MECHANICAL TEST FACILITY

Good Practices on Qualification of Fibre-Reinforced Composite Materials Webinar

National Physical Laboratory

Mechanical Test Facility

This facility, combined with NPL's extensive expertise in materials characterisation and assurance, provides a unique capability for research and commercial testing services. As businesses continue to face diverse challenges due to the pandemic, this facility will help boost UK recovery by serving as a UK centre of excellence.

- **Characterise New Materials & Products**
- **Overcome UK Supply Chain Limitations**
- **Facilitate Quicker Product Development**
- **Support Industrial Innovation**
- **Assist Green Industrial Revolution**

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Good Practices on Qualification of Fibre-Reinforced Composite Materials

Webinar - April 27, 2021

Outline

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- Composites as enabling materials
- Approach to certification
- Material qualification
- Standard Qualification Plan (SQP)
- Application specific considerations
- Statistical analysis
- Summary

Key enabling materials

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Offer	unparalleled weight savings due to their exceptional weight-to strength / stiffness ratio
Provide	high energy absorption for improved strength and crashworthiness
Create	value through parts consolidation
Require	low maintenance and significantly reduced through life costs

- Improve safety
- Improve energy efficiency
- Conserve fuel
- Reduce carbon footprint and waste

Use across industry sectors

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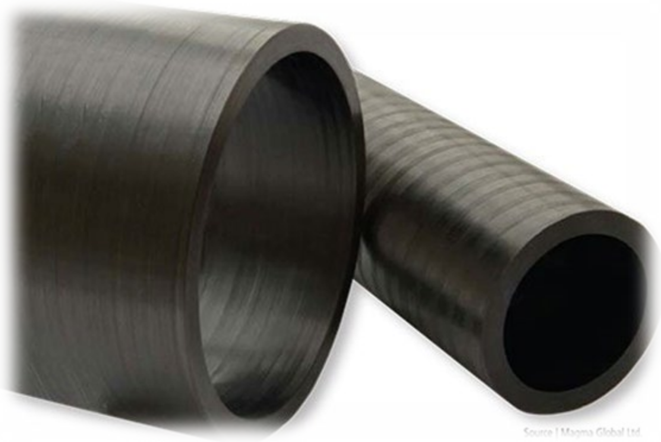
Civil Aerospace

Automotive

Source www.gordonmurraydesign.com/

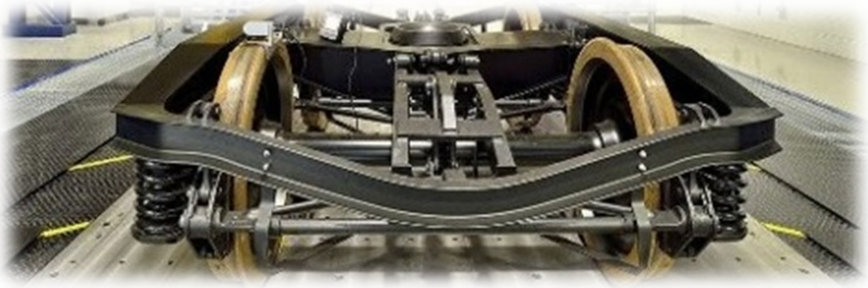
Renewables

Oil & Gas



Source: www.magmaglobal.com/

Rail

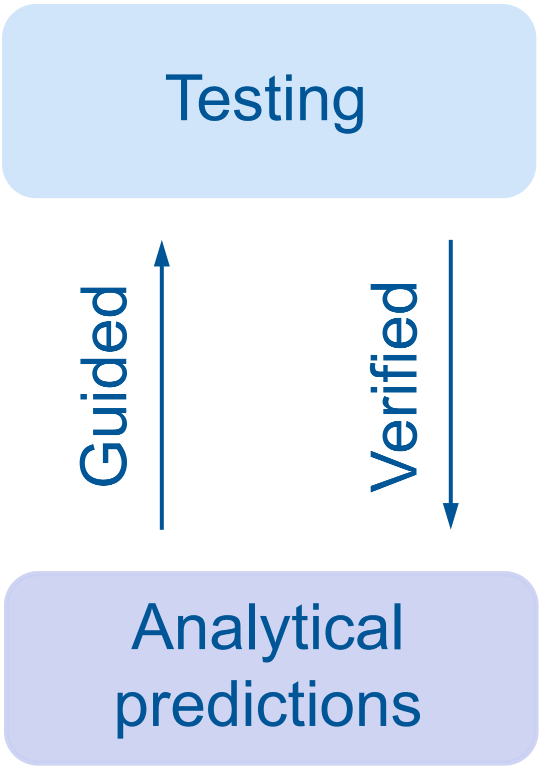


Source: www.magmastructures.com/

Building Block Approach

Testing alone can be excessively expensive

Analysis techniques alone are not usually sophisticated enough to adequately predict results



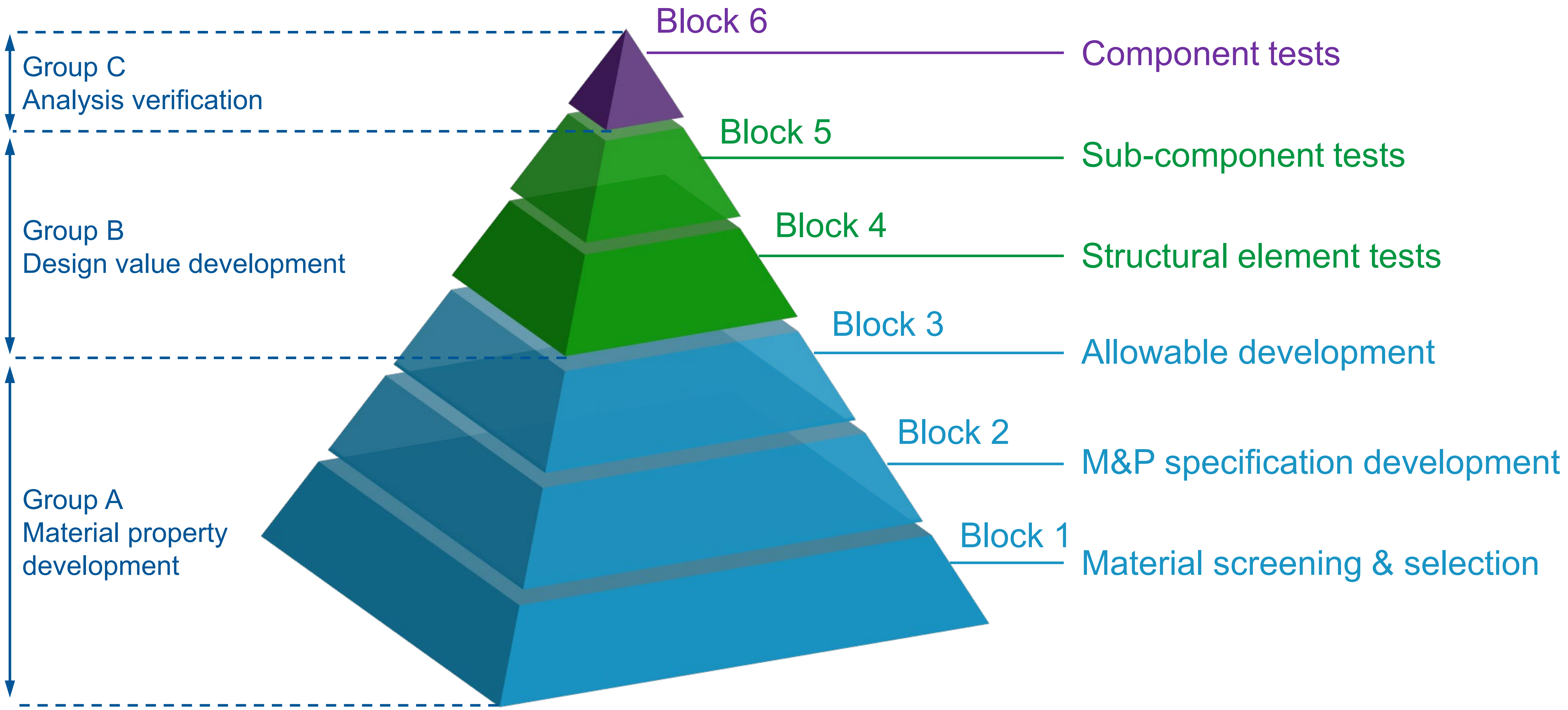
- Validating the structural performance and durability of composite structural components requires a mix of testing and analysis of increasing complexity

The need for a Building Block Approach

- Essential to the certification of composite structures due to
  - the sensitivity of composites to out-of-plane loads
  - the multiplicity of composite failure modes
  - the lack of standard analytical methods

- Reduce cost and risk while meeting all technical, regulatory, and customer requirements

The pyramid of testing



Testing levels

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Materials Screening	Material Qualification	Acceptance	Equivalence	Structural Substantiation
• assessment of material candidates for a given application	• proves the ability of a given material/process to meet the requirements of a material specification	• verifies material consistency through periodic sampling of material product and evaluation of key material properties	• assesses the equivalence of an alternate material to a previously characterized material	• assesses the ability of a given structure to meet the requirements of a specific application

Material qualification testing

- Proves the ability of specific materials/processes to **meet the requirements of a material specification**
- Quantitative assessment of the **variability of key material properties**
- Analysis of qualification data leads to various statistics that can be used to establish

  quality control

  material acceptance

  material equivalence

  design basis values

Composite materials qualification

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- Requires consideration of…
  - test method selection
  - material and processing variation
  - conditioning and non-ambient testing
  - application specific testing
  - variations on coupon configurations
  - material sampling and pooling
  - statistical calculations
  - data normalization

What is a Standard Qualification Plan (SQP)

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- A Standard Qualification Plan (SQP) is a set of composite material test standards that will meet the **minimum common requirements** necessary to allow

Quality control

Initial material selection

Preliminary design

Led by NPL National Physical Laboratory

ISO 20144

July 2019

Fibre-reinforced plastic composites — Standard qualification plan (SQP) for composite materials, including reduced qualification plan (RQP) and extended qualification plan (EQP) schemes

Benefits

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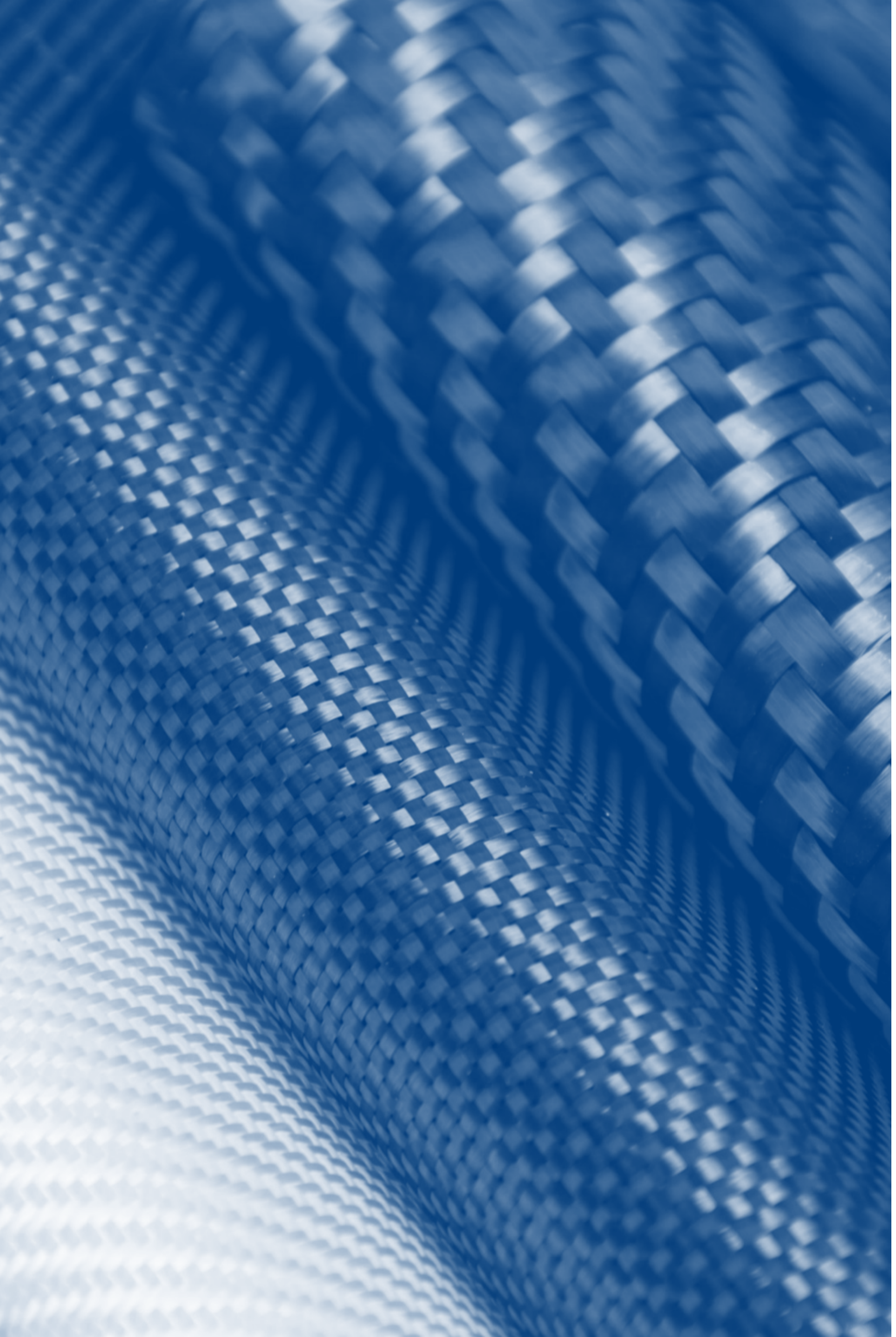
Based on commonly accepted international test methods

Reduced qualification costs

Readily available data for materials selection and preliminary design

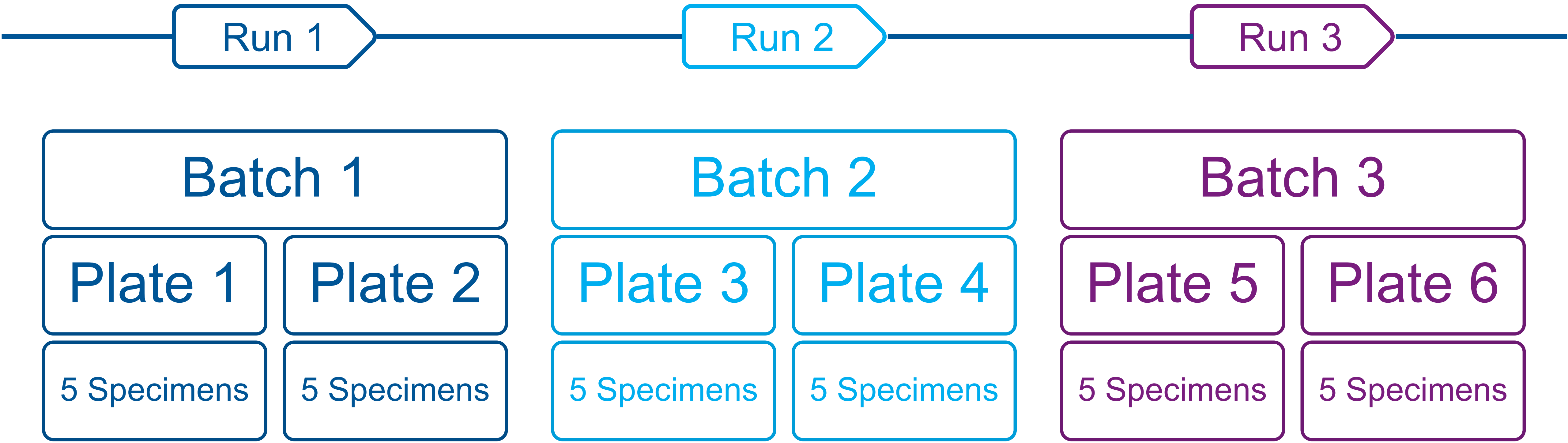


Key SQP elements

- Sampling of specimens
- Test plate preparation and specimen machining
- Test requirements
- Presentation of results
- Statistical analysis

Batch, plate and specimen traceability

material variability



processing variability

Production of test plates

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- The ISO 1268 series provide guidance for the type of material, and related process route (or nearest equivalent)

  Contact and spray-up moulding

  Wet compression moulding

  Moulding of prepregs

  Filament winding

  Pultrusion moulding

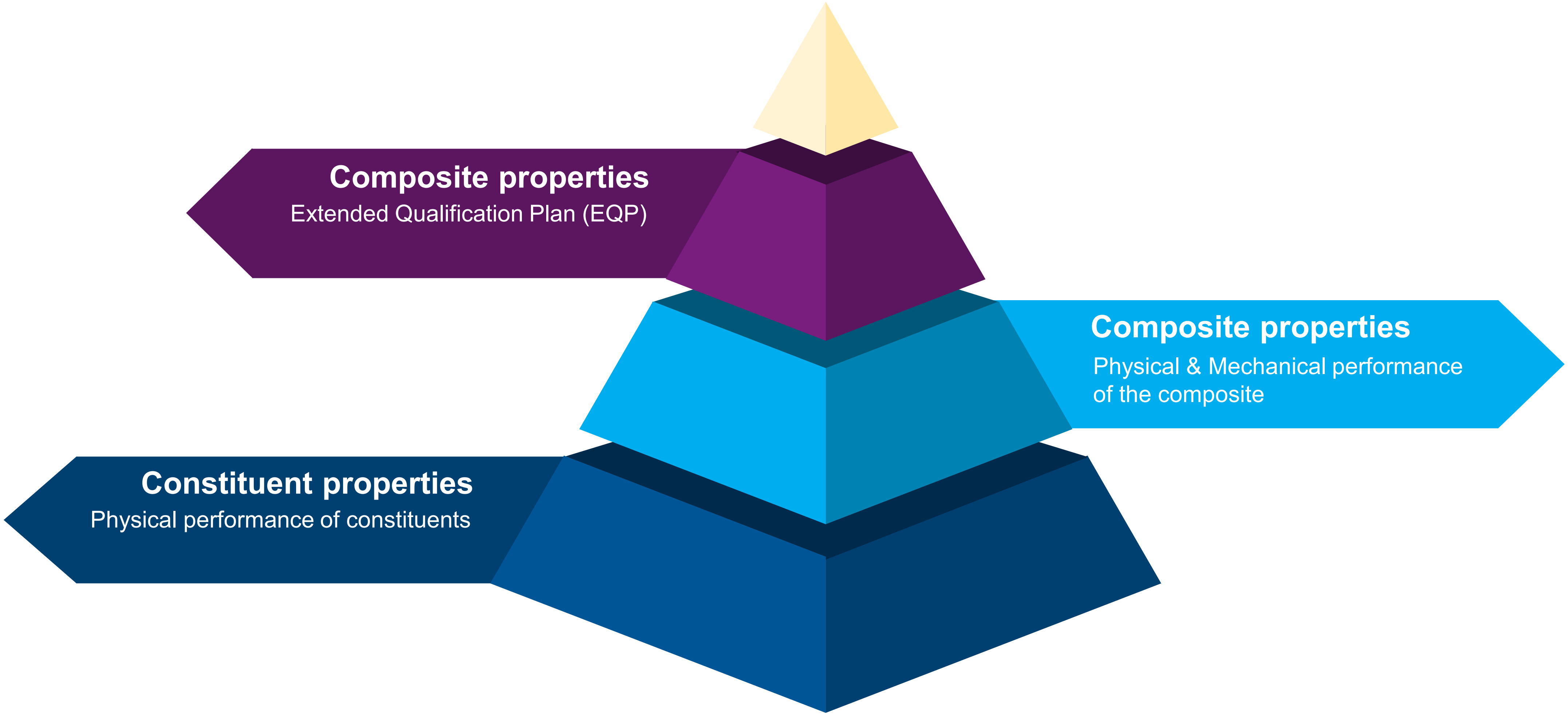
  Resin transfer moulding

  Compression moulding of SMC and BMC [a]

  …

[a] SMC: Sheet moulding compound & BMC: Bulk moulding compound

Test requirements



Constituent Properties

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Property	Unit	No of Material Batches (SQP)	Standard
Mass per unit area	g/m^2	3	ISO 10352
Fibre mass per unit area	g/m^2	3	ISO 10352
Fibre and matrix volume fractions	%	3	ISO 11667
Gel time [a]	Minutes	3	ISO 15040
Matrix flow [a]	% weight change	3	ISO 15034
Glass transition Temperature [a]	°C	3	ISO 11357-2
Percentage of volatile content [a]	%	3	ISO 9782
Density of fibre [b]	g/cm^3	3	ISO 10119
Deflection temperature under load	°C	3	ISO 75-3
Density of matrix	g/cm^3	3	ISO 1675

[a] Test method not suitable for thermoplastic matrix
[b] Carbon fibre based, but usable for other fibres depending on the method

Composite Properties – Physical

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Property	Unit	No of Material Batches (SQP)	Standard
Coefficient of thermal expansion	%/°C	1	EN 821-1 / ISO 11359-2
Moisture uptake – ambient [a]	%	1	ISO 62
Moisture uptake - hot/wet [b]	%	1	EN 2823
Glass transition temperature (DMA) [c]	°C	3	ISO 6721-11
Final ply thickness	mm	3	ISO 16012
Fibre, matrix & void volume percent [d]	%	3	ISO 14127 / ISO 1172

[a] Distilled water at 23 deg-C, report saturation value
[b] Conditioning in 70 deg-C/85 %, report saturation value
[c] T*g* to be taken as the inflection point of storage modulus vs temperature plot
[d] ISO 14127 for carbon-fibre based systems; ISO 1172 for glass-fibre based systems

Composite Properties – Mechanical

Property	Unit	Conditions / Batches						Standard
		Dry				70°C / 85%		
		-55°C	RT	70°C	125°C	RT	70°C	
Tension 11-direction [a] σ_{t11}, E_{t11}, ε_{t11}, ν_{12}, ν_{13}	MPa, GPa, %, -	1	3	1			1	ISO 527-5 / ISO 527-4
Tension 22-direction [a, b] σ_{t22}, E_{t22}, ε_{t22}, ν_{21}, ν_{31}	MPa, GPa, %, -	1	1	(1)			(1)	ISO 527-5 / ISO 527-4
Compression 11-direction σ_{c11}, E_{c11}, ε_{c11}	MPa, GPa, %	1	3	1			3	ISO 14126
Compression 22-direction [b] σ_{c22}, E_{c22}, ε_{c22}	MPa, GPa, %		1	(1)			1	ISO 14126
Shear 12 τ_{12}, G_{12}, γ_{12}	MPa, GPa, %	1	3	1	1	1	1	ISO 14129
Interlaminar Shear Strength τ_1, τ_2 [c]	MPa	1	3	1	3	1	3	ISO 14130
Flexural σ_{f11}, E_{f11}, σ_{f22}, E_{f22} [d]	MPa, GPa		3					ISO 14125

Temperatures and conditioning requirements should be according to the test method used, the relevant material specification or by agreement between supplier and user

Composite Properties – Mechanical

[a] ν_{12}, ν_{13}, ν_{23} only at room temperature dry from 1 batch

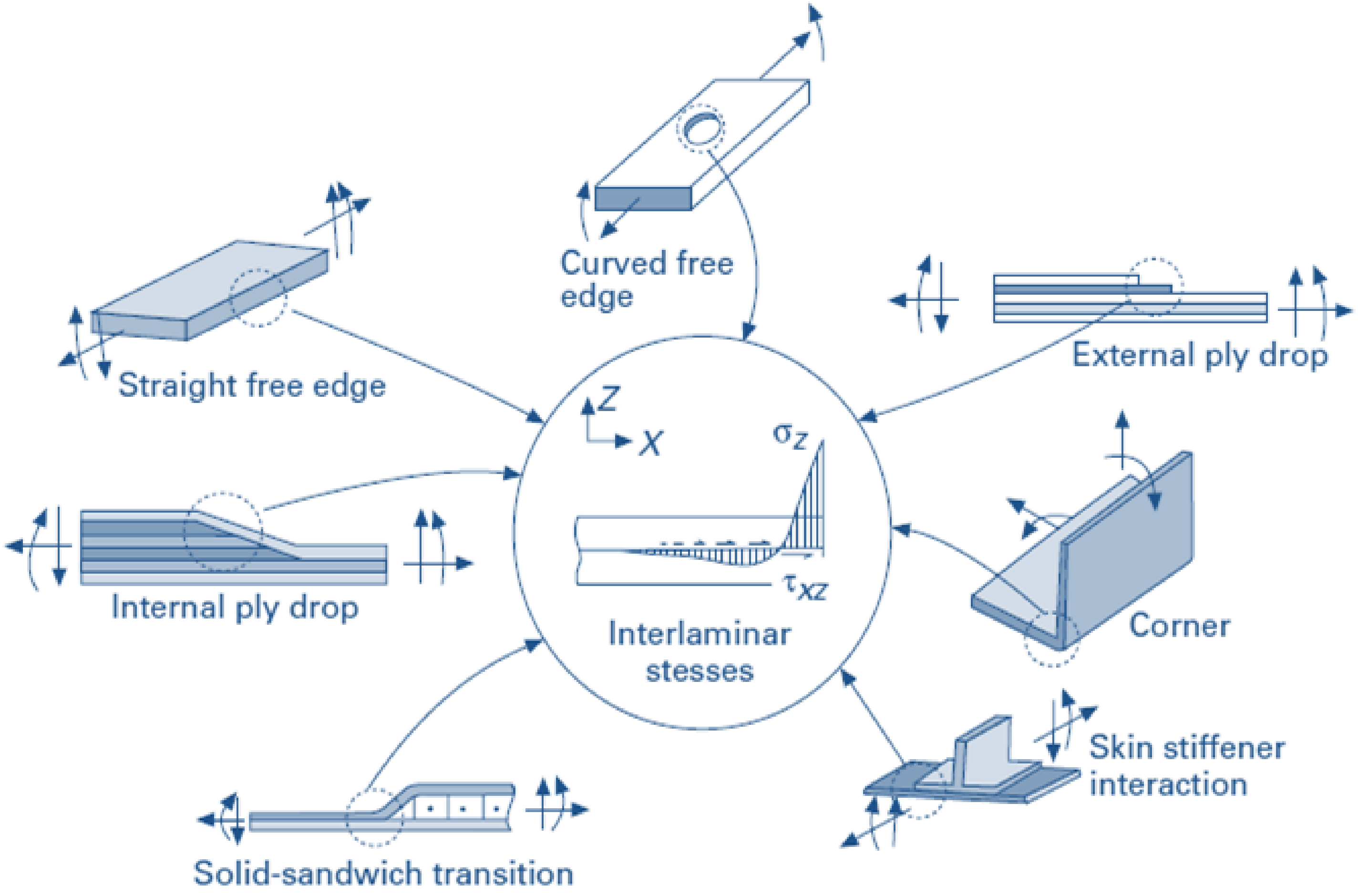
[b] Test in () not required for balanced fabrics → Reduced Qualification Plan (RQP)

[c] ILSS in the 22-direction only at RT Dry & 70°C dry from 1 batch

[d] The default method is Method A, 3- point flexure

Beyond the standard plan

Real life applications typically involve features that promote stress concentration



Source: I.S. Raju and T.K. O'Brien, In Delamination Behaviour of Composites, ed. S. Sridharan (2008)

Composite Properties – Extended Qualification Plan (EQP)

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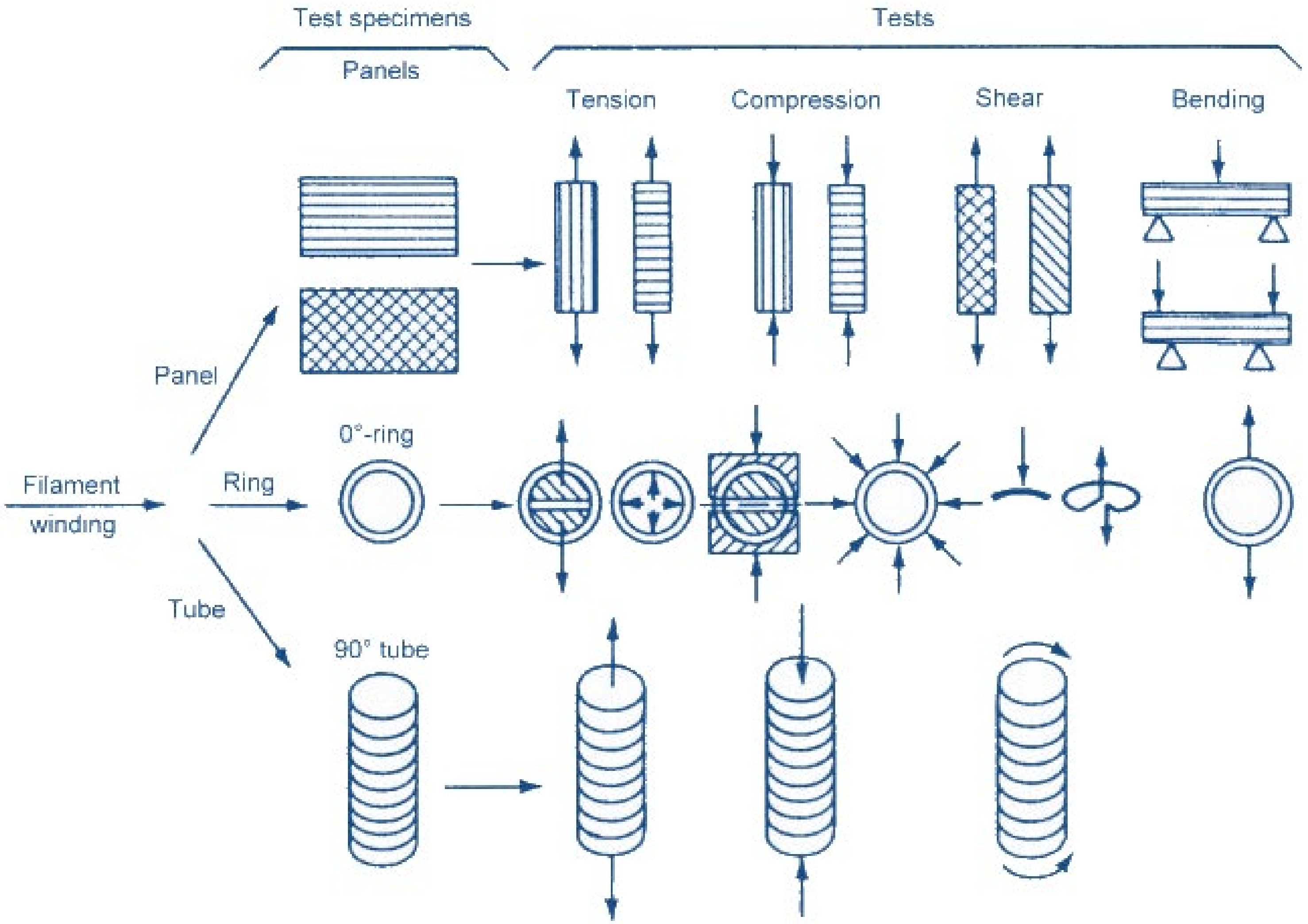
Property	Unit	Conditions						Standard
		Dry				70°C / 85%		
		-55°C	RT	70°C	125°C	RT	70°C	
Open hole tension σ_{OHT} [a]	MPa	1	3				3	ASTM D 5766
Open hole tension σ_{OHC} [a]	MPa	1	3				3	ISO 12817
Plane pin bearing strength σ_p [a]	MPa	1	3				3	ISO 12815
Instrumented impact [a]			3				3	ISO 6603-2
Compression After Impact [a, b] σ_{CAI}, ε_{CAI}, A_D	MPa, %, mm^2		3				3	ISO 18352
Mode I fracture toughness G_{Ic}	J/m^2		3				1	ISO 15024
Mode II fracture toughness G_{IIc}	J/m^2		3				1	ISO 15114

[a] Quasi-isotropic lay-up
[b] Report projected area of damage using ultrasonic c-scanning

Process specific considerations

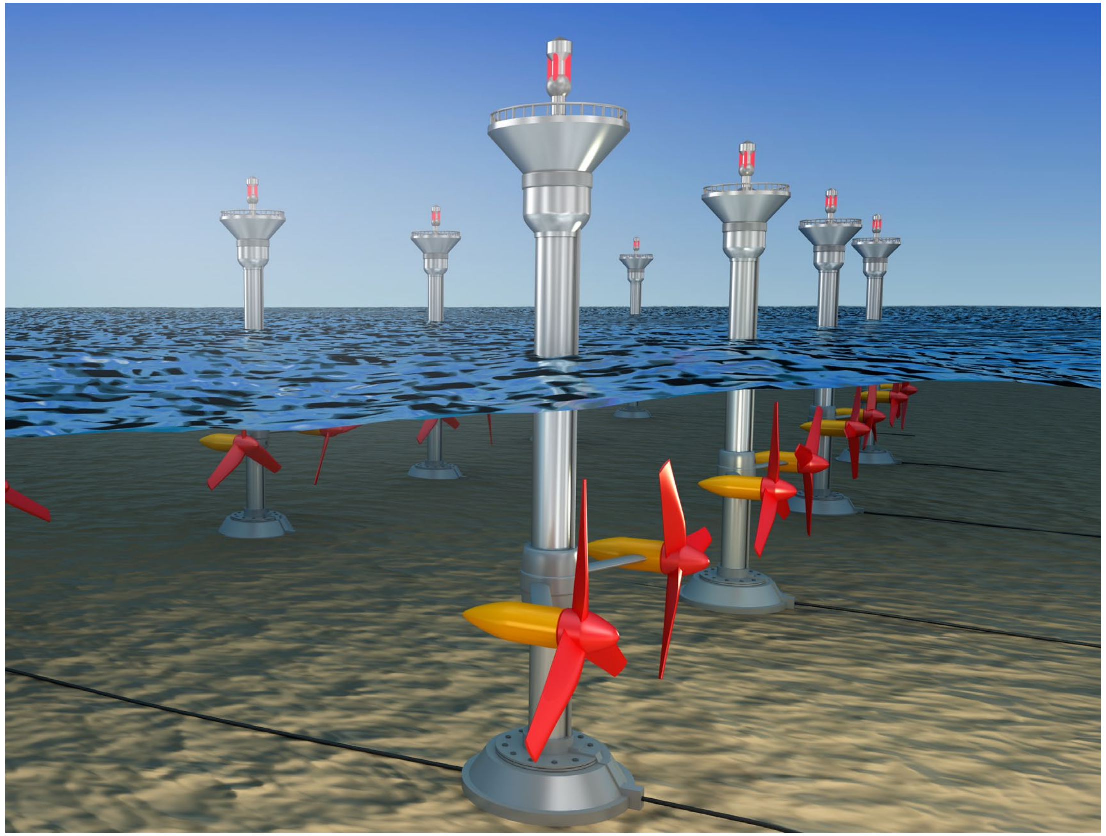


Source: S.T. Peters, In Composite Filament Winding, ed S.T. Peters (2011)

Application specific considerations

- **Seawater** absorption
- Long-term **durability** in a seawater environment
- Fully reversed **stress cycling**

Tidal turbine blades



Application specific considerations

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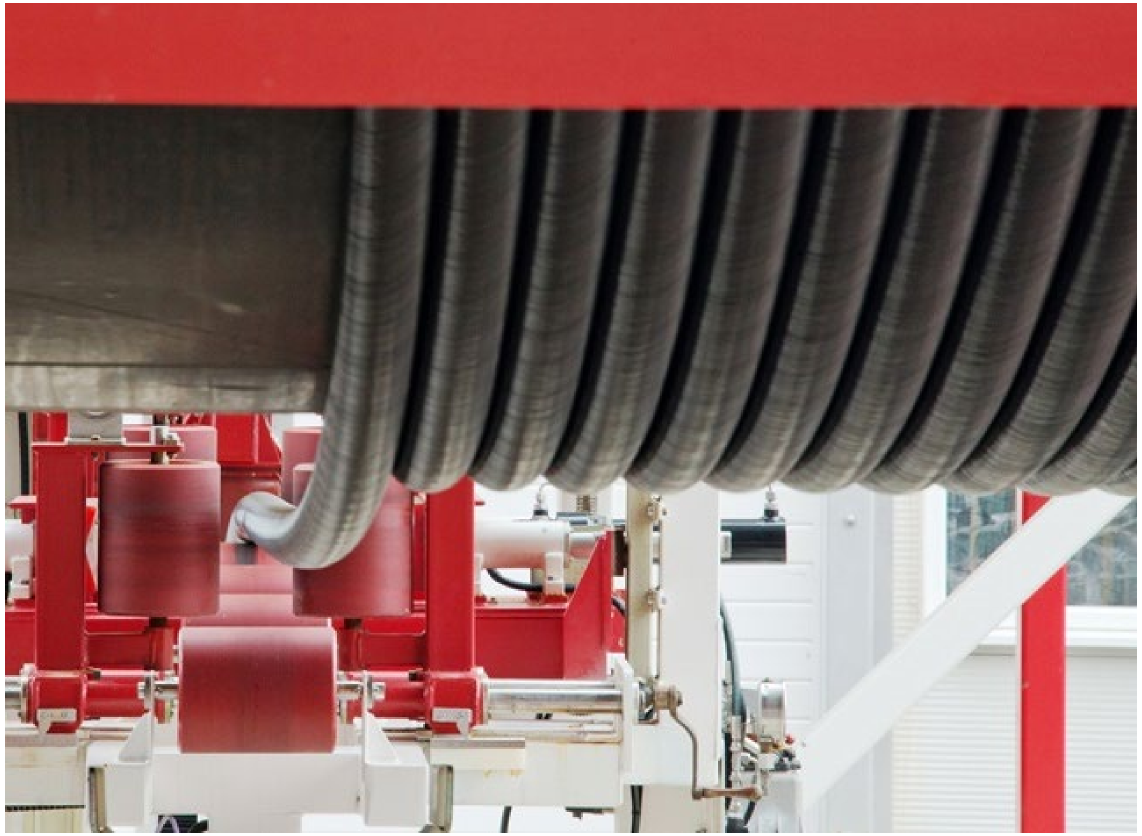
- **Compatibility** to hydrocarbons, seawater, gasses common to an oil & gas environment
- Long-term **creep** performance

Deepsea pipelines

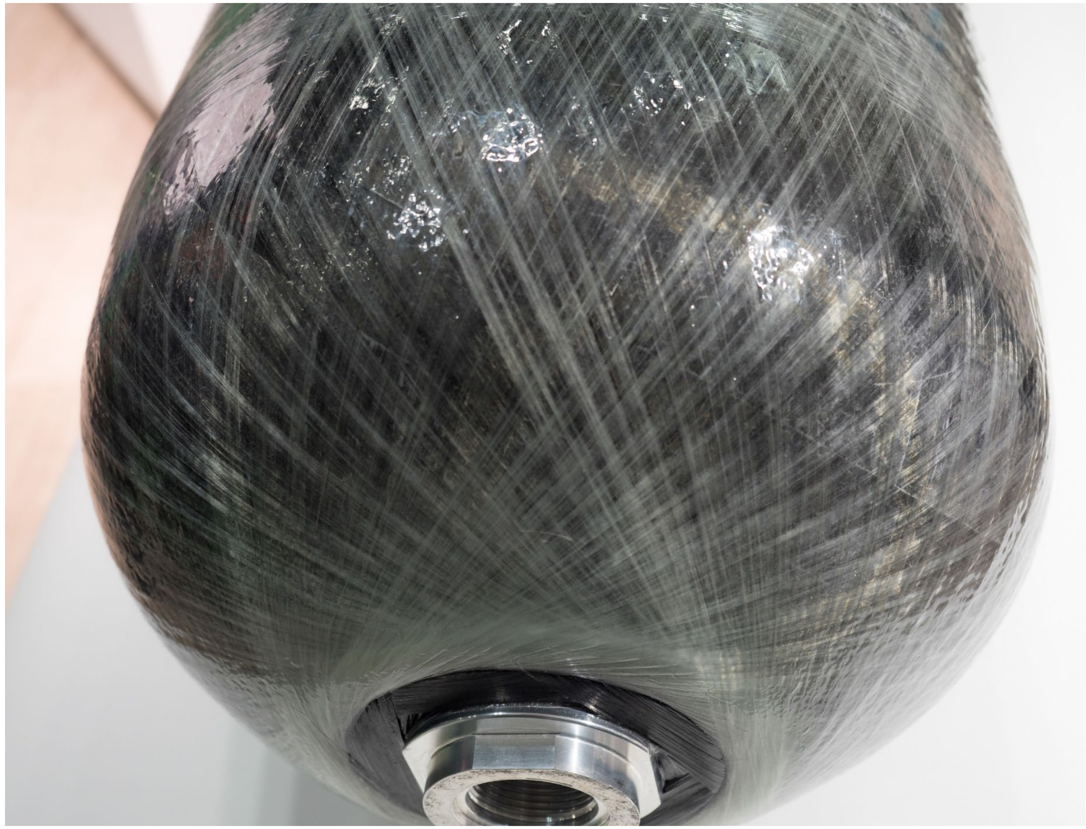


Source: https://www.victrex.com/

Application specific considerations

- Material gas **permeability** over a range of temperatures and pressures
- **Fatigue** performance
- Materials performance and failure at **cryogenic** temperatures

Hydrogen storage



Application specific considerations

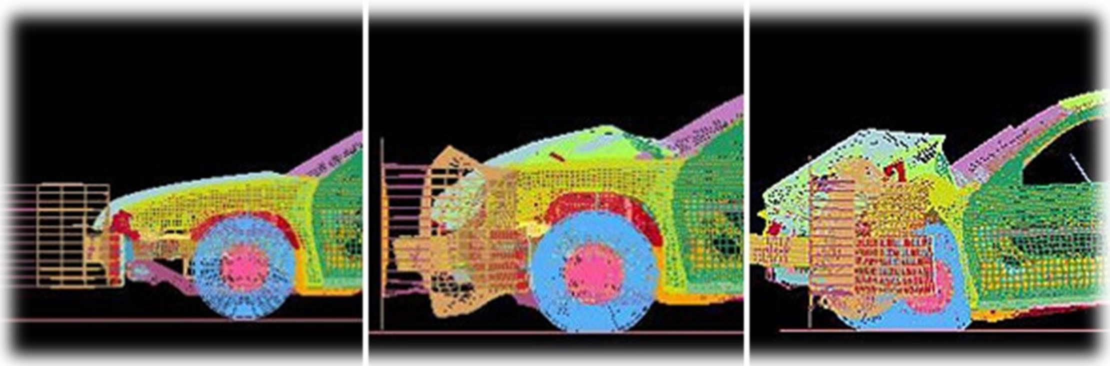
- **Through thickness** (tension and compression) performance

Aircraft engines

Application specific considerations

- **Intermediate** (0.1 – 100 s^{-1}) and **high** (100 – 10^4 s^{-1}) **strain rate** material performance

Automobiles



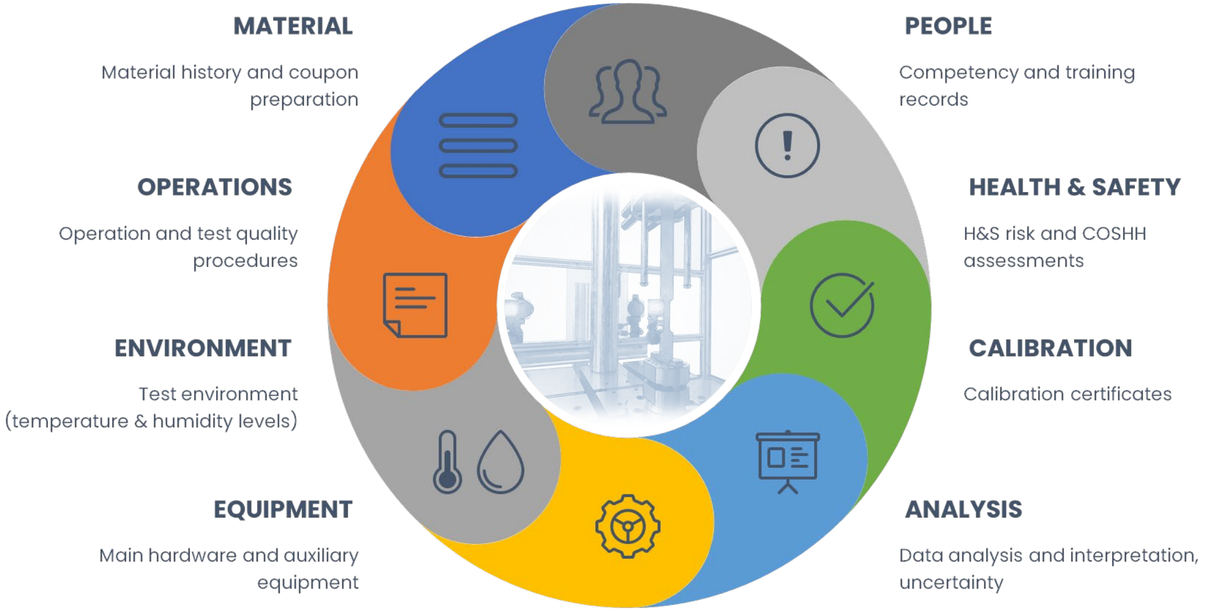
Source: https://www.nytimes.com/2007/06/17/automobiles/17CRASH.html

Results

- ISO 20144 sets out **Standardized Report Sheets** to be used in addition to the as required **metadata** information

  Report sheets → key to formulating a standardized data format and widely share via databasing tools

  Metadata → key in ensuring traceability and data quality



Source: National Physical Laboratory

Statistical Analysis

- ISO 20144 provides a comprehensive guide on evaluating the statistical parameters and design allowable values (Annex B)

- **Important** to choose design values to minimize the probability of structural failure due to material variability

Design basis values

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- **A-basis value →** 95% confidence that 99% of the tested material samples will exceed this value

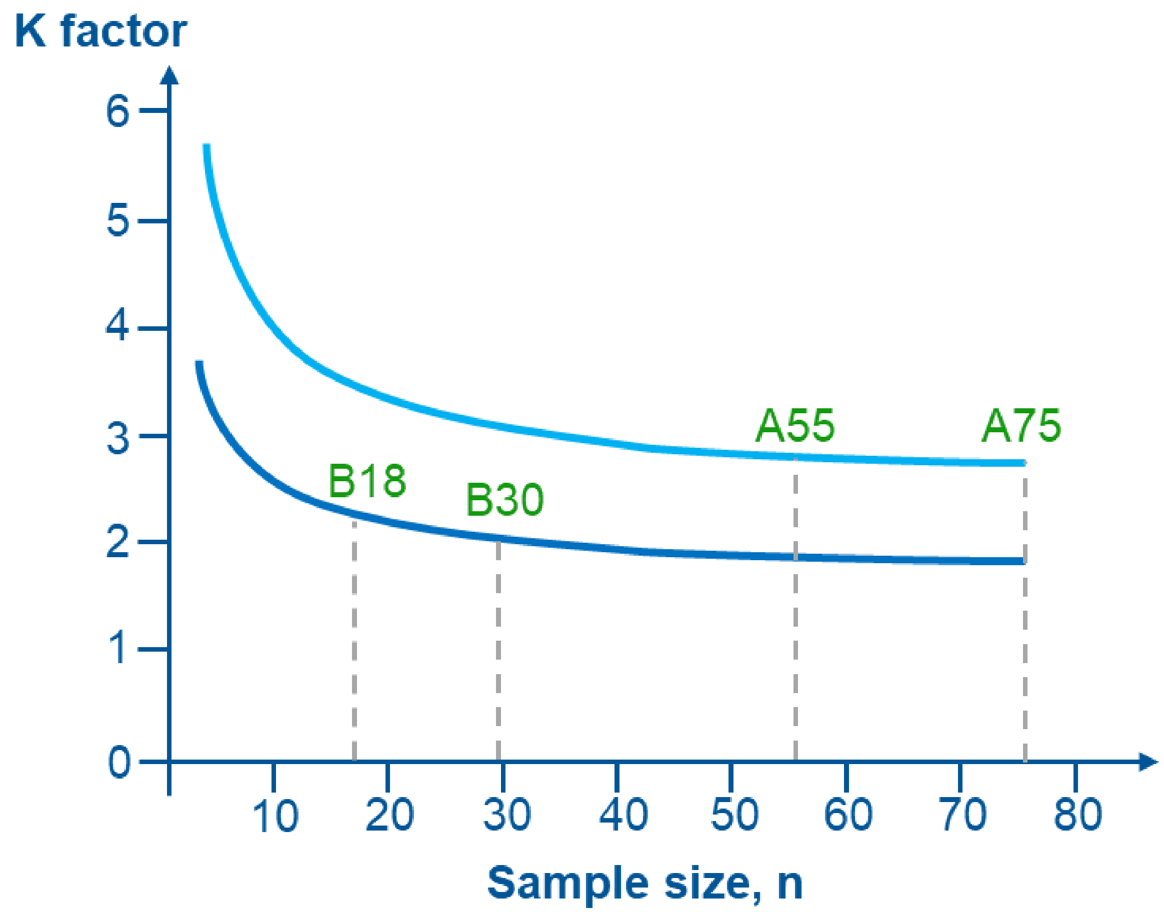
$$A - basis\ value = \bar{x} - (K_A).s$$

- **B-basis value →** a 95% confidence that 90% of the tested material samples will exceed this value

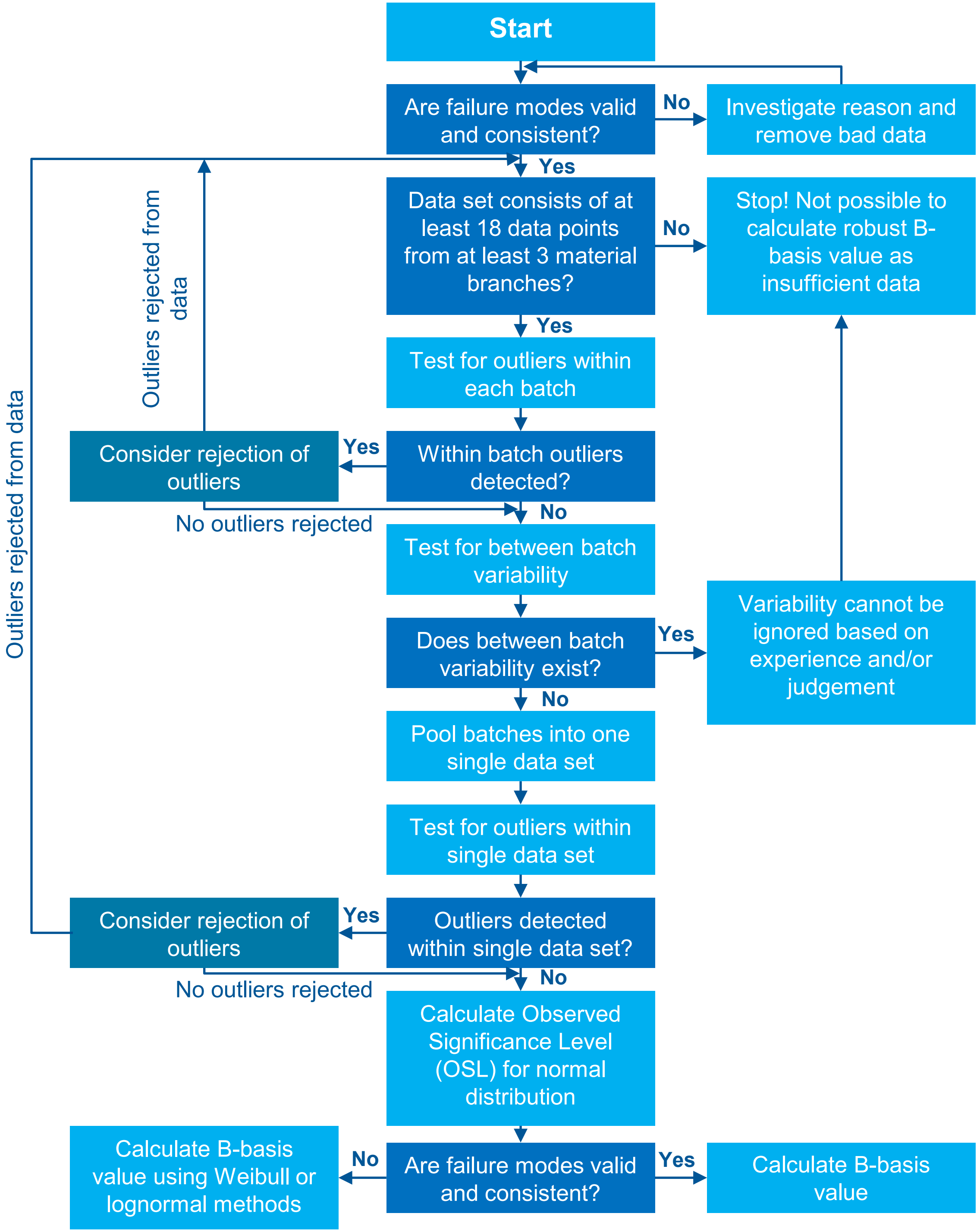
$$B - basis\ value = \bar{x} - (K_B).s$$

Basis values are not material properties. They are not fixed values either because they depend on the number of specimens you test…

Effect of sample size on K_A and K_B

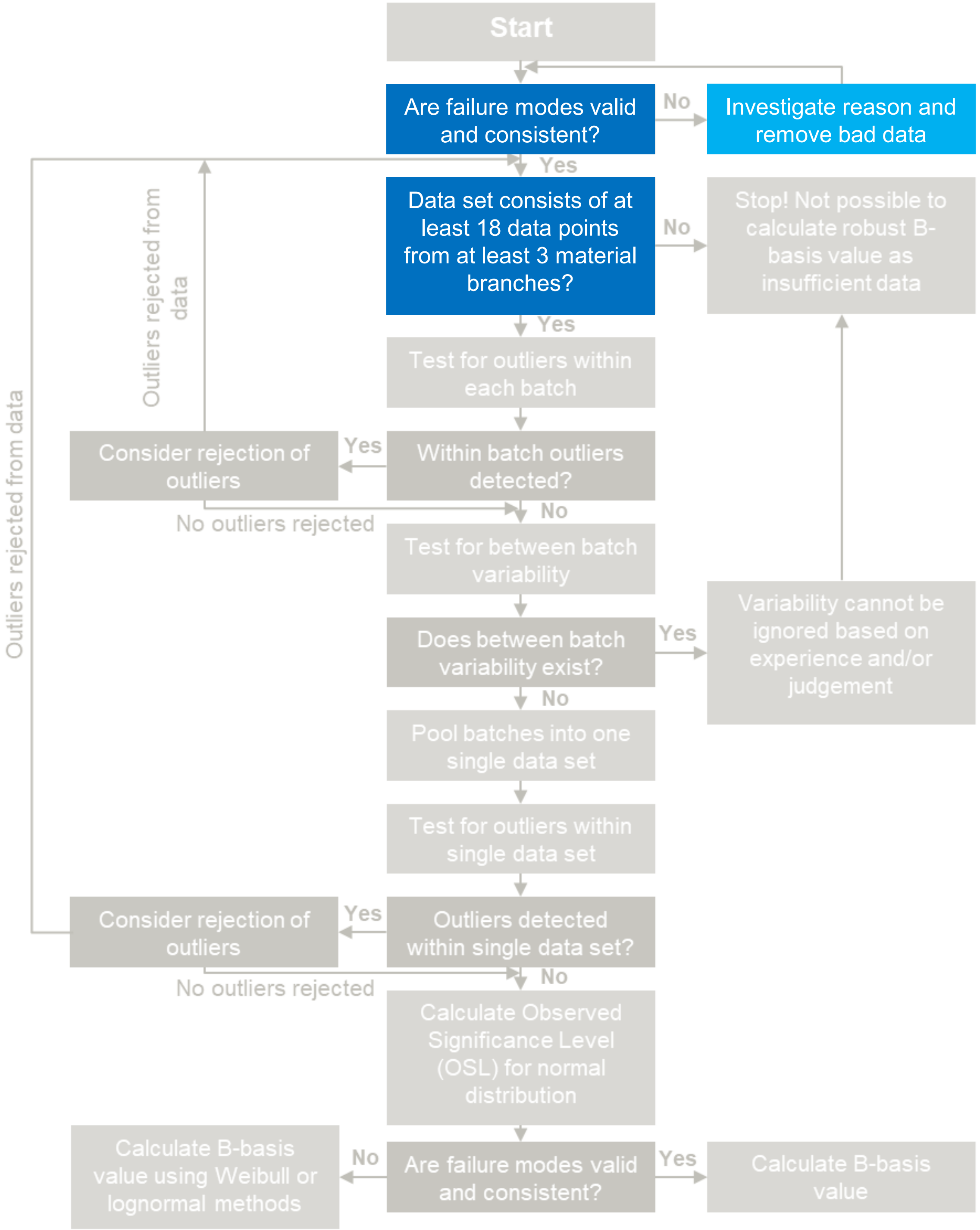


Calculating B-basis values



B-basis design allowables for properties measured from tests on 30 specimens from a minimum of 3 batches of material

Calculating B-basis values



Validity and consistency of failure modes

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- For a particular property, the failure modes should be **valid and consistent** for a given environmental condition
- Specimens failing in **non-acceptable modes** should not be included in the data set
- If a range of acceptable failure modes are observed within a data set, the data should be further examined to see if there is a correlation between strength and the mode of failure
- Should such a correlation exist then investigation of specimen manufacturing and preparation, as well as testing parameters should be undertaken to determine the cause of the different failure modes

Investigation and removal of bad data

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Close investigation of each specimen to identify possible incorrect failure modes

Failure within end-tab region of a compression coupon

Summary

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1

A building block approach is vital for the certification of composite structures. Supports the reduction of cost and risk while meeting all technical, regulatory, and customer requirements

2

A SQP offers clear benefits as it is based on commonly accepted international test methods; can reduce qualification costs and provide readily available data for materials selection and preliminary design

3

Processing and application specific requirements would need to be considered when designing an extended qualification plan for a composite material

Thank you for your time

Department for
Business, Energy
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Q&A Session

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Happy to take any questions

Q&A Session

George Pask – Group Leader
Advanced Engineering Materials, NPL

Dr Stefanos Giannis – Principal Scientist, NPL

Michael Gower - Principal Scientist, NPL

What's New?

Composites Standards & Certification

NPL is offering a two-day course aimed at those who wish to gain an understanding of the roles of composite materials standards and design codes and their use in the certification of composite structures.

- Exclusive course designed to upskill the UK composite community
- Suitable for those who work with composite materials
- Beneficial to all industries that uses composite materials
- Gain understanding of qualification and certification
- Awarded an NPL certification

Follow this link to **register**:
https://training.npl.co.uk/course/composites-standards-and-certification

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Next Webinar:

13th July @ 3:00pm

Advanced Measurement in Wear and Friction Testing

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