Outline

- ELG Carbon Fibre
- Carbon fibre recycling
- Characteristics of recycled carbon fibres
- Products for lightweight automotive applications
- Gordon Murray Design
- iStream Carbon—A case study in the use of recycled carbon fibre materials

About ELG Carbon Fibre

- Established in 2011.
- Part of the ELG Haniel group—a global leader in the recycling of stainless steel and high value materials.
- Patented process for recovery of carbon fibre from manufacturing waste and end-of-life products, using a modified pyrolysis process.
- Extensive R&D programme, working with the leading universities and research organisations around the world to improve understanding of recycled carbon fibres and how they can be used.
- Reclaimed more than 1,000 tonnes of carbon fibre from manufacturing waste in 2015 and converted this into products that were returned to the market.

Carbon Fibre Reclaiming

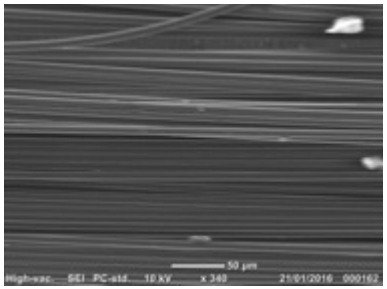
- More than 20,000 tonnes of carbon fibre in manufacturing waste is sent to landfill each year.

- This fibre can be cost effectively reclaimed and reused in the compounding and composites industries.

Feedstock Sourcing and Preparation

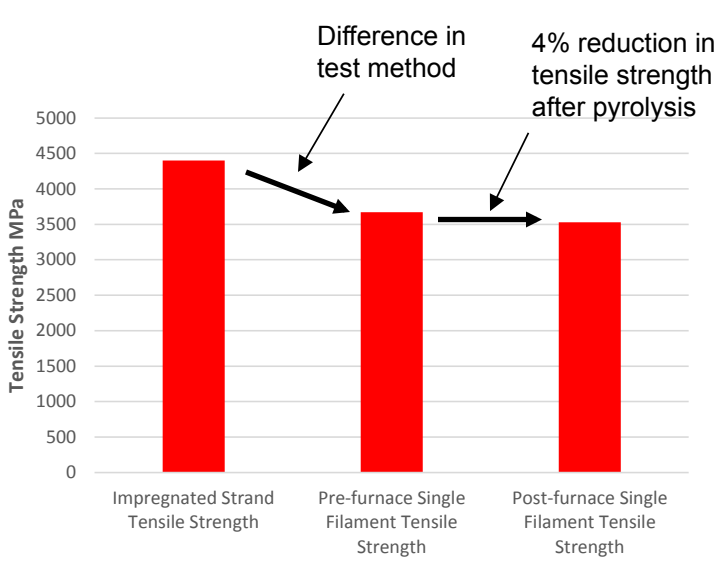
Fibre Reclaiming

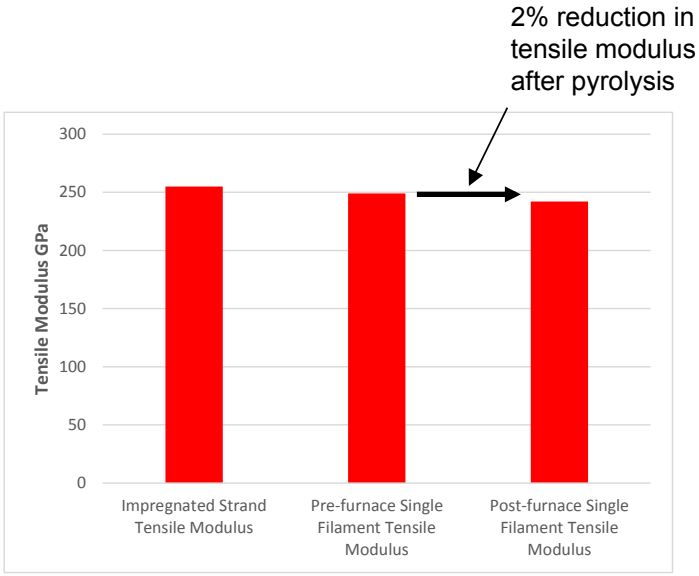
Clean, high quality carbon fibres



Fibre Mechanical Properties

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



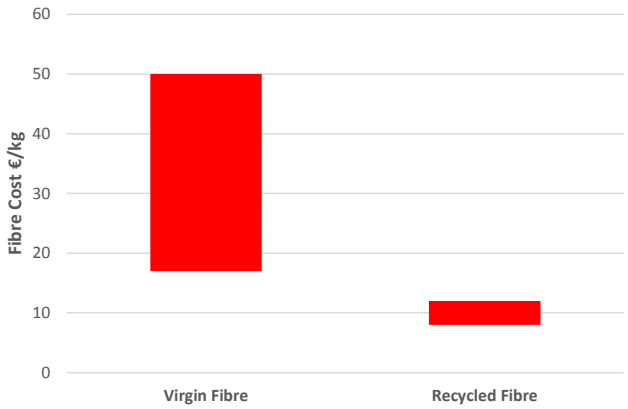


- Reclaimed carbon fibres have similar mechanical properties to the original fibres provided that the reclaiming process is optimised for the type of feedstock being treated.

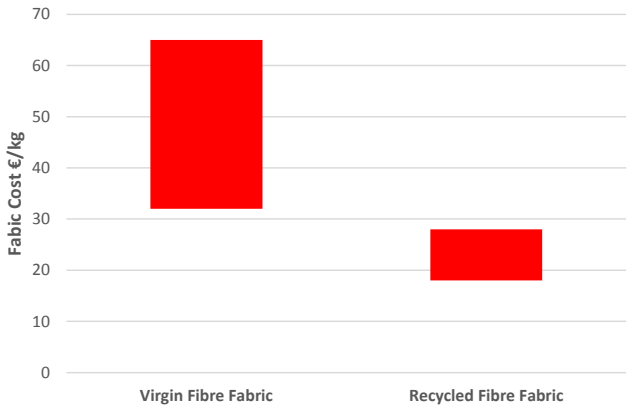
Based on single filament testing of 1484 fibre batches before and after fibre recovery by pyrolysis.

Cost

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



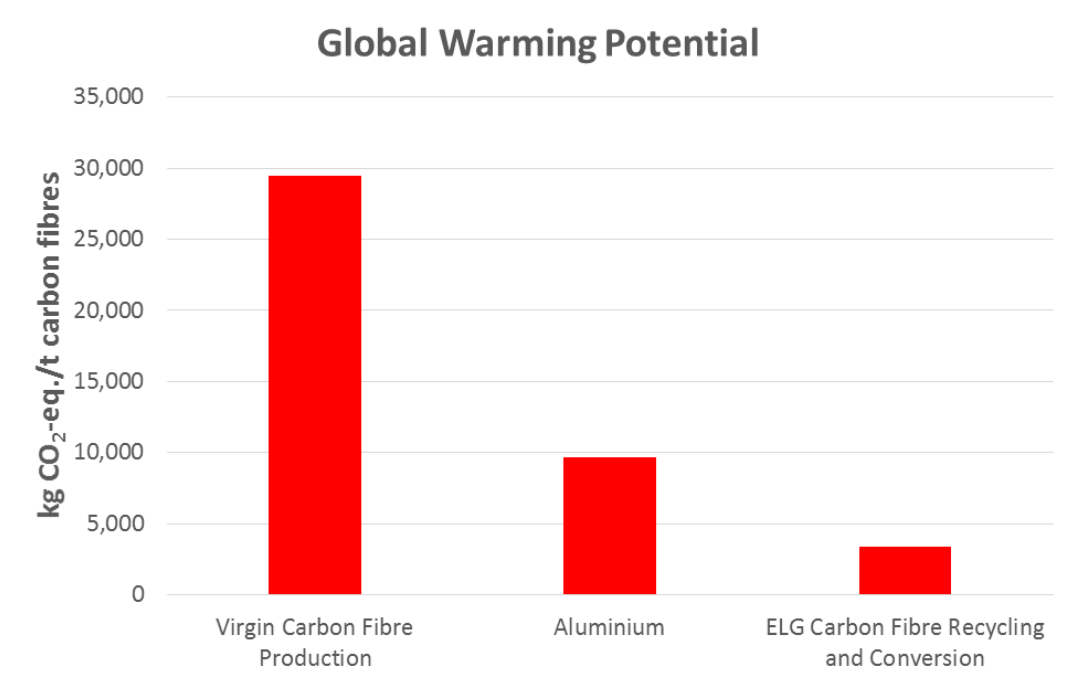
Standard Modulus Fibre



Industrial Grade Fabrics

Environmental Impact

- Recycled carbon fibres have significantly less environmental impact.

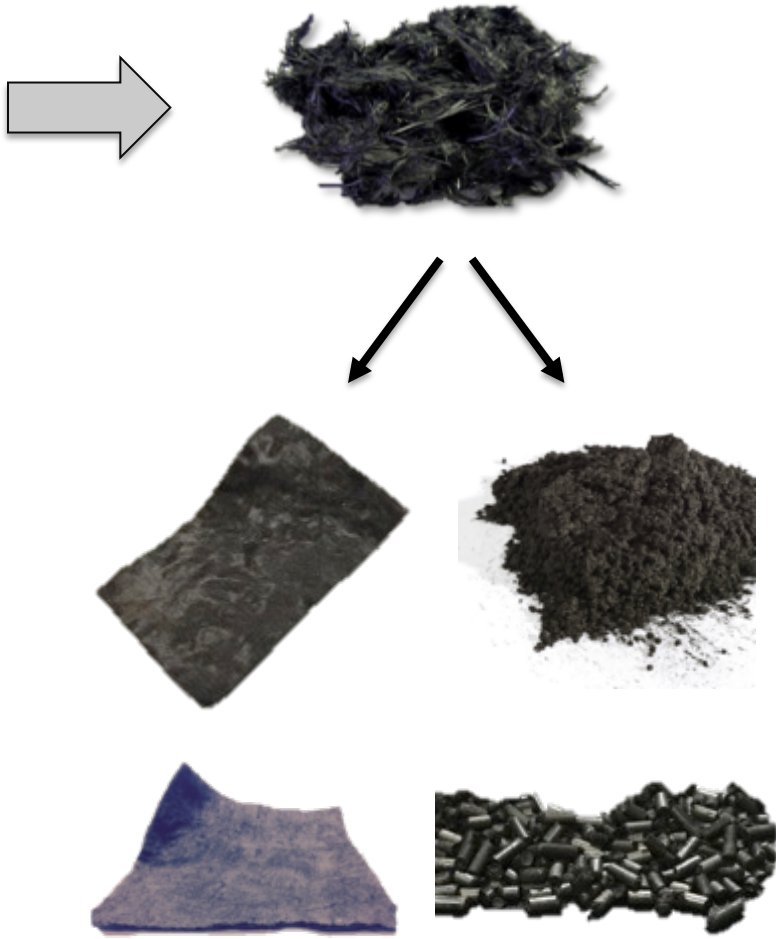


Further 36% reduction in energy consumption per kg achieved in 2015

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

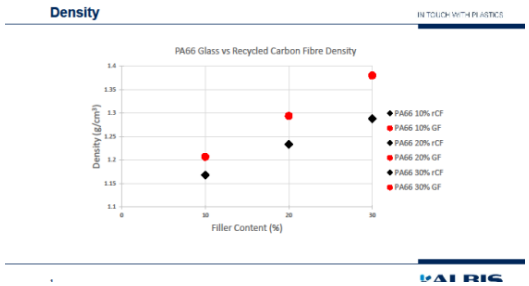
Carbon Fibre Conversion

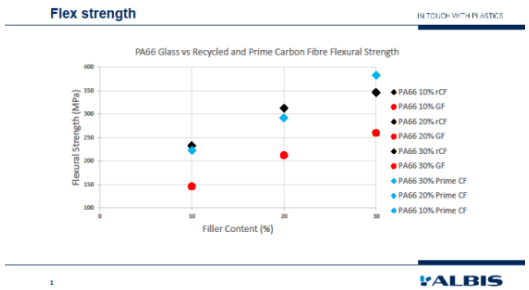
- Carbon fibre reclaiming provides high quality, low cost carbon fibres that can be used for structural applications.
- Fibre needs to be converted into products that can be used in compounding and composites industries.
- Current conversion technologies:
  - Milled, chopped and pelletised fibres for compounding.
  - Nonwoven carbon fibre mats for composites manufacturing.
  - Nonwoven carbon fibre/thermoplastic hybrid mats for composites manufacturing.

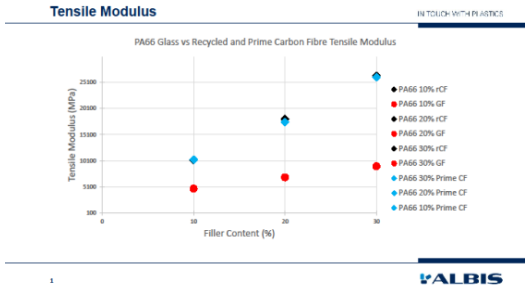


Carbon Fibre Reinforced Compounds

- Milled, chopped and pelletised carbon fibre for reinforcement of thermoplastics.
- Initial testing shows no significant difference in the performance of recycled and virgin carbon fibres.
- Initial testing suggests that 10% addition of recycled carbon fibre provides the same mechanical performance as 30% addition of glass fibre, at a 16% lower density.
- At higher loadings, properties approach those of magnesium castings at a 14% lower density.

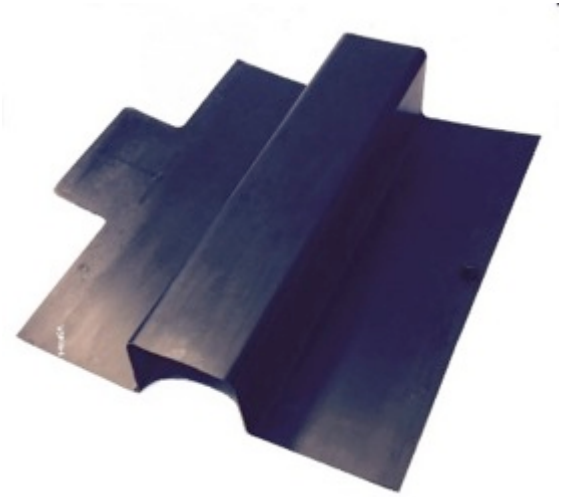






Carbon Fibre Nonwovens

- 100% carbon fibre materials.
- Fibre areal weight from 90gsm to 500gsm.
- Low variability compared to other dry nonwoven manufacturing methods.
- Products available up to 2.7m wide from July 2016.
- Used in liquid moulding processes or as a raw material for SMC and prepreg production.



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

Typical Laminate Properties

SMC Materials

- Initial development focused on a structural SMC product based on carbon fibre nonwoven mats.
- Key characteristics:
  - 12 months shelf life at -18°C.
  - 10 days outlife at 20°C.
  - 4 minute cure cycle at 155°C.
  - 151°C Tg after cure.
- Future developments to include products with enhanced surface finish, low density and high drapeability.

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 (onset)	151°C

Typical Laminate Properties

Carbon / Thermoplastic Nonwovens

- Blends of recycled carbon fibre with polymers such as PP, PA and PPS.
- Typical fibre volume content 35% - 40%.
- Designed for rapid manufacture of parts 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

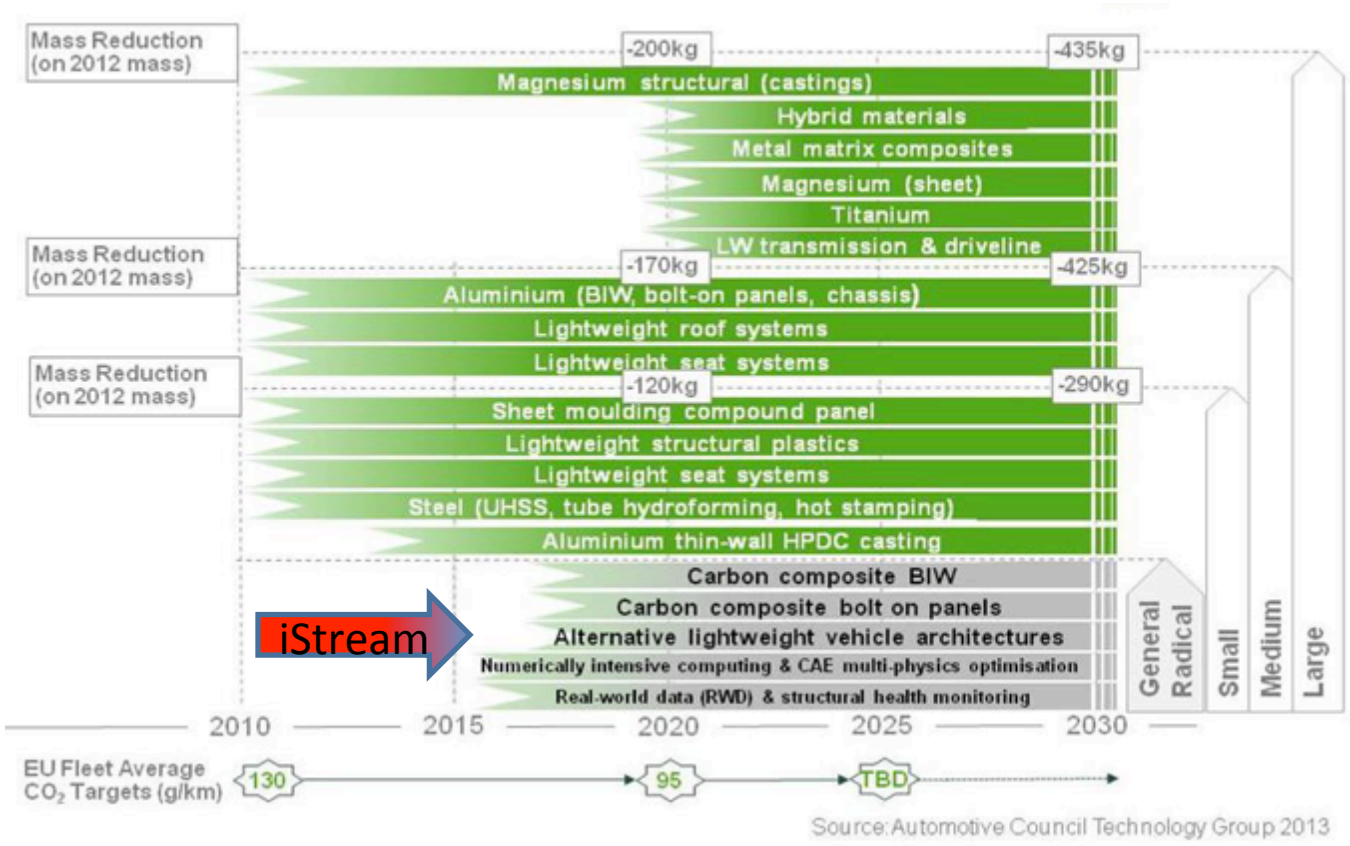
Summary

- Carbon fibre recycling has been established at an industrial scale.
- Benefits include lower cost, low environmental impact and supply chain security via use of waste products from ongoing production processes.
- An initial range of products that allow the cost effective use of carbon fibre in automotive applications has been developed and is now available.

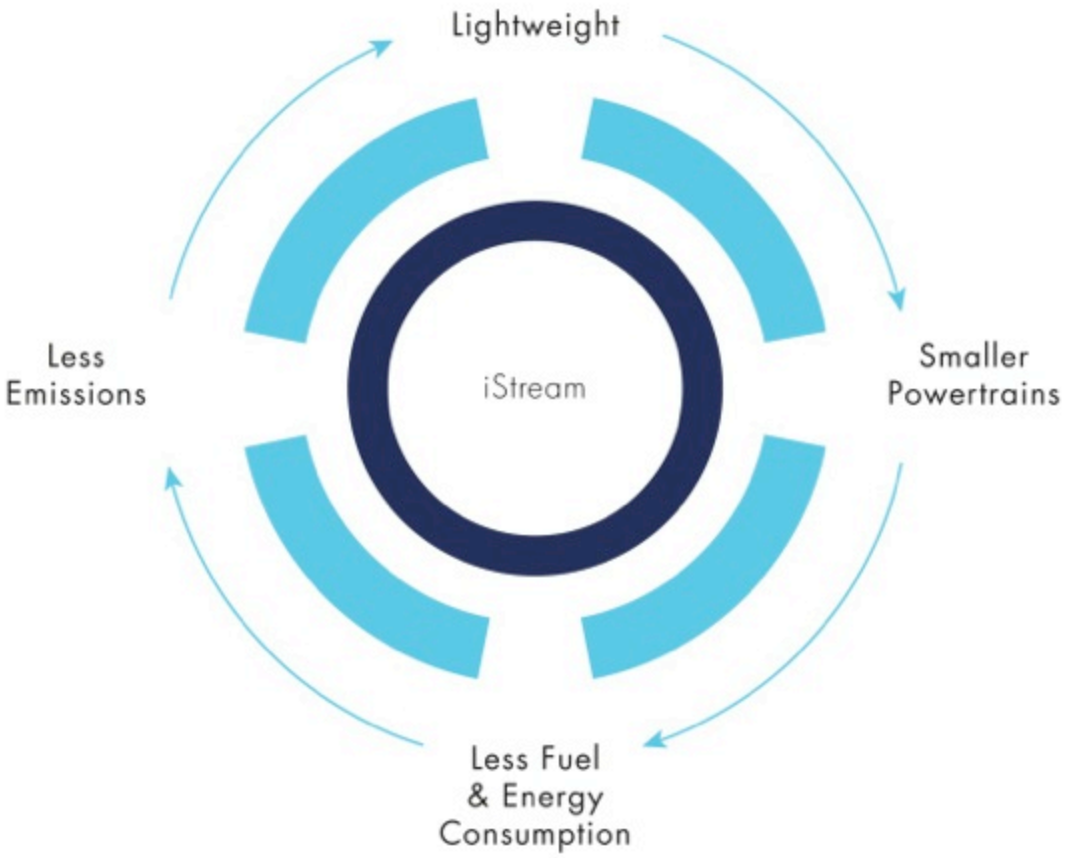
GORDON MURRAY DESIGN - In the beginning

- Gordon Murray Design Ltd – established 2007
- Key objective – to push the boundaries of automotive and engineering design and technology
- Main focus – ‘whole car’ projects, based on Gordon Murray Design patented ‘iStream®’ manufacturing system..
- Expertise – motorsport background with mainstream production vehicle know-how.
- Vast experience – same team delivered iconic programs, i.e.: McLaren F1, Mercedes-Benz SLR McLaren.
- Choice of services – Gordon Murray Design offer a range of disciplines in support of client’s automotive programs.

Automotive Council Lightweight Vehicle & Power-train Roadmap



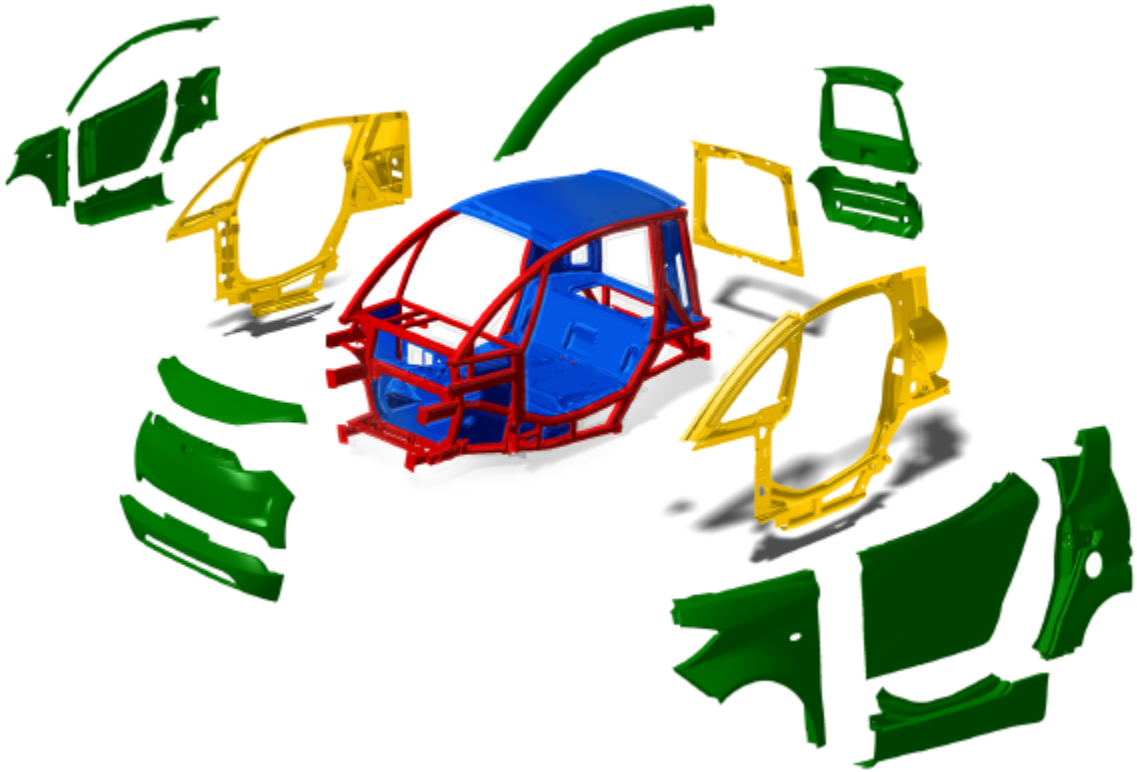
Super Lightweight Structures - Positive effect on consumption & emissions

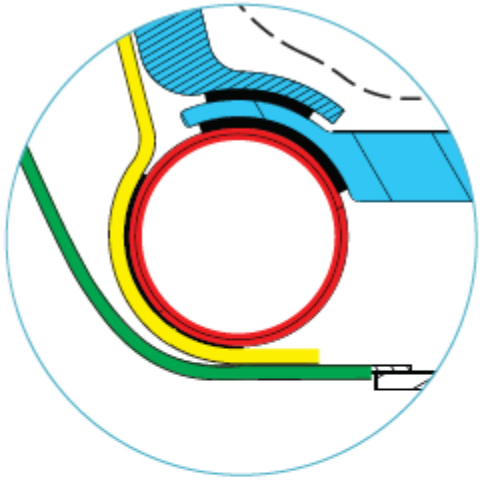


Technology – What is iStream® ?

- Conventional stamped steel chassis: Typically hundreds of stamped metal panels.
- iStream hybrid structural composite chassis: Simple, low cost steel tubular members. 14 composite panels.

iStream® - Full Body in White





iStream® advantages compared to a conventional steel body in white

- Increased torsional rigidity for good vehicle dynamics and quality.
- Increased durability - customer quality benefit.
- High levels of flexibility in styling
- Structural design flexibility
- Low cost prototype
- Powertrain – flexible packaging
- Crash test FEA
- Ultra low capital investment
- Lightweight
- High Levels of Safety.
- Low investment.
- Pick and place factories.
- Plant process
- Re-cycled materials
- Speed to market
- Low energy manufacture
- Low cost mid cycle re-skins
- Packaging
- Flexible platform technology.
- Low tooling redundancy (reusable tooling).
- Better level of NVH control - customer quality benefit.
- Low cost carbon fibre technology.

Development Matrix

SYSTEM	FRAME	MATRIX	REINFORCEMENT	READINESS	SIGN OFF STANDARD	INVESTMENT	COST	FLEXIBLE PLATFORM TECHNOLOGY	MANUFACTURING ENERGY	PERFORMANCE
iSTREAM	STEEL SECTIONS	PU	LONG STRAND GLASS FIBRE	FULLY INDUSTRIALISED	EXCEEDS OEM STANDARDS	LOW	LOW	YES	LOW	20% LIGHTER & 35% STIFFER THAN STAMPED STEEL BIW
iSTREAM CARBON	STEEL SECTIONS	PU	LONG STRAND CARBON FIBRE	2016 ROLL OUT	EXCEEDS OEM STANDARDS	LOW	LOW +	YES	LOW	WEIGHT REDUCTION OVER iSTREAM + MARKETING BENEFITS

- iStream® 1
  Steel + Glass fibre

- iStream® Carbon
  Steel + Carbon fibre

The Barriers to High Volume Use of Composite Materials in the Automotive Sector

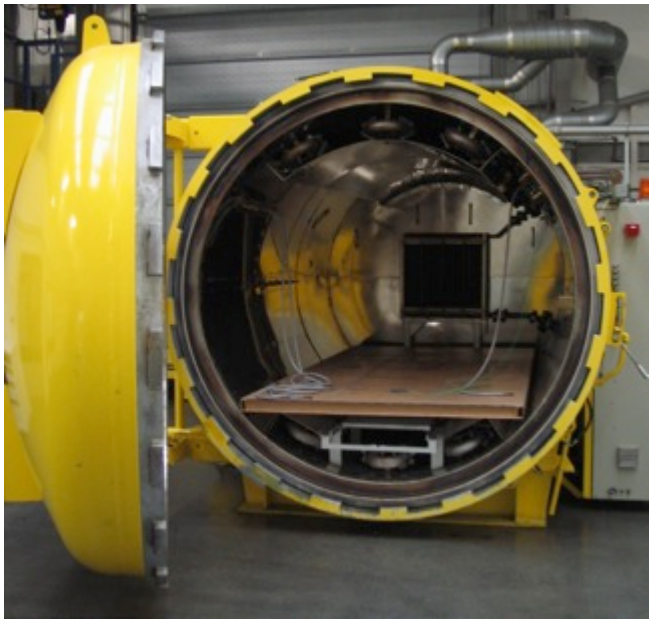
- Cost
- Process Time
- Managing Point Loads
- Design Data

Cost

- Carbon pre-preg panel - €300

- iStream Carbon panel - €30

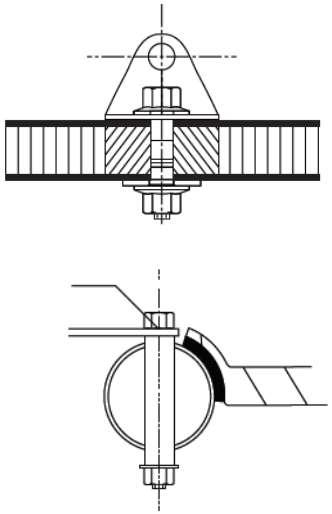
Process Time

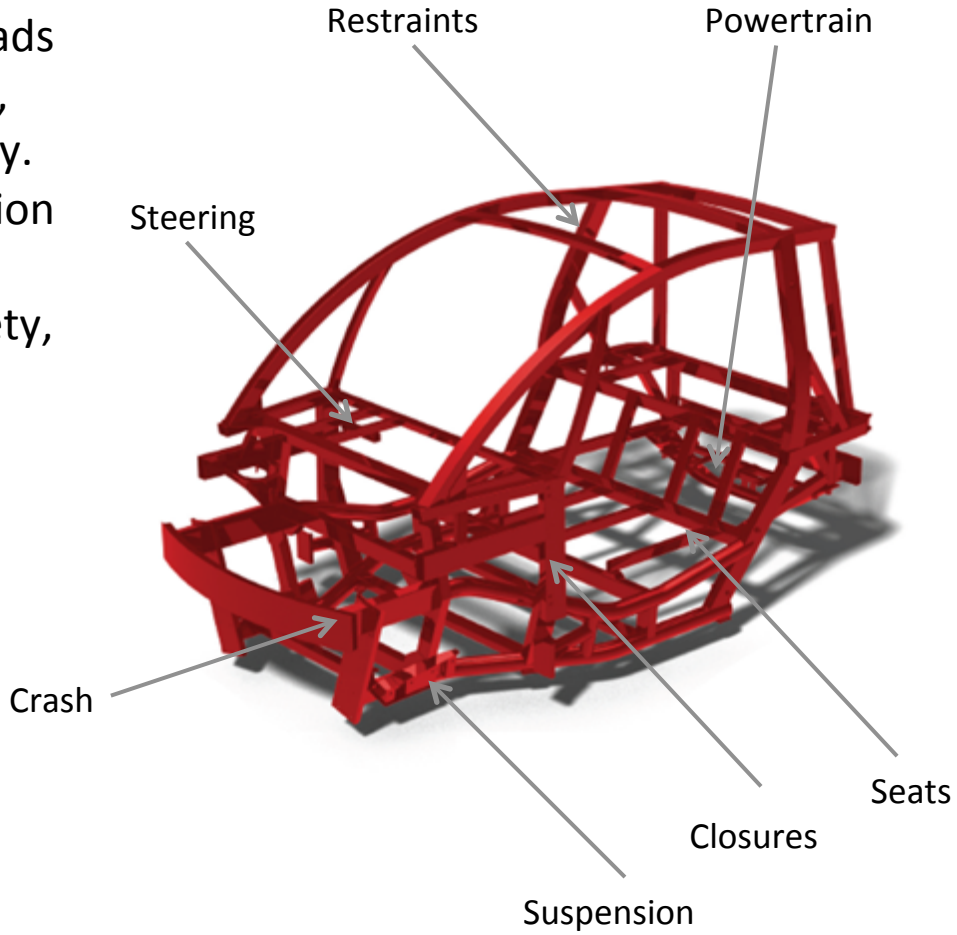


- Conventional Composites ≈ 2 hours
- iPanel ≈ 100 seconds

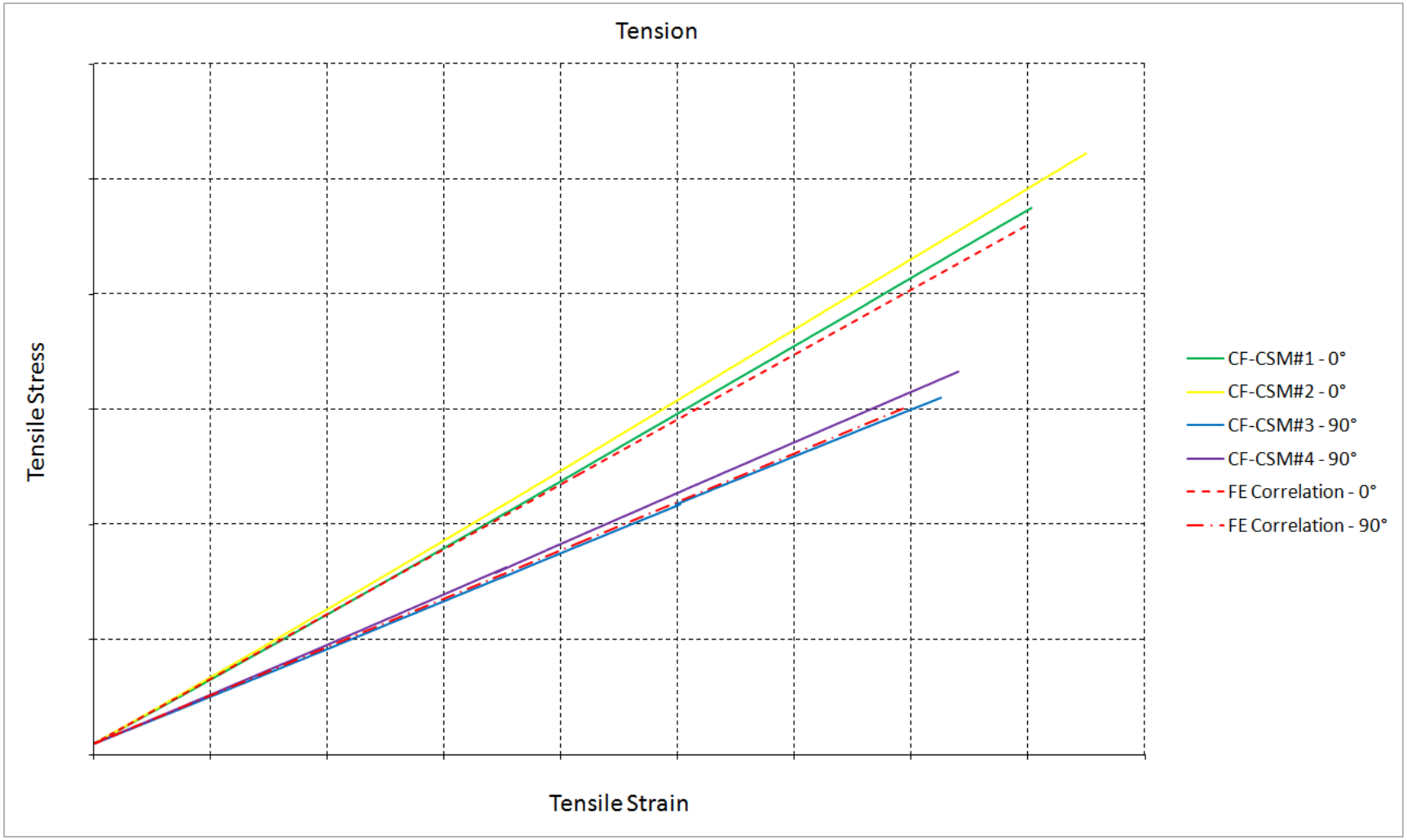
Point Loads

- Very difficult to manage point loads in composite structures in a safe, repeatable and cost effective way. Mounts for Powertrain, Suspension Occupant Restraints, Closures, Steering & Controls, Passive Safety, Crash Rails etc

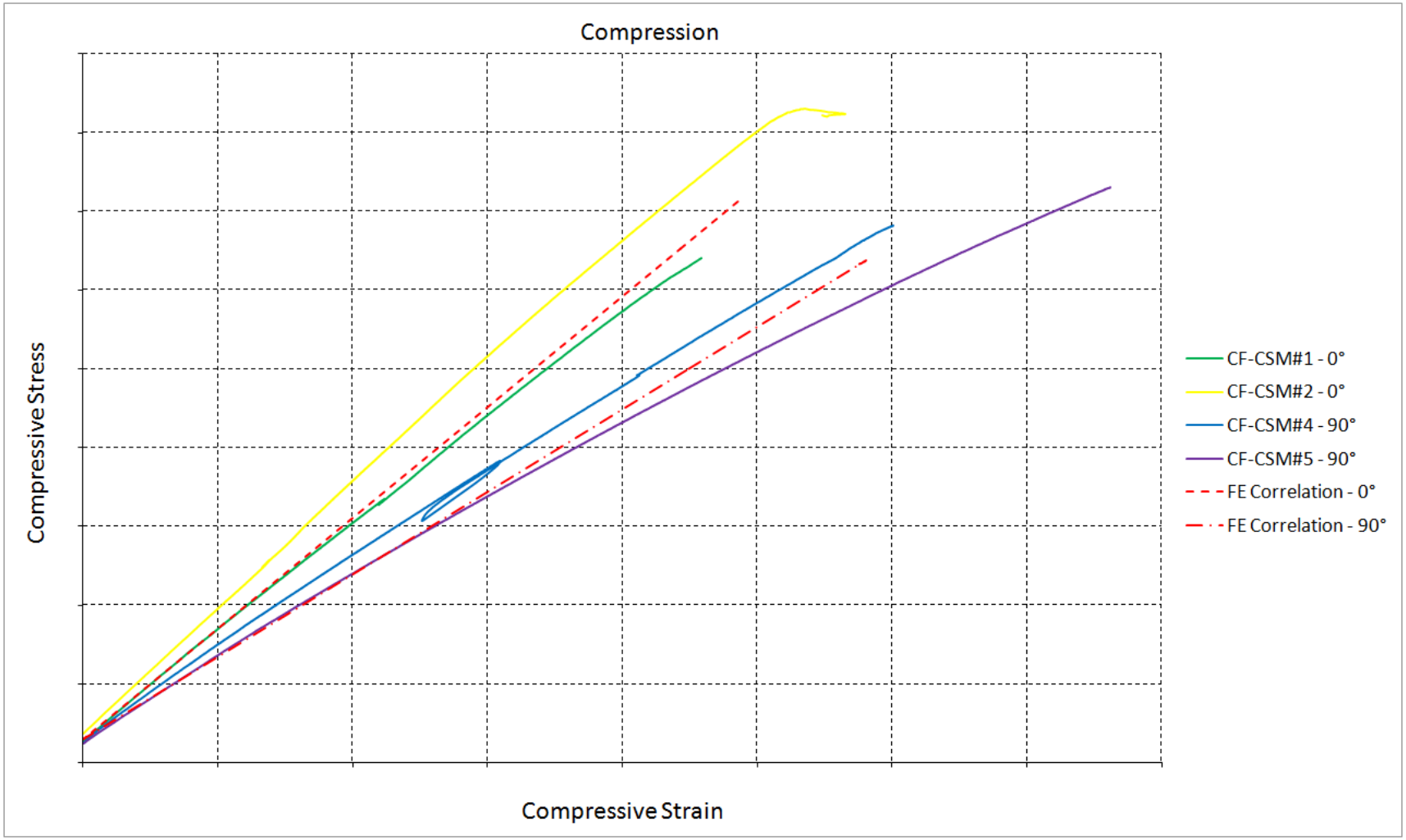




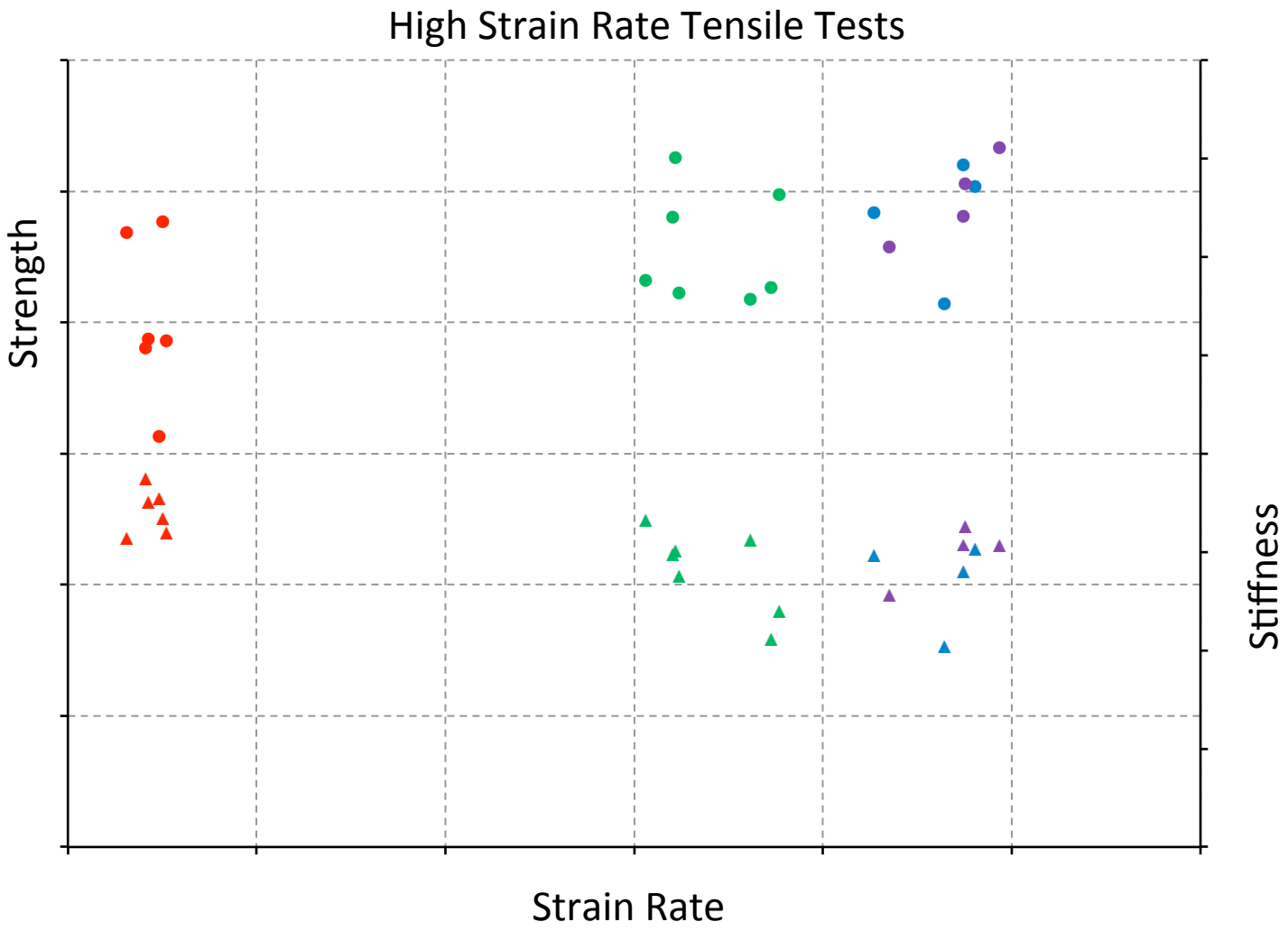
Design Data - FEA Correlation



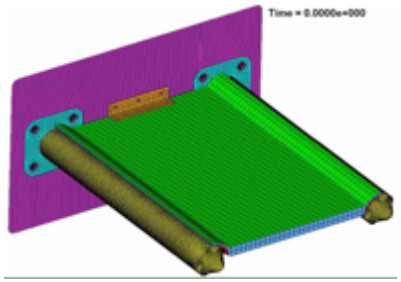
Design Data - FEA Correlation



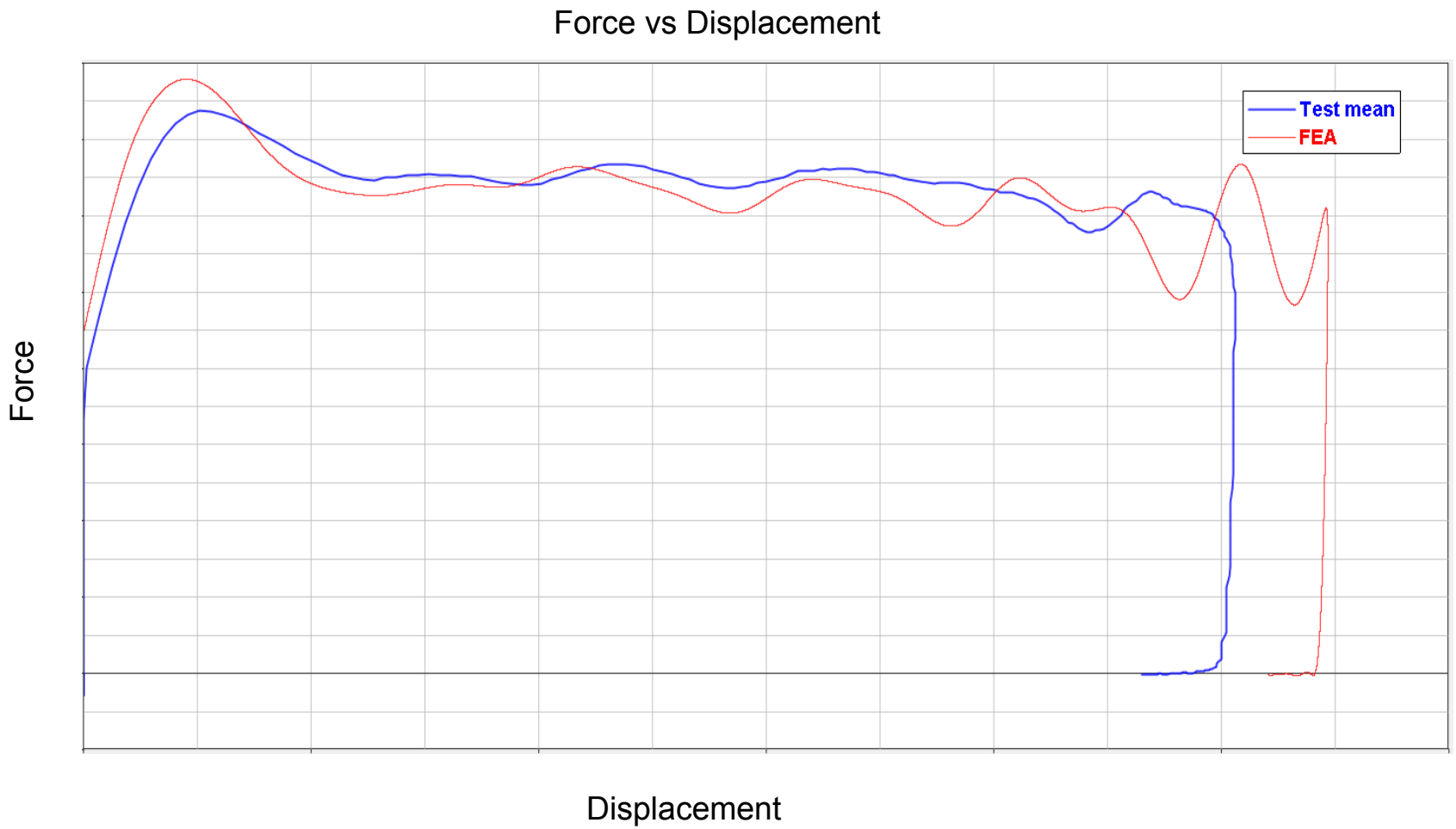
Design Data - High Strain Rate



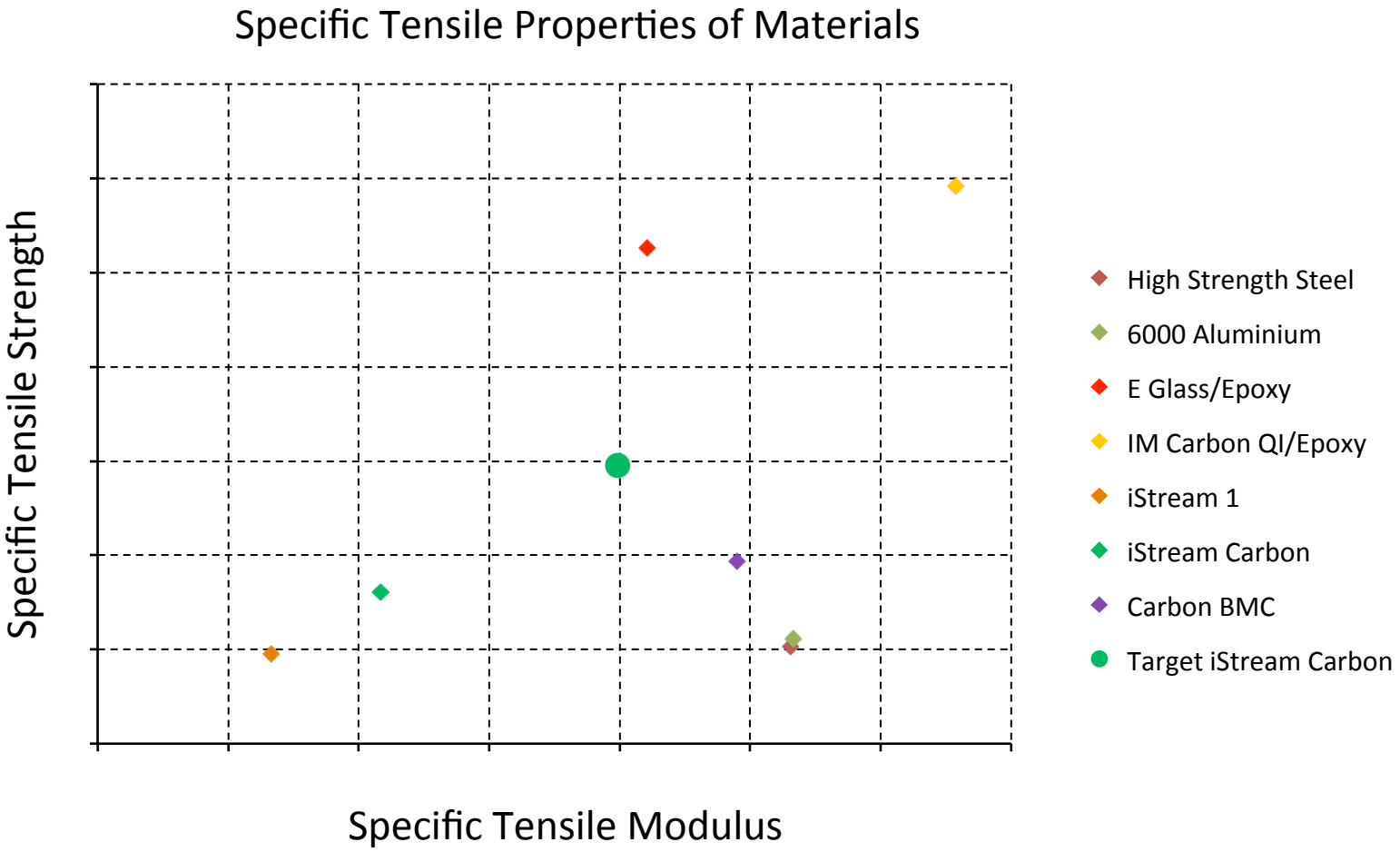
Impact Tests



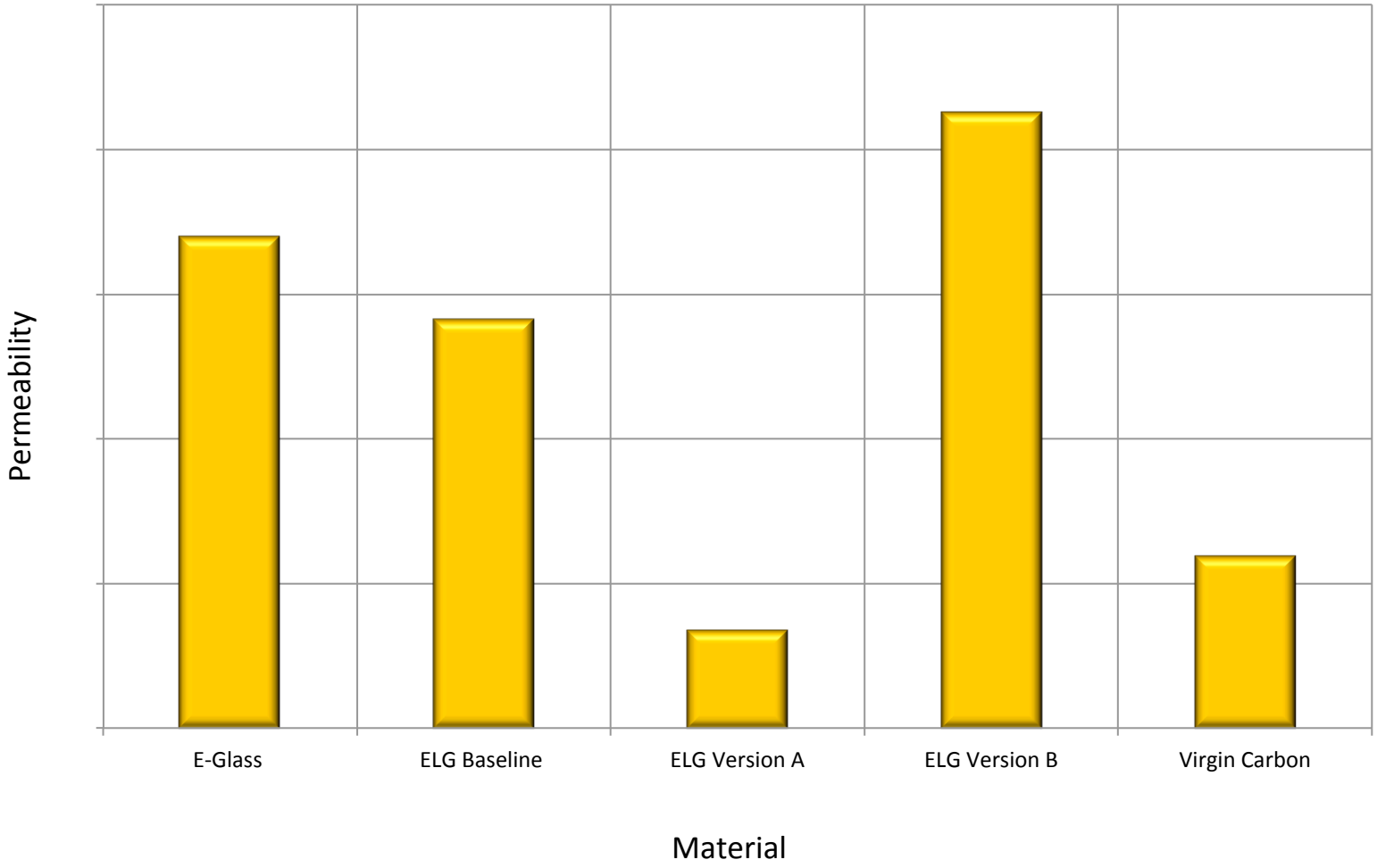
Impact Test Correlation



Material Properties



Permeability



iStream® Carbon