INSPECTION OF PULTRUDED COOLING TOWER COMPONENTS

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Abstract:

Pultruded profiles dominate the cooling tower market as the material of choice for field-erected cooling towers. Pultruded profiles offer many positive attributes. However, unlike the steel, concrete and wood industry, the pultrusion industry has not matured to the point of having ASCE-endorsed design codes and quality requirements.

Therefore, the quality control and quality assurance standards are up to the individual pultruder. This paper will discuss the visual and structural quality assurance and quality control programs utilized by an FRP pultrusion manufacturer and their customer for custom designed FRP structural members. This paper covers QA procedures utilized, both at the production plant and at the construction site.

Keywords: Fiberglass Reinforced Polymer (FRP), Pultrusion, Quality Control (QA)

Introduction

The pultrusion industry has been aggressively pursuing a Load & Resistance Factor Design (LRFD) standard in order to address major component and structure design with pultruded sections. Although the standard will contain a Code of Standard Practice for Fabrication and Installation of Pultruded FRP Structures, it will not address the quality control requirements for the production of pultruded structural profiles.

This paper aims to address critical quality control standards that are essential prior, during and post manufacturing of structural profiles for cooling tower applications. This paper will describe, in general terms, the quality control requirements established between a pultruder and a field erected cooling tower manufacturer.

Inspection of Incoming Raw Materials

Incoming raw materials including resin, roving, fiberglass mats, fillers, and catalyst are required to be purchased based on a Qualified Products List (QPL). The list includes all products that are permitted to be utilized in production. The documented material approval process is required to be followed any time a new material is to be added to the QPL. The process includes an evaluation based on mechanical, physical, and process parameters as compared to the legacy materials utilized for production.

The incoming resin and glass reinforcements require a Certification of Conformance (COC) report, to be delivered to the Quality Assurance (QA) Department, prior to receiving the raw materials. In some instances, actual viscosity, temperature, and weights are verified against the manufacturer's requirements prior to releasing the raw materials to production. The frequency and timing of the inspections should be outlined in the manufacturer's quality manual.

First Article Inspection

The pultrusion die setup and production startup are the two most important processes associated with pultrusion manufacturing. In order to assure that the pultruded profiles meet both customer and internal quality requirements, a documented First Article Inspection (FAI) process is followed. In general terms, the FAI involves the use of an FAI document that contains a series of check boxes corresponding to specific procedures, test results, and measurements.

For example, the following series of check boxes demonstrate the steps necessary to be competed prior to a product being released to production status. Note that many of the check boxes correspond to additional documents required to be completed during the die setup and preproduction stage. For example, the Pultrusion Die Set Up Procedure/Checklist includes many additional documented checks that occur during the die set up and preproduction. One example is a documented audit verifying that the proper reinforcements are in the part at the preproduction stage.

- ❑ **Is the Routing Sheet & Production Orders on Priority Sheet on line?**
- ❑ **Pultrusion Die Set Up Procedure Checklist Complete?**
- ❑ **Does the Resin Mix Sheet Match the Engineering Specification Sheet?**
- ❑ **Does the profile conform to the QA Visual Specifications provided on line?**
- ❑ **Part Conforms to the Dimensional Specifications provided on line?**
- ❑ **Part Conforms to Length Tolerances as Established by Quality Assurance?**
- ❑ **Does the profile pass UL 94V0? _____NA**
- ❑ **Does the profile pass the Full Section Modulus of Elasticity (MOE) Requirement?**

The series of checks ensures that the pultruded sections meet the minimum internal and agreed upon physical properties and that the die was set up via a consistent practice and per the requirements dictated by engineering.

The FAI sheet is required to be signed by both the production line operator and the Pultrusion Supervisor. This action releases the profile to production status. The First Article Inspection ensures that the pultrusion meets the minimum standards at the time the process was started. The First Article Inspection documents are scanned and saved in the internal QA files for future reference.

In-Production Inspection

Once the initial startup has been commenced and the First Article Inspection has been completed, the QA complaint profile is then released to production status. At this time, the In-Process Inspection (IPI) procedure is required to be followed.

Specifically, the IPI procedure details the necessary inspections and the frequency of inspections required to be documented throughout the production shift. The IPI inspections include the following:

1.0 Raw material input checks including documented roving counts and mat audits
2.0 Production line speeds
3.0 Die temperatures
4.0 Resin audit prior to accepting delivery into pump station
5.0 Visual inspections
6.0 Dimensional inspections

The intent of the inspections is threefold. One, document that the parts are in compliance with the standards as set forth between the manufacturer and the customer. Two, document that the part is being manufactured per the engineering specifications. Three, create a production log so that the values can be statistically evaluated for continuous process improvement metrics.

The IPI documents are reviewed by a Quality Technician, for accuracy and completeness, prior to being scanned and saved in electronic format for future reference.

Visual Inspections

It is crucial to establish the visual requirements necessary for the application and for the fitness for use and to convey these requirements to the pultuder. ASTM D 4385 Standard Practice for Classifying Visual Defects in Thermosetting Reinforced Plastic Pultruded Products is an excellent reference document and can be used to establish documented visual standards. Of course, it is always a good idea to modify the document as required depending upon the fitness for use. The standard allows for three levels of visual classification, with level one being very stringent and level three being the least stringent.

Standard visual tolerances should be built around the ASTM D 4385 standard. This standard needs to be clearly communicated to the plant floor. For Example, each production line contains a binder that houses the visual standards, in power point format, with definitions and color photos. An example is presented in Illustration One.

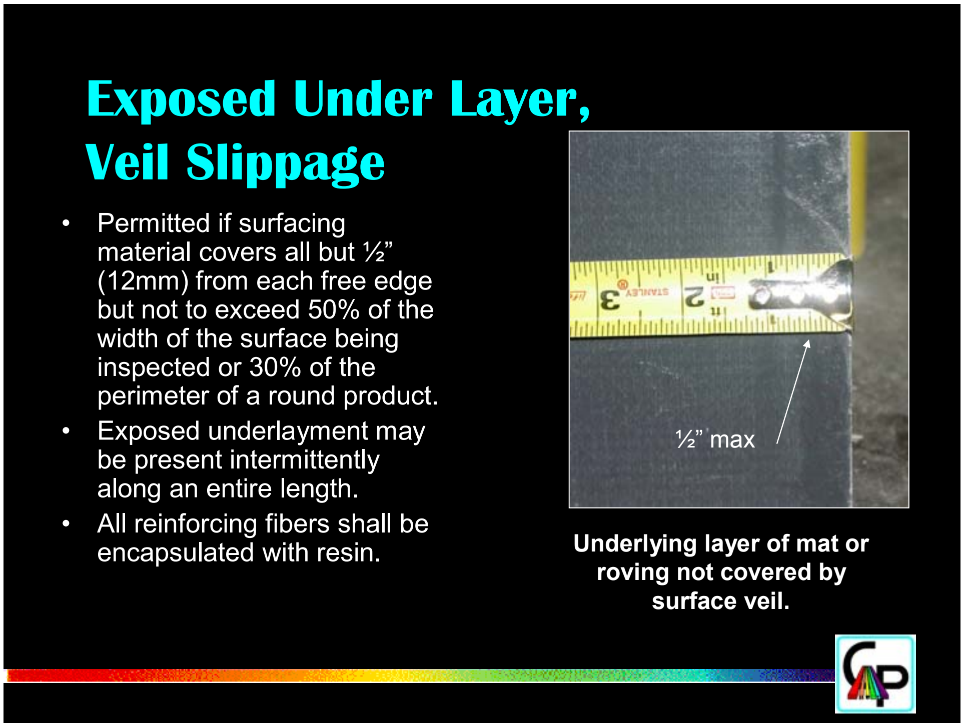

Illustration One

Visual inspections are also critical for evaluating pultruded sections for strength reducing defects. One such inspection is performed visually on each cut section. The cut section should be evaluated for possible delaminations, cracks, dry fiber, and pinholes to name a few.

Illustration Two depicts a delamination or separation of reinforcement plies. Delaminations are critical to the structural behavior of the profile and are cause for rejection. Delaminations are also detected via visual inspection of the interior and exterior of the profile. Delaminations can show up as elevated sections or large blisters on the surface of the profile.

Illustration Two

All end cuts and 100% of the exterior surfaces of the profiles are visually inspected. The Interior of profiles are visually inspected with the aid of a light.

Dimensional Inspections

As with the visual inspections, dimensional requirements are also crucial and should be established dependent upon the fitness for use. Pultruders typically publish their documented dimensional standards on their web site and in product literature. The majority of the industry has standardized on ASTM D3917 as the governing minimum dimensional standard. Dimensional standards should be developed based upon ASTM D3917, your pultruder's experience, and the part application.

In-process dimensional checks are required to be performed as outlined in the internal pultrusion manufacturing procedure. Specifically, QA toleranced drawings along with engineering and visual specifications are required to be on the production floor at the pultrusion machine prior to and during production. The drawings are incorporated into an IPI inspection document as detailed in Illustration Three. The documented inspections are to be completed between every third and fourth hour per twelve hour shift. The operator is responsible for the quality of every part and to document that inspections are being performed and that the pultrusion is being manufactured within the set QA parameters. Illustration Four depicts a wall thickness check of a square tube with calibrated dial calipers that have been calibrated per the documented calibration procedure. Random documented audits are performed by QA personnel in order to verify that the line operators are performing their measurement and inspections per the documented procedures.

QUALITY ASSURANCE STANDARD

CUSTOMER:	Composite Cooling Structures		
PART NAME:	Heavy Column		
PART NUMBER:	CT530	Drawing Number:	ct.530.part Rev. 0
DATE:	April 26, 2004	Revision: 3	

VISUAL STANDARDS

Reference: Creative Pultrusions, Inc. Standard Practice for Classifying Visual Defects
Form: CPQ008-1206.1C

MEASURABLE STANDARDS

- **LENGTH**: Per order (+) 1/4" (-) 1/4".
- **SQUARENESS of END CUT**: (+/-) 1/8" maximum deviation from square.
- **WARPAGE**: 0.025" per foot of all directions. Check with a string (no weight minimizing the warp).
- **DIMENSIONAL SPECS:** (all dimensions in inches)
- **MISCELLANEOUS: Run red thread on the top outside surface.**
- Stamp each part on the end with the date and shift.

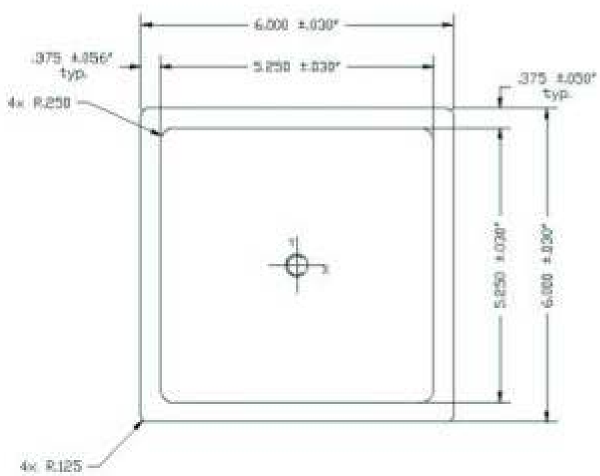

Illustration Three

Illustration Four

Strength of Materials Inspection

Most pultruders convey their products mechanical and physical properties via a pultrusion design manual and product data sheets. Currently there are no set standards for deriving published values. Some pultruders publish values based on two or three standard deviations subtracted from the mean value based on a set number of coupon values. No formal standard exists that describes to the engineering community or to a pultruder how the data is to be determined and reported. For this reason, it is necessary for the customer and designer to understand how a pultruder derived their published design values.

Both custom and standard pultruded shapes require minimum design values to be published which have been agreed upon by both the customer and pultruder. It is essential that a QA system be built around the design requirements of the finished product. For example, both coupon and full section testing should be performed to determine the minimum design values. The data should be derived from multiple production runs and should contain a sufficient number of data points. The number of data points may range from 25 to 50. Typically, two to three times the standard deviation is subtracted from the mean in order to generate the minimum published design values. The manufacturer should then monitor the mechanical property values via coupon and full section testing at some agreed upon interval. As an example, at approximately 5,000 feet intervals, samples are pulled from the pultrusion line, tested and compared to the minimum agreed upon values. The test results can be used for both QA purposes, as well as, continuous process development tools.

An example of some common QA tests can be viewed in Illustrations Five and Six. Illustration Five depicts a full scale beam tested to failure. Specifically, a pultruded beam is positioned in a full section test fixture, and loaded in a three point bend scenario. Load versus deflection measurements are recorded until failure. The load/deflection values are utilized to verify that the minimum stiffness values are being acgieved. The failure load is utilized to verify that the beam meets the minimum strength requirements. Illustration Six depicts a full section test being performed on a connection. The full section test verifies that the minimum hole bearing strength is being achieved. In addition to the full section hole bearing test, coupon level testing is performed to verify the lengthwise compression strength and modulus of elasticity. Both values are critical to the structural behavior to cooling tower structures.

Composite Cooling Solutions CT505.707 Test Report

Test Procedure:	3-point Bend				
Profile Part Number:	**CT505.707**	**Load Pad Size**	4"x12"	**Part wt.**	2.66 lbs/ft
Fabrication Part Number:	NA	**Test Location:**	CPI		
Manufactured Date:	6/25/2008	**Lab Temp**	70F		
Test Date:	6/26/2008				
Length: (in)	120	**Calibration Date:**			
Test Span: (in)	108	**Ix of Profile (in^4)**	17.179		
Test Number:	1	**Sx of Profile (in^3)**	5.726		
		Shear load at failure (lbs)	**4,993**		
		Moment @ failure (ft-lbs)	**22,466**	**Minimum Required**	
		Failure Load: (Lbs.)	**9,985**	**7033 lbs.**	
		Failure Mode:	**Interlaminar seperation of the top plate**		
		Stress at failure (psi)	**47,083**	**40000 (psi)**	
		Avg. E-Modulus (psi)	**5.20E+06**	**5E6 psi**	

Point Load (lbs.)	**Deflection (in)**	**E-modulus**
1000	0.289	5.29E+06
2000	0.579	5.28E+06
3035	0.881	5.26E+06
4000	1.171	5.22E+06
5000	1.465	5.21E+06
6000	1.775	5.16E+06
7000	2.072	5.16E+06
8000	2.385	5.12E+06
9000	2.699	5.09E+06
	Average E-mod.	**5.20E+06**
	9985	**Failure**

Set up

Failed sample

Illustration Five

Lab Analysis CT530.2B3 Strength Verification

Property of Creative Pultrusions, Inc.
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Alum Bank, PA 15521
P:(814) 839-4186
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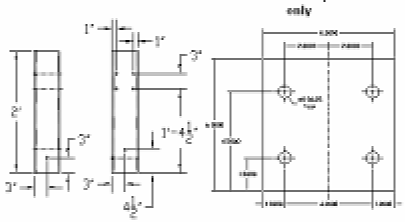
Analysis:CT530.202 QA strength verification based on critical design properties.

ASTM TEST	Coupon Testing	Average Value from 5 Samples	Min. Required
ASTM D695	Comp. Strength LW (psi)	58,786	40,000 psi
ASTM D695	Comp. Modulus LW (psi)	5.19E+06	4.5E+6 psi

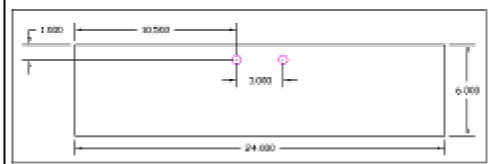
Date Manufactured:	7/2/2008			Temperature:	70°F	Bolt Torque:	25 lb-ft
Date Tested:	7/3/2008			Hole Diameter:	9/16"	Wall thickness (A) t	0.375
Tested By:	D.Crawford			Bolt Diaameter:	1/2"	Wall thickness (B) t	0.384
Construction:	Ref. Spec. Sheet			Bolt Type:	316 SS	Average Wall thickness t	0.380

Drill per the CT530 Connection spec.

Hole diagram for CT530 plate connection Note: Use top two holes only

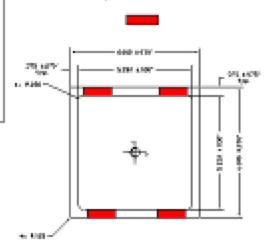


lengthwise Hole Bearing Test

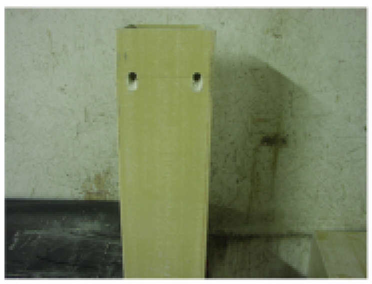


45 degree angle drill pattern

Coupon Extraction Location



CT530
LengthwiseConnection test



Failure Mode

Typical failure mode

45 Degree Angle test

CT530 1/2" dia. Hole Bearing Connection Test Lengthwise Direction

Sample #	Date Produced	Ultimate Load (lbs)	Hole Bearing Stress at failure (psi)	Failure Mode	Min Required (psi)
1	07/02/08	25,480	33,570	Hole Bearing	25,000

Test Procedure:Collect the CT530 sample from the production line and document the details noted above. Drill the profile per the CT530 connection detail. Secure the CT530 profile as depicted in the photo. Secure the aluminum push plate with the 316 SS 1/2" bolts and torque the nuts to 25 lb-ft. Cover the column with the test cap and apply the load until failure occurs. Record the load above. Note: Only two bolts are inserted into the top two holes due to strenght limitations of the test machine.

CT530 1/2" dia. Hole Bearing Connection Test 45 Degree Angle

Sample #	Date Produced	Ultimate Load (lbs)	Average wall Thickness (in)	Number of Bolts	Hole Bearing Stress at failure (psi)	Bolt Diameter (in)	Min Required (psi)
1	07/02/08	21,036	0.380	2	27,714	0.500	25,000

Test Procedure:Collect the CT530 sample from the production line and document the details noted above. Drill the profile per the CT530 45 degree connection detail. Secure the CT530 profile as depicted in the photo. Secure the tube into the fixture with the 316 SS 1/2" bolts and torque the nuts to 25 lb-ft. Apply the load until failure occurs. Record the load above.

Illustration Six

ASTM D 7290-06 initiative

Some specifications, evolving from the LRFD initiative, are leaning towards the adoption of the ASTM D 7290-06 Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications. This ASTM-endorsed procedure describes the statistical method required to provide, the characteristic value material property, representing the 80 % lower confidence bound on the 5th-percentile value of a specified population. Characteristic values determined using this standard practice can be used to calculate structural member resistance values in design codes for composite civil engineering structures and for establishing limits upon which qualification and acceptance criteria can be based. The adoption of this specification will go a long way in standardizing the method used by pultruders to establish minimum design values. The D7290-06 statistical method weighs heavily on the number of specimens tested and the coefficient of variation (COV) between test specimens. Therefore, the tighter the COV, the less the reduction factor applied to the mean property value. Pultruders with good process control, thus less variation in material properties, will be rewarded by publishing higher values than those pultruders with less process control.

The adoption of the standard will encourage the pultrusion industry to strive for continuous process improvement. The end result will be the output of shapes that will be more efficient and cost competitive against wood, concrete and steel.

Fabrication Inspection

Fabrication inspection is very similar to the pultrusion inspection process noted above. The initial fabricated profile is put through a First Article Inspection as outlined in the written procedure. The documented inspection is required to be signed by the Fabricator and the Fabrication Supervisor releasing the part to production status. Then, during the fabrication process, a minimum of three documented inspections are required per shift. The first and last part fabricated requires a documented inspection. The Fabricator is responsible for the quality of each part fabricated and should perform more inspections than are required to be documented. The documented inspections are reviewed by a QA technician, for completeness, prior to being saved in the internal database for future reference. Note that random documented inspections are performed by QA technicians in order to provide oversight to the fabrication inspection process.

Construction Site Receiving Inspection

The Pultrusion manufacturer, in conjunction with the field-erected cooling tower provider, has developed a Quality Assurance/Inspection training program for the construction field superintendents. The program involves arming the field superintendents with manuals that describe possible visual and mechanical defects associated with pultrusion. The superintendents know exactly what to look for when receiving a shipment of pultruded profiles. The pultrusions are visually inspected to ensure, one last time, that the products meet the standards prior to becoming a permanent member in a cooling tower structure.

In the event a substandard section is found, either due to manufacturing defects or shipping damage, a well trained construction superintendent can make the call to either repair the member or replace it. Your inspection training program/inspection manual should include definitive information regarding which types of defects are filed repairable, as well as, a step by step repair procedure for correcting the defects. The manual should also include a repair authorization form, to be completed by the cooling tower provider, and a corrective action plan in order to document the issue and to ensure that actions have been instated to keep similar issues from arising again.

Conclusion

The pultrusion manufacturing process, like many others, can be described as a combination of engineering and art, derived from years of manufacturing experience.   As time progresses and more engineering and process controls are applied to everyday production, the art portion will continue to diminish and sometime in the future will account for less of the pultrusion manufacturing discipline. But, there is no substitute for experience in developing and maintaining a quality FRP pultrusion product.

A quote that I picked up from the book THE TOYOTA PRODUCT DEVELOPMENT SYSTEM has stuck in my mind.   "A company that cannot standardize will struggle to learn from experience and will rely on little more than undocumented hearsay and a wide range of opinions among its employees only to eventually discover that it has been here before." I relate this statement to the pultrusion industry as a whole.   Although the industry uses many ASTM specifications, and I'm sure every pultruder has their own QA/QC systems and procedures, the pultrusion industry has a great need to adopt standards that will place everyone on a level playing field.

The LRFD initiative, along with the adoption of the ASTM D 7290-06, will allow our industry to mature and will allow for the design and construction of more efficient and economical cooling tower structures.

The Cooling Technology Institute will be well advised to monitor and adopt some of the procedures and standards that will come as a result of the pultrusion industry's lead in the **Load & Resistance Factor Design** initiative.

The general description of the QA/QC program between this major pultrusion company, and one of its major customers for structural FRP components is intended to get pultruders, designers, and owners thinking about the importance of an agreed upon manufacturing and design standard, as well as, an agreed upon QA and Inspection Program . As we see more and more pultruded parts being shipped in from new overseas suppliers, it is crucial that all pultruders be held to the same high quality standards.