Optimum Material Solutions
For
Industrial Hydrometallurgical Equipment

T. Johnson, D. Kelley and J. Chen
Ashland Performance Materials
5200 Blazer Parkway
Dublin, Ohio 43017
USA

Abstract:

Hydrometallurgical processes can be exceptionally corrosive. Operating conditions associated with metal extraction and refining require materials of construction that can withstand process acids and acid chlorides at temperatures up to 90°C (194°F). Process vessels, piping, scrubbers and ducting can be rapidly compromised in these aggressive environments if not designed with great care. Design engineers are frequently challenged to find materials of construction that can stand up to hydrometallurgical processes especially for copper, zinc, nickel, cobalt and uranium. This paper will evaluate a variety of material solutions to determine which provide attractive economics for initial procurement as well as high durability for reasonable life cycle costs. The comparative cost and durability information presented is intended to enable design engineers and material specialists to choose materials of construction that will be the most beneficial for their projects.

Introduction:

Mining activity in a number of metal ores has been running quite high over the last few years. In particular, those metals that employ acid functional extraction processes such as copper, nickel cobalt and uranium have been particularly active.

The world's largest nickel mine – the massive $4.76 billion Ambatovy nickel mine on the African island nation of Madagascar is nearing completion. When it reaches its full production capacity in 2013, the mine will produce 60,000 MT/yr of nickel and 5600 MT/yr of cobalt. Coming on the heels of the Ambatovy project is the Long Harbour Processing Plant in Newfoundland, Canada which will process the ore from Vale's Voisey Bay mine in Labrador. Voisey's Bay is expected to generate more than 50,000 MT/yr of nickel ore when it starts up in 2013. Next up will be the Boleo project in Mexico on the Baja peninsula. When commissioned in 2013, the $858 Million Boleo project is expected to produce 60,000 MT/yr copper, 3100 MT/yr cobalt, 36,000 MT/yr zinc and 100,000 – 250,000 MT/yr manganese carbonate.

High nickel alloys and rubber lined steel have been used for decades to design corrosion resistant equipment for mineral processing environments. These materials demonstrate reasonable resistance to corrosion for most environments. Unfortunately, higher nickel alloys are quite expensive. Rubber lined steel is a bit more affordable but requires continuing service over time which ultimately drives up its cost as well. FRP (Fiberglass Reinforced Plastic) has also been used extensively in mineral processing for tanks, piping and ducting employed in aggressive environments. Today, more and more design engineers and material specifiers are calling for FRP composites for both new and replacement equipment used in the refining and processing of a variety of metal ores.

While it is true that corrosion-resistant metal alloy prices have abated somewhat in the last few years, they now appear to once again be on an upswing. As the global economy strengthens and developing nations increase their infrastructure build, we are seeing resurgence in metal pricing – most notably copper, nickel and stainless steel. The charts below courtesy of Infomine.com tell the story.

Due to specialty metals pricing volatility and lack of availability, the use of non-metallic materials of construction in metal extraction and refining processes has increased significantly in recent years. One of the most common non-metallic materials of construction used in metal extraction and refining processes today is Fiberglass-Reinforced Plastic (FRP). These processes often require materials of construction that can resist acids and high concentrations of acid chloride salts. As shown in Table 1, FRP based on epoxy vinyl ester resin has the same chemical resistance to acid and better resistance to acid chloride salts than alloy C-276 and is superior to 2205 stainless steel in both cases.

Table 1. Epoxy Vinyl Ester Resin Chemical Resistance Compared to Metal.

Materials	Sulfuric Acid	Hydrochloric Acid	Acid Chloride Salts
FRP made with epoxy vinyl ester resin	100°C to 30%	80°C to 15%	100°C All conc.
2205 Stainless Steel	30°C to 30%	60°C to 1%	65°C to 2000 ppm @ low pH
Alloy C-276	100°C to 30%	80°C to 15%	65°C to 50M ppm @ low pH

Other non-metallic materials of construction such as organic coated steel and rubber-lined steel are cost competitive with FRP. However, FRP has a much better life cycle cost than these materials, because it requires less maintenance over the life of the equipment made from it. Depending on the environment, FRP can have a 20 year service life or longer.

Moreover, equipment made from FRP costs less than the same equipment made with the specialty metals shown in Table 1, and the cost is more stable from year to year. It should be pointed out that the prices quoted above for FRP are turn-key prices and include installation, whereas the above metal prices are the raw materials only.

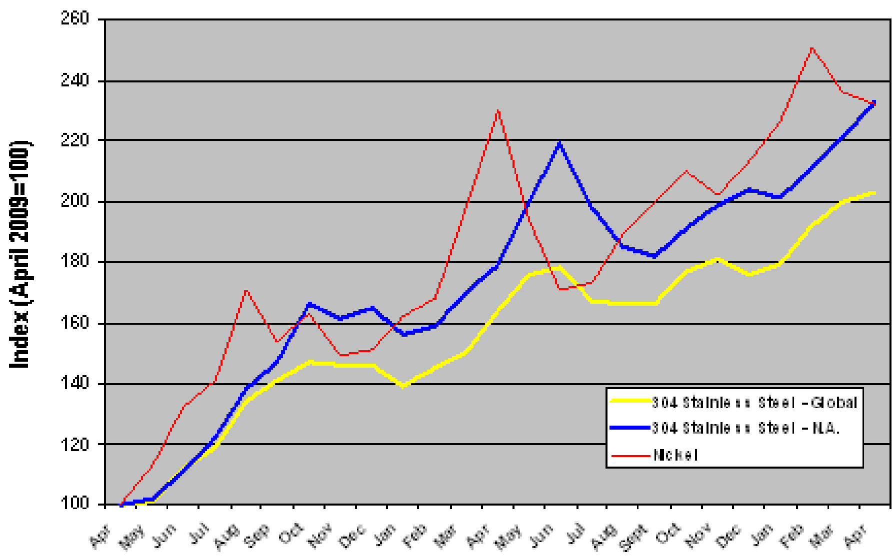
Table 2. 2006 to 2009 Cost Comparison of Construction Materials

Construction Material	Cost*	Cost Ratio
Shop Fabricated FRP	$540 / Sq M	1.0
Field Fabricated FRP	$750 / Sq M	1.4
2205 stainless steel 3/8 inch plate	$2400 / Sq M	4.4
C-276 clad carbon steel	$3550 / Sq M	6.6

*Cost obtained from 2011 Ashland North America survey.

Stainless steel prices continue to trend rapidly upward in concert with the price and availability of nickel. As the global economy strengthens and developing nations increase their infrastructure build, base metal pricing – most notably copper, nickel and stainless steel are expected to continue their upward march (Figure 1). Moreover, the availability of stainless steels and higher nickel alloys is falling off and delivery times are lengthening considerably.

Figure 1. Stainless Steel and Nickel Price Volatility – April 2009 - Present



Source: International Monetary Fund; MEPS Ltd

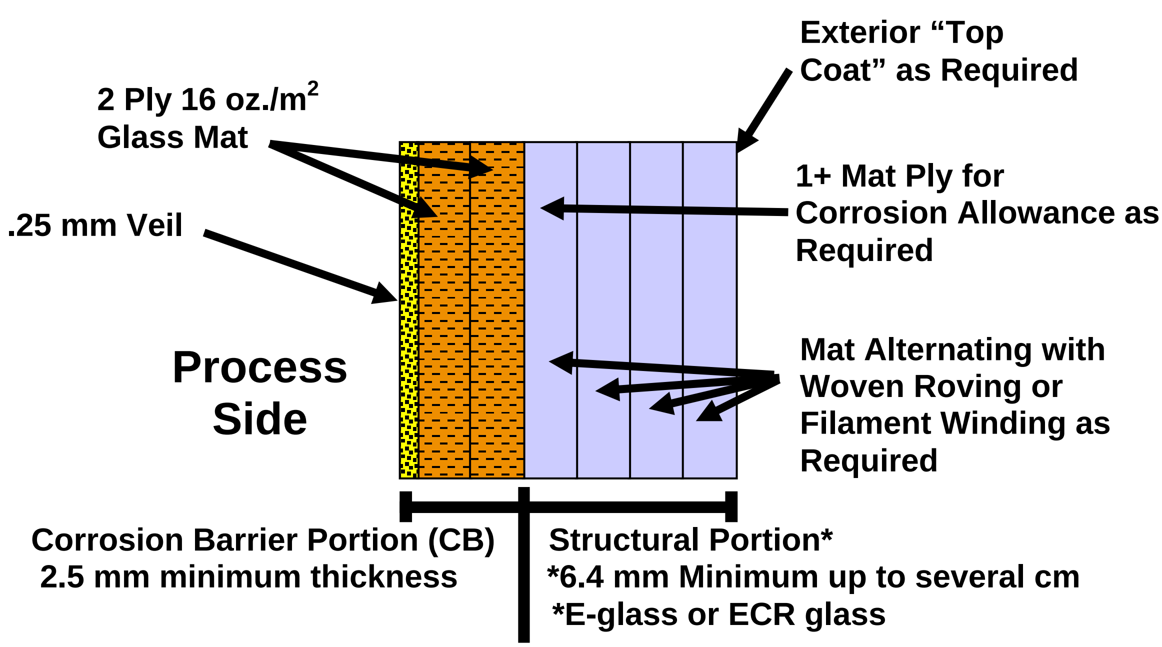
The following sections of this paper will show how corrosion resistant FRP is designed as well as where corrosion resistant FRP can be employed in place of metals and rubber-lined steel in order to significantly reduce cost.

Corrosion Resistant FRP Construction

FRP most commonly consists of glass fibers that are bonded together with a thermoset resin to form a composite structure. The most common corrosion resistant FRP structures are tanks pipes, ductwork, and scrubbers. In corrosive chemical environments, FRP structural layers must be combined with a corrosion barrier to protect the structural layers from chemical attack. The composition of the corrosion barrier takes into account the chemicals present, their concentration, and the operating temperature of the equipment.

The composition of a standard corrosion resistant laminate is shown in Figure 2. From left to right, the figure shows a corrosion barrier consisting of a veil followed by at least two layers of chopped strand mat. The purpose of the corrosion barrier is to provide a resin rich layer of glass to protect the structural layers from chemical attack. The veil layer contains about 90% resin and comes into direct contact with the chemical environment. The chopped strand mat layers back up the veil and contain about 75% resin. The total thickness of the corrosion barrier is normally 100 mils, but the corrosion barrier may be much thicker for very aggressive chemical environments. It is very important to have a properly designed corrosion barrier based on the chemical environment. This information is available from resin suppliers, and they should be contacted for resin and corrosion barrier recommendations.

Figure 2. Typical Corrosion Resistant FRP Laminate Construction



The structural layers, as shown on the right side of the diagram, give strength and stiffness to the FRP. Depending on the fabrication method, the structural layers can consist of a combination of glass types that are applied in layers as needed for the desired properties. The higher the glass content, the stronger and stiffer the FRP becomes. The properties of the structural layer are accomplished through a careful selection of the glass reinforcement types and fabrication methods. The structural layers can consist of heavy layers of woven glass called woven roving alternating with layers of chopped strand mat. Or it can consist of helically wound glass roving interspersed with chopped roving to give high glass content thus high strength structural layers. Others types of construction consist of hoop wound roving with layers of unidirectional glass in the axial direction.

Resin Selection

Resin selection is the first critical step in the design of FRP for chemical service. Not all resins are suitable for chemical resistant applications, so the resin must be carefully selected based on three critical pieces of information: (1) the generic identity of the chemical(s) service, (2) the concentration of each chemical, and (3) the operating temperature of the chemical or chemicals that comprise the chemical environment.

Thermoset resins come in a variety of compositions that greatly affect the chemical resistance of FRP. Corrosion resistant FRP made from epoxy vinyl ester resin has excellent chemical resistance to acids, bases, salts, and many types of solvents. FRP made from epoxy vinyl ester additionally is characterized by unusually good toughness and resistance to cracking commonly caused by mechanical impact and thermal cycling.

In most metal extraction processes, engineering companies will typically specify FRP equipment made from Bisphenol A epoxy vinyl ester resin or epoxy novolac vinyl ester resin. The resin choice will depend on the temperature and concentration of the acid employed in the metal extraction process. FRP made with novolac epoxy vinyl ester resin generally can be used at higher acid concentrations and /or temperatures as well as in solvents. For example, FRP made with Bisphenol A epoxy vinyl ester resin is suitable for 75% sulfuric acid up to a maximum temperature of 38°C (100°F), whereas novolac epoxy vinyl resin is suitable up to 82°C (180°F).

Therefore, when choosing a resin, it is imperative to consult the resin selection guide of a knowledgeable resin manufacturer or contact them directly for a suitable resin recommendation. When dealing with a metal extraction or refining process environment that is not found in the resin manufacturer’s corrosion guide it becomes even more important to contact them directly.

Operating Temperature and Pressure Limitations

Operating temperature limitations are often dictated by the chemical type and concentration. For epoxy vinyl ester resins, most liquids are limited to 100°C (212°F) no matter what the chemical concentration. Gases can be handled as high as 177°C (350°F). The pressure limitation for tanks is 15 psig and 150 psig for pipe. Higher pressures require special fabrication standards and procedures.

Metal Extraction and Refining Applications

In metal extraction and refining processes, FRP is typically used for pipes, tanks, absorption towers, ductwork, solvent extraction vessels, and electrowinning cells. Figure 3 shows typical FRP piping for abrasive/corrosive slurry.

Figure 3. Abrasion Resistant Pipe for Corrosive Slurry

Abrasion resistant pipe is typically made from epoxy vinyl ester resin that has 20 to 30% aluminum oxide or silicon carbide in the corrosion liner. Abrasion resistant FRP piping has proven to last longer and require considerably maintenance than rubber-lined steel. FRP piping for 16% spent sulfuric acid at 35°C (95°F) and 90°C (194°F) is shown in the foreground of Figure 4.

Figure 4. FRP Sulfuric Acid Piping

This epoxy vinyl ester resin based FRP pipe withstands conditions that would require an expensive metal alloy.

Figure 5 shows a FRP sulfur dioxide absorption tower in a copper refining plant.

Figure 5. Sulfur Dioxide Absorption Tower

Installed in 1994, the above FRP absorber replaced a lead and ceramic lined steel vessel. It operates at 60°C (140°F) and recovers 50-60% sulfuric acid from a copper smelter.

FRP mixer-settler tanks, for a uranium solvent extraction process, are shown in Figure 6.

Figure 6. Solvent Extraction Mixer-Settler Tanks

The tanks are used to recover uranium from sulfuric acid leach liquor. The liquor is treated with an amine and kerosene solvent that separates the uranium into an ammonium sulfate solution.

Figure 7 shows an acid gas collection system made from novolac epoxy vinyl ester resin.

Figure 7. Acid Vapor Collection System

The system is in a copper plant and operates at 165-170°C (330-340°F). FRP replaced lead-lined steel in this application. It should be noted that FRP can tolerate much hotter gaseous environments than liquid environments. Also, FRP made from a novolac epoxy vinyl ester resin can operate at much higher temperatures than FRP made from Bisphenol A epoxy vinyl ester resin.

The FRP tanks in Figure 8 were installed in a uranium extraction plant in 1988.

Figure 8. Reagent Storage Tanks

The tanks are currently used to store reagents from bulk extraction, scrubbing, stripping, and mixer-settler operations.

Figure 9 shows electrowinning cells made from mixture of resin and sand commonly referred to as polymer concrete. The cells have a FRP inner liner for additional corrosion protection.

Figure 9. Electrowinning Cells for Copper Recovery

The vapor extraction system is made from solid FRP. Copper electrowinning cells typically contain a solution of 20% copper sulfate and 20% sulfuric acid operating at 65°C (150°F). The non-conductive and corrosion resistant properties of FRP make it an ideal material for this application.

Summary

The operating conditions associated with metal extraction and refining processes require materials of construction that can withstand process acids and acid chlorides at temperatures up to 90°C (194°F). This service is not compatible with most common metallic materials of construction. Only expensive metal alloys offer the corrosion resistance required. The use of fiberglass reinforced plastics for the construction of gas cleaning systems, electrowinning cells, solvent extraction tanks, acid and abrasion resistant piping, and vapor collection systems offer a cost saving solution for these applications. FRP has a distinct advantage over metal alloys, lead-lined steel, and rubber-lined steel with lower installation costs, reduced maintenance, and long service life which has been proven with over 20 yrs of operating experience.

Notice