Plastics Topics – Pultrusion

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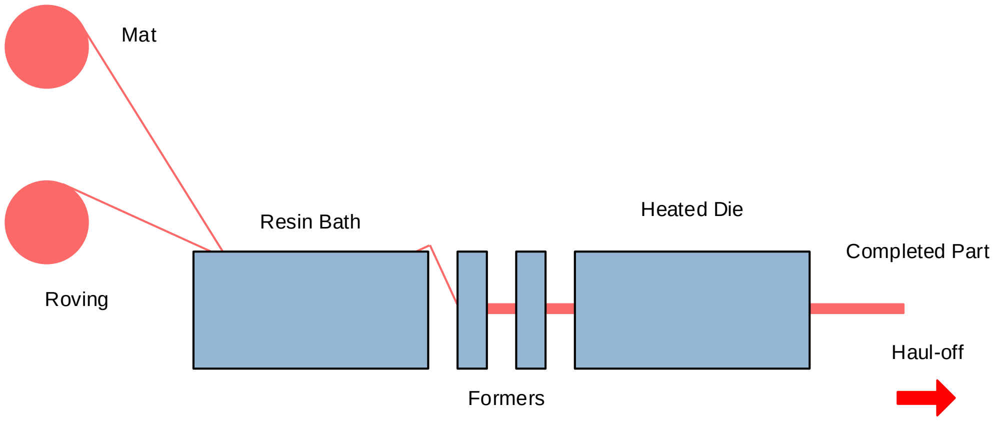
1. Introduction

Pultrusion is a continuous moulding process utilizing glass or other fibrous reinforcement in a polyester or other resin matrix. Pre-selected reinforcement materials like fibreglass roving, matt or cloth, are drawn through a resin bath where all the material is thoroughly impregnated with a liquid thermosetting resin. The wet fibrous laminate is formed to the desired geometric shape and pulled into a heated steel die.

Once in the die, setting of the resin is initiated by controlling precise elevated temperatures. The laminate solidifies in the exact shape of the cavity of the die as it is being continuously pulled by the pultrusion machine.

The haul-off equipment used is either a conventional belt puller (as used in extrusion) or a hand-over-hand reciprocating clamp type. The caterpillar type is a cheaper solution because no motion sequencing is involved but it can be expensive to produce the large number of gripper pads necessary for each profile. The caterpillar type also has the disadvantage that the gripping force cannot be isolated from the pulling force and for large profiles this can damage the profile.



Schematic of the pultrusion process

Hollow profiles are also possible via the pultrusion process and require a mandrel to be used inside the die. The mandrel is fastened securely at the downstream end of the process and should extend downstream of the mould by 400 to 600 mm.

2. General process characteristics

The primary product characteristics of pultrusions are given in below and are similar to the product characteristics of conventional extrusions. There are certain variations due to the fact that pultrusions are fully hardened on exit from the die.

Pultrusion primary product characteristics	
Size	Shaping die and equipment pulling capacity influence size limitations
Shape	Straight, constant cross sections; some curved sections possible
Reinforcements	Fibreglass, Carbon fibre, Aramid fibre
Resin Systems	Polyester, Vinyl ester, Epoxy, Silicones
Fibreglass Content	Roving – 40% to 80% by weight Mat – 30 to 50% by weight. Woven roving – 40 to 60% by weight

Mechanical Strength	Medium to high, primarily unidirectional, approaching isotropic
Labour Intensity	Low to medium
Mould Cost	Low to medium
Production Rate	Shape and thickness related

Pultrusion design guidelines for pultruded products	
Minimum inside radius	1 mm – Roving Shapes 2.5 mm – Mat Shapes
Moulded-in holes	No
Trimmed in mould	Yes
Core pull & slides	Yes
Undercuts	Yes
Minimum recommended draft in deg.	No Limitation
Minimum practical thickness inches	1 to 1.5 mm
Maximum practical thickness	25 to 75 mm
Metal inserts	No
Bosses	No
Ribs	Yes. Longitudinal only
Moulded-in labels	Yes. but not recessed
Hollow sections	Yes. Longitudinal only
Wire inserts	Yes. Longitudinal only
Embossed surfaces	No

3. Materials

Resins

In general, high performance polyester resins are combined with a suitable filler, catalysts, UV inhibitors, and pigments to formulate the resinous matrix which binds the fibres together and provides the structural strength, corrosion resistance and other properties required. Although the vast majority of applications can be achieved by using the variety of polyester resins available, certain applications require the higher strength or corrosion resistance of vinyl ester or epoxy resin systems.

Vinyl esters are used primarily to improve chemical resistance and also to provide better coupling with the reinforcements. They exhibit a 15 – 20% improvement in the strength of the finished laminate. This can be important in terms of the mechanical strength when a light weight is desired and when chemical resistance is an important factor.

Epoxies make a product stronger and produce parts typically 20 – 30 % stronger than polyesters.

Resin Properties			
Property	Polyester	Vinyl ester	Epoxy
Tensile Strength (MN/m^2)	77.2	81.4	75.8
Tensile Modulus (GN/m^2)		3.4	3.3
% Elongation	4.2	4.5	6.3
Flexural Strength (MN/m^2)	123	134	115
Flexural Modulus (GN/m2)	3.2	3.1	3.3
Heat Distortion Temperature (°C)	77	99	166
Specific Gravity	1.13	1.12	1.28

Reinforcements

Although a multitude of various fibres are available the four major types used are E-glass, S-glass, Aramid (Kevlar) and graphite. The most common type used is E-glass. The other reinforcements are generally only used for aerospace and advanced composite applications where cost is not an important factor.

Fibre Properties				
Property	E-glass	S-glass	Kevlar	Graphite
Density (kg/m^3)	2,600	2,490	1,470	1,720
Tensile Strength (MN/m^2)	3,450	4,600	2,950	1,900
Tensile Modulus (GN/m^2)	72.4	86.9	131	379
Elongation to break (%)	4.8	5.4	2.3	0.5

- The fibres are available in various make-ups, these being:
- Glass rovings to provide the high longitudinal strength of pultruded products. The amount and location of these can be determined at the design stage and can alter the subsequent physical properties of the finished product. Rovings are also necessary to provide the tensile strength to pull the other reinforcements through the die: they are therefore a necessary ingredient in the part design.
- Continuous strand mat – to provide the most economical method of obtaining a high degree of transverse physical properties. The mats are layered with roving to form the most basic composite found in pultruded products. The ratio of mat to roving determines the relationship of transverse to longitudinal physical properties.
- Woven products – these are mats available in balanced, high longitudinal, high transverse or 45o bias-ply construction. Since these materials are more costly, composites using these

reinforcements are more expensive than standard pultrusions.

Veils

Pultrusion is low-pressure process and fibre glass reinforcements can find their way close to the surface of the part. These can affect the appearance and corrosion resistance or the handling of the products. Fibreglass and/or polymeric veils can be added to the laminate construction to depress the glass reinforcement from the surface and thereby provide a resin rich surface to the part. The most commonly used veil is a Dacron polyester with no binders. The use of veils improves weatherability and corrosion resistance and it is also claimed to increase die life and production speed. Veils also eliminate any possibility of exposing glass fibres after long term erosion of the surface resin layer.

Chemical resistance

Pultrusions are generally outstanding in their resistance to a wide range of organic and inorganic substances. However, the specific resin and fibre system must be considered if a corrosion resistant product is necessary.

Weatherability

Although a UV stabiliser may be added to the resin system to retard the effect of outdoor weathering, eventually the surface resin of the part will decay and a condition called 'fibre blooming' will occur on the surface of the part with subsequent slight deterioration of physical properties. Veils improve weatherability but for many applications the best solution is a urethane coating. Urethane coating is the optimum method for retaining surface appearance and properties during outdoor exposure. A two-component urethane coating is approx. 0.04 mm thick will provide protection for over 20 years with minimal change in appearance. This is applied as a secondary operation and will shield all parts from UV degradation. Urethane coatings are also beneficial in providing uniformity of colour and for providing a range of colours in a relatively low volume operation.

Effect of temperature

Pultruded parts experience some property loss from continuous exposure to high temperatures.

As a general rule the properties of pultruded parts at 100°C will be approx. 50% of those at room temperature. This is again dependent on the specific resin and fibre system used.

4. Design

Comparative Properties

In almost all cases the mechanical properties of pultruded profiles are superior to those of rigid PVC and may be roughly compared with those of aluminium. By comparing modulus data, for example, to aluminium it can be seen that on a stiffness basis a thicker pultruded member of the same width will required to equal that of aluminium. Other properties need to be examined in the same manner to arrive at the final design dimensions. If, however, the properties are defined in terms of specific properties, that is a property divided by the density then pultruded products are very often superior to aluminium products.

On the basis of these properties, pultruded products are suitable for use as structural members without reinforcement of any kind. Examples of such applications are pultruded ladders, which are used because of the safety aspects when used with high voltages.

Tolerances

Achievable industry tolerances for pultruded parts are given by ASTM D-3917-80. This gives tolerances for pultrusion part dimensions, wall thickness, eccentricity, straightness and other variables. Since this specification is the result of an industry consensus, it might be possible, in some cases, to have suppliers agree to tighter specifications than these for some critical properties, but usually at a cost increase.

Tooling

The same good design features that apply to other polymer moulding tools are generally applicable to pultrusion dies. Generally, pultrusion dies are considerably simpler in construction than most matched metal moulds. Any good tool steel can be used to make a pultrusion die and a reasonably hard mould is required to offset the abrasive action of the glass reinforcement as it is drawn through the die. Dies are usually heat treated after machining to a high hardness and are hard chrome plated. Ceramic coated steel dies have also been used. Due to the high wear which occurs during the process, major reworking of the tool will be required after approximately 50,000 m of production. Some tools have produced approx. 250,000 m of product before further rework becomes impractical (tools are frequently re-chromed to minimize destructive wearing and this maintenance cost is normally amortized into the part price). In order to justify tooling costs typical minimal quantities are in the region of 3,000 m. This constraint should be borne in mind when purchasing pultrusion tooling for large volume production.

Other pultrusion die design details relate to the provision of the bell mouth to assist wet reinforcement to enter the mould, mounting provisions for fastening to the heated platens, die surface finish and the use of a cold junction in the portion of the die that extends outside the heated platen area.

Costs for pultrusion tooling would generally be of the sane order as costs for PVC tooling and the vacuum calibration unit for the same type of profile.

5. Production parameters

The rate at which a part can be produced is determined by the curing time required for the thickest section, for example, a 3 mm thick laminate can be produced at 1 - 1,5 m per minute, whilst in comparison a 19 mm section would have a production rate of approx. 200 mm per minute. An important limitation to the possible production speed is the length of the die, the profile must be fully hardened on exit from the die and this is naturally dependent on die length, to increase production speed requires an increased die length and hence increased die costs. Running too fast will lead to cracks forming as the profile cures and cools. Wherever possible, it is advantageous to design a section with uniform cross-sectional thickness. In general, pultrusion rates of 3 m per minute would be considered excellent and could only be achieved with very thin wall thicknesses. Pultruded sections exhibit a 2 - 3% cross-sectional shrinkage during production. A uniform wall thickness aids in limiting the warpage of the end product because consistent shrinkage will be experienced throughout. Shrinkage can also affect the angular relation of one section to another but proper die design can lessen this problem.

6. Fabrication techniques

Drilling, routing, punching, sawing, milling and tapping and threading are all possible with pultruded products. However, there are certain specific guidelines which should be met when carrying out these operations. These guidelines mainly refer to the production of dust (which can be injurious to health), tool wear (pultruded products create rapid wear on tooling), and minimization of damage to the product.

If mechanical fasteners are required a wide variety are available and the use is dependent on the application.

Adhesive bonding plays a major role in pultrusion assembly. It is recommended that an adhesive bond be combined with a mechanical fastener for optimum performance. This normally speeds up the assembly time since post curing the bond to develop maximum strength can usually be eliminated. The mechanical fastener will protect the adhesive bond until chemical action can develop full bond strength. Adhesives used in pultrusion bonding are:

- epoxies
- urethanes
- acrylics
- polyesters

A wide range of formulations is available and it is often necessary to experiment for the best one. As with any other adhesive joint, the joint design is also very important with pultrusions.