

# **Pultrusion of Glass Fiber Composites**

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**A Technical Manual**





# Pultrusion of Glass Fiber Composites

## Foreword

The manual is intended to provide an overview of the pultrusion process, equipment, reinforcement, and resin considerations, along with troubleshooting guidelines for common pultrusion process problems. We have incorporated an appendix for comparing metric and English units for yield/TEX, filament diameter/micronage, as well as listing suppliers for pultrusion equipment, strand contact equipment, and splicing sources. A glossary of terms is included.

This manual pays particular attention to the selection and handling of glass fiber reinforcements, particularly OC® Single-End Continuous Roving (Type 30®) and OC® Continuous Filament Mat (CFM).

Through use of the guidelines presented here, pultrusion processors can find solutions to many problems.

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## Pultrusion Process Overview

Pultrusion is an automated, continuous process to manufacture reinforced plastic shapes utilizing a heated die to give the part the desired cross sectional shape. The standard pultrusion process combines longitudinal (rovings) and transverse reinforcements (mat) to form a composite through the impregnation of these reinforcements with a polymer resin and curing the composite in a die. The process requires little operator input besides maintaining material supply and it is cost effective in terms of waste.

Reinforcements are pulled through a bath where the fibers are impregnated with resin.

Just prior to the die, the wetted reinforcements are pulled through forming guides where the reinforcements are positioned to deliver the designed mechanical properties as they enter the die. Forming guides also serve to strip off excess resin, reducing the hydraulic pressure caused by the materials entering the die.

The preformed shape is pulled through a heated die, where the laminate takes on its final cross sectional shape. The heat in the die initiates an exothermic reaction within the formulated resin, completing the cure.

The finished shape is continuously pulled from the die by a pulling device.

The finished shape is cut to length by a cut off saw.



## Pultrusion Process Description

There are four components required in any pultrusion processing operation:

1. creels
2. forming or preforming guides
3. resin impregnation systems
4. primary die
5. puller/clamping pads

**Forming guides** – determine how the reinforcement is organized, aligned, and fed into the primary die. There are two primary materials used in the forming guide tooling: steel and ultra high molecular weight polyethylene (UHMWPE).

The advantage of steel is that it is less expensive (if carbon steel is used vs stainless) and standard plate, sheet, bar, and rod can all be used.

A disadvantage is corrosion of non-stainless steel and the difficulty to machine. The advantage of UHMWPE is that it is lighter, resistant to chemical attack, less damaging to the glass reinforcement, and therefore, easier to clean.

A major advantage is that it is easy to fabricate, on-line, when modifications are required. UHMWPE is easy to drill and machine slots for mat. A disadvantage is that UHMWPE wears faster than steel.

Except for the primary die the forming guides and the guiding of the reinforcement into the die is the most important aspect in pultrusion technology.

### Resin Impregnation Systems

It is extremely important to allow the resin and reinforcement enough time to fully wet-out.

The impregnation, or bath system directly impacts wetout.

There are three resin impregnation systems available today. They are:

1. Dip bath
2. Straight through bath
3. Resin Injection systems

#### Dip Bath

The dip bath, or open bath, has the reinforcements traveling from the creels down into the bath where the rovings go through an "S" bar guide, which breaks apart the roving bundle, allowing better coating of the filaments by the resin. The bath system is typically used for all roving reinforcements, as well as for simple mat and roving profiles where the mat can be handled horizontally, or where taking the mat out of the horizontal plane will not induce a bow into the finished profile. This system exposes a large amount of resin to the air and permits styrene evaporation into the plant environment. Styrene emission is an environmental and health consideration, which needs to be assessed with this impregnation system.

#### Straight Through Bath

A straight through resin bath is a trough with forming cards on each end. These cards can also be used to begin the forming process. The cards allow resin to leak from the open areas. The excess resin is then collected and pumped back into the bath trough. The advantage of this design is the reinforcements are taken from the horizontal plane, allowing the profiles to be made with fewer tendencies to warp or bow, and this design also reduces the amount of styrene released into the plant environment.

#### Resin Injection System

The resin injection system is the newest process for impregnation. With resin injection, a steel chamber is attached to the front of die. The chamber contains port(s), which allow resin to be injected into the cavity.

The combination of cavity design, resin pressure, and movement of the reinforcement being pulled into the die generate hydraulic pressure forcing resin to penetrate the reinforcement bundle, resulting in impregnation.

With resin injection the resin is not open to the plant environment, reducing the amount of styrene released into the workplace. Resin injection systems require reduced clean up time, due to resin contact with fewer components.

The disadvantage of resin injection is the potential for incomplete impregnation of profiles with thick walls, or incomplete impregnation in resin systems with high filler loading incorporating a high number of mat or veil reinforcements.

#### Primary Die Design

There are several factors, which must be considered when putting together the tooling package. This is one area where shortcuts should not be taken. Improper design or poor workmanship will affect every foot of production and dramatically affect product quality, machine efficiency, part finish, and product cost. The following are some considerations, which need to be taken into account when purchasing primary dies:

#### Material selection

The die material should be capable of withstanding continual heating and cooling without deformation. Usually this means high-grade tool steel. The material should be capable of resisting wear from abrasion, and be damage tolerant for repeated assembly and disassembly. The material should be capable of receiving chrome plating of 0.001-0.002 inches (0.025-0.0508 mm) of thickness for wear resistance.

Two widely used steels for die manufacture are A-2 hardened to 55-60 Rockwell hardness and P-20 prehardened to 28-30 Rockwell hardness.

## Shrinkage Factors

It is the nature of most resins to shrink after reaching peak exotherm, and during the cooling process. Because of this a shrinkage factor must be calculated into the die design. This will enable the die to form the part to the proper dimensions after the part is completely cooled.

A shrinkage factor cannot be unilaterally determined, as each resin system and reinforcement lay-up is different, however recommended shrinkage factors are:

Thickness dimensions: 1% shrinkage  
All other dimensions 0.3% shrinkage

## Die Opening Design

The die opening design must accommodate the smooth entry of reinforcements into the proper position. Generally a symmetrically shaped die is made to utilize either end of the die as entry or exit, if possible. This enables longer die life between re-chroming. At the opening of a die a minimum radius of 0.250 inches should be used.

## One Piece or Split Cavity Dies

The advantage of a one-piece die is that the finished part will not have a parting line. A one-piece gun barrel drilled die is usually less expensive to manufacture, however it may be more expensive in the long run. If a part seizes up inside a one-piece die during processing, the die may be impossible to repair.

Multiple piece dies have the advantage of being easily opened to allow cleaning and maintenance, however care needs to be given in designing the die so the parting line between the mold halves does not cause a problem with the part being molded.

## Die Surface Treatments

Due to the abrasive nature of fiberglass reinforcements, a protective surface treatment is required on the die cavity. The most commonly used treatment is hard chrome plating at 0.001-.002 inches (25-50 microns) thick.

For dies expected to perform in long term service, nitriding may be considered.

## Die Maintenance

Die maintenance is one of the most important factors in extending die life. Opening the die after each production run and recording the number of feet of production and the wear conditions is important. Testing the die surface with copper sulfate for wear spots is critical. The sooner die wear can be detected and treated the longer the die will last before major rework. The best time to perform die inspection and maintenance is just after the die has been pulled from production, prior to being stored. Inspection just prior to installation is not recommended, as production pressures may make repairs, if needed, difficult, shorting the life of the die and potentially compromising part quality. Acidic mold release agents are often used to ease the separation of the part from the metal die. Steel dies exposed to acidic conditions must be cleaned thoroughly between uses to maximize the lifetime of the die.

Tooling Maintenance – improper handling during cleaning, assembly, and disassembly are the most common causes of premature die wear. The following practices should be observed in die maintenance:

1. Use only soft tools for cleaning dies, such as brass or copper
2. Never strike the tooling with hammers, chisels, screwdrivers, etc

3. Never use abrasives such as sandpaper, emery cloth, or steel wool on tooling. If scrubbing is required, use only copper gauze.
4. Never pry apart multiple piece dies during disassembly. Always use jackscrews and remove dowel pins during disassembly.
5. Always store and handle dies in a secure area. Never leave dies in an area where they can receive impact, be dropped or damaged.
6. When disassembling dies, the pieces of the die should be handled so as to not contact each other or other objects, damaging the die.
7. When assembling dies, always inspect for and repair all burrs, nicks, etc, in the mounting surface area before assembly. These are especially prevalent around threaded holes, dowel pin holes, keys, and keyways. Never file the chrome plated cavity area.
8. Always wait until a die is cool enough to handle before assembly or disassembly.
9. Inspect die for indications of chrome wear with a 10x magnification. If there are any areas of chrome wear through to the steel, the die should be removed from service and rechromed.

## Puller Clamp System

There are two common puller systems

1. Caterpillar belt
2. Reciprocating clamp puller

In both systems, pads, typically made of urethane, must be shaped to match the part profile in order to apply a uniform clamp load, which will not cause damage to the pulled part.

The advantage of the caterpillar belt system is the capacity to provide large pulling force, spread over a larger part surface area. The advantage of the reciprocating clamp puller system is cost, as it requires only 2 puller pads per clamp vs 10-100 depending on the caterpillar belt size.

## Cut off Saws

Most pultruders utilize what are known as flying cut off saws. A flying cut off saw moves at the same speed as the moving part, so the cut edge of the part is square and straight. Using a non-flying saw results in cut edges that are not square and straight. Flying cut off saws are recommended for part quality.

There are two basic types of flying cut-off saws:

1. Wet saw – A wet saw uses water during the cutting cycle to cool and lubricate the blade and flush the fiberglass particulate to a filter. This effectively eliminates dust and airborne particulate.
2. Dry saw – A dry-cut saw uses a continuous rim diamond blade that does not require any fluid during the cutting cycle, but which gives a good clean cut. A dry-cut saw requires a dust collection system to capture the fiberglass dust, both to address operator health and comfort and from a housekeeping standpoint. Using a dry-cut saw without a properly designed dust collection system is not recommended, due to the dust generated during cutting, both from an operator health/comfort and a housekeeping standpoint.

In most cases pultruders will utilize an automatic cut-off saw, which automatically cuts the part into the proper lengths. This enables employees to carry out other duties in order to enhance productivity.

## **Other Considerations**

### **Plant layout**

Plant layout is a critical issue in successful pultrusion operations. Inadequate space and planning will affect the capacity and efficiency of the operation. A minimum of 25 meters is required for a standard pultrusion line.

This will allow for the space needed for a roving creel, mat creel, the machine itself, and 6 meters for finished parts beyond the saw. If space is not an issue 30-38 meters of plant space is desirable. The minimum width necessary for a pultrusion operation is the machine width plus 1.2 meters on each side, to allow the operator movement, maintenance, clean up, resin storage, etc.

### **Material flow**

This is another important factor, which is often overlooked during the planning and plant layout phase.

It is necessary to locate the incoming raw materials, such as reinforcements, near the reinforcement creels to enable the quick and smooth reloading of the creels as they empty. Also the flow of resin to the resin impregnation area should be quick and without interference. Only a limited supply of resin is located at the machine due to pot life and flammability issues, therefore an easy and unobstructed route should be planned. Likewise, finished profiles typically are long lengths, and the planned flow direction should be away from the direction of the machine and with easy access to forklifts, if possible.

Parts should then flow conveniently into packaging and shipping after secondary operations. Consideration should also be made for locating the other processes related to pultrusion, such as slitting of mat, resin mixing, testing and inspection.

### **Basic Test equipment for Pultrusion**

**Heated Water Bath** – A 180°F water bath is useful for the incoming quality control testing of resins

**High speed disperser** – This equipment is needed to mix the resin with the required fillers, color additives, mold releases, catalysts, etc. The selection of a shear blade and the RPM of the blade are dependent upon the desired mix viscosity and thixotropic index required.

**Thermal Analyzer** – This equipment is used to test the reactivity of resin systems and is very useful in quality, process control, and process improvement. Some models allow in-line thermal analysis to determine the peak exothermic temperature and its location within the die. This tool can greatly reduce trial and error in product and process development.

**Barcol Hardness Tester** – This instrument is a quick way to determine the degree of cure of the part.

**Viscometer** – This device is used to measure the resin viscosity and thixotropic index, which affect the ability of the resin to wetout the reinforcements in a specified time frame. This and the thermal analyzer should be used for incoming raw material screening.



## Reinforcement Processes for Pultrusion

Reinforcements for pultrusion processes historically have been combinations of continuous glass rovings, continuous filament (or swirl) mat, stitched and knitted mats, and organic surfacing veils. However, carbon, Aramid, boron, steel, and other organic and inorganic fibers and chopped strand mats have also been pultruded when their cost performance is required for a specific application.

Rovings are typically E-glass while mat can be E or A glass. A glass contains more soda and is more susceptible to corrosion. Owens Corning has developed Advantex® glass fiber reinforcements which combines the electrical and mechanical properties of E glass as well as the corrosion resistance of E-CR glass.

The glass is coated with a sizing that enhances its compatibility with the resin matrix.

Reinforcements serve as the primary load bearing entity in the part; reinforcements can enhance functional performances such as electrical conductivity, radar cross section, and thermal performance. In the process, the reinforcement allows the part to be pulled through the die acting as both a load transfer media as well as the source of bulk, which allows the die to be continuously, uniformly filled.

### Rovings

Rovings are continuous fibers, which are one of the primary reinforcements used in pultrusion. Rovings come in three main forms: Conventional rovings, OC® Single-End Continuous Rovings (Type 30®), or direct rovings, and bulky or texturized rovings.

#### Conventional Rovings

Conventional or multi-end roving is assembled from a number of forming packages into the desired final yield or Tex. Conventional rovings are most commonly used in applications containing large thickness of unidirectional reinforcement. Conventional rovings tend to fill space at lower glass levels, giving a more resin rich cross-section.

#### Single-End Continuous Rovings or direct rovings

Single-End Continuous Rovings or direct rovings are the most commonly used reinforcements in the pultrusion process. Single-End Continuous Rovings combine ease of handling due to low catenary and fuzz, with highly reproducible mechanical properties in both its standard unidirectional usage and when used in stitched and woven fabrics. Owens Corning produces OC® Single-End Continuous Rovings (Type 30®). Single-End Continuous Rovings are widely used due their excellent processing, and laminate performance. Considerably higher shear strengths are achieved with single-end rovings compared to conventional rovings

#### Bulky or Texturized Roving

Bulky, texturized, or fluffy rovings are specialty rovings designed to fill corners in complex shapes, "clean" the die, preventing formation of resin rich areas, which could cause local spalling. Bulky rovings are intended to act as local filler, though they do provide some reinforcement.

### Mats, Complexes (BiPly), and Veils

Mats, fabrics, and veils are used in pultrusion processes to give properties to the part not achievable using roving reinforcement. Mats give the ability to develop off axis structural performance, create a higher resin content part, and develop unique surface qualities for both visual and non-visual attributes, such as corrosion resistance.

#### Continuous Filament Mat

Continuous filament mat or swirl mat is the most common mat used in pultrusion. Continuous filament mats (CFM) provide strength and stiffness in the transverse or non-pulling direction of the pultruded part. They provide a degree of bulk, which improves processing and limits resin rich sections of the part.

This bulk also reduces the glass fraction required for the processing of a specific cross section. CFM mat also improves the shear strength of the laminate produced.

CFM used in pultrusion contains a fast-wetting non-soluble binder that maintains mat integrity through the preforming operations. It is less prone to skewing (misalignment) common in fabrics.

Mats are generally composed of coarse glass strands, which are highly porous thus ensuring complete wet out of each individual filament.

The roll is slit to the appropriate width of the part.

The variation in slitting widths will cause some variation in the localized reinforcement contents within the part; hence there will be an impact on the mechanical strength. Weight variation (as well as resin variation) and shrinkage will also induce variation in product characteristics.

#### Fabrics and Stitched Complexes

Fabrics and stitched complexes are the newest generation reinforcements for the pultrusion process. The construction of fabrics can be tailored to give specific reinforcing properties to the part in order to achieve the needed strength in parts with demanding design requirements.

#### Chopped Strand Mats

The use of chopped strand mats in pultrusion is normally related to specific needs for improved surface or corrosion resistance in flat or gently curved laminates. Care must be taken in selecting a chopped strand mat for pultrusion, as most existing products are not designed to handle the tension associated with the pulling of the product through the process.

#### Veils

Veils in the pultrusion process are designed to establish a high quality surface layer on the pultruded part and protect the die from scarring by the other reinforcements during the pulling process. Veils can be materials such as spun polyester, glass veil, and for special requirements carbon veils have been used. In many cases the veils can have preprinted designs and logos, which become the part surface finish aiding the part appearance.



## OC® Single-End Continuous Roving (Type 30®)

In 1965, entirely new pultrusion rovings were introduced to the industry by Owens Corning. Instead of a two-step process for fabricating multi-strand roving called "conventional roving", Owens Corning produced Direct Draw OC® Single-End Continuous Rovings directly in the glass fiber forming operation.

Together with refinements in process technology, the characteristics of the Type 30 reinforcements are: optimum strand integrity, fast wet-out, zero catenary and excellent runnability.

In the early 1970s, glass fiber process improvements have resulted in a major expansion of the yields available to the industry. Also, development of improved surface treatments now provides excellent compatibility with virtually all major resins used in the global pultrusion industry.

In the mid 1980s, Owens Corning launched a third-generation of Type 30 rovings for pultrusion. Advancements in the sizing or chemical surface treatment made this new series of high-tech reinforcements possible.

Product and process improvement efforts continue in the 1990's. In 1995, we introduced a 52 yield/9600 TEX Type 30 OC® Single-End Continuous Roving (Type 30®) for the first time, which allows a minimum of roving packages in precious creel space, especially for large cross section parts.

Generally speaking, pultrusion is the glass fiber-reinforced plastic (FRP/GRP) fabrication process in which resin impregnated strands of continuous glass fiber rovings are pulled through a constant cross-section closed die and subsequently cured. The new technology of the 1990's resulted in resin injection dies with resin first married with the glass fiber in the die, greatly reducing styrene emission in the workplace.

In the pultrusion process, the amount and orientation of glass in the completed part are closely controlled. Parts made may be cut to whatever part length is desired, and theoretically can be made infinitely long.

The resin matrix has several functions in a pultruded composite. The resin's basic functions are to fill the space between filaments, to fix the strand alignment, and to distribute the bonding and shearing stresses. Due to the much higher modulus of the glass, and its normally high percentage of volume in the composite, the strength effect of the resin is usually quite small. As in the case with all FRP/GRP material systems, the resin plays an important role in determining the chemical and environmental durability of the total system. It also controls the thermal, electrical, and visual appearance characteristics of the final composite material.

As a direct result of the search for improved quality structures, new fiber reinforcements and new resin matrix systems are constantly being introduced.

## OC® Single-end Continuous Roving (Type 30®) for pultrusion

For all of the FRP/GRP processes, continuous glass fiber reinforcements can be described by two basic parameters: 1. Glass form - 2. Sizing

In the pultrusion process these two parameters have special significance for the reinforcements available in today's commercial market. Pultrusion reinforcements were developed to meet the specific requirements of this process.

In the information which follows, the descriptions and uses of glass fiber reinforcements are limited to pultrusion applications.

### Glass Form

The following terminology relates to the way glass fiber reinforcements are made and the form in which they are supplied:

**Filament** – A single glass fiber. In North America, glass filaments are normally coded by a letter, which defines their nominal diameter. A standard code assigns sequential letters in the alphabet to each increment in diameter of five hundred thousandths of an inch. Globally, the filament diameter is designated to the nearest micron (see table 1 on page 7). The code letters generally applicable to filament winding are:

Diameter Range and Nomenclature Table for Glass Fiber Filament

Diameter	Microns	Inches *(ht)
AAAAA	0.05 - 0.2	0.2 - 0.8
AAAA	0.2 - 0.5	0.8 - 2.0
AAA	0.5 - 0.75	2.0 - 3.0
AA	0.75 - 1.5	3.0 - 6.0
A	1.5 - 2.5	6.0 - 10.0
B	2.5 - 3.8	10.0 - 15.0
C	3.8 - 5.1	15 - 20
D	5.1 - 6.4	20 - 25
E	6.4 - 7.6	25 - 30
F	7.6 - 8.9	30 - 35
G	8.9 - 10.0	35 - 40
H	10.0 - 11.4	40 - 45
J	11.4 - 12.7	45 - 50
K	12.7 - 14.0	50 - 55
L	14.0 - 15.2	55 - 60
M	15.2 - 16.5	60 - 65
N	16.5 - 17.8	65 - 70
P	17.8 - 19.0	70 - 75
Q	19.0 - 20.3	75 - 80
R	20.3 - 21.6	80 - 85
S	21.6 - 22.9	85 - 90
T	22.9 - 24.1	90 - 95
U	24.1 - 25.4	95 - 100
V	25.4 - 25.7	100 - 105
X	25.7 - 26.0	105 - 110
Y	26.0 - 26.3	110 - 115
Z	26.3 - 26.6	115 - 120

Notes  
\* in hundred-thousands of an inch  
1 micron = 0.00003937 inch

A more complete table is available in the appendix

**Strand** – A group of filaments which have been collected into a discrete bundle. A strand may contain as few as 204 or more than 4,000 filaments.

**Forming Package** – A package wound with the glass strand in the glass fiber forming operation.

**Roving** – A collection of one or more strands. Roving is commercially available in two forms:

A. *Conventional roving*---Produced in a roving operation that uses forming packages as the input material. Conventional roving for filament winding is a collection of several strands controlled at a number normally from 8 to 60.

B. *Direct Draw Roving*---Produced in a process in which the roving package is the forming package. Direct Draw roving, therefore, is one strand of glass filaments.

Owens Corning's Direct Draw products are called OC® Single-End Continuous Roving (Type 30®).

The weight per unit length, or linear density, of the roving strand used in pultruding glass fiber is described in terms of TEX or yield:

**TEX** – the weight of the glass fiber roving strand in terms of grams per 1000 meters.

**Yield** – A length per unit weight measure; the number of yards of roving strand, which weigh one pound.

Thus, a roving package with a "250 yield" contains one or more strands, and each 250 yards length of roving weighs one pound. Typical roving yields used in Owens Corning pultrusion rovings are 52, 103, 113, and 250 yards per pound. This corresponds to 9600, 4800, 4400, and 2000 TEX respectively.

The word "yield" can also be used to specify the amount of glass in one of the strands used to produce conventional roving. In this case, the proper expression is "strand yield."

A comparison of TEX and yield values is shown in table 2 on page 21. The conversion factor between Tex and Yield:  
 $TEX = Yield/496,053$

## Sizing

All pultrusion reinforcements have a chemical surface treatment or sizing applied to the filaments before they are gathered into a strand. This treatment performs a number of important functions, the prime one being to bond the glass to the resin used in the composite matrix.

The surface treatment must also hold the filaments together, lubricate the roving for contact with guiding devices in the process, and allow the glass fibers to "wet" thoroughly in a liquid resin without entrapping air. Ingredients to provide these characteristics are chosen so that they will not interfere with the primary function of resin bonding.

It is the responsibility of the pultruder to use a reinforcement surface treatment, which is compatible with the resin. This is the only way to achieve the full potential of strength and durability inherent in the process.

Sizings are typically classified by their compatibility in various types of resins; polyester, vinyl ester, epoxy, and phenolics are typical pultrusion resins. Knowing the resin type the glass is to be used with will aid in selecting the proper reinforcement.

Owens Corning will be glad to make suggestions for glass type, based on the end use application and resin type.

## OC® Single-End Continuous Roving (Type 30®) for Pultrusion

### Advantages of OC® Single-End Continuous Roving (Type 30®)

As previously noted, the OC® Single-End Continuous Roving (Type 30®) package contains one strand of glass as opposed to the multi-strand approach of conventional rovings.

This characteristic offers several important advantages to the pultruder:

- 1. Optimum Strand Integrity:** Since the OC® Single-End Continuous Roving (Type 30®) is produced in one operation, the strand is untouched until used by the fabricator. Thus, the amount of strand integrity, or bonding between the filaments, is controlled for the pultrusion process and not for efficiency in a secondary roving fabrication operation.
- 2. Fast Wet-Out:** With a controlled degree of strand integrity, the chemical surface treatment wets-out quickly in contact with resin. In conventional rovings, specific lubrication is usually necessary to control broken filaments in roving fabrication process. This additional lubrication often interferes with wet-out in the pultrusion operation.
- 3. Zero Catenary:** A very serious deficiency, which occurs in conventional rovings is small variations loop length during the roving process creating differences in the length of each strand. Thus some strands in a conventional roving will sag lower than others when the entire roving bundle is held taut. This is known as catenary. Having catenary can lead to rovings snagging on stationary contact points during processing.
- 4. Runnability:** Since all filaments in each OC® Single-End Continuous Roving (Type 30®) bundles are of the same length and under the same tension, they can be positioned and tensioned accurately in the pultrusion process.

Packages contain only one strand, so there is no difference in the length of any portion of the roving. OC® Single-End Continuous Roving (Type 30®) has "zero catenary".



OC® Single-End Continuous Roving (Type 30®)

### Advantages of Conventional Rovings

Conventional roving may be better in achieving thin, flat, low profile parts or in runnability where outside pull is used to minimize strand twist.

### Disadvantages of Conventional Rovings

Runnability is a problem using inside pull stationary packages because catenary and strand loops tend to tangle strands in the process. Also, it may be difficult to achieve very high glass contents in laminates with the bulkier, lower density roving strands.

### Reinforcement Processing for Pultrusion

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In the pultrusion process, the reinforcement must be unwound from the package, impregnated with resin, and pulled through a constant cross-section die. The fabricator must understand the function of each step and the various alternatives available. Each of these steps in the process requires proper design and use of equipment, based on the overall job requirements.

### Glass Storage

Glass Fiber roving may be stored in a non-climate controlled environment, as long as it is well protected from the elements. Roving that becomes wet from rain or flood cannot be dried and used because the sizing chemistry is damaged; it should be scrapped. If possible, store roving at 72°F (22°C) and 60% relative humidity for best results in processability. At the least, allow roving to be stored at room temperature for 24 hours or more before use, especially if stored outside in very cold weather. Stored properly, roving should still work well for a year or more after it has been produced.

### Introduction to Glass Handling

The primary objectives in handling dry roving are to carry the roving from the creel to the resin:

1. Without damage,
2. Without tangling,
3. With gradual break-up of the strand integrity for fast wet-out, and
4. With gradual reduction of the space occupied by the band of rovings so that they can be fed into a resin impregnation tank of reasonable size.

All continuous glass reinforcements should be handled with the understanding that they are relatively fragile textile filaments. The roving packages should not be dropped or crushed. The lay of the continuous roving strand inside and outside on the roving package must not be disturbed in order to have smooth running in the filament winding process. Do not use the roving package as a stepladder or stool.

This means that, in the pultrusion process, all contacts with the glass roving should be smooth and of large enough radii so that the glass filaments do not break from abrasion or from being excessively bent through sharp angles. Roving packages with cut or damaged strands will cause fuzz, strip-backs of filaments, and eventually breakouts in the process. The undamaged roving package should completely run out and transfer to a back-up roving package without any trouble.

The best materials for guiding dry rovings are the ceramic guides used for textile strands. These can be made from alumina or Titania and are available in many sizes and shapes and from several major sources in the textile industry. These sources have extensive experience with glass textile materials and can supply guiding devices for pultruders to do a specific job.

Ceramic hardware, used in the electrical industry, is not recommended because the glazed surface introduces tension variation and small surface defects may abrade the roving.

Other materials can be used for guides. For example, solid steel is used in rod stock form; however, polished stainless steel is recommended. Generally, when using a non-recommended material for guides, tension should be kept low. See page 23 for guide material sources of supply.

## Types of Creels for Pultrusion

### Creeling - Rovings

The creel should provide a position from which the roving can be fed to the pultrusion process under controlled and uniform tension. It also provides a location for the transfer of the roving strand from the running package to a second back-up package for continuous uninterrupted production. There may even be room for extra roving packages for replacement or maintenance as required.

The size, shape and type of creel will normally be determined by space considerations such as roving package dimensions, the distance the strand must be conveyed and the number of packages to be handled. The amount of glass being used on a continuous basis must also be considered.

The two common types of creels used are shown. Each creel arrangement has a range of possible number of packages for the best process efficiency:

Table creel - up to 50 packages - Figure 1

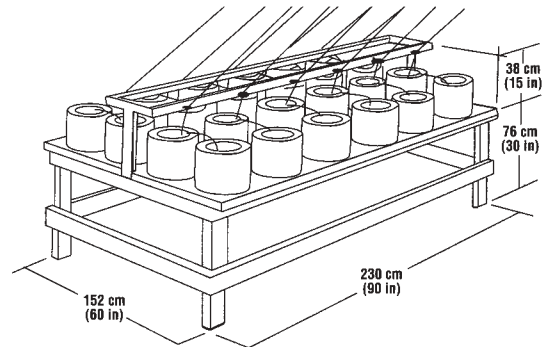
Bookshelf creel - 20 to several hundred packages - Figures 2 & 3.

The bookshelf-type creel is the most common and usually provides the best balance of accessibility and maximum utilization of floor space. The size will vary widely, but the creels shown provide a standard module concept for creeling. Shown are creels for handling 32 packages (16 active-16 transfer) in both a side pull and end pull configuration. To handle different numbers of packages, the creels can be increased or decreased in length or multiple creels can be used.

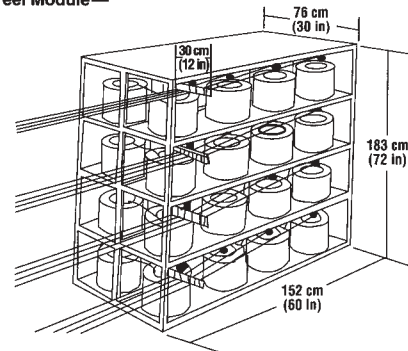
In the end pull creel, commonly used in pultrusion, it may be necessary to guide each strand within the creel using steel rods or ceramic guide eyes. This can prevent sagging and whipping could tangle two or more strands on the same shelf.

Most pultrusion processes use stationary roving packages on bookshelf or table creels, pulling the roving strand from the inside of the roving package. For some applications requiring minimal strand twist for better wet-out and a flatter and wider strand profile, pulling the roving strand from the outside of the roving package may be an option.

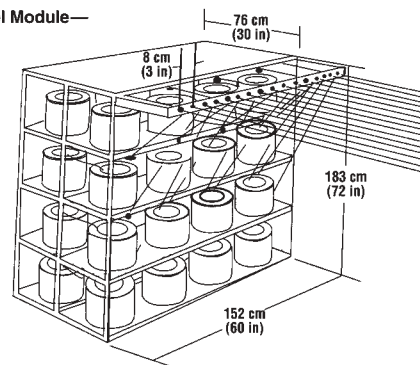
**Figure 1**  
Table Creel



**Figure 2**  
Bookshelf Creel Module—  
End Pull



**Figure 3**  
Bookshelf Creel Module—  
Side Pull



With outside pull, roving packages with core tubes may be placed on expandable mandrels as shown. There is a need for back tension on the package to prevent strand overfeeding with winding starts and stops because of the rotation momentum of the 20.5 KG package.

When considering inside pull versus outside pull creeling:

#### Inside Pull

- Ability to transfer from roving package to package for continuous processing and higher operating efficiency;
- Minimal packaging waste;
- Simple creel design and strand tensioning;
- There is roving strand twist coming out of the stationary package.

#### Outside Pull

- NOT able to transfer from package to package; more process downtime;
- Need to dispose of inside cardboard tubes;
- More packaging material to dispose of;
- Need rotating spindles or mandrels;
- Need more complex tensioning methods and devices;
- Outside pull DOES eliminate strand twist.

### **Principles of Creeling**

With any bookshelf or table creel, there are several important principles to follow for best performance.

1. Cover the surface of the shelves with a smooth material for sliding roving packages into position.
2. Handle roving packages with care. Dropped, dented, or cut packages will result in tangling or fuzz problems.
3. Stand the package upright and pull the strand from the inside.
4. Do not remove the paper or plastic film packaging material, which protects the bottom of the package from abrasion.
5. Contact points should be ceramic, polished steel or chrome steel.
6. Contact points must be kept clean to reduce fuzz build-up.
7. Mount the first strand guide 3-6 inches (75 – 150 mm) directly above the center of the package. This distance will allow room to replace packages easily as they run out.

8. The first strand guide eye should have a minimum 0.47 inches (12 mm) inside diameter to minimize whipping and to allow more uniform strand tensioning.
9. Make sure there are no projections or foreign objects close to the packages. As the roving pulls from the package, it may whip in a circular fashion; and if it catches, a breakout is likely.
10. Do not pull roving from more than one package through the same initial guide eye.
11. Do not backthread the strand through a single guide eye.
12. The transfer tail on the running package should be tied or spliced to the strand from the back-up package. Place the back-up package near the running package in such a way that the transfer tail does not interfere with the running strand.
13. Since there is likely to be a considerable amount of unsupported length between the creel and the resin tank, it is important to provide some tension at or very close to the creel. Methods for providing this initial tension system are shown.

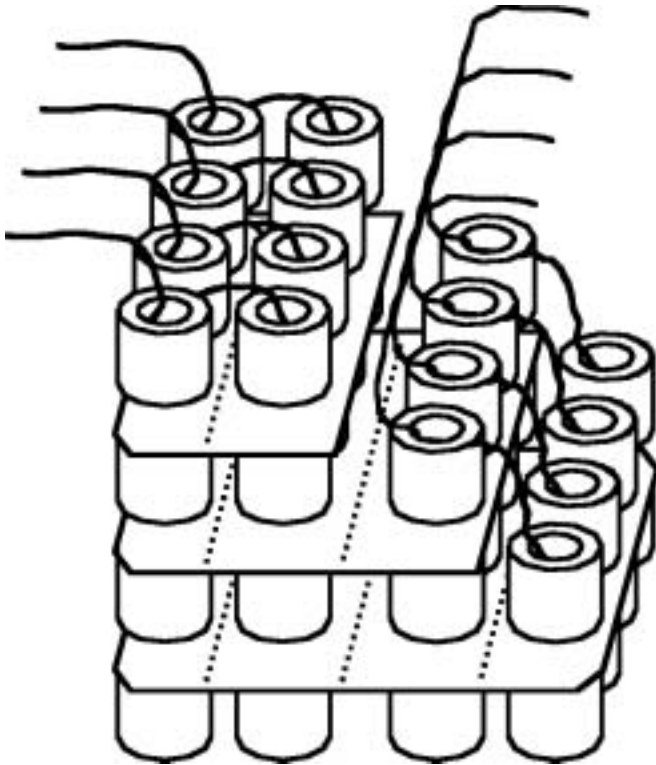


Creel Eye



Roving and Creel

Another creel option is to utilize Owens Corning unique pallet design running the packages directly off the pallet, saving the cost of creels, reducing labor, and reducing operator injury potential, by eliminating the need to manually lift packages into creels.



The unique pallet design allows 8 packages to be run off the pallet simultaneously; allowing vertical transfer within the pallet as packages run out.

## Mat Creeling

If mats, veils, or fabrics are utilized a mat creel will be required to delivered these reinforcement systems. Ideally the mat creel should have a sufficient number of positions to hold the mat, fabric, or veil needed and a backup roll. This back up roll capacity is necessary for the efficient process of feeding in the next roll when a roll empties. Since there are only 400-600 ft (122-183 M) of mat per roll, this is a time consuming step in the pultrusion process. Otherwise, if done slowly, or inefficiently the line will have to be paused and could potentially shut down, costing lost productivity and labor. The width of the mat creel must be sufficient to cover the entire width of the machine. This will ensure the full utilization of the machines capability in profile width. Building mat creeling capability into the machine will give the pultruder the flexibility to handle current and future products and not be limited to rovings.

## Glass Fiber Roving Splicing Methods

Several methods may be used to join the roving transfer tail from the running roving package to the start-up strand from the inside of the back-up roving package:



Knots

1. Knots - the oldest method is tying a square knot or a weaver's knot; however, problems occur because of the large knot, which can cause a breakout in the process or a raised surface blemish on the finished part. Also, a knot may work loose if strand tension is relaxed.
2. Air splicer - equipment is available (see on page 23 for sources of supply) to provide a roving splice using air pressure to effectively tangle the roving strands together. The advantage of air splicers are they are strong, wet well in resin, are small and less likely to produce a defective area in the part, and quick and easy to produce.



Air splice

3. Chemical - several glues are available, such as 3M's Spray 77 adhesive or Super Glue™ (Woodhill Chemical Sales Corporation), which can provide a chemical splice where the roving strands are overlapped about an inch and the tails smoothed down to not catch on contact points in the process. Usually the glued area will not wet-out. The chemicals may be troublesome to work with by hand.
4. Wrap - The Illman splicer is one piece of equipment available (see on page 14) that can wrap a very small thread around the overlapped roving tails to create an effective splice; however, the area of the splice will usually not wet out.



Over wrap splice

### Continuous Filament Mat Splicing

CFM splicing is easily accomplished in several ways. In all cases it is best to cut a taper (arrow shape) on the leading edge of the new roll of mat. 1.) feed the tapered end under the tail of the current mat, 2.) split the tail of the current mat into two ultra-thin layers and insert the tapered end of the new roll between the ultra-thin layers. Use a sailor's needle and thread in both cases if the mats will see considerable contact or tension in the pre-formers.

### Glass Handling-Creel to Resin Bath for Pultrusion

The roving path from the creel to the impregnation bath should incorporate a minimum number of dry glass contact points. The strand tension progressively builds through the system and has a multiplying, not an additive effect.

For example, if the tension at the first contact above the package is doubled, the tension at every successive contact will double its original value. Generally, excess tension is to be avoided because it not only causes glass fiber breakage, but also can induce unwanted bow in the finished product.

In designing an overall system for handling the dry glass rovings, the following principles should be kept in mind:

1. After initial tensioning at the package, use the minimum number of guides for changes in direction.
2. The maximum change of direction through any one guide eye should be 90 degrees (1.60 Radians). Do not backthread glass roving through a single guide eye. Use multiple guides or bars if greater directional changes are necessary
3. Where the strands must travel over long distances use additional guides only to prevent excessive bouncing and tangling.
4. Avoid combining strands in the same guide eyes once carried together, the strands may twist together and it may be difficult to separate them. Also due to the twist and uneven tension, catenary or fuzz may be generated.

After initial tensioning at the creel, guides should be used primarily to provide necessary changes of direction of the strand. If many rovings are traveling to a narrow resin bath, some additional guides may be necessary to prevent tangling. In this case, individual guide eyes or metal combs should be used to keep the roving band in controlled groups. Bars are sometimes used to provide intermediate support, but strands can "wander" along the bar.

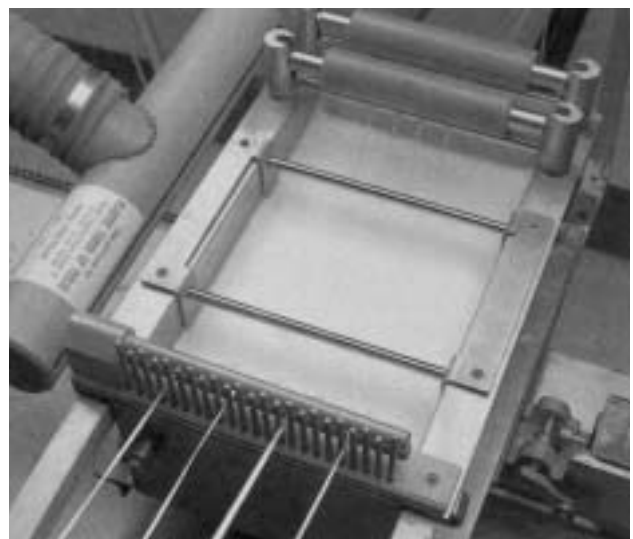
To prevent breakouts, the strands must not be allowed to touch each other.

As the roving strands pass over each contact point on the way to the resin bath, there will be a small increase in tension and a small decrease in strand integrity. At the entrance to the resin impregnation bath, the rovings are usually crowded so closely together that a guide eye thread board or a stainless steel comb is necessary to prevent tangling and maintain alignment. Upon leaving this contact, the strand integrity of the roving should be completely broken. If it is not, additional strand break-up should be provided before the strands are put into the liquid resin. This may be accomplished with a small increase in tension at the creel, taking advantage of the multiplying effect through the thread line.

Alternatively, an additional contact in the strand line of travel or at the resin bath will normally provide the necessary breakup. Ideally, the entire band of rovings should enter the resin as soft parallel groups of filaments; not broken and not bonded to each other. In this condition, they will wet-out quickly, entrap little or no air, and will be lubricated by the resin for delivery to the die.

A controlled environment is generally not necessary for the creel and glass handling area. However, effort should be made to eliminate dirt and dust particles in the air and overspray of resin so that the reinforcement does not become contaminated. In a few instances, high temperature conditions may promote the formation of fuzz and gum on contact points. To provide optimum running of the roving, a routine maintenance program should be followed.

The fuzz or gummy build-up on guide eyes and all contact points should be solvent-cleaned regularly to assure smooth running. At the same time, worn or broken guides should be replaced.



CFM coming of creel



## Resin Impregnation of Glass

The resins, which have been used successfully in pultrusion, are:  
 Polyester – Isophthalic, Orthophthalic, & DCPD (dicyclopentadiene) modified  
 Vinyl ester  
 Epoxy -- Anhydride cure and Amine cure.  
 Acrylic  
 Phenolic

The impregnation system must accomplish two things:  
 1. It must wet the strands with a controlled amount of resin.  
 2. It must provide additional tension to the strands in preparation for delivery to the die.

There are many different designs for impregnation units. This is an area of the process that tends to be highly individualistic. Although "standard" impregnation units can be purchased from several manufacturers of pultrusion equipment, most fabricators build their own.

The design of an impregnation unit is dependent upon:

1. The amount of glass, i.e.
  - a. The number of roving strands
  - b. The yield of the roving strands
2. The process speeds
  - a. The speed of the strands being fed through the unit
  - b. The spacing of the strands
  - c. The desired resin content of the wet ribbon
  - d. The desired tension in the wet ribbon
3. The characteristics of the resin, i.e.
  - a. Viscosity of the resin
  - b. Temperature of the resin
  - c. Gel time

Impregnation units in successful production operations are normally located in line between the creel and the pultrusion die. The impregnation tank technique is used by most fabricators because thorough impregnation and wet-out of the strand at this point can be easily achieved by the proper "working" of the strand under the resin.

(show resin bath diagram and pictures)  
 The overall length of the impregnation tank is dependent upon the speed of the operation. Normally, the strands will never be under the resin for less than six inches or more than three feet.

The amount of necessary "working" of the strands under the resin depends upon the desired wet-out and tension of the wet ribbon. Normally, if the strand integrity is properly broken up prior to entrance to the resin, not more than three contact points under the resin are required for wet-out. Any more than three will only increase the tension. However, at or in the resin bath is the best place to add strand tension if needed.

All contact points in the resin bath should be 1/2 to 1 inch (12 – 25 mm) in diameter. This ensures a "wiping" action on the strand which helps remove entrapped air and prevents filaments from being broken or abraded. The contacts should also be non-rotating. This prevents broken filaments from wrapping around the rollers and eventually breaking the entire roving strand.

The overall width of the resin bath depends on the number of roving bundles being fed into it. Ample spacing for the dry strands at the collection point will prevent strands or groups of strands from tangling. Normally, the groups should not be spaced closer than one inch apart at the bath collection point just prior to entering the resin bath.

Rectangular baths should be avoided in warm environments using low temperature peroxides, since gelation may occur in the corner where resin circulation is low.

As the strands feed into the resin, they may be gathered more closely together. This may be accomplished either with an additional comb or by feeding the strands from different heights to the first wet contact point. At this point, strand spacing of from 1/4 to 1/2 inch (6-12 mm) is adequate to prevent tangling.

Resin temperature and production stability may be maintained with the use of a heated resin bath. This is accomplished by using a heater jacket around the resin bath. Bath temperature to maintain will depend on the resin manufacturer's recommendations, but generally is from 105 to 140°F (40 to 60°C).

The Best Place To:	Is:	Is Not:
Combine strands	entrance to bath	at creel or along thread line
Break up strand integrity	along the thread line	in the resin
Control the resin content and tension of the ribbon	with controlled tension during impregnation	with increased tension on the dry glass



## Resin Consideration in the Pultrusion Process

Unsaturated polyester resins, such as isophthalic polyesters or isopolyesters are common. The pultrusion polyester must have the ability to gel and cure rapidly to form a strong gel structure required for release at the die wall. Generally resins with viscosity around 500 cP are used for pultrusion. Higher viscosity and low-reactive monomer resins can be blended with additional styrene to suit the processing need. The styrene level must be properly maintained to achieve good cross-link structure without having residual (unreacted) styrene in the finished composite.

The resin system selected for a pultrusion process depends on the part design and end use, but generally fall into four main types:

### Polyester Resins

The most commonly used resin in pultrusion is isopolyesters. Typically isopolyesters are used because of their good physical properties and reasonable cost. Isopolyester resins have a good balance of strength and elongation, as well as reactivity which is useful in pultrusion processing.

Isopolyester resins can be characterized as follows:  
Good corrosion resistance when exposed to water, salts, bases, dilute acids, and aliphatic hydrocarbons.

However, composites based on polyesters retain a high percentage of their electrical insulation properties even if used continuously at temperatures up to 200°C.

They are less desirable when exposed to aromatic hydrocarbons, ketones, high pH and concentrated acids.

A high degree of unsaturation in the polyester chain leads to shrinkage of up to 7% after the finished part is cured. This level can be reduced by using fillers and low-profile additives. These fillers and additives can reduce micro cracking and sink marks, which occur when unfilled isopolyesters are used

Reinforced composites using isopolyester resins can continuously operate at temperatures of 238-292°F (150-180°C) while maintaining a high degree of electrical properties. Above 418°F (250°C) isopolyesters will begin to chemically decompose and lose properties.

Isopolyester resins range from brittle to tough. Normal elongation up to 5% is typical

The weatherability of isopolyester resins is reasonably good. Its performance can be improved by the use of UV absorption additives and/or veils.

Isopolyesters have the ability to gel and cure quickly, which is advantageous for efficient and economical part manufacture.

### Vinyl Ester Resins

These resins are used when additional performance is sought. Vinyl esters (VE) offer better corrosion resistance, higher mechanical properties at elevated temperatures, and improved toughness properties such as impact and shear. (They provide very efficient wet out and they have higher temperature capability with improved flexibility compared to polyester resins)

VE resins are superior to polyesters, but this advantage comes at a cost in two ways:

1. VE resins can be as high as double the cost of polyester resins
2. VE resins usually run at speeds about 2/3 the speed of polyester due to their lower cross-link density. Many VE have a narrow temperature window. A 10°C temperature change can cause blistering in pultruded profiles. Operators should be aware of the small processing window which VE resins have.

### Epoxy Resins

Epoxy resins typically offer the highest physical property performance as well as the best strength retention at high temperatures of all the resins used in pultrusion. Epoxies are frequently used for primary electrical insulation, aircraft, aerospace, and defense applications. Epoxies can be used in continuous use applications at 300°F (150°C) and epoxies provide increased flexural strengths and shear strengths when compared to polyesters and VE. Epoxies have excellent corrosion resistance and electrical properties.

The disadvantages of epoxy resins can be:  
Poor toughness as a result of their rigid structure  
Can be more expensive to purchase  
Slower processing speeds vs Polyester and VE resins  
Lower pot life  
Mold sticking considerations  
More difficult to clean up

They require a higher reinforcement content than either polyester or vinyl ester

### Methacrylate Vinyl Ester Resins

Designed to have excellent weathering characteristics and process at high speeds. MVE have very low viscosity which allows them to be highly filled, reducing their high purchase cost, and the use of fillers aids in delivering excellent flame and smoke properties. One concern with MVE is odor which plant personnel may find objectionable

## Phenolic Resins

Phenolics are highly attractive when the specification seeks excellent flame, smoke and fuel contribution. Phenolics sell at prices closer to VE resin prices, a further penalty is the slower processing speeds phenolics require. A significant difficulty with acid-cured phenolics is related to polycondensation, which releases water. The presence of water, if not properly eliminated, may affect the bond between glass and resin.

## Fillers and Additives

Filler and additives are used to enhance specific performance, reduce cost, influence viscosity, or improve processability of resin systems. Fillers can be incorporated into the resins in quantities up to 50% of the total resin formulation by weight. There are three fillers frequently chosen for use in pultrusion. These fillers are:

Calcium carbonate is the most popular and is used as a volume extender. Calcium carbonate is generally used where performance is not critical

Clay (alumina silicate) fillers are used for their corrosion resistance and in profiles requiring electrical insulation. They can provide very good surface finish.

Alumina trihydrate is used when flame or smoke suppression is desired.

Whatever filler is used, it is mandatory to make sure it is dry. Moisture is detrimental to the resin cure reaction and may generate steam and blistering.

Other additives may include antimony oxide for flame retardance, UV radiation screens for improved weather resistance, pigments for coloration and low-profile agents for surface smoothness and crack suppression characteristics.

**Mold releases** – are one of the necessary additives used in resin formulations. They are typically metallic stearates or organic phosphates esters (fatty acids) that can be processed at high temperatures. These provide adequate release of the curing resin from the die wall, reducing the pulling load on the machine. Care needs to be taken in the formulation, as too little mold release will not provide sufficient release from the mold, too much will inhibit the bond between the profile and the paint, if the part is painted. In polyesters, release agent concentration is often around 0.5 to 1.0 pph on resin. Low shrink resins Bisphenol A or Epoxy may require higher amounts.

**Pigments** – may be used to impart color, weatherability, or flame retardancy ( $Sb_2O_3$ ) to the finished part. Caution should be used in selecting pigments to ensure that toxic pigments are not used in certain applications, and that pigment hardness does not exceed hardness of the die surface. Hardness of greater than 6 Mohs (such as rutile  $TiO_2$ ) is generally unsuitable. Certain pigments will inhibit resin cure

Resin formulation is a key technology in pultrusion and the pultruder should work closely with a resin manufacturer to formulate a resin that meets their needs.



## Trouble Shooting Guide for Pultrusion

There are many commonly encountered problems in the pultrusion process. Some of the probable causes and potential solutions have been discussed previously, but this synopsis provides a useful, quick reference.

### Patience Is the First Step

Every pultrusion operation is unique. But even though operating conditions vary widely, there are still many common problems and defects. In each case, before taking corrective action, we recommend doing the following steps:

Thoroughly identify and define the problem.

- Thoroughly define the frequency and location of the defect.
- Determine what changes have occurred (either intentionally or unintentionally) prior to, during, and after the problem first appeared.
- Review the lists of possible causes and select the most appropriate.
- Begin implementing the suggested corrective action. During our discussion of pultrusion troubleshooting we will offer several suggestions on what may be causing the difficulty and how to stop it. Don't take a shotgun approach. Instead, determine the most logical alternative(s) on a priority basis.

Whenever a corrective action is implemented, it takes time for that change to stabilize and produce results. Each action must be allowed to show its effects prior to proceeding further. Otherwise, you may never know what action either helped or hindered the problem solving process.

Make sure to allow yourself plenty of time and testing to ensure that this is indeed the proper alternative and that the corrective action will fix the problem.

### Scaling

This problem occurs when cured resin particles exit the die with the part. When serious, it's called scaling or flaking; when it is minor it's called scumming. In either event, there is no need to tolerate it.

### Corrective Actions

- Increase the temperature of the entrance end of the die. This will strengthen (cure) the surface resin earlier and permit it to resist scaling.
- Slow the line speed to reduce friction and allow the resin to cure earlier within the die.
- Purge the mold of resin flakes by stopping the line for 30-60 seconds.
- If the above steps are ineffective, increase the low temperature initiator concentration. This also will cause the resin to cure earlier and harder on the surface.
- If radio frequency (R.F) equipment is used, adjustments will have no effect on scaling.

### Blisters

When blisters, or bubbles, appear on the part's surface, consider these steps of action.

### Corrective Actions

- Raise die temperature at entrance end of die to increase resin cure. It will now have higher strength and resistance to blistering upon exiting the mold.
- Reduce line speed to cure the resin more completely while in the mold and under compression. This will reduce the possibility of the part expanding and forming a blister upon exiting the die.
- Increase reinforcement (usually mat) level. Often the blister is a void created by low glass content. Upon exiting the die, the entrapped air in the void expands due to temperature and appears as a blister.
  - Check for excess water contamination. If a new mix capability is available, dry all ingredients prior to mixing.
  - If R.F. is used, increasing temperature could lower blisters. Normally this is a problem not associated with parts cured with R.F. equipment.
  - Reduce line speed ensure thorough wetting of the reinforcement.
  - Reduce exit zone temperature of the die to reduce excessively high exotherm of the part

### Surface Cracks

Surface cracks (not more than 1/4 of the part's thickness) are normally a result of excess shrinkage.

### Corrective Actions

- Raise die temperature, either totally or at the entrance. This will start the cure earlier, and give the resin more strength to resist cracks from shrinkage.
- Reduce line speed to increase surface resin cure and strength.
- Either increase the level of low temperature initiator or use a lower temperature initiator than you are currently using. Either will start resin cure earlier and increase resin strength.
- Increase the filler loading or glass content this can toughen the resin-rich surface to reduce shrinkage, stress and surface cracking.
- Add surfacing mat or veil to the part.
- Lowering the R.F. input slightly keeps more resin on the surface, raising the input has the opposite affect. Either action can reduce cracking.

### Internal Cracks

Normally only a problem with thick cross sections, the cracks this time are in the center of the laminate and may or may not appear on the surface.

### Corrective Actions

- Raise entry temperature so the cure will occur earlier in the die and therefore resist cracking.
- Lower die temperature at the exit end of the die. This will lower the peak exotherm of the part by acting as a heat sink.
- If changing temperature is impossible, increase line speed to lower the heat profile and peak exotherm, thus reducing thermal stresses.
- Reduce initiator level, especially the high temperature initiator. This is the best permanent solution, but will require some experimentation.
  - When using R.F., raising the R.F. temperature will assist in a more uniform cure throughout the profile.
  - Change high temperature initiator to one with a lower exotherm but good thru-cure. (see peroxide vendor)

### Spaces or non-fills

Spaces may occur as internal voids or spots on the surface which do not conform to the die shape.

### Corrective Actions

- Add reinforcement, such as bulky rovings, because resin shrinks during cure and will leave a void if not properly reinforced.
- Check alignment. The reinforcement may be "wandering" to one area of the mold and thus leaving another area with low glass content.
- Adjusting R.F. equipment will have no effect on non-fills.

### Streaking

Streaking is discoloration running parallel to the roving reinforcement.

### Corrective Actions

- Check wet-out bath for complete impregnation. All it takes is one glass end not getting enough resin to cause a streak.
- Reduce back tension on roving. Too high a tension can cause poor wet-out.
- Make sure that glass ends are aligned when using Type-30 roving.
- If pigment separation or change is the cause, check the pigment grind and pigment compatibility.
- Adjusting R.F. equipment will not affect streaking.

### Phasing

Phasing, or color shifts in localized sites, is usually a result of hot spots which cause uneven shrinkage.

### Corrective Actions

- Check the heaters. Either the strip heaters or the band heaters may have "wandered" from their settings, thus producing uneven temperature on the die.
- Check resin mixes to make sure fillers and/or pigments haven't started to settle or separate.
- Adjusting R.F. equipment will have no effect on phasing. The R.F. energy field itself, however, may cause nonuniformity. Try switching the equipment off for brief periods.

Note: Metallic pigments are not recommended for R.F. equipment because they may change R.F. coupling to your system.

### Barcol Hardness

Low readings on the Barcol hardness test are normally a result of undercuring. Improving cure will normally improve Barcol hardness.

### Corrective Actions

- Reduce line speed to increase resin cure time.
- Raise die temperature to increase rate and degree of cure within the die.
- Check formulation for plasticization agent or other contaminants, such as water or certain pigments, both of which can affect cure rate.
- Raise the R.F. to increase the cure of the resin.

### Puller Crushing

Structural damage to the finished piece occurs when it enters the first pulling station. Often this is result of low Barcol.

### Corrective Actions

- Follow corrective actions associated with low Barcol.
- Set clamp pressure at the minimum necessary to pull the part without clamp slippage.
- Lower the temperature of the part entering the puller by using a physical cooling medium such as air or water spray. A common reason for puller crushing is insufficient cooling of the part. Physically cooling the part is recommended over some of the other approaches available.
- Reduce the line speed so part can cool before it reaches the puller.
- Raise the R.F. to increase resin cure and strength.

### Shrinkage

Surface nonconformities are caused by excess shrinkage.

### Corrective Actions

- Add more glass to reduce shrinkage during resin cure.
- Add a shrink reduction agent and/or increase filler loading.
- Increasing R.F. will increase resin cure with minimal contribution to shrinkage.

### Die Plugging

The mold is plugged with glass, causing the part to break out or the puller to be incapable of moving the part (slip).

### Corrective Actions

- Reduce die entry temperature; pre-gel at die entry can cause a plug.
- Reduce reinforcement level. Only a limited number of fiber ends can be placed in a given space. If pulling multicavity, check to make sure all ends are going into the right mold.
  - Rethread and try again. Plugging can occur without apparent reason.
- Reduce the section of preshaping guides (or add narrower preshaping guides). They will squeeze the resin excess and lower the pressure within the die. This may be particularly important when the resin viscosity is high, either due to the presence of filler or due to a low resin temperature. Raising resin temperature may also help squeezing the excess resin. Acceptable pre-shaping is achieved when rovings are perfectly aligned through each shaping guide and no fiber breakage or twisting occurs at the shaping guides.

- Check mold surface. An undercut in the die will eventually cause the part to break out. This may appear as a plug, but is actually a tearing of the part.  
An excessively rough (worn) die surface can cause the same problem.
- Lowering R.F. will reduce the tendency of pre-gel and subsequent plug formation at the die entry.

### Mat Tears

The mat tears prior to entering the mold, usually between resin impregnation and die entrance.

### Corrective Actions

- Insure a smooth, snag-free path for the mat, from the roll to the die entrance.
- Be certain the mat slits have smooth edges and are the right size for the part design.
- Ensure the mat performing dies does not give too much tension or drag on the mat.
- Add carrier rovings to assist mat through higher tension areas, such as wet-out breaker bars and mat preforming dies.
- R.F. adjustments will not affect mat tear.

### Warpage

The part bends after die exit and cooling.

### Corrective Actions

- Check for a symmetric reinforcement pattern, especially where the mat is used. Uneven glass levels will cause warpage. Adjust reinforcement layout to counter part warpage.
- Check for symmetric heat patterns; unbalanced heating causes uneven cure rates, thus producing different shrinkage.
- Check part design. Some unsymmetrical designs are conducive to warpage. If that is the cause, the use of cooling jigs may be necessary.
  - Raising R.F. temperature can lock the fibers in place earlier and result in a more complete curing within the mold, thus reducing warpage.
  - Check preformers for excessive or uneven tensioning of reinforcement.
  - Reduce roving tension from creel to die entrance.
  - Straighten reinforcements entering bath if creel is offset from bath
  - Check the perfect alignment of die and pulling system. Imperfect alignment might be required if part is asymmetric.

### Porosity

Pinhole defects or air bubbles appear on the surface - a difficult problem.

### Corrective Actions

- Check for excessive moisture or solvent in the mix, or incorrect heating of the part. Water and solvents can boil off during exotherm and cause porosity.
- Slow the line speed and/or increase mold temperature to give the surface resin a harder skin to better resist the problem.
- Use a surfacing veil or mat. This will add some reinforcement to the surface resin and resist porosity.
- Lower R.F. temperature slightly to bring more resin to the surface and help "fill in" minor porosity.

### Contamination

This is the presence of foreign matter in the resin or reinforcement.

### Corrective Action

- Identify and remove the source of contamination.

### Package Transfer

Poor package run-out or transfer can be handled in several ways:

### Corrective Actions

- Inspect packages for damage before creeling. Avoid sliding the ball on the creel shelf since abrasion of the bottom surface may result. Cover creel shelves with a smooth surface.
- Check for proper guide-eye location. The first should be centered above the roving package, 3" to 6" above the ball. Make sure there is nothing for the roving to catch on if it whips or loops while exiting the package.

### Fuzz

Fuzz is merely broken glass filaments.

### Corrective Actions

- Inspect packages for damaged or abraded edges. Don't slide ball over a rough shelf.
- Check guide eyes and other contact points for size or gummy build-up. Clean guide-eyes with solvent to remove any gummy build up.
- Institute creel and guide-eye maintenance programs to ensure no recurrence.
  - Inspect and replace all worn guide eyes. If strand passes over a bar, it may wear a groove; inspect and replace if necessary.
  - Make sure all contact points are equipped with unbroken, unabraded and clean ceramic guide-eyes.
- Inspect guides and bars for resin build-up from overspray and clean with solvent if needed.
- Check for excessive tension. Reduce the initial tension at the first contact point and at all following contact points.
- Minimize the number of contact points and the bend angle (direction change) around these points.

### Break-Outs

Individual filament ends break and cease running through the process.

### Corrective Actions

- If caused by "fuzz balls" caught in the wiping device, clean guide-eyes and/or lower tension to minimize fuzz.
- Eliminate tangled ends by increasing strand spacing in the resin bath. Also check strand path to maintain uniform tension. Untensioned strands can loop and cause a break. Increased tension will prevent this.
- Replace worn or broken wet guides. If operating intermittently, remove tacky or cured resin from guides which carry wet roving.
- Avoid rolling contacts on which the strand can wrap and break out.

## Typical Pultrusion Resin Formulation - Ingredients

	Range (PHR)	Description	Characteristics	Effects
Resin	100	Polyester Vinyl Ester Epoxy	Low Viscosity, High Chemical Resistance Low Exotherm	Processing Corrosion/High Temp. Electrical/High Temp.
Thermoplastic	0-10	Polyolefin Polyvinyl Acetate Polystyrene	Low Molecular Weight	Lower Shrinkage Increase Lubricity
Filler	0-10 Typical, Can Be Up to 40	Clays, Carbonate Hydrated Alumina Micro Balloons	Low Oil Absorption Small Particle Size	Improve Surface Reduce Cost/Weight Fire Retardant
Release Agent	0.5-2.0	Phosphate Esters Stearate Organics	Compatible with Resins	Release Part from Die, Reduce Friction, Lower Pulling Loads
Pigment	0-2	Dispersed Systems Compatible with Resins, Dyes	Temperature Stable, Preferable Non Interactive	Appearance Opacity
Air Release	0.5	modified polyester	Facilitates air release from filler	

PHR=per hundred parts resin

### Typical Pultrusion Initiators (Catalysts)

#### Low Temperature 180-200°F (82-93°C)

Bis(4-t-butylcyclohexyl) peroxydicarbonate

t-Butyl peroxyneodecanoate

#### Moderate Temperature 230-280°F (110-138°C)

Benzoyl peroxide

t-Butyl peroxy-2-ethylhexanoate

2,5-dimethyl-2,5-bis(2-ethylhexanoylperoxy)hexane

t-Amyl peroxy-2-ethylhexanoate

#### High Temperature 290-310°F (143-154°C)

t-Butyl peroxybenzoate (TBPB) or t-Butylperbenzoate

Cumene hydroperoxide

Bis (4-t-butylcyclohexyl) Peroxydicarbonate

T-butyl peroxyneodecanoate

#### Some Typical Trade Name

Percadox 16N-92%

Percadox 1635-35% (KONINKLIJKE INDUSTRIELE  
MAATSCHAPPIJ NOURY & VAN DER LANDE N.V. CORPORATION)

Espercarb 1043 (U.S. PEROXYGEN COMPANY)

Lucidol 10M75 (NOVADEL PROCESS CORPORATION)

BPO

t-Butyl peroctoate 97%

Trigonox 21 or 21LS (KONINKLIJKE INDUSTRIELE MAATSCHAPPIJ  
NOURY & VAN DER LANDE N.V. CORPORATION)

Lupersol PDO 50% (NOVADEL-AGENE CORPORATION)

Lupersol 256 (NOVADEL-AGENE CORPORATION)

USP 245

Lucidol 575-75 (PENNWALT CORPORATION)

USP Esperox 570 (WITCO CORPORATION)

USP Esperox 10 (WITCO CORPORATION)

Trigonox C (KONINKLIJKE INDUSTRIELE MAATSCHAPPIJ  
NOURY & VAN DER LANDE N.V. CORPORATION)

Lucidol (PENNWALT CORPORATION)

Cumene hydroperoxide

Percadox 16N-92%

Percadox 1635-35%

Lucidol 10M75

Note: Choosing the proper initiator and/or initiator blend is dependent on part design and especially thickness. For the proper initiator level, consultation with a technical representative is recommended.



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## Roving Count Calculation

This section is intended to provide a "rule of thumb" to determine the number of roving packages required to fill a part.

1. Calculate the cross sectional area of the part
2. Calculate the theoretical weight per linear foot
3. Determine glass weight per linear foot from percent glass
4. Divide glass weight by weight of one roving per foot

Example:

Glass yield = 113 yd./lbs. = 1/113 yd./lbs. x 3 ft/yd = 0.00295 lbs.

One inch diameter solid, round rod

Specific gravity of typical laminate part at 70% glass = 1.95

70% glass loading

Weight of water = 0.0361 LB/inch cubed

1. Cross sectional area = **0.7854 sq. inches**
2. Total weight/foot = 0.7854 sq. inches x 12 inches/ft x 1.95 x 0.0361 LB/inch cubed = **0.663 lbs./ft**
3. Glass weight = 0.663 LB/ft x 70% glass = **0.464 LB/ft**
4. Roving count = 0.464 LB/ft / 0.00295 lbs. = **157 rovings of 113 yield**



## Sources of Supply

### For Strand Guides

*Aluminum Oxide, Titanium Oxide, Ceramic, Stainless & Chrome Steel*

- Advanced Cerametrics Inc. • P.O. Box 128, 245 North Main Street, Lambertville, NJ 08530 • 609-397-2900
- Mitchell-Bissel Co. • P.O. Box 518, Rosman, NC 28772 • 704-862-4201
- AISiMag Technical Ceramics, Inc., • One Technology Place, Laurens, SC 29360-0089 • 800-845-9761

### Europe:

Ceramiques Techniques Desmarquest • CICE - Tital®  
63, Rue Beaumarchais • F-93104 Montreuil Cedex (France)  
ph. +33-(0)148.59.11.80 • fax +33-(0)148.58.25.70

Centner Fils  
Rue de Liege, 30  
B-4800 Verviers (Belgium)  
ph. +32-87-23.24.40  
fax +32-87-23.24.50

### India:

Marchon Textile Industries Pvt. Ltd., J.B.Nagar, Andheri Kurla Road, Andheri (E), Mumbai - 400 059, India.  
Ph. +91 (22) 834 7047 / 832 2883 / 836 4409.  
Fax +91 (22) 836 4408.  
Email [marchon@bom3.vsnl.net.in](mailto:marchon@bom3.vsnl.net.in)

### For Pultrusion Equipment

- Creative Pultrusions 214 • Industrial Ln Alum Bank, PA 15521 • 814.839.4186
- CMI/Composite Materials, Inc. • 4677 Worth St., Los Angeles, CA 90063 • 213-269-0131
- EnTec Composite Machines Co., • 2975 South 300 West, Salt Lake City, UT 84115 • 801-486-8721
- Michigan Roll Form, Inc. • 9100 Hubbell Ave., Detroit, MI 48228 • 313-836-1844
- Strongwell • 400 Commonwealth Ave, Bristol, VA 24203-0580 • 703-645-8000

### Europe:

- Pultrex Ltd, Brunel Rd., Clacton-on-Sea CO15 4LU Essex, Great-Britain • ph. +44-(0)1255-42.98.11  
fax +44-(0)1255-43.64.51
- TopGlass, Via Bergamo 15, I-20096 Pioltello (Italy) • ph. +39-02-92.91.86.30 • fax +39-02-92.91.86.20

### For Splicing strands, air or wrap method

- Mill Devices Company, Div. of AB Carter Inc., P.O. Box 518 Gastonia, NC 28053 • 704-865-7314
- Mesdan spa, I-25087 Salo' (Brescia) Italy • Ph. +39-0365-52.10.00 • Fax +39-0365-52.09.98
- JointAir 116 Air splicer

## Glossary of terms

<b>A-glass</b>	A soda lime glass similar to window or bottle glass, with lower chemical and water resistance than E glass. Used primarily in surfacing mats, in pultruded profiles
<b>Accelerator</b>	A chemical used to increase the rate of cure of polyester resin at room temp.
<b>Additive</b>	Any substance added to the resin, usually to improve properties
<b>Advantex®</b>	A trademarked Owens Corning E glass with higher corrosion and temperature resistance than conventional E glass. Satisfies ASTM D578-98 for E glass, and satisfies the description of both E and E-CR glass according to ISO 2078. Advantex qualifies as an E-CR glass as per DIN 1259 and ASTM D578.
<b>Aramid</b>	A generic name for aromatic polyamides (Kevlar and Nomex are examples of Aramid)
<b>Aspect ratio</b>	The ratio of length to diameter of a reinforcing fiber
<b>Balanced laminate</b>	A composite laminate in which all laminae at angles other than zero and 90 degrees occur only in pairs.
<b>Ball</b>	A commercial package of roving
<b>Barcol hardness</b>	A measurement of hardness of the part. It also serves as an indicator of the degree of completion of cure of a composite. Values of 50 or greater are desirable in pultruded composites
<b>Biaxial Material</b>	Material having fibers oriented in both the warp (0 degree) and weft (90 degree) direction
<b>Binder</b>	The agent applied to glass roving, glass mat or preforms to bind the fibers prior to laminating or molding.
<b>Breaker bars</b>	A series of bars in the resin dip bath, which separate the planes of roving and mechanically break the roving bundles into individual filaments for thorough wetting by the resin
<b>Bundle</b>	A general term for a collection of essentially parallel filaments or fibers
<b>Carbon Fiber</b>	Fibers made from an organic precursor by oxidation and carbonization and not having a graphite structure
<b>Catalyst</b>	A substance that changes the rate of a chemical reaction without itself undergoing permanent changes in composition
<b>Catenary</b>	A measure of the differences in length of the strands in a specified length of roving, as a result of unequal tension. Catenary can create difficulty in pultrusion processing
<b>Cavity</b>	The female portion of a split cavity or gunbarrel drilled mold, the portion of the mold that encloses and shapes the molded article, also referred to as the die
<b>Composite Material</b>	A combination of 2 or more materials (reinforcing elements, filler, and resin). The constituents retain their identities, though they act in concert
<b>Continuous Strand Mat</b>	A type of fiberglass reinforcement used in pultrusion, where the filaments are continuous and swirled together and bonded with a binder, creating a web. Mat sizes are in ounces/sq. ft, with 1.0, 1.5, and 2.0 being the most common mat weights
<b>Creel</b>	A device for holding the required number of roving balls or mat plies in the desired position before they are fed into the resin bath

<b>Creel Cards</b>	Cards, usually made from high density polyethylene or steel to guide the roving and mat in an organized fashion through the material handling creels to the resin bath
<b>Cure</b>	To irreversibly change the properties of a thermosetting resin by chemical reaction
<b>Cure time</b>	The time needed for liquid resin to reach a solid state after the catalyst has been added, and initiation has progressed
<b>Delamination</b>	The separation of layers of material in a laminate, either local or covering a wide area. A failure of internal bonding between layers of resin and reinforcement
<b>Dielectric Curing</b>	The curing of a thermosetting resin by the passage of an oscillating electric field produced by an oscillating electric field. Commonly called RF (radio frequency) energy
<b>E glass</b>	A borosilicate glass, type most commonly used in glass fibers for reinforced plastics, suitable for electrical laminates because of its high resistivity. Also called electrical glass. Defined by ASTM D578-98
<b>EPA</b>	Environmental Protection Agency
<b>Exotherm</b>	The liberation or evolution of heat during the curing of a plastic product
<b>Extenders</b>	Low cost materials used to dilute or extend high cost resins with little lessening of properties
<b>Fabric, nonwoven</b>	A textile structure produced by bonding or interlocking of fibers bonded by mechanical, chemical, or solvent means, or combinations of all the above
<b>Fabric, Woven</b>	A material constructed of interlaced yarns, fibers, or filaments
<b>Fiber</b>	A general term used to refer to filamentary materials, it is the general term for a filament of finite length
<b>Glass Fiber</b>	An individual filament made by attenuating molten glass
<b>Fiber glass</b>	Any composite in which the reinforcement is glass fiber
<b>Fiberglass Reinforced Plastic (FRP)</b>	Generic description of polymeric matrix reinforced with fiber glass. Also known as fiber glass
<b>Filament</b>	The smallest unit of fibrous material.
<b>Fill</b>	The group of fibers running in the direction perpendicular to the length of the fabric, also referred as the weft or 90 degree fibers
<b>Filler</b>	A relative inert substance added to a material to alter its physical, mechanical, thermal, electrical, other properties or lower cost
<b>Finish/size</b>	A mixture of materials for treating glass fibers. It contains a coupling agent to improve bond of resin to glass
<b>Forming Guides</b>	Tools used in the preforming stage of the pultrusion process; generally carding plates that control reinforcement placement in-feed through the resin bath and to the die
<b>Gel</b>	A partial cure of polymer resins; a semi-solid state similar to gelatin in consistency
<b>Gel Time</b>	That interval of time, in connection with the use of thermosetting resins from the introduction of an initiator into a liquid resin system, until gel formation yielding a semi-solid nonflowable material
<b>Glass fibers</b>	A fiber of glass, which has cooled into a rigid condition without crystallization
<b>Glass, % by weight</b>	$(\text{weight of glass} \times 100) / \text{weight of laminate}$
<b>Heat treat</b>	Term used to cover annealing, hardening, tempering or other thermal treatment of tooling steels

<b>High Frequency heating</b>	The heating of materials by dielectric loss in a high frequency electrostatic field. Radio Frequency (RF) is used most commonly for thermosetting resins
<b>Ignition loss</b>	The difference in weight before and after burning. For glass reinforcements, it is a measurement of the amount of binder or sizing
<b>Impregnate</b>	In reinforced plastics the saturation of the reinforcement with a resin
<b>Inhibitor</b>	A substance that retards a chemical reaction, typically used to prolong storage life
<b>Initiator</b>	A material used as a source of free radical, frequently referred to as a "catalyst"
<b>Interface</b>	The boundary or surface between two different media; on glass fibers the contact area between glass and sizing or finish, in a laminate the contact area between the reinforcement and the laminating resin
<b>Isophthalic polyester</b>	An unsaturated polyester resin prepared with isophthalic acid as the starting acid constituent
<b>Isotropic</b>	Having the same properties in all directions
<b>Kevlar®</b>	Dupont's trade name for an organic polymer composed of aromatic polyamides having a para type orientation
<b>Knitted fabrics</b>	Fabrics produced by interlooping strands of yarn, roving, etc
<b>Laminate</b>	Material composed of successive layers of resin and reinforcement bonded together
<b>Loss on Ignition</b>	(LOI) weight loss, usually expressed as percent of total, after burning off an organic sizing from glass fibers, or an organic resin from a glass fiber laminate
<b>Mandrel</b>	The male section of a die which is cantilevered into the female cavity to form a hollow pultruded profile
<b>Mat</b>	A fibrous material for reinforced plastic consisting of randomly oriented chopped filaments, or swirled continuous filaments loosely held together with a binder; available in various widths, weight, and lengths
<b>Matrix</b>	The essentially homogeneous material in which the fiber reinforcement system of a composite is imbedded
<b>Modulus of elasticity</b>	The ratio of the stress to the strain produced in a material that is elastically deformed. If a tensile strength of 1000 psi results in an elongation of 1%, the modulus of elasticity is $1000/0.01 = 100,000$ psi
<b>Mold</b>	The cavity or matrix into which the plastic composition is drawn and from which it takes form; to shape plastics parts or finished articles by heat and pressure
<b>Mold release, external</b>	A substance used to coat the mold to prevent sticking of the resin that will be used to make the part
<b>Mold release, internal</b>	A lubricant, liquid, or powder used to prevent sticking of molded articles in the cavity by incorporation into the resin formulation
<b>Monomer</b>	A single molecule which can react with like or unlike molecules to form a polymer; the smallest repeating structure of a polymer(s)
<b>Orthophthalic resin</b>	An unsaturated polyester resin of which phthalic anhydride was the starting point
<b>Parting line</b>	A continuous mark in a pultruded piece where the sections of a mold have met in closing. Tight mold tolerances can minimize this objectionable mark
<b>Phenolic resin</b>	A thermosetting resin chosen for its excellent flame and smoke resistance characteristics
<b>Plastic</b>	A material that contains as an essential ingredient, an organic substance of large molecular weight, is solid in its finished state, and at some stage in its manufacture or its processing can be shaped by flow

<b>Platen</b>	The mounting plates of a pultrusion machine in which the entire mold is contained for the dual purpose of restraining and heating
<b>Polyester resin</b>	The term generally used for unsaturated polyesters, formed by the reaction of dibasic organic acids and polyhydric alcohol
<b>Polymer</b>	A high molecular weight organic compound, natural or synthetic, whose structure can be represented by a repeated small unit, for example – polyethylene, rubber, polyester, cellulose
<b>Polymerization</b>	The name for the reaction that takes place when a resin is activated
<b>Postcure</b>	Additional elevated temperature cure, usually without pressure, to improve final properties and/or complete the cure
<b>Postforming</b>	The forming, bending, or shaping of fully cured, C-staged thermoset laminates that have been heated to make them flexible. On cooling, the formed laminate retains the contours and shape of the mold over which it has been formed
<b>Pot life</b>	The length of time that a catalyzed thermosetting resin system retains a viscosity low enough to be used in processing. Also known as working life
<b>Precursor (for carbon or graphite fiber)</b>	Either the PAN or pitch fiber form which carbon and graphite fibers are derived
<b>Preheating</b>	The heating of an impregnated material prior to molding, to facilitate the operation or to reduce the molding cycle
<b>Prepreg</b>	Abbreviation for pre-impregnated reinforcement fibers. Prepreg is any reinforcing material loaded with B-stage resin, catalyst, and pigment ready for placement in the mold
<b>Profile</b>	A shape, referring to the cross-section of the part to be pultruded
<b>Promoted resin</b>	Resin with accelerator added but not catalyst. Primarily applicable to room temperature cure resins, not s system used in pultrusion process
<b>Pulforming</b>	A composite process to produce profiles that do not have a constant cross-sectional shape but do have constant cross-sectional area. Like pultrusion, materials are pulled but the pulling mechanism is a compression molding-like die that processes a product of a defined length with a constant cross-sectional area
<b>Puller pads</b>	Used to grip and pull the profile during the pultrusion process. Usually made of a soft but durable material such as urethane with high non-slip properties
<b>Pultrusion</b>	A continuous process for manufacturing composites with a constant cross-sectional shape. The process consists of pulling a fiber reinforcing material through a resin impregnation bath and into a shaping die, where the resin is heated and cured
<b>Reinforcements</b>	Material used in pultrusion (and other plastic processes) to give physical and mechanical properties that plastic alone cannot provide. Typically fiberglass, graphite, Kevlar®, and others, roving mat and or fabric form
<b>Reinforced plastics</b>	Molded, formed, filament wound, pultruded, or otherwise shaped plastic parts consisting of resins to which reinforcing fibers, mats, fabrics, etc have been added before the forming operation
<b>Release agent</b>	A lubricant, either external or internal, that prevents the adhesion of the part to the mold
<b>Resin</b>	A solid or pseudosolid organic material, usually of high molecular weight, that exhibits a tendency to flow when subjected to stress. Most resins are polymers. IN reinforced plastics, the material used to bind together the reinforcement material, the matrix
<b>Resin dip pan</b>	A resin impregnation system where reinforcement materials leave a horizontal plane, dipping into the open resin bath, than returning to the horizontal plane before entering the die. Pan incorporates breaker bars, which separate the planes or roving and mechanically break the roving bundles into individual filaments for thorough resin wetting
<b>Resin mix</b>	The mixture of the base resin with additives used for specific desired properties needed for the process and the part

<b>Resin-rich area</b>	Space which is filled with resin and lacking reinforcing material in a pultruded part
<b>Roving</b>	A number of strands, tows, or ends collected into a parallel bundle with little or no twist of reinforcing fibers
<b>Roving ball</b>	A term used to describe the supply package offered to the pultruder. It consists of a number of ends or strands wound to a given diameter and length
<b>Roving yield</b>	A unit of measure of the linear density of a fiberglass roving. Given in yards/lbs., the lower the number the larger the size of the roving bundle
<b>S-glass</b>	A magnesia-alumina-silicate glass, especially designed to provide very high tensile strength glass filaments
<b>Shelf life</b>	The length of time a material can be stored under specified environmental condition and continues to meet all applicable specifications requirement and/or remain suitable for its intended processing function
<b>Shrinkage</b>	The relative change in dimension between a dimension measured on the mold when it is cold and the dimension of the molded object 24 hrs after it has been molded
<b>Sizing</b>	Any treatment consisting of starch, gelatin, oil, wax, or other suitable ingredient that is applied to yarn or fibers at the time of formation to protect the surface and aid the process of handling and fabrication. The treatment contains ingredients that provide surface lubricity and binding action, but no coupling agent
<b>Sloughing</b>	The condition of excess resin particles curing to the surface of the part during the pultrusion process. These particles are not part of the product and can be removed from the surface
<b>Specific Gravity</b>	The density (mass per unit volume) of any material divided by that of water at a standard temperature
<b>Splice</b>	The joining of two ends of glass fiber roving or mat by several techniques
<b>Spun roving</b>	A bulky, low cost glass fiber strand consisting of filaments that are continuous but doubled back on each other, providing some level of off-axis reinforcement
<b>Straight through</b>	A resin impregnation bath that allows the reinforcement material to enter the back of the bath, get saturated with resin, and exit the front of the bath without the material leaving a horizontal plane. Resin, which leaks from the front and back of the bath, is recirculated by means of a catching trough system, a resin holding tank and a recirculating pump. Frequently used with mat and roving profiles
<b>Strand</b>	Normally an untwisted bundle or assembly of continuous filaments, including slivers, tow, ends, and yarn. Sometimes a single filament or fiber is called a strand
<b>Structural Mat</b>	A continuous strand mat which provides significant weight percentage of a composite and having major contribution to directional physical properties
<b>Styrene Monomer</b>	A water-thin liquid used to thin polyester resins prior to cure and which serves as the chemical which links the polyester chains together during the curing process (see monomer)
<b>Surfacing Agent</b>	An oily or waxy material which rises to the surface of a polyester resin during cure
<b>Surfacing mat</b>	A very thin ply, usually 7-20 mils thick, of highly filamentized fiberglass, or synthetic fibers, used primarily to produce a smooth, cosmetic surface on a reinforced plastic laminate
<b>Tensile strength</b>	The maximum tensile stress sustained by a specimen prior to failure in a tensile test
<b>Terephthalic resin</b>	An unsaturated polyester resin prepared with terephthalic acid as the starting acid constituent
<b>Thermoplastic</b>	Capable of being repeatedly softened by increase of temperature and hardened by decrease in temperature; applicable to those materials whose change upon heating is substantially physical rather than chemical and that in the softened stage can be shaped by flow into articles by molding or extrusion
<b>Thermoset</b>	A plastics that, when cured by application of heat or chemical means, changes into a substantially infusible and insoluble material

<b>Thickeners</b>	Materials added to the resin to thicken it or raise the viscosity of the resin so that it will not flow as readily. Used most frequently to produce sheet molding compound (SMC)
<b>Thixotropic</b>	Describes the property of becoming a gel at rest, but liquefying again on agitation
<b>3D-Pultrusion™</b>	A variation of the 2-D Pultrusion process where steel molds is mounted to the caterpillar puller. The molds are heated and when the pullers are activated, they simultaneously clamp, pull and mold 3 dimensional shapes. The process may be adaptable to permit changes in cross-sectional area
<b>Tow</b>	An untwisted bundle of continuous filaments, commonly used in referring to man-made fibers, particularly carbon and graphite fibers
<b>UHMWPE</b>	Ultra High Molecular Weight Polyethylene – a thermoplastic material composed of many molecules of ethylene and exhibiting extreme toughness and abrasion resistance. Frequently used in the pultrusion process for creel cards and forming guides
<b>Ultraviolet (UV) stabilizer</b>	Any chemical compound which, when admixed with a thermoset or thermoplastic resin, selectively absorbs UV rays
<b>Undercure</b>	A condition of the molded article resulting from the allowance of too little time and/or temperature for adequate hardening of the molding
<b>Undercut</b>	A negative or reverse draft on the mold. Split molds are necessary to shape pieces that are undercut
<b>Unidirectional laminate</b>	A reinforced plastics laminate in which substantially all of the fibers are oriented in the same direction. In pultrusion, unidirectional products are produced with continuous rovings
<b>Upstream tooling</b>	That part of the pultrusion process that organizes, orients, and forms the raw materials before they reach the primary steel die. Specifically refers to the forming guides, but can generally include mat and roving creels, creel cards, resin baths, and resin impregnation systems
<b>Veil</b>	A surfacing material used in pultrusion to enhance surface finish, weatherability, appearance, and smoothness to the touch (see surfacing mat)
<b>Vinyl ester</b>	A family of thermosetting resins having no ester linkages along the polymer chain but monoxilated bisphenol A plus acrylic acid only at the ends of the molecule, providing improved corrosion resistance
<b>Viscosity</b>	The resistance to flow exhibited within the body of a material. Viscosity is the ratio of shear stress to shear rate (shear stress/shear rate)
<b>Voids</b>	Gaseous pockets that have been trapped and curing into a laminate. Porosity is an aggregation of microvoids. Voids are essentially incapable of transmitting structural stresses or nonradiative energy fields
<b>Weft</b>	The transverse threads or fibers in a woven fabrics; those fibers running perpendicular to the warp. Also called the fill or filling yarn
<b>Wet-out</b>	The ability of a resin to saturate glass reinforcement quickly
<b>Warp</b>	The yarn running lengthwise in a woven fabric; a group of yarns in long lengths and approximately parallel
<b>Woven Fabrics</b>	Fabrics produced by interlacing strands at more or less right angles
<b>Woven Roving</b>	A heavy glass fiber fabrics made by the weaving of roving
<b>Yield</b>	The maximum allowable stress in a material, less than the maximum attainable stress, at which an increase in strain occurs without an increase in stress. Only materials that exhibit this unique phenomenon of yielding have a yield point. Fiberglass reinforced thermoset plastics generally do not exhibit a yield point. Also a term to describe weight per unit length in yards/lbs., for example a 113 yield product weighs 113 yards/LB

**Sources:**

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Pultrusion Design and Process Guide, Pultrusion Technology, Inc, 1987  
Volume 1 – Composites Engineered Material Handbook, Compiled by Harry E. Pebly, US Army Armament R&D Center, ASM, Metals Park, OH 1986



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