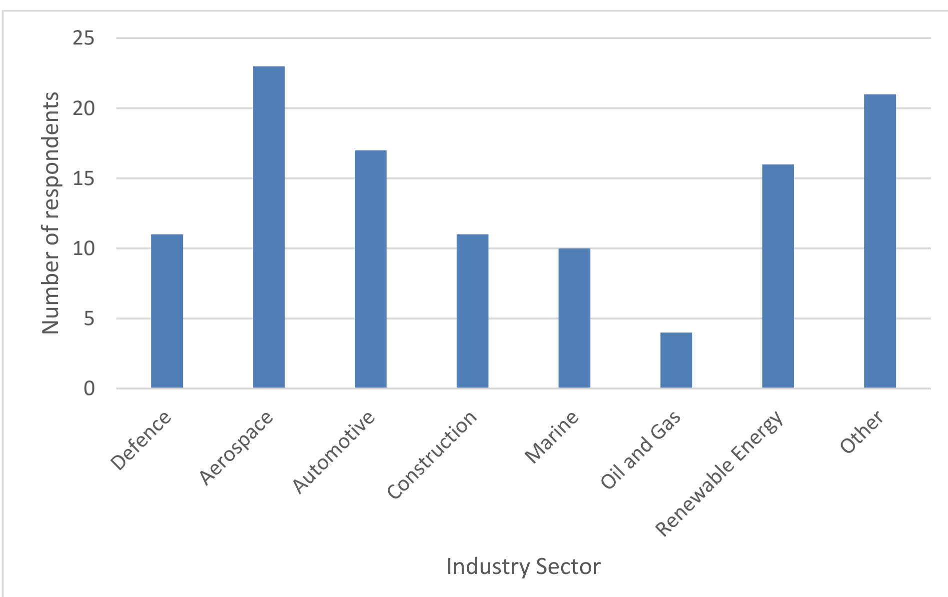


Figure 1: Industry sectors represented by respondents of the survey.

2.1.1 Market

When asked their views on the current market for recycled fibre products, 66% of respondents felt that the market demand for recycled fibre products was moderate, high or very high. 61% reported that recycled fibres were already in use in their organisation while 26% are planning to use recycled fibres in future. The highest areas of envisioned use were automotive (76%), construction (74%) and sporting goods (61%).

The main barriers to the uptake of recycled fibres were viewed as technical concerns (74%), availability (53%) and cost (42%). Quality assurance, regulations and cost were seen as the most important factors that need to be addressed for increased adoption of recycled fibres.

In addition to recycled fibres, 74% of respondents currently or plan to use resins that are recyclable or contain recycled content.

2.1.2 Properties

Overwhelmingly, respondents reported that the most critical property for recycled materials was mechanical performance, followed by fibre characterisation (length and surface quality). When comparing virgin with recycled fibres, 74% of respondents in their experience found that the mechanical properties of the recycled fibres were worse than virgin fibres. With respect to test scales, most respondents stated that testing at the coupon, sub-component and component level were most important when compared with tow and fibre level testing.

Some respondents noted a decline in mechanical properties and a change in processability due to removal of the fibre sizing, however it was also noted that any change or decline in properties was dependent upon the reclamation method used.

When consulted on whether recycled materials met performance requirements, views were mixed, with just below half of the respondents (47%) reporting that the consistency in performance of recycled fibres is worse than the equivalent virgin fibres while 34% reported the performance to be equal or better. 53% of respondents felt that there is insufficient data to prove that recycled fibres meet performance requirements and 66% have found there to be variability in the quality between different batches of recycled fibres.

2.1.3 Quality and standards

58% of respondents felt that there is a need for the development of new standards relating to recycled fibres, in particular respondents were concerned with the classification of recycled fibres. However many respondents currently use existing composite materials and testing standards and felt that these were sufficient.

The two primary quality related areas of concern to respondents (outside of performance) were contamination of the recycled fibres and traceability (79%).

It was also noted in this consultation that virgin fibres do not offer perfectly consistent quality and performance, which must be taken into account when being compared with the variability in quality and performance of recycled fibres.

2.2 RESULTS FROM THE IAG WORKSHOP

Attendees at the NPL's 15th Composites and Polymers IAG meeting represented a number of organisations across RTO's, universities and industry. During a workshop session, participants were asked their views on the following questions:

1. What properties related to recycled fibres need to be measured? This can be for the recycling process, recycled product, or finished component. At what scale would validated measurements be most important? (i.e. fibres, coupons, component)

2. What are the gaps in standards and procedures preventing the uptake of recycled composites?
3. What are the gaps in measurement capability/infrastructure for evaluating the quality of recycled materials?
4. How important is the traceability of materials to recycling of composites and use of recycled products? What are the barriers to traceability?

Of the companies that attended the IAG, one of the overall major concerns relating to recycled composites was the full life cycle of the material. Life-cycle Assessment (LCA), durability and recyclability of products made from recycled constituents, and the economic vs environmental benefits of recycling composite materials were all raised as issues.

Traceability of waste feedstock was highlighted as another significant concern, with attendees noting a lack of information available from manufacturers of virgin products to aid in the traceability of materials throughout the lifetime of the product. Further, it was observed that by the time a material has reached its end-of-life and is ready to be recycled, the material will have been in circulation for enough time to possibly be in a degraded condition. One participant suggested other industries may already have processes for recording the quality and traceability of recycled products that could be applied to recycled composites.

Regarding material properties, participants stated that it was crucial to have a clear understanding of recycled material performance, fibre length, and surface quality. In addition, knowledge of the effect of different recycling methods on material properties was important.

For quality purposes, participants highlighted that it was important to measure any contamination of the fibres, as well as variability in fibre properties, e.g. fibre length, surface quality and strength.

3 CONCLUSIONS AND RECOMMENDATIONS

A consultation with industry on the recycling of composites through an online survey and in-person workshop led to the highlighting of 5 key concerns:

- Traceability of waste feedstock
- Confidence in mechanical performance
- Surface quality, including contamination and sizing
- Clear descriptors of fibre properties and characteristics (i.e. length)
- Life-cycle assessment of recycled materials

Participants provided mixed views on the need for new standards specific to recycled composites, however all agreed that confidence in the performance of recycled materials was required. Two ISO standards projects in the area of recycled carbon fibres have recently seen development, which may address some of the issues raised during the consultation:

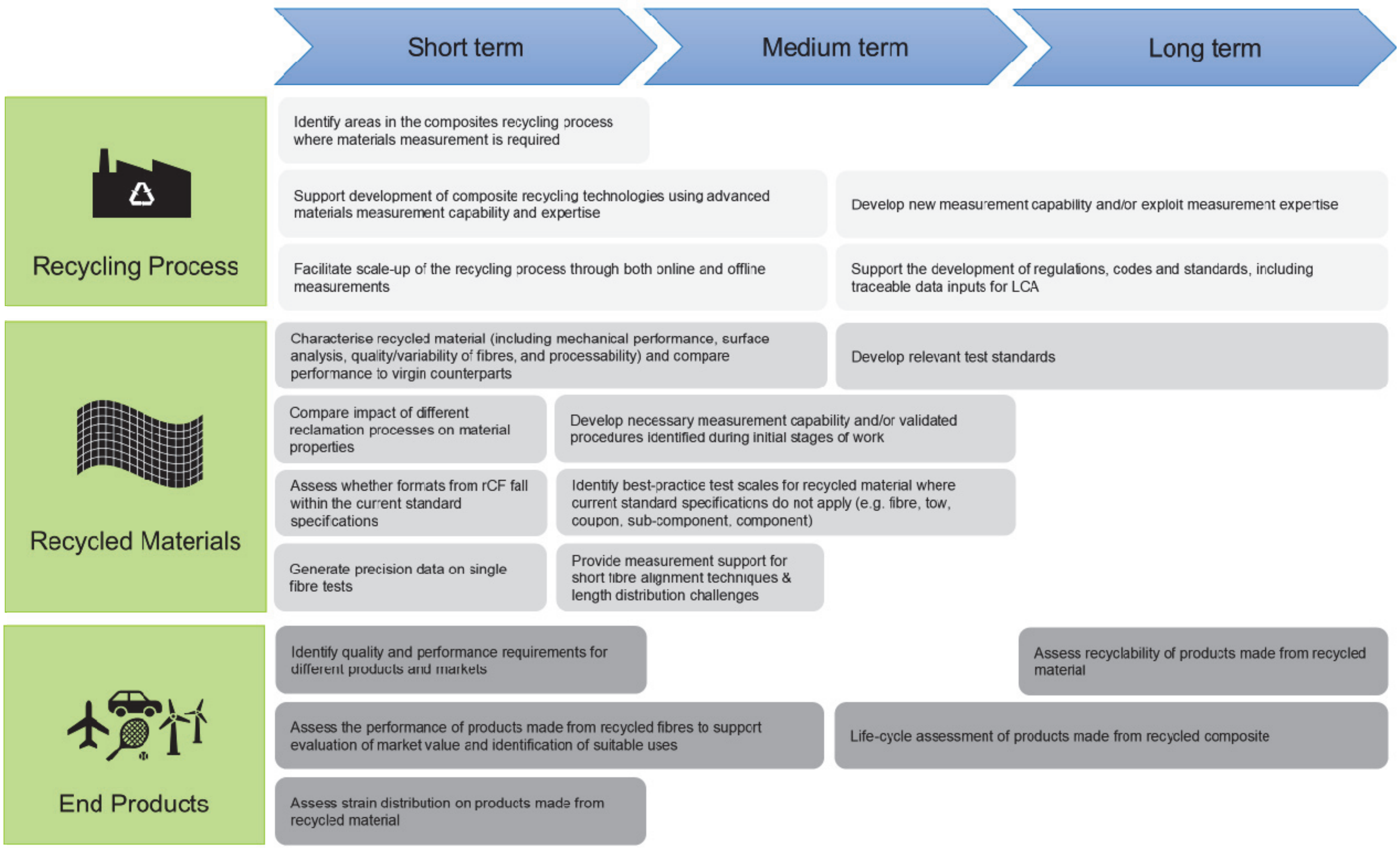
1 ISO/CD 19374 Recycled carbon fibres — Designation system for recycled carbon fibres has progressed through the Committee Draft (CD) stage and will move to the Draft International Standard (DIS) stage, whereby the draft is available for public comment. Depending on the level of technical comments received at DIS ballot the standard will either be published or require an additional ballot at Final DIS (FDIS) stage prior to publication. Within this standard, a designation system for recycled carbon fibres has been outlined. This includes recording details of the source material, the recovery process used, recycled fibre format, sizing and resin compatibility. Successful publication of this standard would provide a template for addressing a number of concerns raised during the industry consultation process.
2 ISO 19350:2025 Recycled carbon fibre — Determination of tensile strength distribution and interfacial shear strength of single filament embedded in matrix polymer has now been published. This standard provides guidance on testing of mechanical properties at the fibre level.

To assess the need for any additional standards relating to other properties of recycled composites, it is necessary to first understand which existing standards are valid. Of those properties for which existing standards do not apply, new best practice guidance would have to be developed. To address the priority issues raised during the industry consultation process, the following actions are proposed:

- Understand which regulations, codes and standards that are currently in existence can be applied to recycled products, covering constituents (resin/fibres), coupons, and components, and assess whether these tests are scientifically valid for a recycled composite. Develop methods for performance testing that are not covered by existing methods.
- Establish best practice guidance on surface characterisation of recycled fibres.
- Provide an assessment of the performance of recycled composites, including comparisons for material recycled using different reclamation methods.
- While not covered in the industry consultation, identify any metrological challenges in support of the reclamation process, e.g. design of process parameters.
- Develop a Life-cycle Assessment methodology for recycled composites.

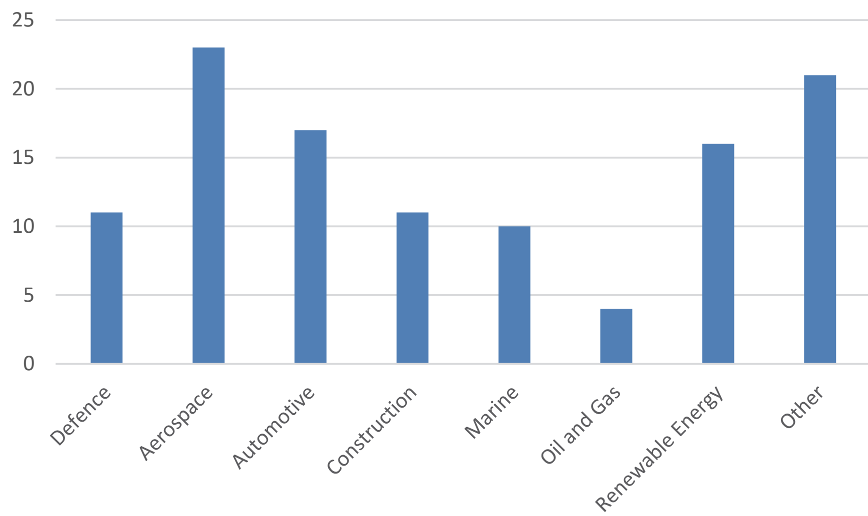
To support the development and uptake of composites recycling and manufacture of products using recycled material, the roadmap presented overleaf is proposed. Research activities have been separated into those which apply to the recycling process, the recycled material, and the second life products manufactured using recycled material.

Metrology roadmap for composites recycling



APPENDIX A: RESPONSES TO THE INDUSTRY SURVEY

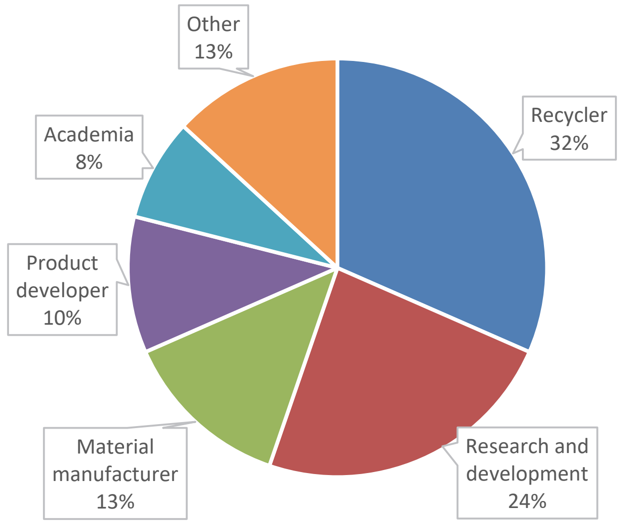
1. What is the main industrial sector that your organisation operates in? (Select all that apply)



2. If you have selected Other to the previous question, please specify

- Recycling of composites (5 responses)
- Sports (5 responses)
- Research (2 responses)
- Machinery
- Telecommunications (optical fibre manufacture)
- Industrial
- Space
- Academia
- Materials (2)
- Chemicals
- Safety in technology and chemistry

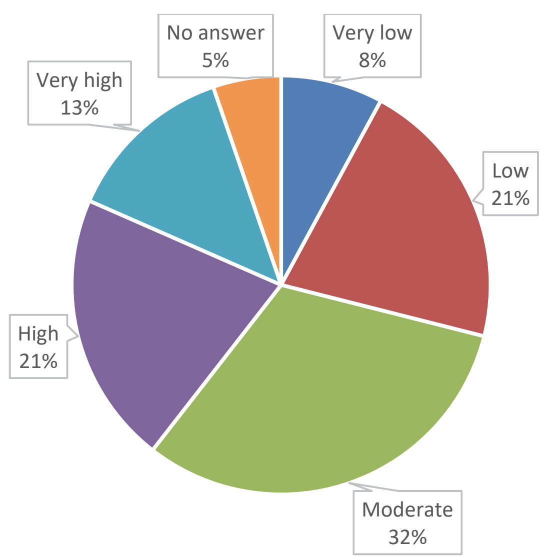
3. Which of the following best describes your organisation's area of work?



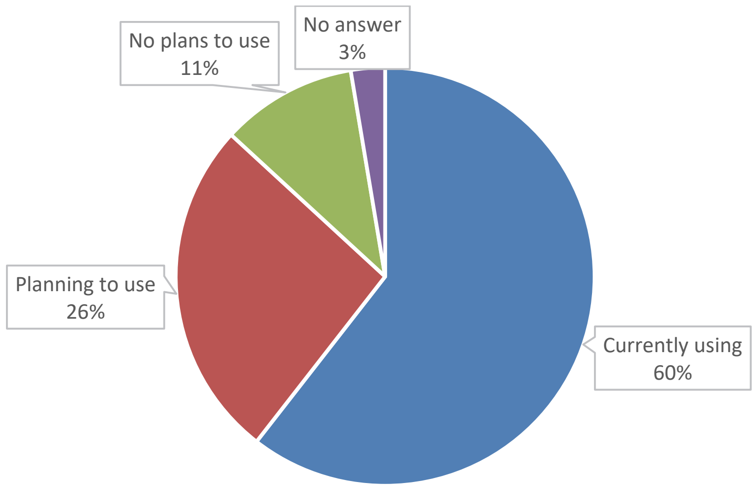
4. If you have selected Other to the previous question, please specify

- Research institute in the field of Composite Recycling
- Strategic Advisor
- Industry Trade Association
- Specialist Machinery Builder

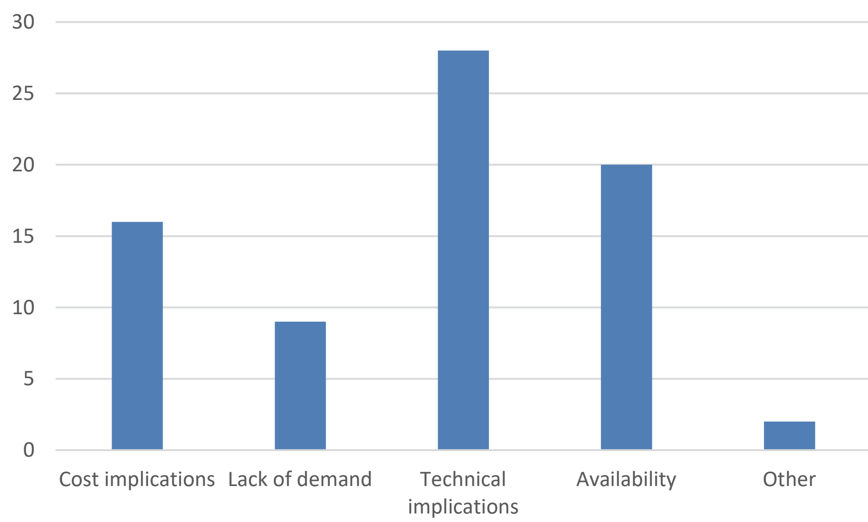
5. How would you rate the current market demand for products made with recycled fibres?



6. Please indicate your current or planned status regarding the use of recycled fibres in your organisation



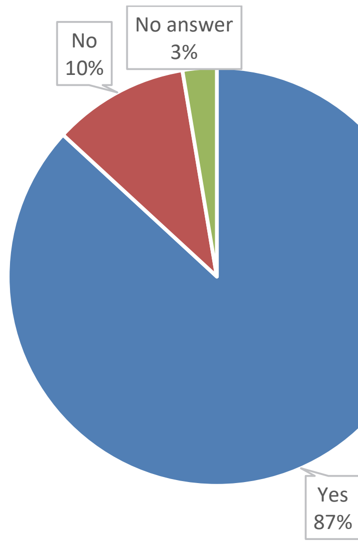
7. Please identify the challenges or barriers that your organisation faces in incorporating recycled fibres into its products. (Select all that apply)



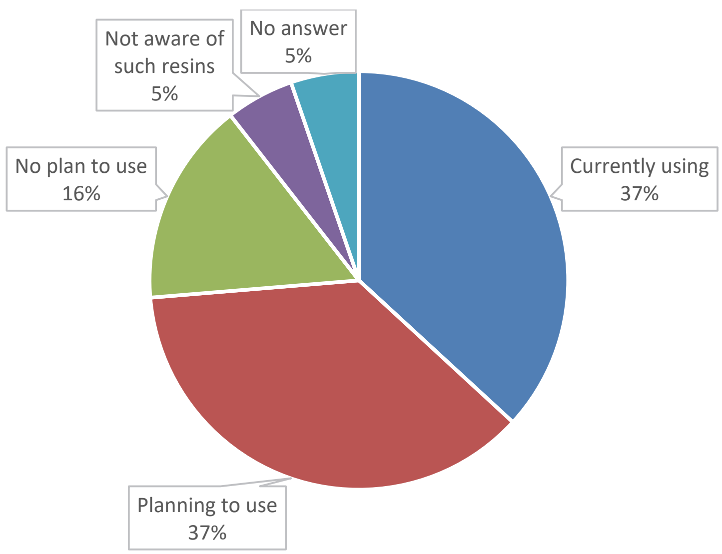
8. If you have selected Other as option to the previous question, please specify

- We do supply recycled fibres
- We do not produce composite parts as a business

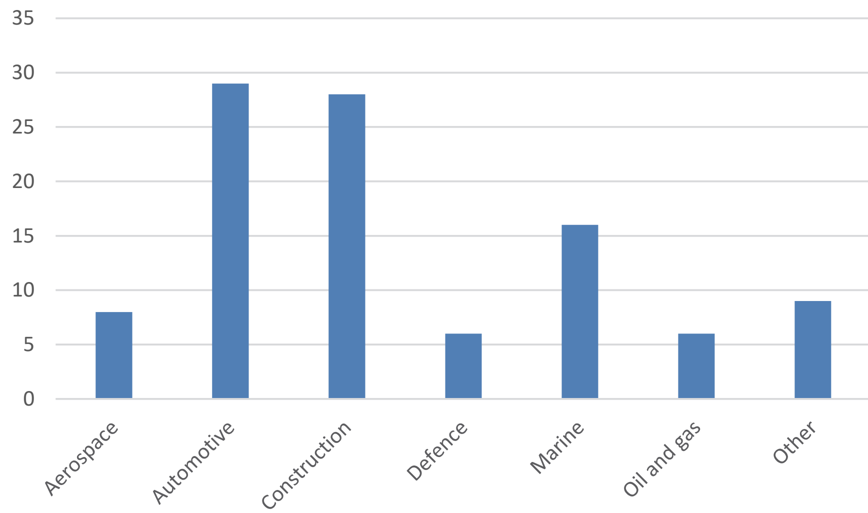
9. Is your organisation aware of recyclable resins or resins that contain recycled content?



10. Please indicate your current or planned status regarding the use of recyclable resins or resins that contain recycled content in your organisation.



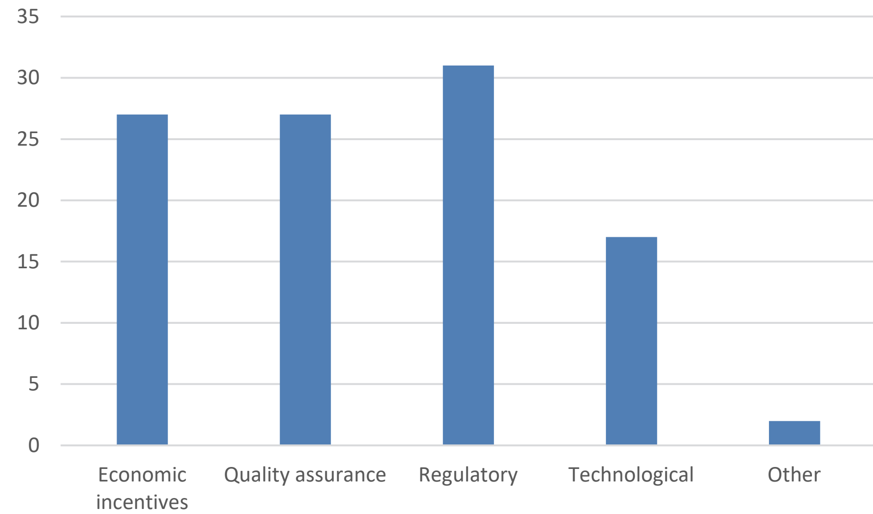
11. In which applications do you see the greatest potential for components manufactured with recycled fibres / resins? (Select all that apply)



12. If you have selected Other as option to the previous question, please specify

- Recycled resins have broader application
- Furniture
- Railway
- Chemicals and foundation industries direct
- Design
- Domestic products like garden, rail
- ALL sectors MUST adopt
- FRP and Optical Fibre and Cables
- Industrial

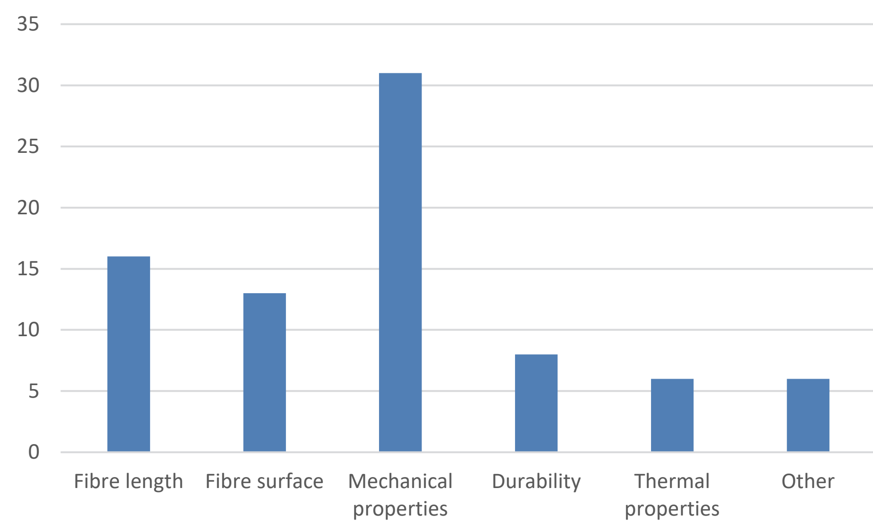
13. What factors do you believe would influence the adoption rate of recycled fibres in the market? (Select all that apply)



14. If you have selected Other as option to the previous question, please specify

- Better cost to performance ratio
- Supply chain availability and case studies

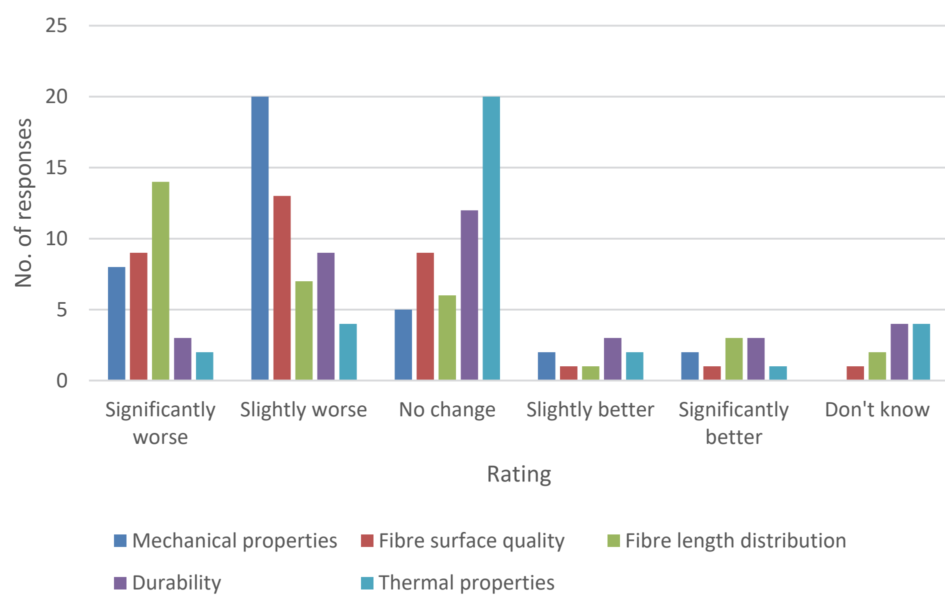
15. What is the most critical property for recycled fibres in your application? (Select all that apply)



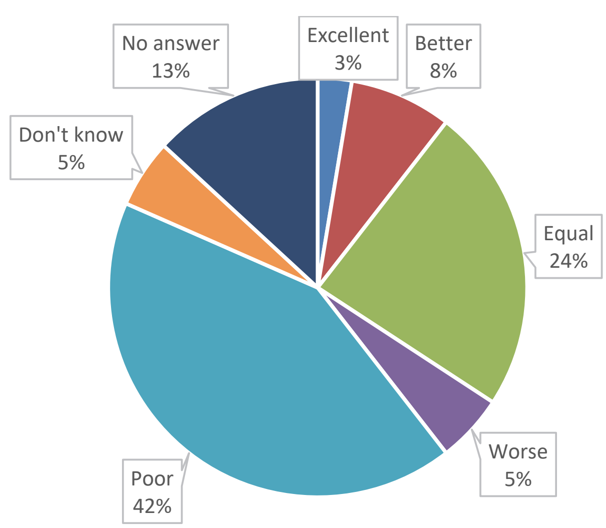
16. If you have selected Other as option to the previous question, please specify

- Mechanical properties of the final part
- Fibre orientation
- Consistency of quality and repeatability of properties.
- Consistency of these properties
- Processability (difficulty in handling the fibres)

17. Based on your expertise, please evaluate the performance of recycled fibres in comparison to virgin fibres in the following categories:



18. In your experience, how consistent are the properties of recycled fibres compared to virgin fibres?



19. Based on your experience, have you identified any material properties in virgin fibres that are notably declined or absent in recycled fibres?

- Diameter distribution
- The change from continuous to discontinuous affects processability. Tensile strength reduces, depending on the thermal conditions of the fibre reclamation process and the fibre type. Fibre sizing is typically removed which also affects processing and handling (fibres will fray).
- Durability
- Fibre length
- It depends if they are remelted or not.
- Absence of dust
- Depends on applications
- Depending on the way of freeing the fibres from the matrix
- Adhering into a new matrix, reduction of tensile strength
- Fiber orientation in semi-finished products made of carbon fibres
- Volume fraction of fibre is reduced in rCF composites.
- Much less mechanical resistance, less modulus (but could be almost equivalent)
- Strength
- All measures of fibre dominated mechanical properties
- Interface properties (reduction in functional groups on carbon fibre and removal of sizing in glass fibre)
- Reduced strength in glass fibres (surface defects after removal of sizing)
- Sizing for traditional processes
- It strongly depends on the reclamation process; however, strength might be significantly reduced; moreover, a comminution phase is often necessary to perform reclamation; finally, any pre-existing architecture is generally lost.
- Pressolysis-reclaimed fibres and resins have zero difference to virgin.
- Mechanical performance. Surface quality also highly dependent on recycling process
- Tensile and thermal properties
- Strength
- Tensile and flexural properties
- Lower strain on dynamic range
- Stiffness, strain properties
- It depends on the method of recycling, Pyrolysis and Solvolysis can have a notable detrimental effect on fibre properties. Pressolysis would appear to have no ill effects, and on occasion has been better.

20. Based on your experience, are there any measurement methods that are insufficient for quantifying the material properties of recycled fibres or components made with recycled fibres?

- Final material properties
- Reliance on expensive and time-consuming single fibre tensile tests (SFTT), which have varying methodologies. Need to improve standard, maybe with tow testing rather than SFTT.
- Density measurement
- Fiber length is hard to measure
- Insufficient: Single fibre testing - its costly and a bit meaningless when comparing with virgin (often continuous) fibre or laminate properties. Insufficient: Surface analysis (at rate) for fibre; continuous and short.

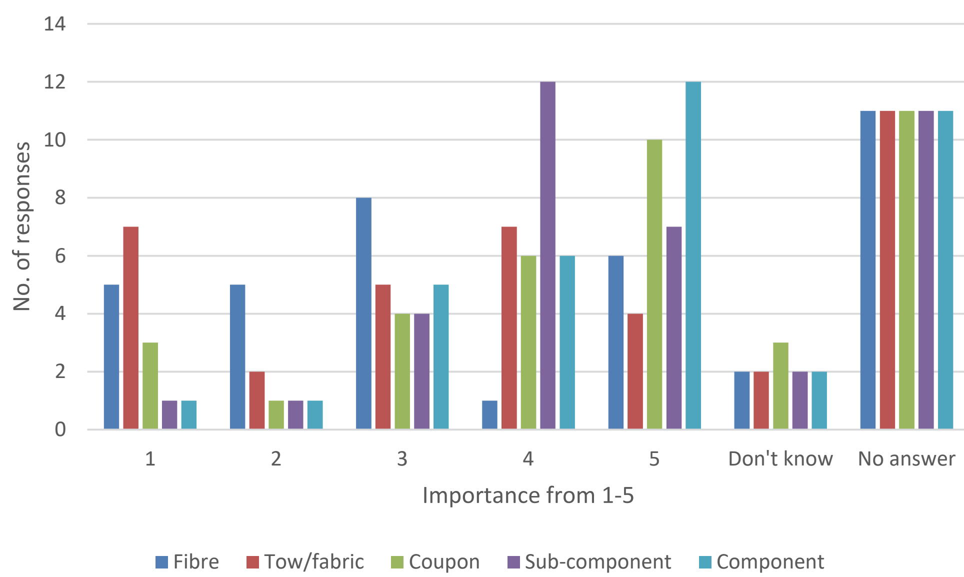
- It is important to compare mechanical properties of the composites, not the monofilament. Because de mechanical properties of monofilament rCF are almost the same than vCF.
- Interface properties
- Comparing with traditional materials (e.g. plywood) without considering the difference in process (e.g. no need to dehydrate material) and durability
- No, a series of single fibre tensile tests are usually sufficient, even if testing a significant number of fibres might be extremely time consuming.
- Recycled fibres need to meet the same measurement standards as virgin fibres even though the actual properties may be different.
- Still working on this element
- Assuming that “new” equals 100% performance is misleading. Understand the delta.
- Lack of ability to tow test is a barrier
- ILSS to measure fibre-matrix adhesion (which is generally insufficiently studied and difficult to interpret)
- Because of the forms of some of the recyclates, short fibres are the only route to end use, which by their very nature are hard to measure.

21. Based on your experience, do you have any specific technical or quality related concern while using recycled fibres instead of virgin fibres in your product?

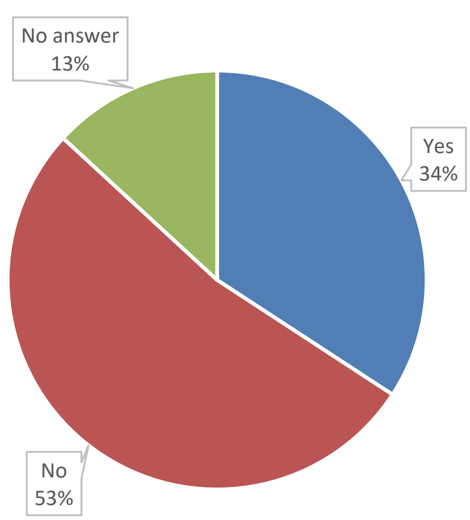
- Quality Assurance
- Alignment is key from a technical perspective, as is fibre length. Quality depends on reclamation process and whether the fibre has been damaged. Damage assessment is critical
- Contamination with other material
- The recycling process is defining everything.
- Environmental due to fine fragments
- None, if the testing of the final product meets the standard
- We need some standards on what is meant by comparing recycled fibre with virgin. Comparing short fibre with continuous is rather meaningless outside of idealized scenarios
- Need to have investable cost/environmental metrics accompanying recycled fibre. Our customers want to know how much GWP saving there is and what the cost is over and above virgin
- There is no fabric similar to virgin fabrics when we talk about recycled fibres. Mat have really low mech properties
- It depends on the application I would say. High performance GFRP parts will not be using recycled fibres due to the lack of consistency in the quality (which impact the mechanical properties)
- In glass fibre - reduced strength
- In carbon fibre - interface, fibre length
- One of the key challenges in recycled fibre is in their discontinuous format (fibre fluff) and the difficulty of handling this in automated processing and compounding systems
- Our process accept any kind of composite waste, we do a mechanical process that bond together the composite in particles, main issue is presence of wood or balsa as reinforcement - core material , that rot and expands
- No as I don’t use them, but if I did I would want them to be assessed against the same standards as virgin fibres even if the actual properties are different.
- No but we are looking at a matrix to get through this
- Chain of custody. Availability of consistent feedstock
- Yes, variability, property reduction, contaminants - many concerns
- Quality

- Yes, we must have a consistent set of mechanical properties. With those we can engineer a solution. Otherwise, it would be relegated to semi-structural applications.
- Uncertainty and heterogeneity with the latter being a big problem for industrial application
- Plastic inclusions on nodule amplitudes
- Mechanical properties
- The presence of char on the recyclates could have a detrimental effect on the finished composite properties.

22. If you are using recycled fibers in your product, please rate the importance of the following testing scales for your application. Use a scale from 1 to 5, where 5 indicates the highest priority and 1 indicates the lowest priority.



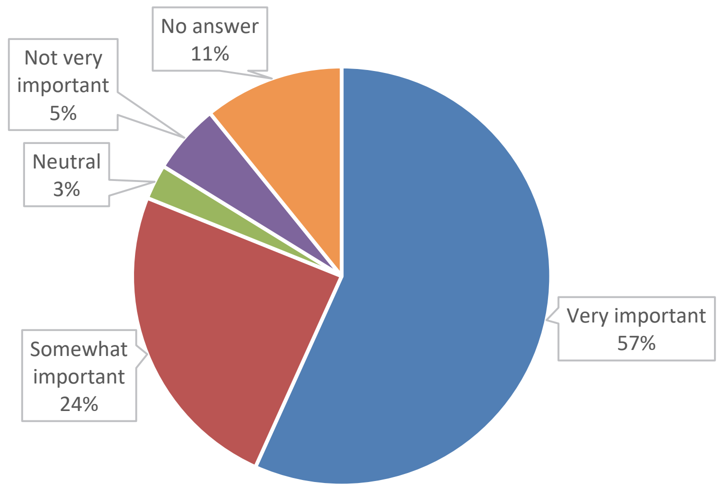
23. Based on your experience, do you believe there is sufficient data to support and to prove that recycled fibres are meeting performance requirements?



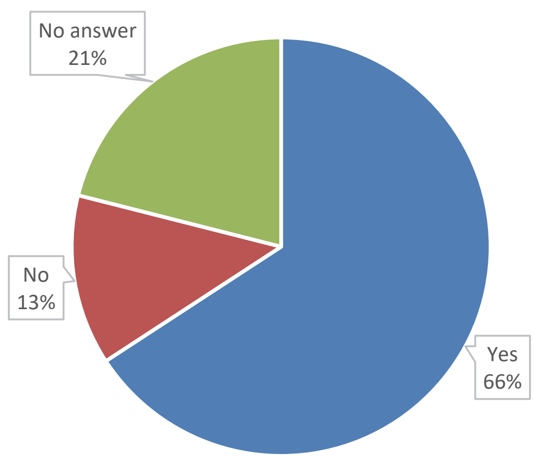
24. In your opinion, how can metrology improve the recycling process and ensure the quality of recovered fibres?

- Establishment of relationship between recycling process and final material properties needed
- Traceability
- Security of supply
- I think metrology processes will likely be the same as with virgin fibres, given the tests indicating fibre quality specific to the recycling impact would likely be earlier in the material development (SFTT, SEM, tow testing, fibre length measurement, microscopy of coupons).
- Improve cutting technologies for better length control and reduction of dust
- Need: training and measurement capability for recyclers to improve their cost/energy efficiency whilst retaining quality. Need: support to industry on design-of-experiments to optimise towards targets. Need: Targets for recyclers that are measurable. Need: repeatable and standardised classification of recycled fibre that are like-for-like with virgin.
- Create standard tow / fabric level testing for recycled fibres
- Metrology is ok, but creating standards is the most important
- The problem is the supply chain not the metrology
- In-line surface characterization methodologies
- Any improvement will be more than welcome
- The problem is that the provenance of the materials from which the fibres are reclaimed is unknown, therefore it is impossible to certify the rCF properties only knowing the reclamation process, therefore test able to quickly measure, at least stiffness and strength, of many fibres is needed.
- Same tests and standards as virgin. Recycled fibres should be treated no different than virgin fibres in equivalent applications.
- Open-source data library
- Stop viewing them as recycled and test like any other new material.
- Rapid low-cost testing of surface chemistry, FLD, char levels would be a great start
- Traceability of waste and low impact reclamation processes
- By maintain and sustain the quality
- Not sure how metrology can improve the recycling process itself, other than more data is required for recovered fibres. They need to have their own place in an Ashby type diagram, so they are considered in design
- Developing testing and evaluation methods that are close to industrial component testing rather than textile or matrix properties in simple shapes alone
- Consistency in sizing the geometry
- Because of the nature of the disparate forms of material for recycling it is very hard to fix a standard. Much like in virgin carbon fibre manufacturing where there are specific metrics that start at Polymerisation through Spinning and onto Carbon Fibre that give us traceability and process chain properties, doing the same with recyclates will pose a challenge.

25. How important is traceability in the supply chain of recycled fibres for your company?



26. Have you noticed any variability in the quality of recycled fibres between batches?



27. How does your organisation assess the quality and consistency of recycled fibres, and what measures are implemented to ensure these standards are met?

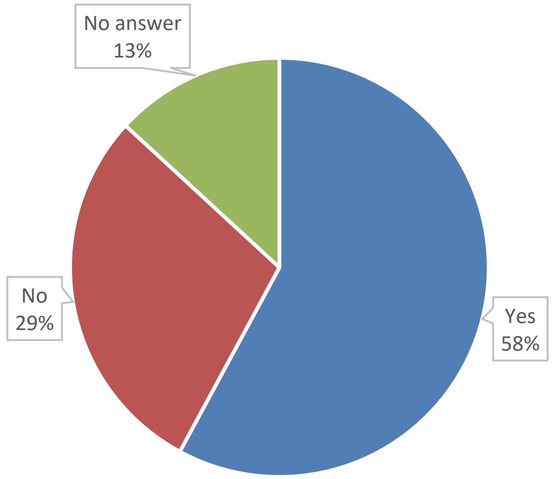
- Ongoing research
- SEM microscopy to observe damage, TGA to understand success of matrix removal, image based fibre length distribution measurement, and microscopy of cured coupons to measure alignment. Also tensile testing regimes in 0, 45, and 90 degrees at both coupon and component level.
- Own lab
- It depends on the quality and consistency of the input of material to recycle in our process.
- Testing with final product

- Single fiber tensile tests
- Coupon tests of panels made of the recycled carbon fibers
- Various methods - mostly for research purposes and/or to validate datasheets. For assessment of recycling technologies Single fibre tensile, microdroplet testing, visual (inc optical/SEM), laser (e.g. for distribution), Raman and more.
- Most tests are inconsistent, prone to failure. Only successful tests are reported, which omit statistical defects. If 50% single fibre tensile tests fail due to premature breakage and only successful tests pass, then that's indicative of a problem - but the reported data often omits/fails to recognise this.
- Developing (via the CEAMS programme of which NPL are a partner) continuous fibre testing/tow testing methods and capabilities"
- Double check traceability data from the suppliers + internal testing
- Test methods: single fibre test, pull-out test, fibre length measurement, TGA, SEM, dry tensile test of nonwovens, mechanical characterization on composite level, micrographs
- We collect all the rCF data in an internal database and can then quickly compare different materials
- AV at single fibre level
- There is no such thing as a uniform rCF. A reclaimed T300 fiber will have entirely different properties compared to T700, T800, or high modulus carbon fibers. Yet, many discussions on rCF fail to acknowledge this variability, often overlooking the original source of the fiber. Since different types of carbon fibers have distinct properties, it's no surprise that rCF behaves similarly. However, rCF is frequently treated as a uniform material, which is like comparing apples to oranges
- We do a comprehensive tracking of the feedstock, from waste analysis of single batches to the processing in production line to the final product, that will keep all the data from source and process in a RFID or NFC tag
- We do research, so either we trust the data sheet, or we measure the properties in our lab.
- Random measurements/testing, batch review
- We're in an R&D context rather than end use. We do filament tensile testing, surface chemistry
- Individual test on dispersion and mechanical testing on samples
- Comparing the standards of virgin materials
- Conduct our own tests
- "Fiber length and distribution measurements before and after processing
- Typical material property testing and benchmarking"
- We haven't yet
- Sizing, random testing
- As stated before, there are no standards as yet, each case is different. If we know what the source material is, we measure against this. That said not all virgin CF specs are the same, hence why on occasion we have had better than virgin results.

28. Do you use any standards or certifications specific to recycled fibres or products made with recycled fibres?

No – respondents only quoted existing composites test standards.

29. Based on your experience, do you feel Is there a need for development of new standards relating to recycled fibres?



30. If you answered yes to the previous question, could you specify the areas that need more standardisation?

- Measurement of fibre length distribution, measurement of fibre alignment, tensile testing appreciating the increased variability between batches, assessing degradation of reclaimed fibres (more than SFTT).
- We need norms (ASTM etc) to define what is a recycled fibre: mechanical recycling destroys the fibres, thermal preserves them, it is not the same "recycling".
- According to the recycling methods, minimum specs like strength, surface etc
- Testing of recycled fibres
- Specification of recycled fibres and how to name them correctly
- Biggest issue is repeatability & applicability for fibres which may have had damage (i.e. break early) and therefore separation of operator error from a defect in the fibre.
- Tow / fabric level testing for recycled fibres
- Create a standard for measuring residual resin on recycled fibres
- DIN SPEC for single fibre test of recycled carbon fibres
- Length distribution, possibly interface/sizing. Strength.
- Recycled content
- Post consumer source/Industrial source
- Circular economy content
- Nomenclature, especially regarding provenance.
- A unified way to define the composites’ recycling process is needed. After pyrolysis, solvolysis etc. the fibres are simply reclaimed, they cannot be considered recycled until they are reformatted into a new material
- British standard for recycling fibre glass material
- British standard - for the material passport in the above process- nation composites materials library to accelerate the UK in the recycling and manufacturing sectors
- Filament testing does a good job of intrinsic properties but doesn’t capture surface, FLD aspects. Laminate testing then introduces a resin aspect possible unwanted fibre alignment etc and is a pain to perform. Neither option really does what people need
- Formability
- We need assurance that what we are getting is to a specific standard and that it will behave in a predictable manner. I don't yet have enough experience of recycled fibres to comment on specifics, but their adoption (as stated above) is at least in part going to be influenced by how well they can be characterised and their consistency.
- Fibre length and distribution, mechanical and thermal properties

- ILSS
- In component testing generally (given that most specimen for composite testing are rather simple geometries)
- Yes, new standards relating to recycled fibres.
- Quality acceptance test

APPENDIX B: RESPONSES FROM THE IAG WORKSHOP

1. **What properties related to recycled fibres need to be measured? This can be for the recycling process, recycled product, or finished component. At what scale would validated measurements be most important? (i.e. fibres, coupons, component)**

   - How degraded are fibres at end of life? How does this compare in value to manufacture waste?
   - Primarily for continuous/long surface quality; residual char (not always bad), reactivity/surface chemistry, morphology/new defects, twists.
   - Length distribution. Comminution is a big challenge e.g. baled cars prior to shredding
   - Recycled fibres; impact of previous service life on properties (variability). Surface properties – poor adhesion (CMCS), good adhesion (PMCS). Fibre performance is less critical in CMCs (focus is improving toughness not strength)
   - Surface and sizing characterisation
   - Durability
   - How to preserve fibre length
   - The presence of residual sizing
   - Effects on coefficient of variability. In many design codes, the CoV drives allowable strengths
   - On fibre strength, surface properties, chemical handling properties
   - Interfacial and ability to resize
   - Surface properties
   - Tensile props. Individual fibres
   - Finished component – recreate qualification/specification. Testing
   - How are recycled fibres processed to form reinforcements?
   - ‘Real’ comparisons – original Vs recycled
   - Comparisons of recycling processes
   - Uniformity
   - Fibre lengths
   - Alignment of fibres. To improve final props
   - Effects of feedstock and impurities
   - Process parameter variation
   - Resin permeability of recycled fibre (reinforcement)

2. **What are the gaps in standards and procedures preventing the uptake of recycled composites?**

   - LCA; ‘cradle to gate’ Vs ‘cradle to cradle’
   - Fibre scale Vs coupon scale tests
   - Quality of fibres; virgin Vs reclaimed and variation from multiple sources
   - Comparing short with long at single fibre – potentially misleading. Omits the Vf & orientation challenge in coupon
   - How do other regulated industries (e.g medical devices) deal with use of recycled materials (e.g plastics)?
   - Standard on discontinuous fibre composites
   - Uses of recycled fibres in concrete

- Mostly market issues
- Are current standards applicable?
- LCA (carbon footprint)
- Supply chain gaps – recovery, traceability
- Design codes
- Design for EOL/recovery

3. What are the gaps in measurement capability/infrastructure for evaluating the quality of recycled materials?

- Pitch base fibre
- Test standard for recycled fibres.
- How many times can a material be recycled?
- End of life value assessment of a material – relife Vs recycling
- Use of recycled carbon fibres for CMC or CSC application
- Effect of solvents on fibre length/interface
- Lack of measurement infrastructure (standard) for pristine fibre – how do you compare for evaluating qualities of recycled materials?
- Broaden to policy? What gaps are there in data preventing legislation/regs/codes/standards
- Consider the CO^2 impact. EPD/GWP/LCA
- Market for recycled materials driven by lifecycle CO^2 emissions reductions
- Legislation
- Are the materials there yet?
- Coordinated funding and programmes
- Recycling plants for composites
- Cost of recycling
- Scale of recycling. Still small!
- LCA
- HSE compliance, e.g. emissions
- Long term reliable material – product – EOL (recycled). DATA
- Resin!
- Economic value Vs Sustainablity

4. How important is the traceability of materials to recycling of composites and use of recycled products? What are the barriers to traceability?

- Very important
- Accept a lack & dev rapid profiling pre-reclamation & commoditize output
- Traceability from ‘raw materials’ to recyclate for use
- ‘Waste’ collection
- Lack of industrial material data. Any EPR or IP issues.
- Legislation or policy to extend responsibility for recycling. Manufacturers – users – waste.
- Recycling markers on products, like domestic plastics
- Depends on the next user. Most useful is to distinguish between IM and HT grades
- Length of service. Design today for EOL in 2045!
- Complex components containing mixed composites, metal, paints, etc

- Traceability very important. HS Vs IM CFs
- Maintenance of records
- Different processes to recycle EOL components
- MDSystem.com. IMDS – AUTO
- Circularity – emphasis should also be on minimise & life extend – upcycle apps