ELG Carbon Fibre Ltd.
RECYCLED CARBON FIBRE

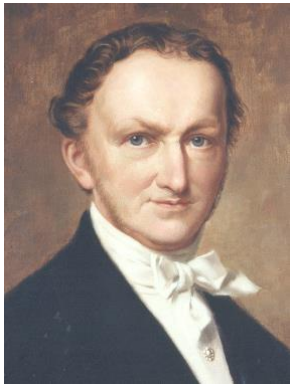
Recycled Carbon Fibre: A New Approach to Cost Effective Lightweighting

Content

- ELG Carbon Fibre
- Rationale for carbon fibre recycling
- Carbon fibre reclaiming
- Carbon fibre conversion
- Recycled carbon fibre products
- Quality and environment
- Summary

Introduction to HANIEL

More than 250 years of History



Franz Haniel,
1779 – 1868

Owners	approx. 680+ shareholders 100% family-owned since 1756
Corporate Governance	Separation of ownership and management
Group Structure	Four corporate divisions with totally different activities + Investment in METRO: - more than 800 companies in majority ownership - about 11,500 employees
Corporate Divisions:	focus on core businesses & market leadership

Introduction to **ELG Haniel Group**

Stainless Steel Scrap	Superalloys Scrap	Other Materials
Recycling alloyed scrap	Recycling High-Ni Alloys, Titanium	Ferrochrome, **Carbon Fibre** Carbon Scrap, Long Products
Europe 485 Employees*	**ELG Superalloys**	**Other Materials**
Overseas (incl. US, AUS, Asia) 270 Employees*	110 Employees*	165 Employees*

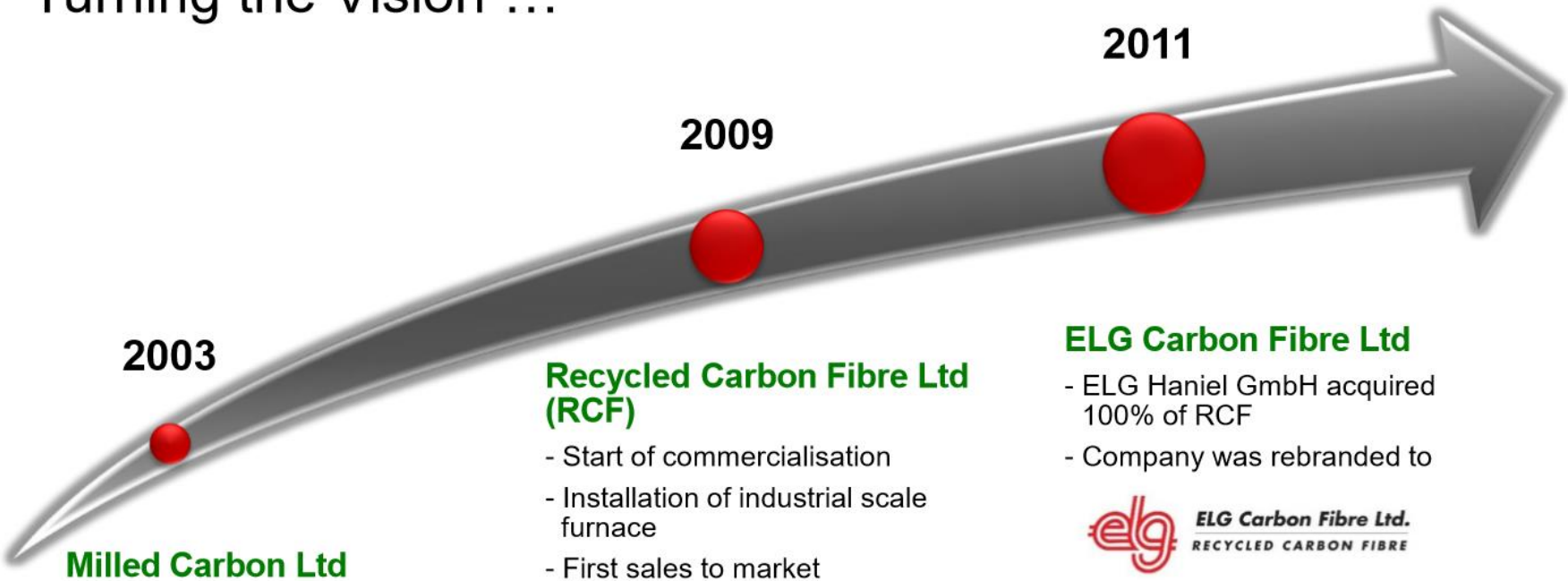
ELG Haniel GmbH (Holding Company)
23 Employees*

** Total Employees = Ø 1055 Headcount*

- Recycling of High Performance Materials (NEW: **Carbon Fibre**)
- 3 business units with the core market segment in stainless steel
- Global market leading company with 45 operational yards worldwide

ELG Carbon Fibre

Turning the Vision …



2003

Milled Carbon Ltd

- Established as an R&D company
- Pilot scale furnace
- Proof of concept phase

2009

Recycled Carbon Fibre Ltd (RCF)

- Start of commercialisation
- Installation of industrial scale furnace
- First sales to market

2011

ELG Carbon Fibre Ltd

- ELG Haniel GmbH acquired 100% of RCF
- Company was rebranded to

ELG Carbon Fibre Ltd.
RECYCLED CARBON FIBRE

- Focus on high volume carbon fibre recovery, conversion to recycled carbon fibre products and QA/QC systems.

… to Commercial Reality

Our Value Chain

Feedstock

Dry

Prepreg

Laminate

Intermediate Processing

Shredding

Pyrolysis

Chopping

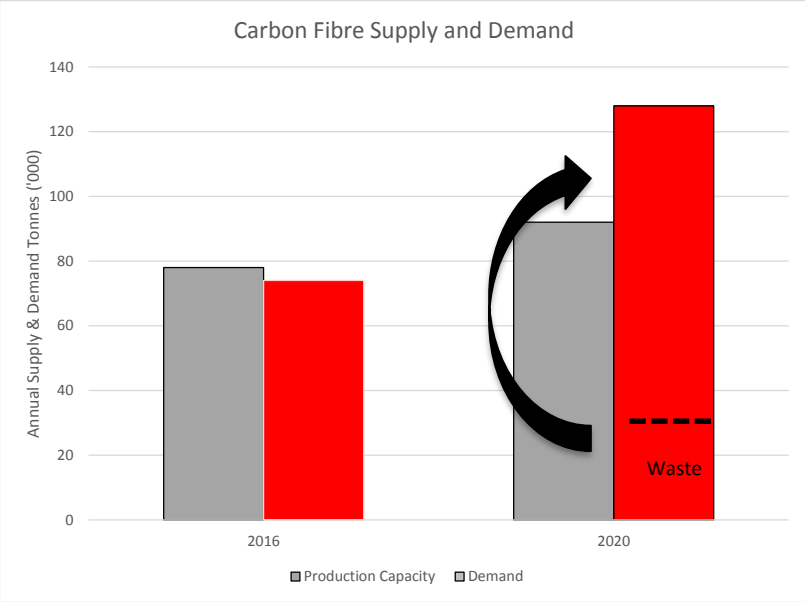
Intermediate Product

Staple Carbon Fibre

The CF reclamation is the HEART of our process, but only one challenge to 'close the loop'!

Why Recycle?

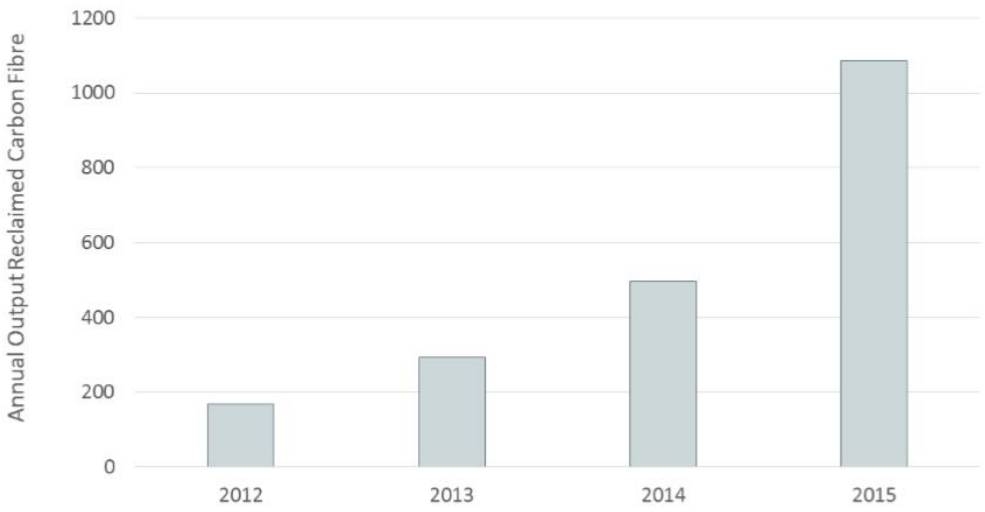
- Cost: recycled carbon fibre products can reduce the cost of lightweight structures and components.
- Environmental benefits: significantly reduced global warming potential.
- Legislation: increasing onerous legislation regarding the disposal of composite manufacturing and end-oflife waste.
- Supply chain security: mitigates against shortages in virgin carbon fibre supply.



Recycling of manufacturing waste can help fill the forecast gap between carbon fibre supply and demand

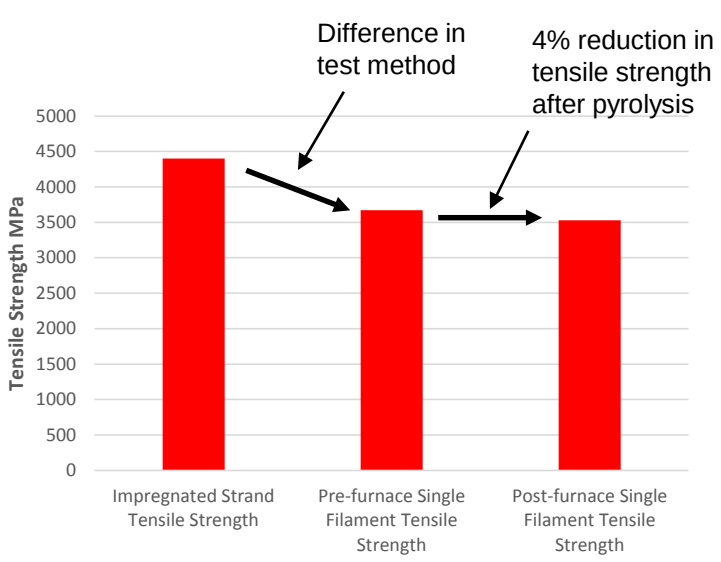
Carbon Fibre Reclaiming

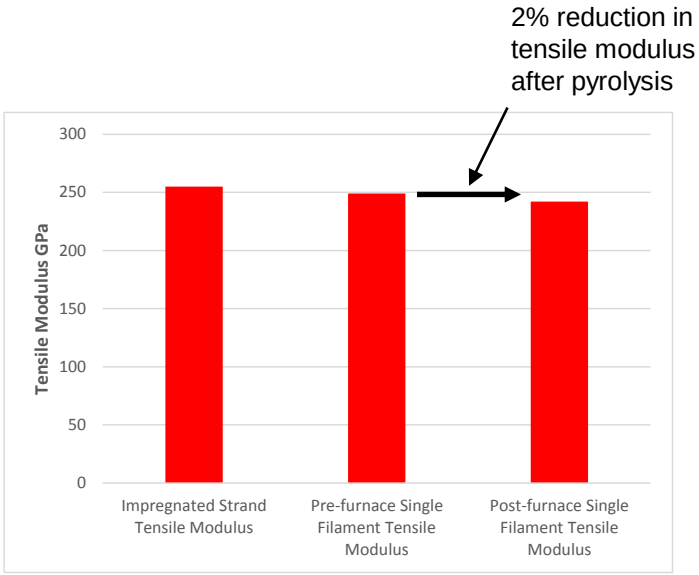
- ELG can produce more than 1,000 tonnes of recycled carbon fibre products each year, using a patented process that results in 95% strength retention and 99% modulus retention.



Fibre Mechanical Properties

- Fibre mechanical properties measured using single filament testing before and after pyrolysis for classification and quality control purposes.



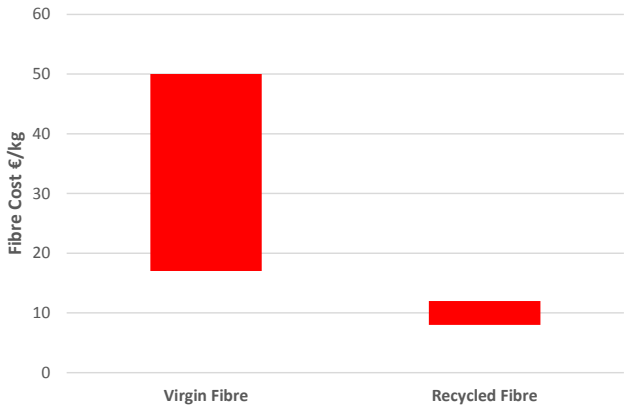


- Reclaimed carbon fibres have similar mechanical properties to the original fibres provided that the reclaiming process is optimised for the type of feedstock being treated.

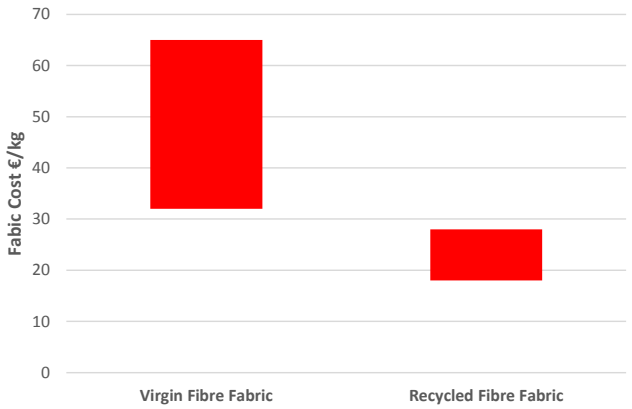
Based on single filament testing of 1484 fibre batches before and after fibre recovery by pyrolysis.

Cost

- Recycled carbon fibres and recycled carbon fibre products offer significant cost advantages.



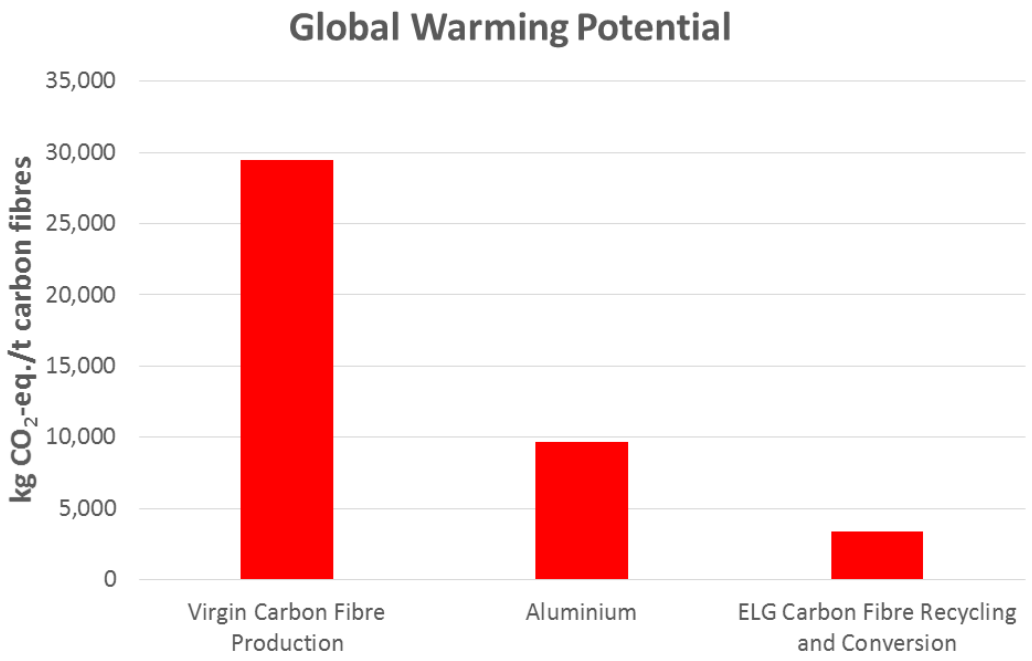
Standard Modulus Fibre



Industrial Grade Fabrics

Environmental Impact

- Recycled carbon fibres have significantly less environmental impact.



Further 36% reduction in energy consumption per kg achieved in 2015

Global warming potential comparison prepared by Fraunhofer UMSICHT based on ELG CF 2014 operational data.

Advantages of recycled carbon fibre

Excellent products

- After the fibres go through our process, there is a small loss in Tensile Strength (<4%), and almost no loss in Modulus.
- We measure the properties of each batch and issue fibre certificates.

Economic gains

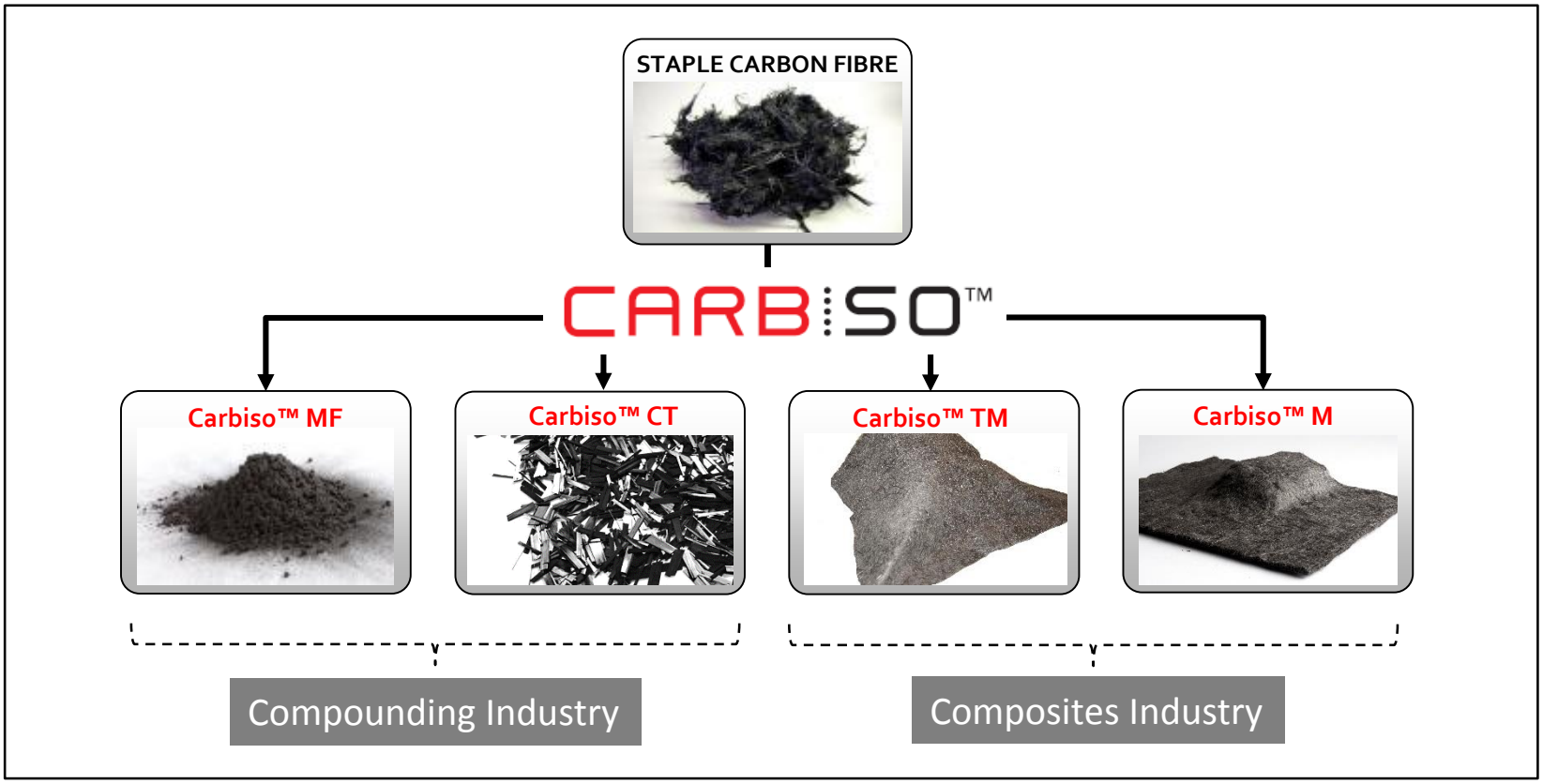
- Lower-cost, high-value products
- Stable pricing - not affected by world-wide carbon prices, so we can hold prices stable on a long-term basis.
- Stable supply - not be affected by any carbon shortages when supply 'tightens'

Social responsibility

- Reduce Carbon Footprint - The recycling process uses **< 10%** of the energy required to produce virgin carbon fibre.
- Minimise waste going to landfill / incineration.

Recycled Carbon Fibre Products

The product range – Carbiso™



Milled CF

Carbiso™ **MF**

- Standard milled CF
- Average fibre length 80µ or 100µ
- High bulk density
- Typical coefficient of thermal expansion (CTE):
  - Axial: -0.4 x 10-6mm/mm˚C
  - Transverse: 15 x 10-6mm/mm˚C
- Typical thermal conductivity: 5.40 W/(m.K)

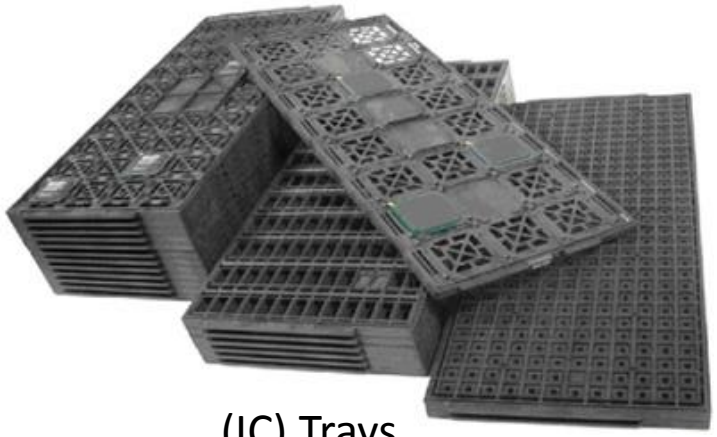
Carbiso™ MF has been qualified by an aircraft OEM for additive manufacturing.

Applications for rCF - Milled

Subsea buoyancy
deep sea oil and gas exploration. Highest volume market for milled carbon fibres.

Conductive materials
milled carbon fibre is used to provide electrical conductivity / antistatic properties in polymer compounds and coatings:

- microelectronics industry established standards for safe handling, transport and storage of Integrated Circuits (ICs)
- epoxy antistatic floor coatings



(IC) Trays

Applications for rCF - Milled

Additive manufacturing — milled carbon fibre is used to make filaments with improved mechanical properties for additive manufacturing (3D printing) processes.

CF reinforced PLA filament: Ideal for the fabrications of prototyping objects and drones

First 3D-printed car from Local Motors - 80% ABS plastic and 20% CF

Compounding — milled carbon fibre is used to improve the mechanical properties (mainly stiffness) in polymer compounds for injection moulding.

Chopped CF

Carbiso™ C

- Randomly chopped CF
- Standard fibre length distribution: 10-30mm
- Also available in 30-60mm and 60-90mm
- No sizing

Carbiso™ CT

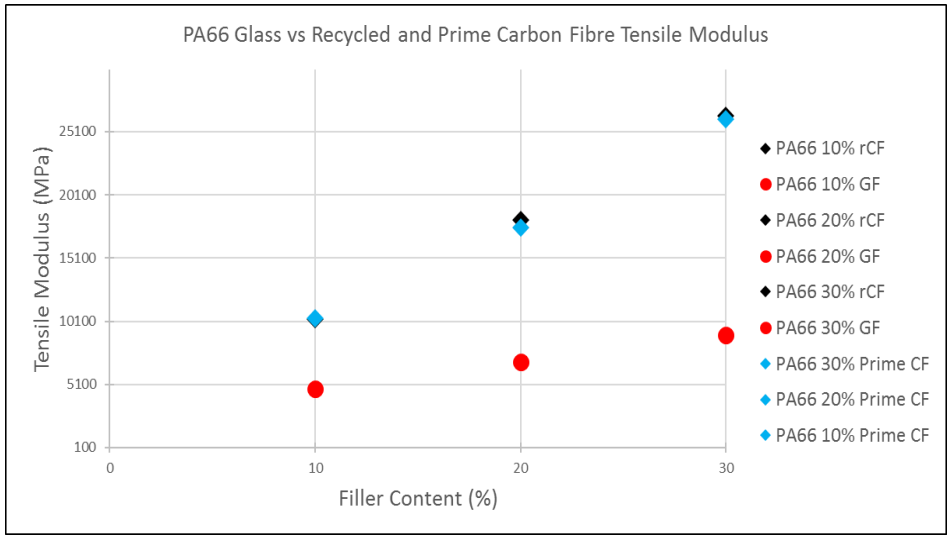
- Precisely chopped tow
- Standard fibre length: 6mm or 12mm
- Sizing (<2%)
- Sizing tailored to customer needs

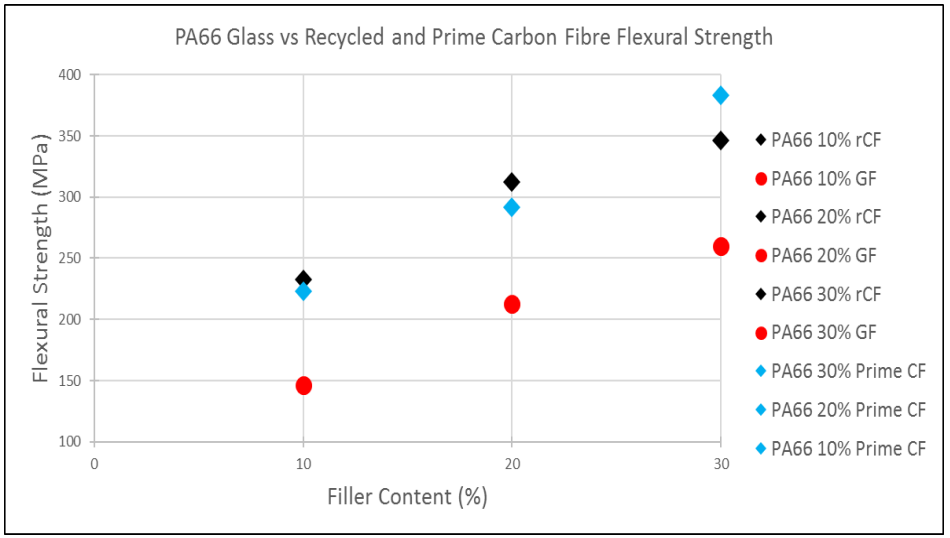
Applications for rCF – Chopped/Pellets

SMC and BMC moulding compounds
used in areas where long fibres cannot conform to complex geometry or where there are exacting surface quality requirements.

Net shape manufacturing
Chopped fibres being used in several research projects investigating net shape manufacturing processes--preforming for resin transfer moulding or stamp forming applications.

rCF compounds: Mechanical Properties





- Recycled CF give the same mechanical property enhancement as virgin CF.
- 10% loading of recycled carbon fibre provides the same mechanical properties as 30% loading of glass fibres:
  - 23% density reduction.
  - 4% material cost increase.
- 30% to 45% loadings of recycled carbon fibre provide mechanical properties comparable to magnesium castings and aluminium castings.

Performance Comparison

15% weight reduction

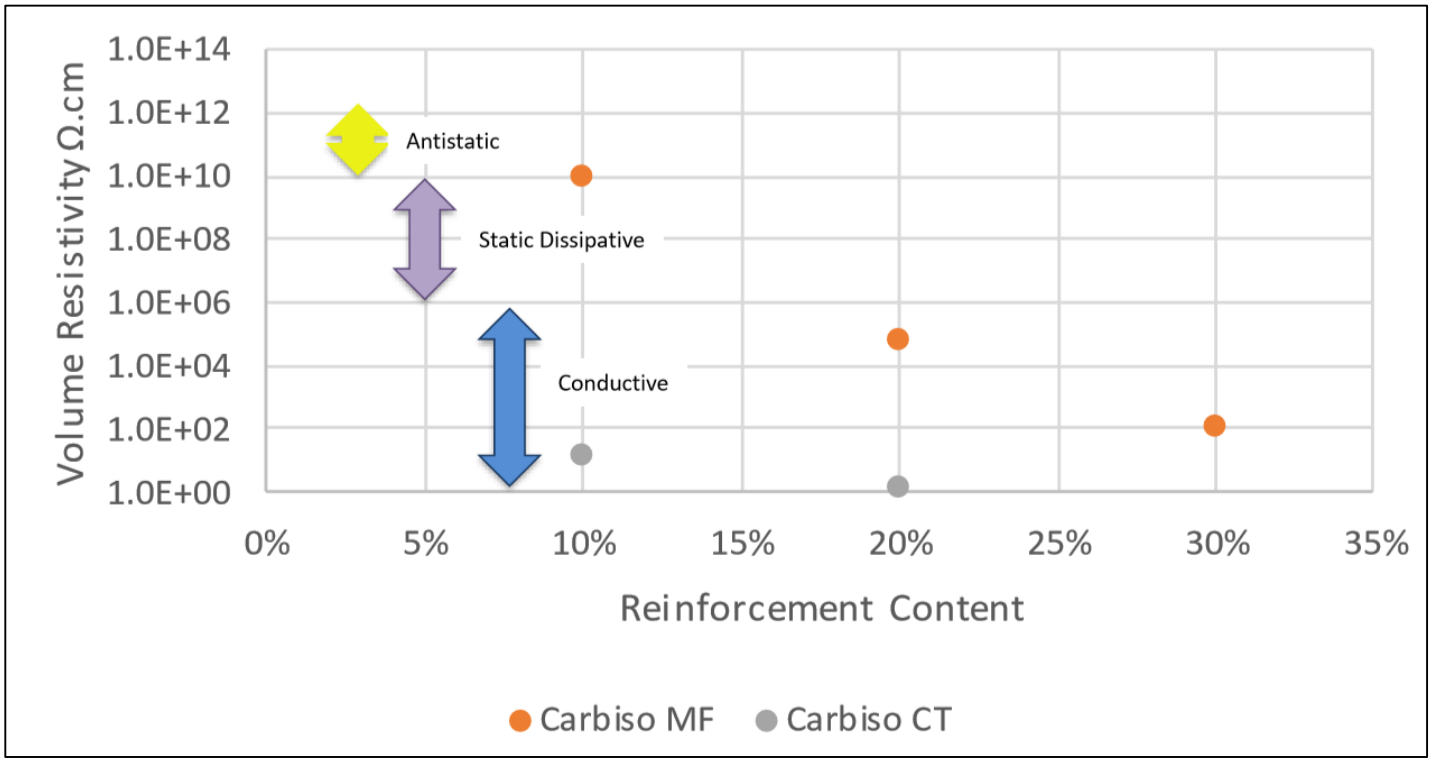
30% glass fibre reinforced PA66
56.9g

10% rCF reinforced PA66
48.7g

Higher mechanical properties

- With product optimization, 21% weight reduction can be achieved whilst providing the same mechanical performance without redesigning the parts.
- Part cost increase to achieve this weight saving ~2%.
- Over 750,000 tonnes of 30% glass reinforced PA66 compounds used for air inlet manifolds and cam covers each year by the automotive industry
  => potential for over 150,000 tonnes of weight saving!

rCF compounds: Electrical Properties



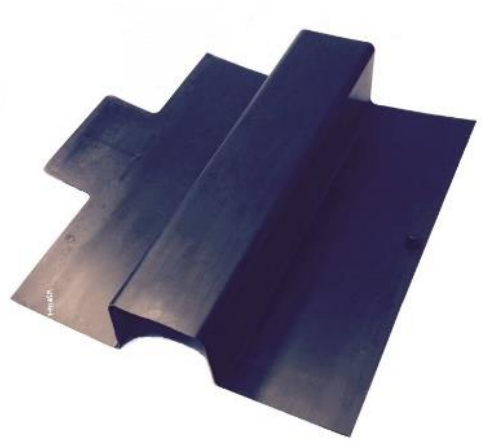
Recycled CF products are used to enforce the <u>electrical properties of engineering plastics:</u>

- Milled CF to achieve anything from antistatic to conductivity; targeted properties are subject to CF content
- Chopped tow enables conductivity at low CF content

Carbon Fibre Nonwovens

- Directly in composite manufacturing processes such as liquid compression moulding.
- Used as a raw material for prepreg and SMC products.

Nonwoven Mat



Part Made By Resin Transfer Moulding

Property	Value
Tensile Strength	344 MPa
Tensile Modulus	36 GPa
Compression Strength	361 MPa
ILSS	42 MPa

Typical Laminate Properties

iStream* Carbon

- Conventional stamped steel chassis: Typically hundreds of stamped metal panels.
- iStream hybrid structural composite chassis: Simple, low cost steel tubular members. 14 composite panels.
- iPanels based on recycled carbon fibre cost approximately €30 each, compared to €300 each for panels made from conventional woven fabric prepreg.

** iStream photos and information courtesy of Gordon Murray Design Ltd.*

Structural rCF - SMC

- Sheet moulding compound designed for the rapid production of structural and semi-structural components.
- 12 months shelf life at -18°C.
- 10 days outlife at 20°C.
- 4 minute cure cycle at 155°C.
- 167°C TG after cure.

SMC Laminate

Property	Value
Density	1.4 g/cm^3
Tensile Strength	370 MPa
Tensile Modulus	33.3 GPa
Flexural Strength	650 MPa
Flexural Modulus	41.7 GPa
Compression Strength	264 MPa
Compression Modulus	33.2 GPa
ILSS	62 MPa
TG	150°C

Typical Laminate Properties

Hybrid Nonwovens

- Blends of recycled carbon fibre with polymers such as PP and PPS.
- Used in compression moulding processes for interior and exterior parts in the automotive industry.

Nonwoven Mat

Part Made By Compression Moulding

Property	Value
Tensile Strength	235 MPa
Tensile Modulus	29 GPa
Compression Strength	253 MPa
Impact Strength	25 kJ/m^2

Typical Laminate Properties

Opportunities and Barriers

- Milled and chopped recycled carbon fibre products provide a cost effective alternative to virgin fibres in the coatings and compounding industry.
- Nonwoven mats can be used alone or in combination with virgin fibres in the composites manufacturing. It is estimated that 75% of automotive and 90% of electronics applications for carbon fibre could be met with recycled carbon fibre products.
- Recycled carbon fibres are new and relatively unknown, hence there are several barriers that have to be overcome before the materials become widely used:
  - Improved understanding of the fundamental characteristics of recycled carbon fibres.
  - Availability of design and processing data for recycled carbon fibre products.
  - Demonstration of the economic, technical and environmental performance of components made from recycled carbon fibres.

Focus of ELG R&D programmes

Research and Developments Partners

- California Polytechnic State University (US)
- CSIRO (Aus)
- Deakin University (Aus)
- Dresden University of Technology (DE)
- Imperial College of Science & Technology (UK)
- ITV Denkendorf (DE)
- National Composites Centre (UK)
- RWTH Aachen University (DE)
- University of Bristol (UK)
- University of Nottingham (UK)
- University of Warwick (UK)

Quality Assurance / Quality Control

- **Accredited to BS EN9100 (AS9100C)**
- **Comprehensive quality control procedures throughout the process**
  - Classification of incoming feedstock
  - Fibre mechanical property testing through the process
  - Fibre length and fibre length distribution for milled and staple fibre products
  - Flow characteristics of milled fibre
  - Metal detection and separation at key stages of the process

BUREAU VERITAS Certification

Certificate of Approval

This is to certify that the Quality Management System of:

ELG CARBON FIBRE LTD

UNIT 27 CANNON BUSINESS PARK, DARKHOUSE LANE, COSELEY, DUDLEY, WEST MIDLANDS, WV14 8XR

has been audited in accordance with the requirements of EN 9104-001:2013 by Bureau Veritas Certification and conforms to the following Quality Management Systems Standards detailed below

Standards

BS EN ISO 9001:2008
EN 9100:2009
(Technically equivalent to AS9100C)

Scope of certification

RECOVERY OF CARBON FIBRE FROM MANUFACTURING WASTE AND END-OF-LIFE PRODUCTS; MANUFACTURE OF RECYCLED CARBON FIBRE MATERIALS AND PRODUCTS.

Certification Structure: **Single Site**

This certificate forms part of the approval identified by certificate number: **UK792015-1**

Original ISO Approval: **26 OCTOBER 2015**

Original ASCS Approval: **26 OCTOBER 2015**

Certificate Issue Date: **26 OCTOBER 2015**

Certification Expiry Date: **25 OCTOBER 2018**

Andrew Kirkby
Authorised Signatory

ADS aerospace sector certification scheme

UKAS MANAGEMENT SYSTEMS 008

Further clarifications regarding the scope of this certificate and the applicability of the management system requirements may be obtained by consulting the organisation.

Certification Body: Bureau Veritas Certification Holding SAS-UK Branch 5th Floor, 66 Prescot Street, London, E1 8HG, United Kingdom.

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Summary

- Carbon fibre recycling has been established at an industrial scale.
- QA and QC controls implemented to ensure that the requirements of mass production markets can be met.
- An initial range of products is now available for the compounding, coatings and composites manufacturing industries.
- Through a comprehensive R&D programme, ELG CF is now addressing the issues of design data availability and technical / economic performance demonstration that will support widespread application of recycled carbon fibres.

Thank You!

Marco Gehr
COO

ELG Carbon Fibre Ltd.
Office: +44 (0) 1902 406010
Email: mgehr@elg.de
Web: www.elgcf.com