Section
3

Materials Comparison

Comparison between pultrusion and conventional materials

Introduction

There are a number of differences between designing with pultrusions and designing with conventional materials. The designer, whilst following the guidelines in the pultrusion guide should remain aware of the following:

Anisotropic

Pultrusions are not homogeneous or isotropic. The mechanical properties are directional and it is important to consider both the transverse and longitudinal cases.

Modulus of Elasticity

Pultrusions tend to have a high strength to stiffness ratio. Whilst the strength is comparable, the modulus of elasticity of pultrusions is approximately one-tenth that of steel. As a result deflection may be the controlling design factor.

Shear Modulus

The shear modulus of pultrusions is relatively low compared to metals.

Temperature

Pultrusions do not perform as well as metals at elevated temperatures, as they are susceptible to property degradation. Resins need to be carefully selected for continuous operation at elevated temperatures. However in cold temperatures the mechanical properties of pultrusions improve.

Comparative Performance of pultruded and Steel Sections

The following table attempts to illustrate some of the above points. The material property data which has been used is typical of the Force 800 structural range of profiles.

It can be seen that the tensile strength of the pultrusion is higher in this case than the steel, but that the tensile modulus of steel is much higher than the pultrusion.

The strength performance is compared by considering the bending moment at which it will fail. It can be seen that the pultruded sections can sustain much higher loads than the steel sections. The steel sections are much stiffer than the pultrusions and deflection may be the controlling design factor.

When the specific properties (performance per weight) are considered, pultrusions have excellent tensile and flexural strengths and the specific stiffness is of the same order as the steel sections. If necessary the designer has the option to increase the overall dimensions whilst maintaining the cross sectional area thus increasing dramatically the stiffness of the pultruded section and achieving a considerable weight saving over a steel section of comparable stiffness.

Comparative Performance of Custom Pultruded Sections and Steel Sections

	Units	**Steel Box 50x50x3**	**GRP Box 50x50x5.57**	**GRP Box 50x50x4**	**Steel Angle 50x50x6**	**GRP Angle 50x50x5.75**
Tensile Strength	N/MM^2	265	300	300	265	300
Flexural Strength (bending moment at failure)	KN.M	2.4	4.8	3.5	1.0	1.1
Tensile Modulus	KN/MM^2	210	19	19	210	19
Flexural Rigidity	KN/M^2	44	6.6	5.6	28	3
Density	Kg/M^3	7800	1650	1650	7800	1650
Specific Tensile Strength	N/MM^2 (Mg/M^3)	34	180	180	34	180
Specific Flexural Strength	KN.M (Mg/M^3)	0.31	2.9	2.1	0.13	3.67
Specific Tensile Modulus	KN/M^2 (Mg/M^3)	27	12	12	27	12
Specific Flexural Rigidity	KN/M^2 (Mg/M^3)	5.6	4	3.4	3.6	1.8
Weight	Kg/M	4.4	1.7	1.2	4.7	0.95

Table 3.1

Frequently a designer has to make a decision whether to use a pultruded section as an alternative to traditional materials such as steel, aluminium or wood. Selected relative properties are listed in the table below

Some Mechanical Properties of Pultruded sections and Traditional Materials

	Tensile Strength N/mm²	Rigidity kN/mm²	Flexural Strength N/mm²
FRP Pultrusions 50% Mat and Rovings 70% Rovings	207 690	17 21	207 550
Wood Maple Pine	100 60	12.4 12.1	55 35
Metals Aluminium Steel	280 690	70 210	280 690
Thermoplastics Reinforced (typical) Glass Reinforced (typical)	55 100	3.4 6.9	55 140

Table 3.2

It is important to remember that the mechanical properties of pultrusions can be modified by the use of different fibers (Glass, Carbon or Aramid) and by substituting longitudinal fibers for random mats. As so many options exist it is difficult to provide an all inclusive list of properties.

The designer must learn to exploit the specific fiber characteristics to achieve the desired performance characteristics whilst using the orientation opportunities available from the different reinforcement types.

Table (4) compared various materials in terms of absolute strength or stiffness. It is often desirable to determine the thickness of the pultrusion necessary to achieve the strength or rigidity equivalent to that of other materials. Such an analysis is shown in Table 5

This highlights that, for example, a standard E17 (European Std 17GPa Modulus) construction would need to be 1.16 times as thick as the aluminium section to achieve the same "flexural" strength

Equivalent Performance Factor of FRP Pultrusions to Conventional Structural Materials:

		Steel			**Aluminum**			**Wood**		
	Specific Gravity	Tensile Strength	Rigidity	Flexural Strength	Tensile	Rigidity	Flexural Strength	Tensile Strength	Rigidity	Flexural Strength
E17	1.85	2.5	2.15	1.82	1.0	1.49	1.16	0.25	0.79	0.45
70% Rovings	2.00	1.0	1.71	1.12	0.4	1.19	0.71	0.10	0.63	0.27

Table 3.3

(Note: A factor of 1.0 indicates equal performance).

When the application does not require equivalency the product thickness can be reduced accordingly to yield savings in material and processing costs.

EXEL COMPOSITES FRP VS CONVENTIONAL MATERIALS

Designing with Exel Composites FRP, using this manual is not much different than designing with other materials. The designer should, however, keep the following primary differences in mind:

Relatively Low Modulus of Elasticity

The modulus of elasticity of Exel Composites FRP is approximately one-tenth that of steel. As a result, deflection is often a controlling design factor.

Anisotropic

Pultruded composites are not homogeneous or isotropic; therefore, the mechanical properties of Exel Composites FRP are directional. When designing with Exel composites FRP structural shapes, it is important to consider stresses in both the transverse and longitudinal directions.

Relatively Low Shear Modulus

The shear modulus of pultruded FRP shapes is low compared to metals. Accordingly, the designer should be aware that shear stresses add deflection to loaded beams above the classical flexural deflection. Refer to Section 8 – Flexural Members for more detailed information and design examples.

The Effect of Temperature

Exel Composites FRP structural shapes are more susceptible to property degradation at high temperatures than are metals. The designer should keep this in mind where the design temperature is above 150°F for polyester and 200°F for vinyl ester. Contrary to intuitive thinking, Exel Composites FRP shapes become stiffer in cold temperatures. See "Temperature Effects" in Section 2 – Properties of Exel Composites FRP Structural Shapes for expanded discussion of the effects of temperature.

Corrosion Resistance

Exel Composites FRP shapes are often placed in corrosive environments. Generally Exel Composites shapes offer superior corrosion resistance when compared to conventional building materials. See Section 23 – Corrosion Resistance Guide for guidance.

Exel Composites Structural Pultruded Tube is Not Designed as a Pipe

Exel Composites FRP tubes have been designed for structural applications such as columns and handrails and not as fluid carrying pipe. Exel Composites FRP tube may be used to carry fluids if there is not internal pressure. The end-user should consult Section 23 – Corrosion Resistance Guide to confirm the suitability of the resin to handle the fluid being considered and should also test the FRP tube to confirm its ability to carry the fluid without leaking.

EXEL COMPOSITES FRP VS. OTHER PULTRUDED PRODUCTS

The designer should be aware that two pultruded shapes with identical external dimensions can vary dramatically in physical properties depending on the resin formulation and the amount and type of reinforcement. This manual should not be used for FRP shapes other than Exel Composites FRP structural shapes.

The key word in describing Exel Composites FRP structural shapes is "standard". Exel Composites FRP structural shapes are a product line of standard shapes with standard mechanical properties. If the pultruded product is not Exel Composites, we refer to it as a "custom pultrusion", as described in the next section.

Exel Composites FRP Vs. Traditional Materials (Property Comparison)

MECHANICAL		500/525 Shapes◊ PE	625 Shapes◊ VE	Thermal Cure Rod & Bar◊	Carbon Steel (M1020)	316 Stainless Steel	Hastelloy C-276 (ANNLD.)	Aluminium 6061-T61 T651	Ponderosa Pine	Rigid PVC	Glassfiber Compression Moulding (SMC)	Spray-Up (30-50% Glass)
Tensile Strength	LW	207	207	689	414	552	689	310	2.90	42.7	55.2-138	62.1-124
(N/mm^2)	CW	48.3	48.3	-	414	552	689	310	-	42.7	55.2-138	62.1-124
Tensile Modulus	LW	17.2	17.9	41.4	207	193	179	68.9	-	2.69	11.0-17.2	5.52-12.4
($x10^3$ N/mm^2)	CW	5.52	6.89	-	207	193	179	68.9	-	2.69	11.0-17.2	5.52-12.4
Flexural Strength	LW	207	207	689	414	552	689	310	106	75.8	124-270	110-193
(N/mm^2)	CW	68.9	68.9	-	414	552	-	310	64.8	75.8	124-270	110-193
Flexural Modulus	LW	13.8	15.2	41.4	207	193	179	68.9	6.89	2.41	9.02-12.4	6.89-8.30
($x10^3$ N/mm^2)	CW	5.52	5.52	-	207	193	179	68.9	-	2.41	9.02-12.4	6.89-8.30
Izod Impact	LW	1.33	1.33	2.14	N/A	.454-587	-	-	-	0.085	.534-1.07	.214-.641
(J/mm)	CW	0.214	0.214	-	N/A	-	-	-	-	0.085	.534-1.07	.214-.641
Specific Gravity		1.7	1.7	2.0	7.8	7.92	8.96	2.5	0.520	1.38	1.5-1.7	1.4-1.6
PHYSICAL												
Density ($x10^{-3}$ g/mm^3)		1.72-1.94	1.72-1.94	1.99-2.10	7.86	8.03	8.97	2.55	0.526	1.44	1.49-1.69	1.39-1.63
Thermal Conductivity ($W\text{-}m/m^{-2}/C°$)		83.1	83.1	104	5400-9554	1994-3842	1475	24923	1.66	27.0	1.12-1.27	1.04-1.23
Coefficient of Linear Expansion ($x10^{-6}$ mm/ mm/C°)		7.00	7.00	5.45	10.9-14.5	16.4-18.2		24.5	3.09	67.3	18.2-32.7	21.8-36.4

Table 3.4

◊Values are Minimum Ultimate Properties from Coupons

Glassfiber Pultrusion Thickness relative to Steel, Aluminum or Wood∞

GLASSFIBER PULTRUSION CONSTRUCTION	*STEEL			*ALUMINIUM			*WOOD		
	Tensile Strength	Flexural Modulus	Flexural Strength	Tensile Strength	Flexural Modulus	Flexural Strength	Tensile Strength	Flexural Modulus	Flexural Strength
50% Mat & Roving	2.5	2.15	1.82	1.0	1.49	1.16	.25	.79	.45
70% Roving only (Thermal Cure Rod & Bar)	1.0	1.71	1.12	.4	1.19	.71	.10	.63	.27

Table 3.5

Materials Handbook, Vol. 1, "Composites", pg. 541

As an example, a 50% mat & roving glass fiber pultrusion would need to be 1.82 times as thick as a steel part to achieve the same "flexural strength"

Pultrusion Vs. Timber

COMPARE!	Structural Timber Douglas Fire	Pultruded Glassfiber Structural Shapes
CORROSION RESISTANCE	Can warp, rot and decay from exposure to moisture, water and chemicals. Coatings or preservatives required to increase corrosion or rot resistance can create hazardous waste and/or high maintenance.	Superior resistance to a broad range of chemicals. Unaffected by moisture or immersion in water if ends are properly sealed. Surfacing veil and UV additives create excellent weatherability.
INSECT RESISTANCE	Susceptible to insect attack (marine borers, termites, etc.) Coatings to increase resistance to insects can be environmentally hazardous.	Unaffected by insects.
STRENGTH	Extreme fiber bending = up to 2800 psi.* Compression parallel to grain = up to 1800 psi.*	Pultruded glassfiber is stronger, and has higher flexural strength than timber. Ultimate flexural strength (fu) LW = 30.000 psi, CW = 10,000 psi. Compression strength is 30,000 psi.
STIFFNESS	Modulus of elasticity = up to 1.8 x 10^6 psi.*	Pultruded glassfiber is approximately 1-1/2 times as rigid as wood. Modulus of elasticity LW = 2.5 x 10^6 psi.
ELECTRICAL CONDUCTIVITY	Timber can be conductive when it is wet.	Non-conductive – high dielectric capability.
WEIGHT	Specific gravity = .51 (oven dried).*	Specific gravity = 1.7 Pultruded glassfiber has significantly higher strength-to-weight ratio. 100mm square post
FINISHING COLOUR	Must be primed and painted for colours. To maintain colour, repainting may be required.	Pigments added to the resin provide color throughout the part. Special colors available. Composite design can be customized for required finishes.
COST	Lower initial cost.	Lower maintenance, longer product life often equals lower overall costs.

Table 3.6

* Surface dry at 19% max moisture content

Design Values for Wood Construction, National Design Specification for Wood Construction.

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Pultrusion Vs. Steel

COMPARE!	Steel A-36 Carbon	Pultruded Glassfiber Structural Shapes
CORROSION RESISTANCE	Subject to oxidation and corrosion. Requires painting or galvanizing for many applications.	Pultrusions are available in either polyester or vinyl ester resin for resistance to a broad range of chemicals. Painting required only when exposed to direct sunlight.
WEIGHT	Could require lifting equipment to move and place. ½ " thick plate = 20.4 lbs./sq. ft.	Lightweight – weighs 75% less than steel. ½" thick plate = 4.7 lbs./sq. ft.
CONDUCTIVITY	Conducts electricity. Grounding potential. Thermal Conductivity 260-460 (BTU,SF/HR/F°/IN).	Does not conduct electricity. Low thermal Conductivity 4 (BTU/SF/HR/F°/IN).
STRENGTH	Homogenous material. Yield strength (Fy)	Pultrusions have a high strength-to-weight ratio, and pound-for-pound are stronger than steel in the lengthwise direction. Ultimate flexural strength (Fu) LW = 30 ksi CW = 10 ksi
STIFFNESS	Modulus of elasticity 29×10^6 psi	Modulus of elasticity LW = 2.5×10^6 psi CW = 0.8×10^6 psi Will not permanently deform under working load.
IMPACT RESISTANCE	Can permanently deform under impact.	Glass mat in pultruded parts, distributes impact load to prevent surface damage even in sub-zero temperatures. Will not permanently deform under impact.
EMI/RFI TRANSPARENCY	Can interfere with EMI/RFI transmissions.	Transparent to EMI/RFI transmissions.
VERSATILITY	Must be painted for colour. To maintain colour and corrosion resistance, repainting may be required.	Pigments added to the resin provide colour throughout the part. Special colours available.
EASY FIELD FABRICATION	Often requires welding and cutting torches. Heavier material requires special handling equipment to erect and install.	Pultruded glassfiber can be field fabricated using simple carpenter tools with carbon or diamond tip blades. Lightweight for easier erection and installation.
COST	Lower initial material cost.	Lower installation and maintenance costs in industrial applications often equals lower lifecycle costs.

Table 3.7

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Pultrusion Vs. Aluminum

COMPARE!	Aluminium Extruded Shapes	Pultruded Glassfiber Structural Shapes
CORROSION RESISTANCE	Can cause galvanic corrosion. Corrosion resistance can be increased through anodizing or other coatings.	Superior resistance to a broad range of chemicals. Surfacing veil and UV additives improve weatherability.
WEIGHT	Lightweight – about 1/3 that of copper or steel. 1m Al plate.	Very lightweight – about 70% the weight of aluminium on a density basis.
ELECTRICAL CONDUCTIVITY	Conducts electricity – grounding potential.	Non-conductive – high dielectric capability.
THERMAL CONDUCTIVITY	Heat conductor – high thermal conductivity. 150 (BTU/SF/HR/F°/IN); thermal coefficient of expansion 11-13 (IN/IN/F°) 10^6.	Insulates – low thermal conductivity, 4 (BTU/SF/HR/F°/IN); low thermal coefficient of expansion 4.4 (IN/IN/F°) 10^6.
STRENGTH	Flexural strength (Fu) 35 ksi. Homogenous material.	Ultimate flexural strength (Fu) LW = 30ksi CW = 10KSI. Pultruded glassfiber has 86% of the yield strength of aluminium and, pound-for-pound's stronger than aluminium in the lengthwise direction.
FINISHING AND COLOUR	Silver colour. Other colours require prefinishes, anodic coatings and paints. Mechanical, chemical and electroplated finishes can be applied.	Pigements added ot the resin provide colour throughout the part. Special colours available. Composite design can be customized for required finishes.
EMI/RFI TRANSPARENCY	Highly reflective.	Transparent to radio waves, EMI/RFI transmissions; used for radar and antennae enclosures and supports.
FABRICATION	Good machinability – welding, brazing, soldering or mechanical joining.	Easy field fabrication with simple carpenter tools – utilizes adhesive bonding and/or mechanical joining. No torches or welding.
COST	Extrusion tooling is relatively inexpensive. Part price comparable or slightly lower.	Slightly higher tooling costs; price per lineal foot marginally higher.
IMPACT RESISTANCE	Easily deforms under impact.	Glass mat in Pultruded glassfiber distributes impact load to prevent surface damage even in sub-zero temperatures. Will not permanently deform under impact.

Table 3.8