Mechanical assessment of fibreglass laminates

Investigating properties for lining and coating applications

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Introduction: Why Fibreglass?

Fibreglass composites, used for linings, coatings and mouldings are highly versatile, durable and robust. Proven over decades, these cost-effective and multi-functional systems are gaining ever increasing application across many industries.

Fibreglass (GRP) is a composite material that combines both polyester resin matrix and glass fibre reinforcement. Using pre-defined quantities, a thin layer of catalysed polyester resin (matrix phase) is applied to the intended surface, prior to the application of glass fibre chopped strand mat (reinforcement phase) and eventually a pigmented resin topcoat.

How does it work? The glass fibres have higher strengths and stiffnesses and polyester resin has a higher degree of elongation. When combined in a fibreglass (GRP) composite, the combination of these two components leads to the creation of a composite that utilises the best properties from both ingredients. Indeed, real world and laboratory-based performance testing has shown fibreglass to have a high strength-to-weight ratio, degree of flexibility, water resistance, broad chemical and abrasion resistance and low cost relative to other composites like carbon fibre. Furthermore, the strong bond that can be created between the resin-saturated laminate and the underlying base surface makes it an ideal protective system for surfaces and structures. These benefits – and several others – make it perfect for a range of applications relating construction, such as: flat roofing (new installations, repairs and refurbishments), storage tanks and bund linings, water feature/pond linings, etc. Enhanced safety features can also be added, including flame retardant ingredients to ensure compliance with BS 476-6 and BS 476-7 and non-slip grit to support HSE regulations on flooring.

These properties help overcome the drawbacks of concrete, timber and other porous structures, which while being very strong, lack the impermeable properties of fibreglass.

Built GRP offers two types of fibreglass laminate system for protective lining and coating applications: a single-layer 600 gram CSM system (S600) for standard lining and coating applications and a dual-layer CSM system (D600) for more heavy-duty applications.

The following technical presentation highlights the physical and mechanical properties of both laminate types.

For more information on Built GRP Fibreglass, please contact us at enquiries@builtgrp.com

Aim, Materials & Methods

Aim

- Characterise the physical and mechanical properties of both the single layer laminate (S600) and dual layer (D600) laminates
- Designed to indicate the consistency, quality and performance of both laminates that would be replicated in a real world setting.

Materials & Method

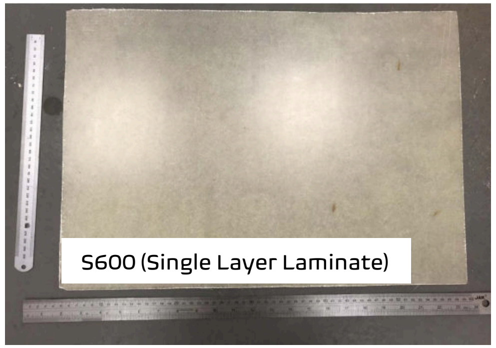
- Single-layer and dual layer laminate samples were prepared in-house
- Third-party, independent testing was performed to measure the physical and mechanical properties

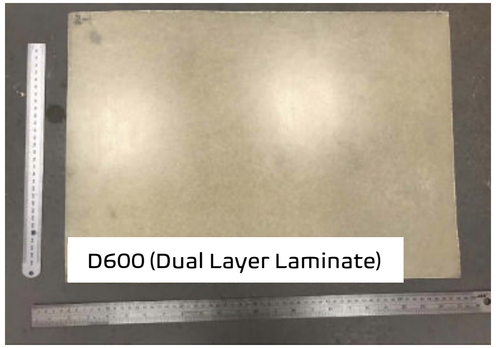
Laminate Preparation

Polyester resin was combined with 600 gram glass fibre chopped strand matting. Two laminate types were created: (1) single-layer laminate and (2) a dual-layer laminate.

Preparation involved the application of around 1.5 kg polyester resin per square meter of CSM. A 2% v/w quantity of MEKP catalyst was added to the polyester resin and carefully mixed. The resin mixture was applied immediately to the glass fibre CSM using a polyester roller followed by a paddle roller to consolidate the laminate.

Cured Laminate





Design		Glass Fibre CSM					Polyester Resin		MEKP Catalyst		
Laminate	Layer	Width (m)	Length (m)	Surface area (m2)	CSM (kg)	Section (kg)	Resin	+ Resin (kg)	Catalyst (%)	Mass (kg)	Volume (mL)
Single (S600)	1	0.57	0.40	0.23	0.6	0.14	0.20	0.5	2	0.01	10
Dual (D600)	2	0.54	0.38	0.20	0.6	0.12	0.18	0.8	2	0.016	16
		0.54	0.38	0.21	0.6	0.12	0.18				

Physical Characteristics

Shore D Hardness: Experimental Setup

Shore D Hardness Scale measures the hardness of hard rubbers, semi-rigid plastics and hard plastics.

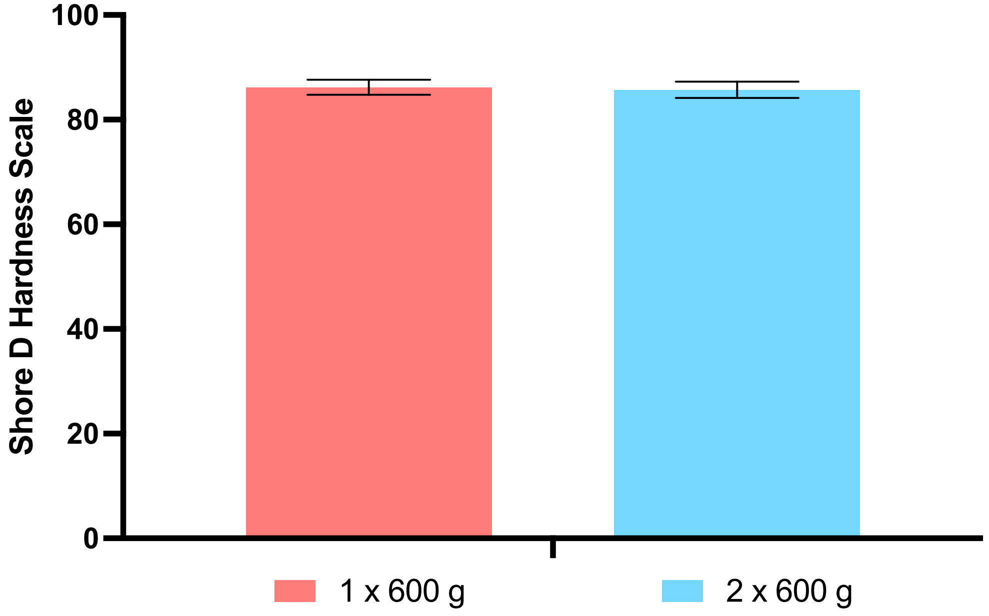
The Shore D hardness was measured in accordance with ISO 868. Sections of 50 mm x 50 mm were cut from each sheet. In order to satisfy the thickness requirements of the standard, the dual 600 g laminate was tested with a specimen consisting of 2 plies, whereas the single 600 g laminate was tested using specimens of three plies. Measurements were performed at 23 ± 2^{o}C after a 15 second dwell using a Durotech D202 stand mounted durometer fitted with a Shore D module.

Shore D Hardness: Experimental Setup

- Shore D Hardness Scale measures the hardness over a range of 0 – 100.

- The data (n=5) shows that both single (1 x 600 g) and dual (2 x 600 g) laminates are in good agreement showing a high level of hardness, with 86.2 +/- 1.4 and 85.7 +/- 1.6 respectively.

- This translates to excellent puncture resistance and a high degree of consistency between both laminate types.



Weight per Unit Area: Experimental Setup

The weight per unit area was measured using sections of 50 x 50 mm.

These sections were cut from each sheet and the width and length of each specimen was measured using vernier callipers.

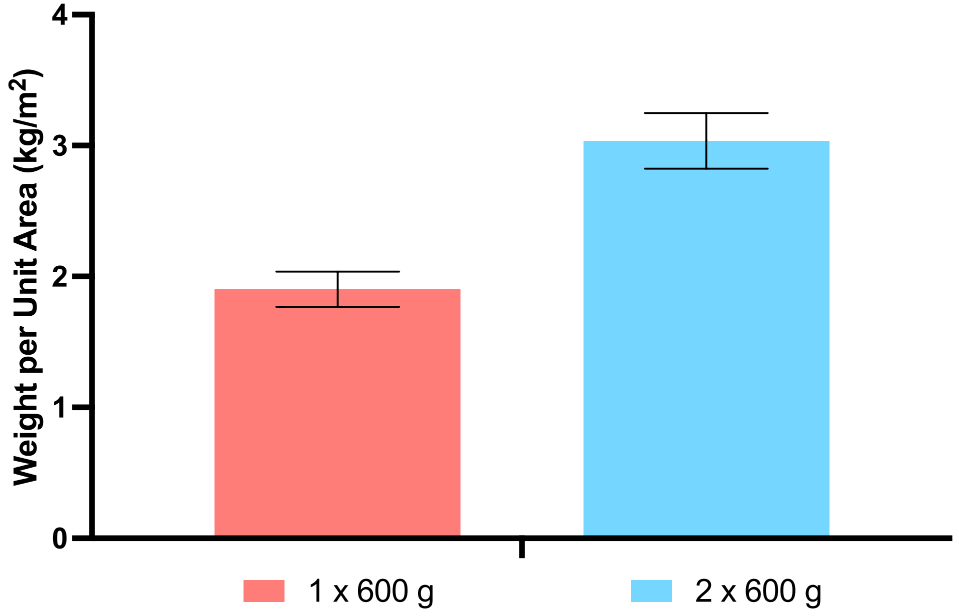
The mass of each samples was recorded and the weight per unit area calculated.

Weight per Unit Area: Experimental Setup

- Weight per unit area (n=5) was 1.9 + /- 0.1 kg/m2 for the single layer laminate and 3.0 + /- 0.2 kg/m2 for the dual layer laminate.

- The increased size and weight of the dual layer laminate also translates to improved mechanical properties.

- Notably, thicker specimens like the dual laminate layer can incur greater variability due to the increased probability of internal or inter-crystalline variability.



For a protective lining and coating, these weights per unit surface area (kg/m2) are negligible relative to the surfaces – such as thick concrete and timber, which they are intending to protect. As such, thickness and weight can be neglected from calculations measuring - the priority is to focus on the load.

Glass Content: Experimental Setup

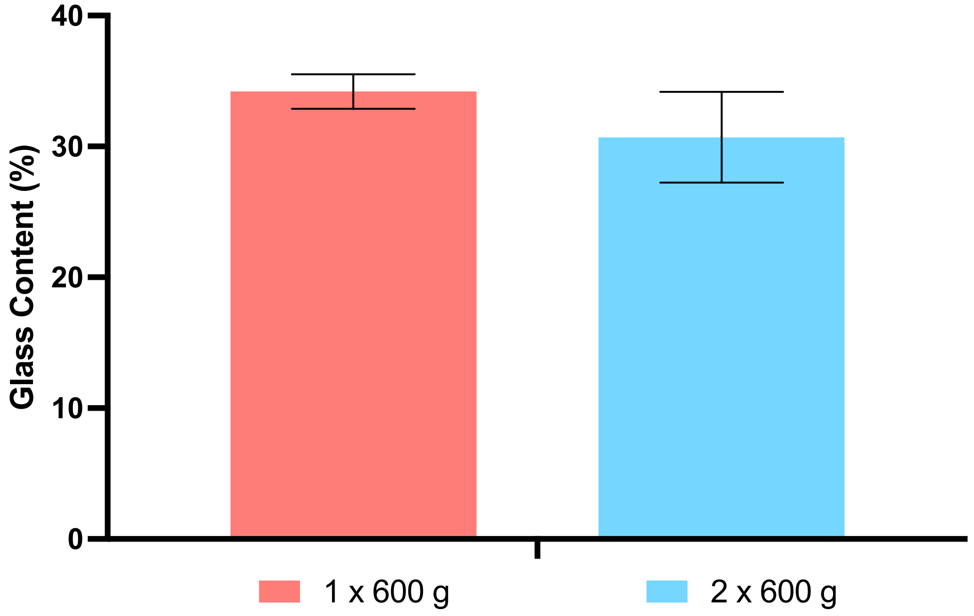
The mass ratio of glass to resin was determined for each material to the procedure described in Annex 7 – Method G of ASTM D3171.

Tests were performed in triplicates for each material using samples of mass circa 1.5 grams. Each sample was heated in separate conditioned alumina crucibles to 600 ^{o}C in a muffle furnace and held at temperature until on the glass fibre remained.

The mass of each sample was measured in its respective crucible, before and after pyrolysis.

Glass Content: Measurements

- This data represents the percentage of glass fibre in the laminate.
- On average, the single layer laminate shows an average of 34.2 +/- 1.3 % E-glass, whilst the dual laminate shows 30.7 +/- 3.5 % E-glass.
- Whilst in good agreement for a hand laminating method, these minor differences are attributed to the variation impacted by a hand laminating method. It is a well known fact that increased laminate thickness causes an increase in variability.



Density: Experimental Setup

Density was determined at 23±2 ºC in accordance with ISO1183-1 Method A (Water Immersion Method).

Sections of 50 x 50 mm were cut from each sheet and weighed first in air and then completed submerged in water.

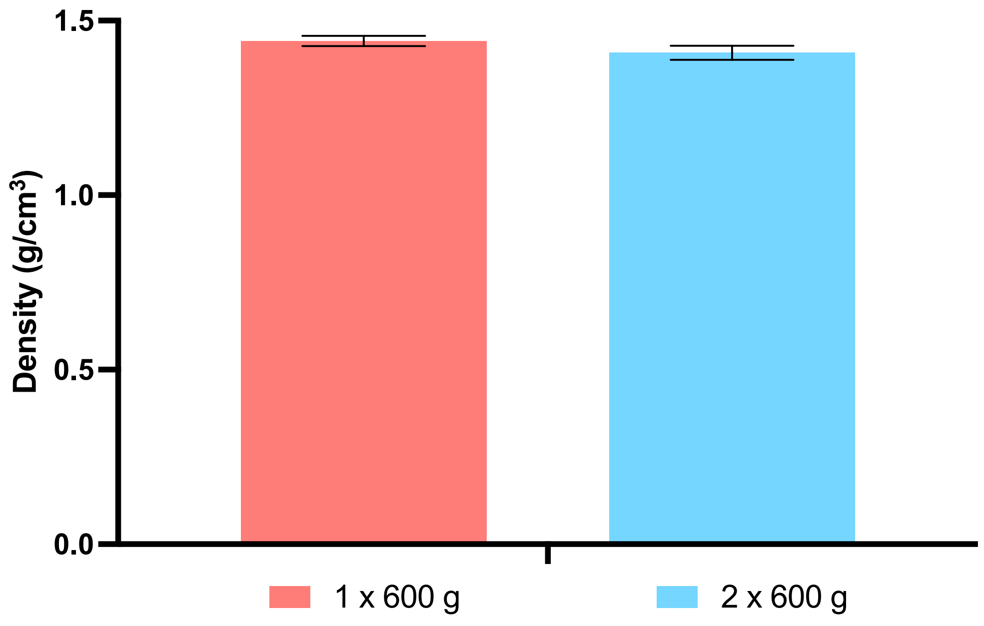
The density was calculated as per the standard.

Density: Measurements

- For density measurements (n=5), the single layer laminate shows an average of 1.44 +/- 0.01 kg/m^3, whilst the dual laminate shows 1.41 +/- 0.02 kg/m^3.

- Whilst the dual layer laminate is thicker, its overall density is near identical to that of the single layer laminate.

- These measurements show excellent consistency between both laminate types.

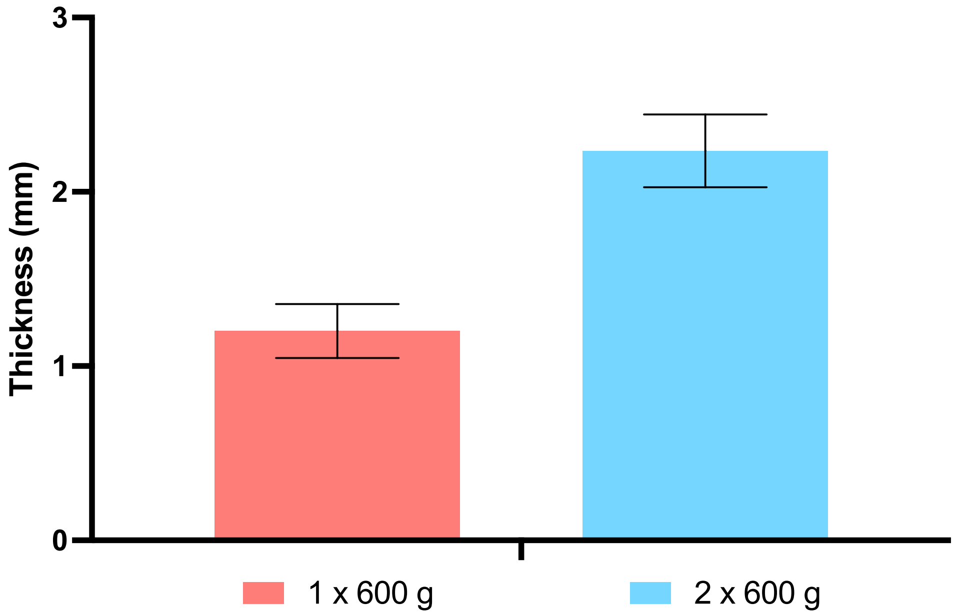


Thickness

- The single layer laminate has a thickness of 1.20 +/- 0.15 mm, whilst the dual layer laminate has a thickness of 2.23 +/- 0.21 mm.

- Thicker laminate shows greater variation – a feature attributed to the higher propensity for variation seen with multi-layered laminates.

- The dual layer was approximately 1.85 times thickness of the single layer, almost double.



Tensile Properties

Tensile Properties: Experimental Setup

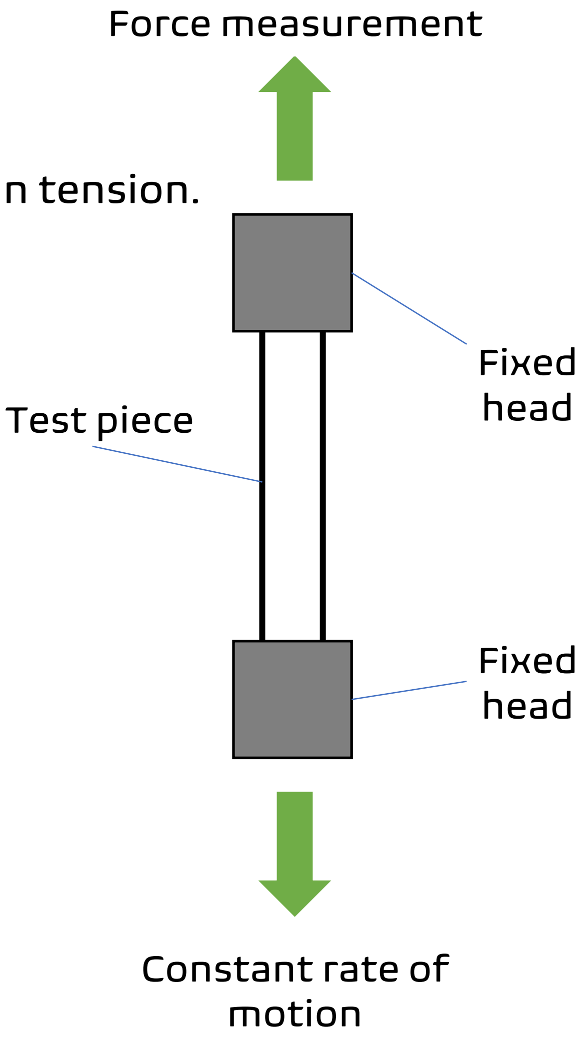
Tensile properties evaluates the capacity of a material to resist forces that are applied in tension.

- Tensile property testing of a composite comprises:

    - **Tensile strength**: also known as ultimate tensile strength, is the maximum stress that a material can withstand while being stretched or pulled before breaking

    - **Tensile modulus**: The tensile modulus (also known as Young's Modulus of Elasticity) is a mechanical metric measuring stiffness. It is defined as the ratio of its tensile stress (force per unit area) to its strain (relative deformation) when undergoing elastic deformation.

These qualities are important in a linings/coating laminate because they indicate a resistance to bending force-induced deformation. This means that laminates expecting foot traffic frequently or equipment placement should



Tensile Modulus: Experimental Setup

The tensile properties were measured using the ASTM D3039 standard for determining the tensile properties of a polymer matrix composite

Five flat strips specimens with rectangular cross-section (250 mm x 20 mm x laminate thickness) were cut from each composite.

Aluminium tab ends were bonded to the samples to reduce the potential of failure at the machine grips.

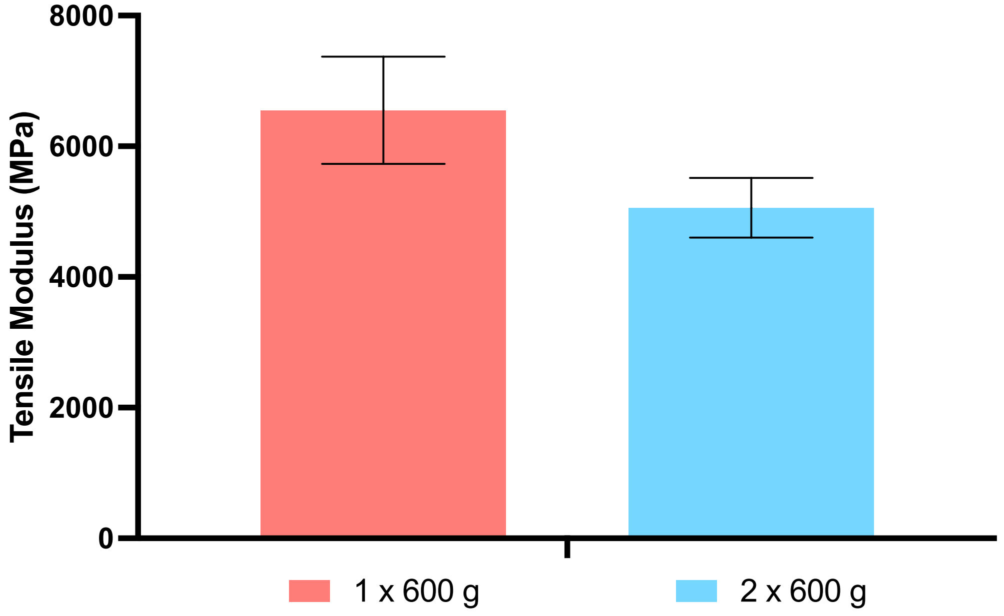
Tensile tests were performed on five replicate samples of each of the two materials using a Zwick 147R tensile machine fitted with a 100 kN load cell.

Tensile Modulus

- The tensile modulus (also known as Young's Modulus of Elasticity) is a mechanical metric measuring stiffness.
- It is defined as the ratio of its tensile stress (force per unit area) to its strain (relative deformation) when undergoing elastic deformation.
- It is useful for measuring the level of stiffness of a material – namely how much it will deform (elastically) when subjected to a load. The higher the tensile modulus is, the more force is required to deform it.
- A tensile axial load (pulling force) was applied to one end of the sample, with the other remaining stationary. This force gradually elongates the specimen at a standard rate until it ruptures.
- It is useful for measuring the level of stiffness of a material – namely how much it will deform (elastically) when subjected to a load. The higher the tensile modulus is, the more force is required to deform it.

Tensile Modulus

Data (n=5) for the single and dual laminate layers have a tensile modulus of 6552 +/- 819 MPa and 5058 +/- 457 MPa respectively.

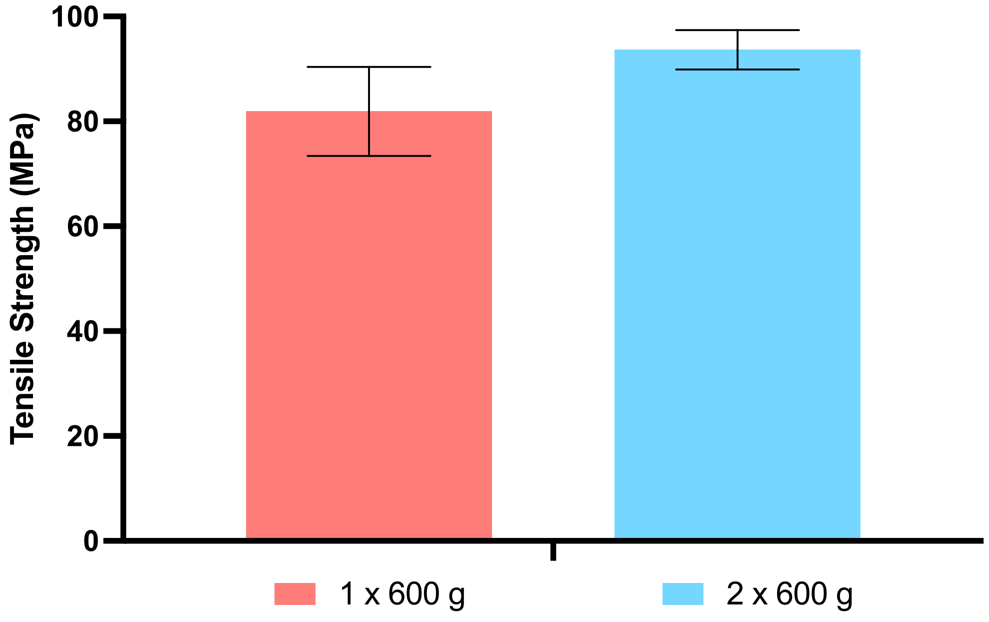


Tensile Strength

The data (n=5) showed the single layer laminate to produce an average tensile strength of 81.9 +/- 8.5 MPa MPa and the dual layer laminate to produce an average of 93.7 +/- 3.8 MPa.

Both laminate types have very similar tensile strengths. The difference between the average tensile strengths shows the dual layer to be X % more than the single layer.

The variation in tensile strength between each laminate could be attributed to the propensity for thicker laminates (e.g. the dual layer) to possess a more favourable internal structure.



Accounting for thickness, these findings show the dual layer laminate to be marginally higher. However, the thickness and weight of the laminate are considered negligible when considering practical lining and coating application.

Tensile Force Displacement

Tensile force displacement data are presented in the table below.

	Max force (N)	Deflection at max force (mm)	Deflection at break (mm)
S600	2577 ± 534	0.63 ± 0.08	0.64 ± 0.07
D600	5009 ± 234	0.77 ± 0.05	0.77 ± 0.05

Tensile force displacement charts are displayed in the following slide.

The maximum force applied was almost 2x for the dual layer (2577 ± 534 N) versus the single layer (5009 ± 234 N)

Deflection at maximum force was slightly lower for the dual layer (0.63 ± 0.08 N) versus the single layer (0.77 ± 0.05 N)

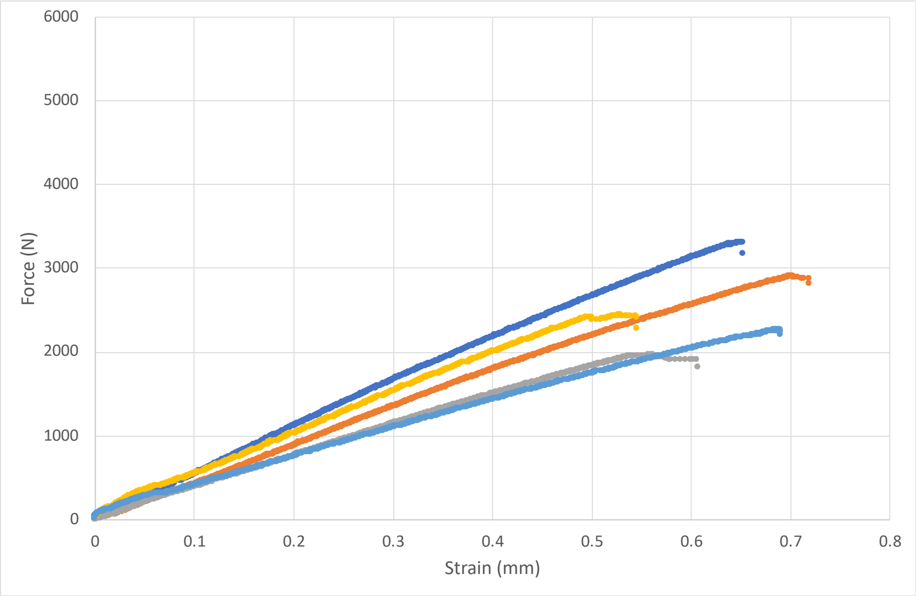
Deflection at break was slightly lower for for the dual layer (0.64 ± 0.07 N) versus the single layer (0.77 ± 0.05 N)

Overall the D600 laminate has a higher tensile load capacity before breaking versus the S600, but a slightly lower strain capacity.

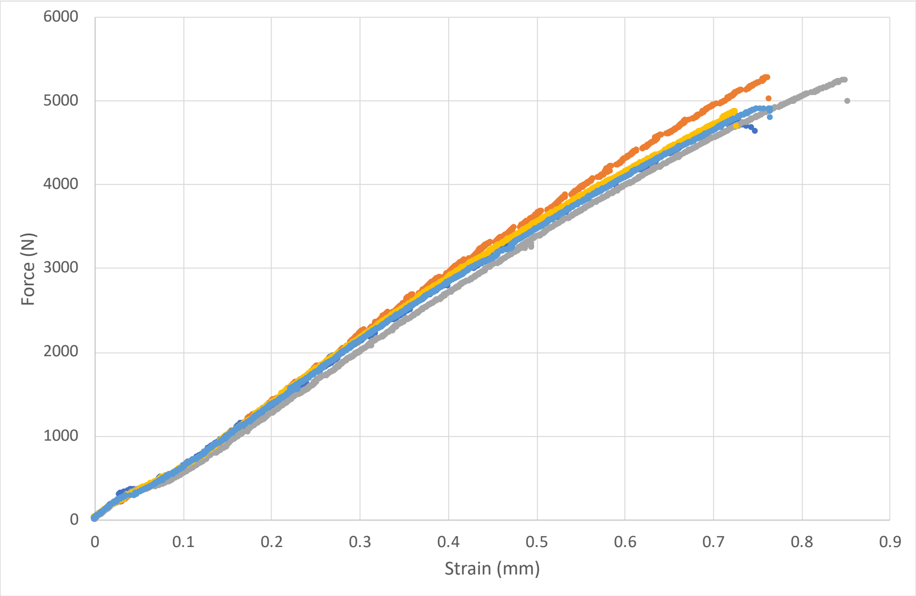
Tensile Force Displacement

Tensile force displacement data are presented in the table below.

S600 (Single layer laminate)



D600 (Dual layer laminate)



Flexural Properties

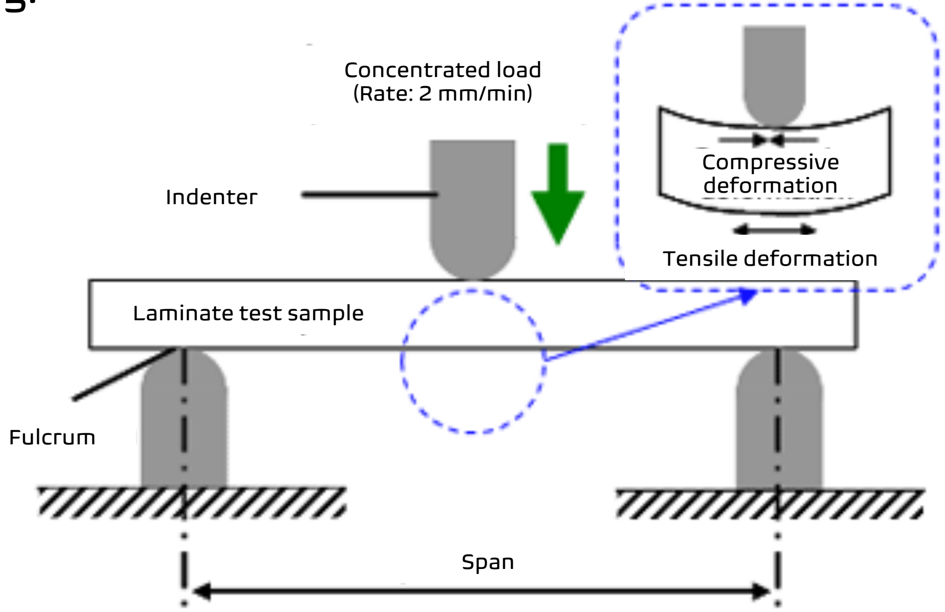
Flexural Properties: Experimental Setup

The flexural test measures the force required to bend a beam under three point loading conditions. The data is often used to select materials for parts that will support loads without flexing.

- Flexural property testing of composite comprises:

    - **Flexural strength**: defined as the stress in a material just before it yields in a flexure test. The vertical stress generated by this bending moment is called the "flexural strength." It indicates the force applied until rupture occurs in the outer surface of the laminate – or until a maximum strain of 5% is achieved – whichever occurs first.

    - **Flexural modulus**: used as an indication of a material's stiffness when flexed.



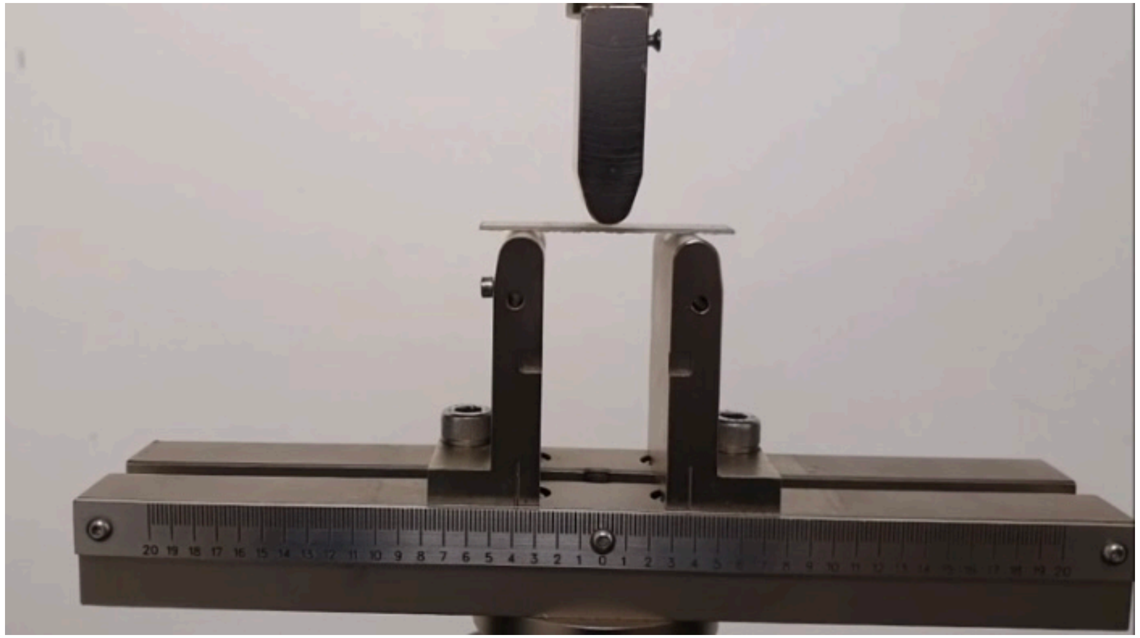
These qualities are important in a linings/coating laminate because they indicate a resistance to bending force-induced deformation. This means that laminates expecting foot traffic frequently or equipment placement should

Flexural Properties: Experimental Setup

Flexural properties were measured in accordance with the ASTM D7264 standard Procedure A – Three Point Bending. All tests were performed at a standard laboratory temperature of 23+/-2ºC using a Zwick 1474R tensile machine fitted with a 200 N load cell.

The standard requires that a span-to-thickness ratio of 32:1 is used with a specimen length being approximately 20% greater than the span. The test speed was calculated to give a strain rate of 0.01 /min.

Ipolytech machined parallel sided samples 13 mm wide from a single direction of each sheet.

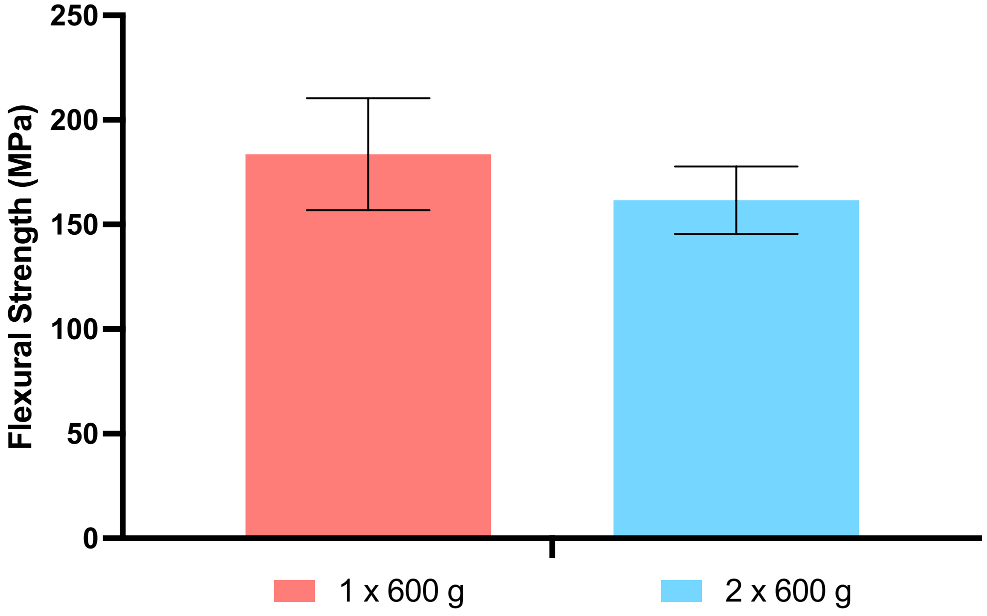


Flexural Strength

The flexural strength (n=5) is marginally greater for the single layer laminate versus the dual one, with 183.6 +/- 26.8 MPa and 161.6 +/- 16.1 MPa respectively.

Data show the values to be in agreement, indicating a good degree of consistency between laminate types.

The marginally lower value for the dual layer is attributed to the increased probability for thicker laminates to present greater differences in inter-crystalline structures - a feature commonly observed as laminate thickness increases.



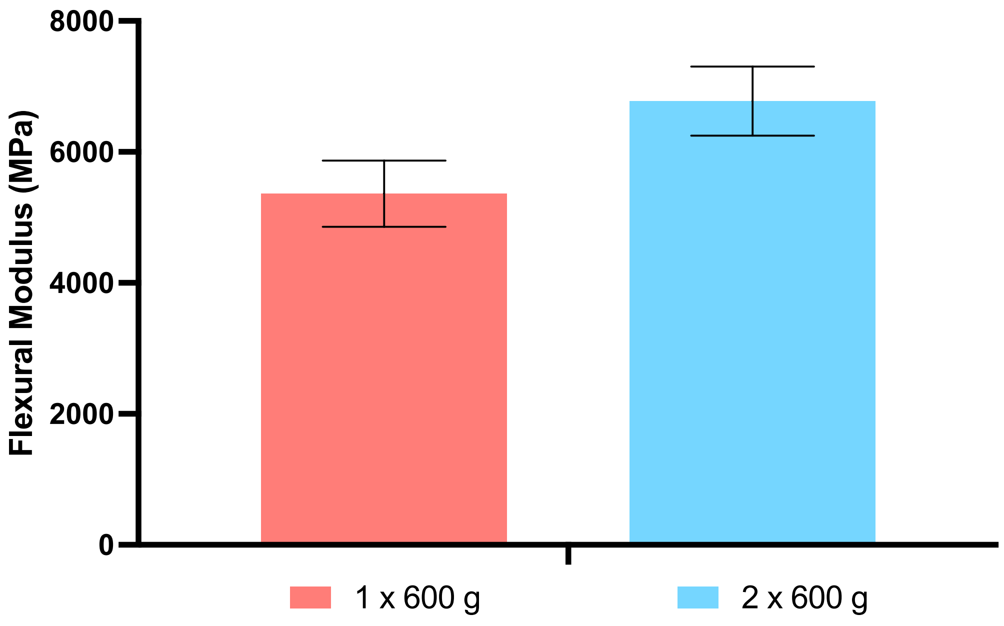
Note: in practical lining/coating applications the thickness (and associated weight) is deemed negligible, so these parameters can be removed to determine the load forces applied in order to determine the flexural strength.

Flexural Modulus

The flexural modulus (n=5) indicates the dual layer's higher degree of resistance to bending versus the single layer laminate, with 5364 +/- 507 MPa versus 6776 +/- 528 MPa.

This also supports the intended application for the dual layer, which is for it to be used as a protective lining/coating on projects where heavier objects (e.g. foot traffic and equipment placement) are expected.

The average flexural modulus was around 1.25x greater for the dual layer laminate versus the single layer.



Flexural Force Displacement

Flexural force displacement data are presented in the table below.

	Max force (N)	Deflection at max force (mm)	Deflection at break (mm)
S600	64.4 ± 16.6	6.9 ± 0.9	9.2 ± 0.7
D600	114.4 ± 9.6	12.6 ± 1.6	14.6 ± 1.1

Flexural force displacement charts are displayed in the following slide.

The maximum force applied was almost 2x for the dual layer (114.4 ± 9.6 N) versus the single layer (64.4 ± 16.6 N)

Deflection at maximum force was 2x for the dual layer (12.6 ± 1.6 N) versus the single layer (6.9 ± 0.9 N)

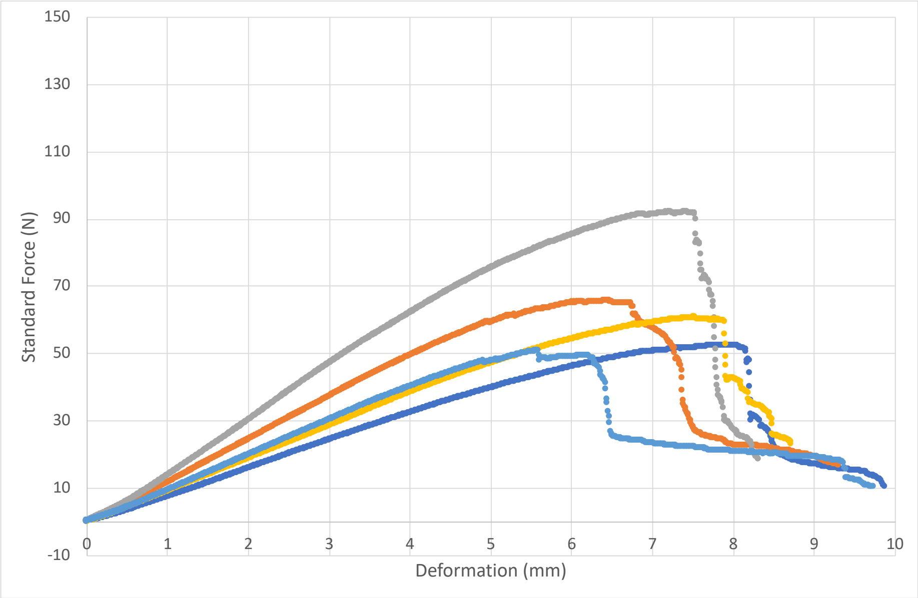
Deflection at break was slightly under 2x for the dual layer (9.2 ± 0.7 N) versus the single layer (14.6 ± 1.1 N)

Overall the D600 laminate is more rigid versus the S600, but it can withstand a higher flexural load before breaking.

Flexural Force Displacement

Flexural force displacement data are presented in the table below.

S600 (Single layer laminate)



D600 (Dual layer laminate)