

Review

Assessment of fiberglass fortified plastic and rapid cooling tower

Avicenna E. saadi

Department of Mechanical Engineering, Islamic Azad University of Mashhad, Mashhad, Iran.
Email: prof.saadi07@yahoo.com

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An evaluation of applicable materials for an industrial cooling tower is presented in this study. Advantages and disadvantages of different sets of materials including reinforced concrete and FRP (Fiber-Reinforced Polymer Composites) for cooling tower structure are discussed. After evaluating each material characteristic, the one case study of cooling tower is considered for cost estimation. The results showed that the FRP is best structural material for cooling tower construction mainly due to its superior performance in sea water corrosive environment. From the economical point of view, although the construction cost FRP structure is a little higher, this can be easily balanced by less maintenance costs of FRP structure considering its high durability in hostile environments.

Key words: Fiber-reinforced polymer composites (FRP) cooling tower, concrete cooling tower, polyvinyl chloride (PVC) fills.

INTRODUCTION

Current paper covers a review of applicable materials for an industrial cooling tower. Cooling towers are usually exposed to severe internal operating conditions such as high temperature, wet, corrosive and abrasive environments and sustained loading. After many years of utilizing redwood in cooling towers because of its natural tendency to inhibit decay, the quality of redwood diminished and Douglas fir was introduced to the market. However, the negative effect of Douglas fir was that it deteriorated rapidly in comparison to the redwood. Various methods of pressure treatment and incising were developed to offset the micro-organisms that attacked and eventually depleted the wood. In addition to the wood being supplied and utilized by the tower market, other materials such as galvanized steel, stainless steel, concrete, and in some cases asbestos cement board casing panels were utilized on field erected towers. During the 1970s, the environmental movement caused several industries to be scrutinized. The chemicals used to pressure treat the wood were viewed as possible hazards, therefore resulting in tighter controls and new formulations to be applied. The end result was an increase in the material cost of wood. Asbestos was also

under scrutiny and ultimately dropped from the industry due to the threat it posed of potential health hazards.

Through the 1980s and into the early 1970s, various existing cooling tower companies as well as newly formed organizations were looking for alternative building materials that would offer comparable if not greater strength to the materials being utilized while remaining competitive.

FRP materials have been employed in cooling towers as secondary components (including pipes and fan stacks) for over 30 years, the primary structure traditionally being constructed from wood, concrete or steel. However, FRP composites are now prevailing as the most suitable primary structural material in view of their superior performance in hostile environments and other beneficial properties. Consequently, the cooling tower industry has seen a rapid uptake of FRP towers in recent years. The design flexibility of FRPs has allowed new types of cooling tower to be developed which are more efficient and cost effective than previous designs and materials. The modular, cellular construction systems provide structures of high integrity that can be rapidly installed. The desirable environmental properties of FRP

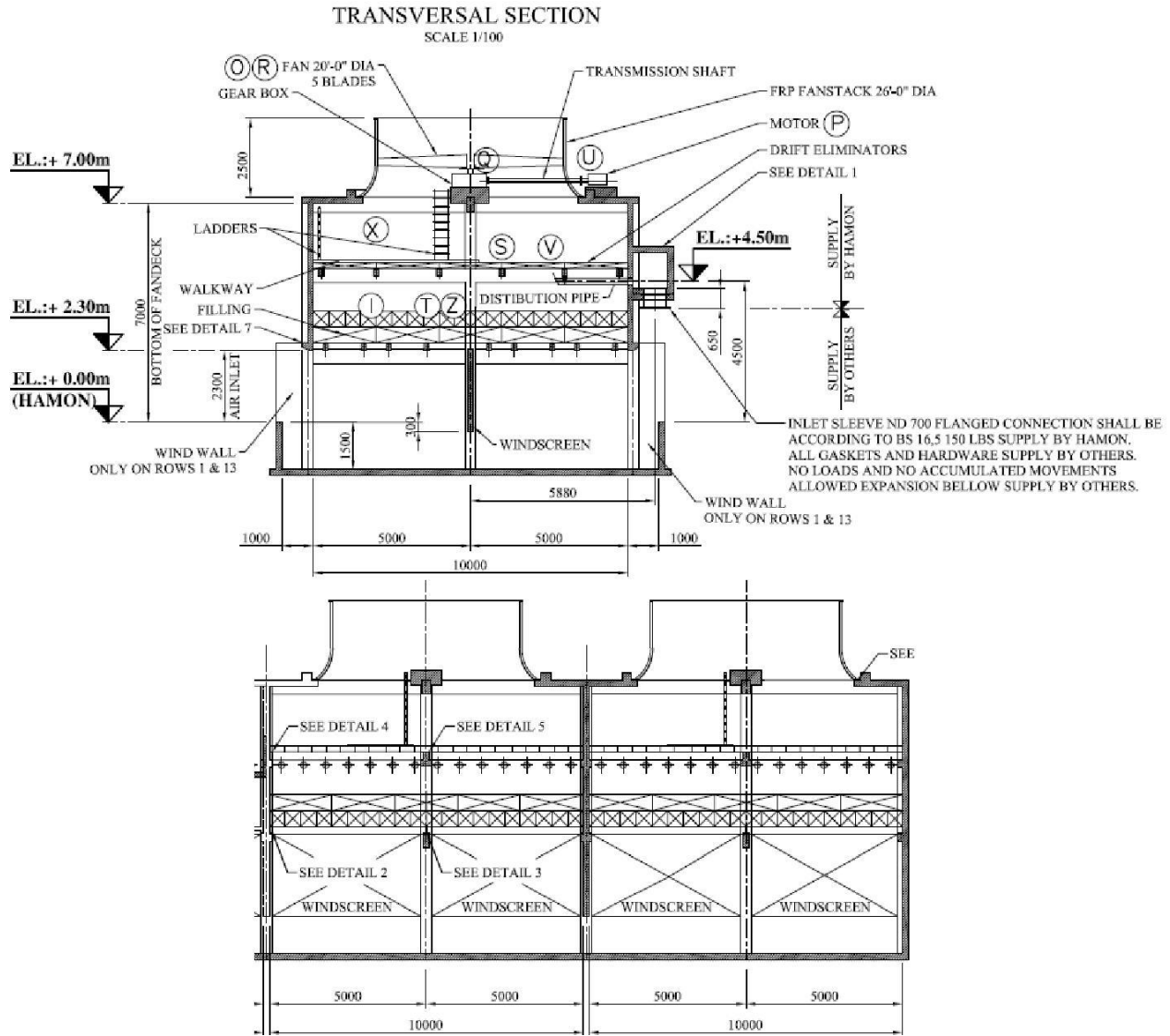


Figure 1. Section of cooling tower

materials also help the structures meet the increasingly stringent legislation imposed on them.

In order to recognize the advantages and disadvantages of different applicable materials as cooling tower structural members, a brief review of these sets of materials are presented subsequently. The configuration of cooling tower is shown in Figure 1.

REINFORCED CONCRETE COOLING TOWERS

The complete structure including exterior walls, fan deck, partitions and windscreen are designed in order to be executed in reinforced concrete material with all the specific requirements of this particular application. The fill consists of modules designed with vertical flutes, 20 mm

opening, for optimum cooling and minimum fouling characteristics. The fill comprises of vacuum formed PVC (polyvinyl chloride) sheets, bonded to form modules 500 mm high by 500 mm wide with a nominal length of 2000 mm. Fill is supported from below by tower structural beams and covers the entire internal plan area of the tower. Hot water is introduced to the tower through ground headers, valves and risers provided by others. Tower headers have one outside flanged connection per cell. The main header consists of a concrete flume. PVC distribution pipes are fitted into the flume and uniformly cover the plan area of the tower; these pipes are securely fitted with spray nozzles. The main header consists of concrete flume. The fan consists of multiple, manually-adjustable blades attached to a steel hub. The fan deck is accessed by a caged ladder and/or concrete stairway.

Hand railing is provided around the perimeter of the fan deck. Access to the inside of the tower is through a lockable hatch in the fan deck, with a ladder leading down to the drift eliminator level for inspection of the cooling tower internals. From there, removable FRP grating allows access to the whole plan area and to a second ladder leading up to the gear reducer. The fan stacks, as standard, are constructed of heavy, ribbed fiberglass panels bolted together.

FRP COOLING TOWERS

FRP materials have many key properties which make them suitable for use in cooling tower applications. Their inherent corrosion, moisture and temperature resistance significantly increases the durability and service life of the structure, as well as reducing the need for maintenance. FRP structures also exhibit superior dynamic response to high wind loads in comparison with conventional structural materials. Maximizing the glass volume not only enhances the material strength and stiffness properties, but reduces creep and hydrothermal effects due to the lower resin content. FRP parts offer more flexibility of shape than steel or timber. Components can therefore be manufactured with features that enable rapid connection and modular construction, minimizing the material content whilst providing the required buckling strength. The modular design methods associated with FRP structures are quicker and easier. A standard range of field erected towers can be formulated efficiently from the initial design. Suitable limit-state design methods account for the variability of all the material parameters - allowing production of safe but efficient designs.

Although comparable to conventional tower structure materials in initial cost, FRP materials offer significance through life cost savings. They have longer service lives, lower replacement frequency and require little maintenance. The lower replacement frequency also reduces the significant process downtime costs associated with structure replacement. Less raw material use in the overall structure brings associated cost savings and gains are made from the rapid installation, which is much less labor intensive due to the lightweight components. Transportation costs are also reduced as less, lighter weight material is required.

FRP is preferable to wood in instances where environmental issues are a factor since it contains no preservatives that could leach into the water being cooled. FRP materials can aid compliance to legislation regarding discharge to rivers. Greater cooling capacity means that the water released can closely approximate the temperature of the river as stipulated in regulations. It has also been proved that composite tower structures offer reduced noise emission due to their preferable dynamic behavior. It is worth-mentioning that the acceptance of pultruded FRP towers has become so

widespread that it is estimated over 70% of new and replacement field erected towers in the USA are specified with pultruded FRP structures. Pultruded FRP cooling towers are in service today in numerous applications.

Type II, III, IV pultruded shapes are acceptable with a synthetic polyester fibre-surfacing veil with a minimum effective thickness of 10.0 ml minimum to provide long term UV (ultraviolet) protection.

Grade 1 or grade 3 resins are acceptable for the structure with a flame spread rating of 25 or less per ASTM E84 flame spread test (CTI STD 137, 94). The resin must be high quality and chemical resistant. The resin shall be an isothallic polyester, vinyl ester or urethane type resin system.

The glass reinforcing may be continuous roving, continuous strand mats; woven or non-woven fabric, unidirectional fabric or a combination of these. The reinforcing shall be made from type C or type E glass fibers.

Additives to the resin mix may be used to improve performance characteristics of the final composite. Typical additives are UV inhibitors, antimony trioxide as an improved flame retardant and a minor percentage of fillers. Any mold release that is used must not reduce the long-term strength of any epoxy joint that may be used in the tower structure.

In general, advantages and disadvantages of the FRP materials can be noted as follows:

Advantages:

1. High specific strength.
2. Good in-plane mechanical properties.
3. High fatigue and environmental resistance.
4. Adjustable mechanical properties.
5. Lightweight.
6. Quick assembly/ erection.
7. Low maintenance cost.
8. Highly cost-effective.

Disadvantages:

1. Lightweight (problematic in wind resistant design).
2. Brittle.
3. High initial costs.
4. Low to moderate application temperature (-20 up to 80°C).
5. Low fire resistance (sometimes with unhealthy gases).

Most structural profiles are produced in conventional profile shapes similar to metallic materials. Being somehow similar in geometry and properties, however not standard geometry, mechanical and physical properties are used by all manufacturers.

A variety of continuous and woven reinforcement types are commonly used in fiberglass pultrusions. The four major types are E-Glass, S-Glass, Aramid, and Carbon.

Table 1. Typical properties of fibers used in pultruded structural profiles.

| Property | E-Glass | S-Glass | Aramid | Carbon |
|---------------------------------------|---------|---------|---------|-------------------|
| Density (lbs/in ³) | 0.094 | 0.090 | 0.053 | 0.064 |
| Tensile strength (psi) | 500,000 | 665,000 | 400,000 | 275,000 - 450,000 |
| Tensile modulus (10 ⁶ psi) | 10.5 | 9.0 | 9.0 | 33-35 |
| Elongation to break (%) | 4.8 | 2.3 | 2.3 | 0.6-1.2 |

Table 2. Typical properties of resins used in structural pultrusions.

| Property | Polyester | Vinylester | Epoxy |
|--|-----------|------------|--------|
| Tensile strength (psi) | 11,200 | 11,800 | 11,000 |
| Elongation (%) | 4.5 | 5.0 | 6.3 |
| Flexural strength (psi) | 17,800 | 20,000 | 16,700 |
| Flexural modulus (10 ⁶ psi) | 0.43 | 0.54 | 0.47 |
| Heat distortion temperature (°F) | 160 | 220 | 330 |
| Short beam shear (psi) | 4,500 | 5,500 | 8,000 |

The most commonly used reinforcement is E-Glass. Other reinforcements are more costly, and therefore are used more sparingly in construction. Table 1 provides some physical properties of the four reinforcing fibers CTI (CTI STD 137, 94).

FRPs are produced usually by pultrusion method. There are two types of reinforcing fibers in FRP materials called continuous strand mat and continuous strand roving

Continuous strand mat

Long glass fibers intertwined and bound with a small amount of resin, called a binder. Continuous strand mat provides the most economical method of obtaining a high degree of transverse or bi-directional strength characteristics. These mats are layered with roving, and this process forms the basic composition found in most pultruded products. The ratio of mat to roving determines the relationship of transverse to longitudinal strength characteristics.

Continuous strand roving

Each strand contains from 800 to 4,000 fiber filaments. Many strands are used in each pultrusion profile. This roving provides the high longitudinal strength of the pultruded product. The amount and location of these "rovings" can, and does alter the performance of the product. Roving also provides the tensile strength needed to pull the other reinforcements through the manufacturing die. Since pultrusion is a low-pressure process, fiberglass reinforcements normally appear close

to the surface of the product. This can affect appearance, corrosion resistance or handling of the products. Surface veils can be added to the laminate construction, and when used, displaces the reinforcement from the surface of the profile, creating a resin-rich surface. The two most commonly used veils are E-Glass and polyester. Resin formulations typically consist of polyesters, vinyl esters, and epoxies, and are either fire retardant or non-fire retardant.

Resins are another important component of FRP materials. Polyesters and vinyl esters are the two primary resins used in the pultrusion process. Epoxy resins are typically used with carbon fiber reinforcements in applications where higher strength and stiffness characteristics are required. Epoxies can also be used with E-glass for improved physical properties. Typical physical properties of resins used in pultruded structural shapes are given in Table 2.

Various fillers are also used in the pultrusion process. Aluminum silicate (kaolin clay) is used for improved chemical resistance, opacity, good surface finish and improved insulation properties. Calcium carbonate offers improved surfaces, whiteness, opacity and general lowering of costs. Alumina trihydrate and antimony trioxide are used for fire retardancy. Alumina trihydrate can also be used to improve insulation properties. Resin formulations in a pultruded fiberglass structural shape can be altered to achieve special characteristics as dictated by the environment in which the shape is intended for use.

FRP CASE STUDIES

A case study design of FRP cooling tower is considered

here. The tower is a FRP structure with PVC fills. The scope of the project was to furnish and install a multi-cell induced draft counter flow FRP structure cooling tower, custom designed to be field erected within a contractor-supplied reinforced concrete basin. The tower structure was field erected from pultruded FRP structural members that were designed specifically for cooling tower application.

The FRP members were constructed of a fire-retardant, self-extinguishing resin system with a flame spread rating of 25 or less. The FRP members were also protected from UV degradation by the use of surfacing veils and UV stabilizers incorporated in the resin system. The tower structure was designed in accordance with CTI STD 137 (94) to withstand the following dead and live loads as per the following:

1. Wind load: Per applicable building code. Wind load is to be applied to tower walls and fan stack. Tower casing shall not be considered as sacrificial when calculating tower structure loads.
2. Seismic load: Per applicable building code, to be applied to total operating weight of the tower.
3. Deck dead load: Weight of deck materials.
4. Deck live load: 60 PSF (280 kg/m²) equally distributed load over entire usable roof deck.
5. Fill support dead load: Dry weight of fill material plus water hold up weight plus 15% additional allowance for fill clogging.
6. Fill support live loads: 300 lbs (140 kg) of concentrated load for temporary maintenance foot traffic.
7. Eliminator dead and live load: Dry weight of drift eliminators.

The strength of the FRP members was de-rated for long term temperature exposure. The maximum operating temperature exposure for design purposes was 40°C.

When designing connections, the minimum service factor for dead loads allowed for a connection is 4.0. The service factor for connections with temporary loads due to wind, seismic, etc. may be reduced to 2.5. Either a mechanically bolted joint or combination of mechanical and adhesive (epoxy) joints may connect the union of two or more FRP components. Either joint is acceptable when properly designed and installed. When connecting hollow type structural members by the use of bolted joint, the service factor for bearing dead loads must be 4.0 minimum and 2.5 minimum for live and dead loads.

Bearing hole elongation of 4% or greater is considered failure when stress is applied to any joint. On bolted joints of hollow tube members, 304 stainless washers are required to keep the connections tight as well as protect the FRP members from over tightening and cracking the FRP (CTI STD 137, 94).

REINFORCED CONCRETE CASE STUDIES

A case study design of concrete cooling tower is considered here. The concrete tower structure was designed in accordance with ACI codes (ACI 318, 2004) to withstand the ASCE 7 dead and live loads (ASCE 7, 2005). Earthquake load in this study is calculated based on ASCE 7 (Ultimate level) therefore earthquake load used in the load combinations should be divided by 1.4 to decrease it to service level.

COST ESTIMATION

In order to compare construction costs of concrete and FRP structure cooling towers, cost estimation is conducted based on structural analysis and design for the cooling tower under study. The construction cost of FRP structure is about 10% higher than the reinforced concrete one, which is due to the fact that FRP products are more expensive than common structural materials like structural steel and reinforced concrete. But considering less maintenance costs of FRP structures due to the high durability in corrosive environments, this increased construction cost of 10% appears to be nothing, making FRP a suitable material for cooling tower structures.

CONCLUSION

An evaluation of applicable materials for an industrial cooling tower located was presented in this study. Advantages and disadvantages of different sets of materials including reinforced concrete and FRP for cooling tower structure were discussed. After evaluating each material characteristic, FRP was selected as the best structural material for cooling tower construction mainly due to its superior performance in sea water corrosive environment. From the economical point of view, though the construction cost FRP structure is a little higher, this can be easily balanced by less maintenance costs of FRP structure considering its high durability in hostile environments.

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