Improved Glass-Lined Process Equipment Offers Matchless Characteristics

Ronald A. Stella, Pfaudler Reactor Systems

(Released for publication Feb. '07)

Introduction:

The first use of glass-lined steel equipment dates to the late 19th century—and the brewing of beer. A young machinist named Casper Pfaudler searched for a way to speed up fermentation by applying a vacuum to the process. This required a suitable sanitary container. After much experimentation with materials such as wood, stone and terra cotta, the unique solution was glass-lined steel. Although the vacuum process proved unsatisfactory for the fermentation of beer, the by-product of this process, glass-lined steel equipment was used for the handling, storing and transportation of beer and became the basis for a new industry. The demand for glass-lined vessels grew rapidly along with the brewery industry. After the passage of the U.S. Pure Food & Drug laws in 1906, sanitary, easy to clean equipment was needed for food and dairy products. Glass-lined steel was ideal for these purposes. In the 1920's, the chemical processing industry began to grow in the U.S. and a corrosion resistant material was needed. Pfaudler's scientist modified the brewery glass formulation to provide the increased acid resistance needed for this industry. In the 1940's, the co-polymerization of styrene and butadiene into synthetic rubber was developed. Now large, one-piece, high pressure vessels were required to process this new material. Pfaudler scientists and engineers met this difficult task and many glass-lined polymerization reactors were produced to meet this demand. About this time, the chemical and pharmaceutical industries began to rely more and more on Pfaudler equipment. Sulfa drugs, antibiotics, synthetic vitamins, insulin and vaccines were

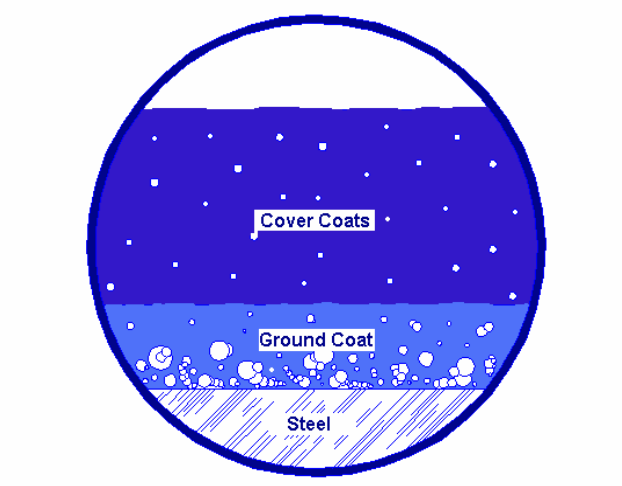
produced in Pfaudler reactors. The many advantages of glass-lined steel as a material of construction made this equipment indispensable to these emerging industries. Now, many years later, the chemical and pharmaceutical industries still rely on the outstanding characteristics of Pfaudler glass-lined equipment:

- Superior corrosion resistance.
- Essentially inert.
- Exceptional surface quality.
- Competitively priced.
- A strong, reliable material.

So What Is Glasteel®:

Glasteel® is a unique composite material consisting of glass fused to a steel substrate. This composite combines the corrosion resistance of glass with the strength of steel. Glasteel® is a highly modified soda-lime formulation. The chemical resistance in both acid and alkali actually exceeds that of a borosilicate glass such as Pyrex®.

Cross Section of Glasteel®

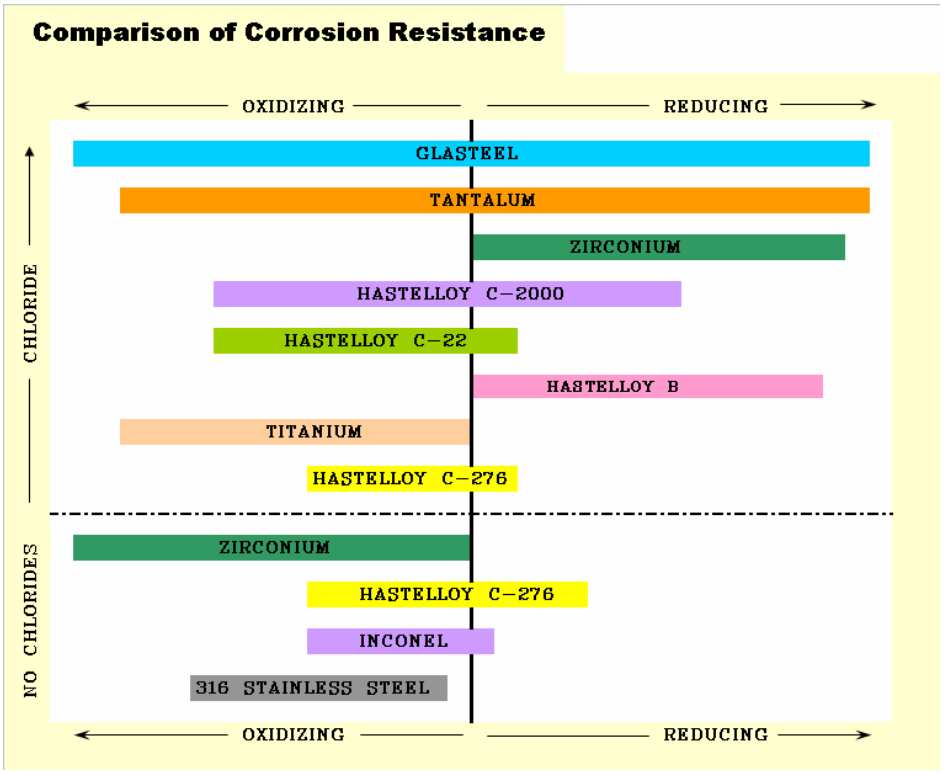


Producing Glasteel® equipment occurs in two paths – one for the substrate material and one for the glass lining. First the steel must be suitable for coating. This requires a particular steel chemistry, special fabrication techniques, high quality welds and a grit blast surface preparation. Then a glass particulate slurry or dust is sprayed on the substrate steel in approximately 0.010" (0.25 mm) layers, each layer followed by a high temperature fusing operation. The first one or two layers comprise the ground coat whose specialized formulation promotes adherence to the steel. These coats are fired at approximately 1650°F (900°C). Approximately three to five cover coats are then applied, each fired at approximately 1550°F (850°C), and applied to an overall thickness that achieves an optimum balance of corrosion resistance, thermal properties, mechanical strength and surface finish. A rather unbelievable strength of the critical glass-to-steel bond of greater than 14,500 psi (100 N/mm2) is achieved.

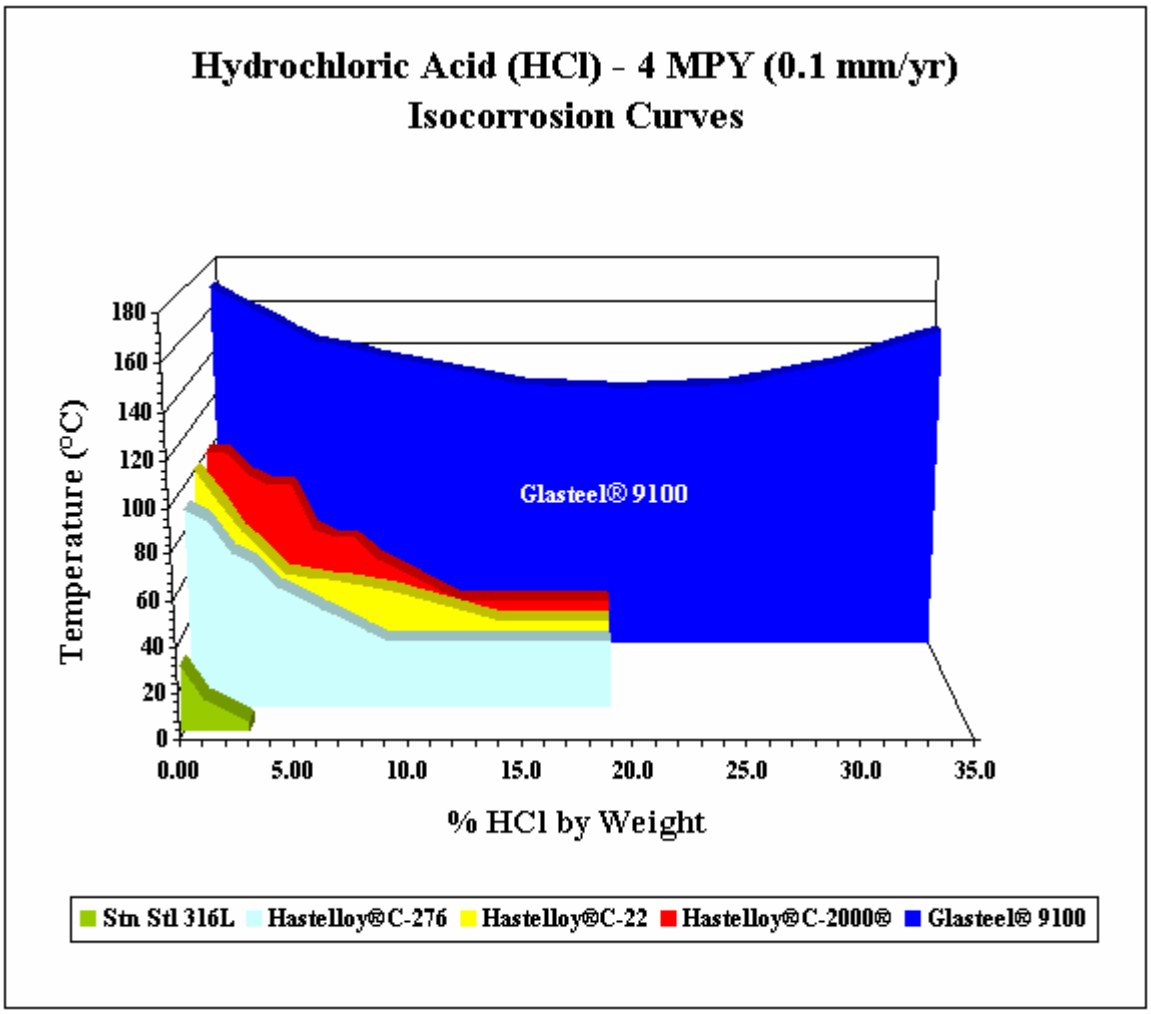
Today, improvements in substrate and coating materials, coating practices, vessel design, and vessel maintenance have virtually eliminated concerns over the reliability and durability of glass linings and have extended the operating lifecycle of Glasteel® equipment. In short, Glasteel® is an exceptionally strong, reliable, and affordable composite material with unmatched properties. It provides significant advantages over other material options for reactors, storage vessels and other equipment used in the chemical and pharmaceutical industries.

Superior Corrosion Resistance:

Glasteel® equipment has superior corrosion rates even under extreme thermal conditions. In fact, in comparison with other materials not even tantalum has a wider range of corrosion resistance across oxidizing and reducing conditions! The modified Bishop-Stern bandwidth chart below shows Glasteel® outperforming all other materials, including stainless steel and nickel-based alloys, in common acidic environments.



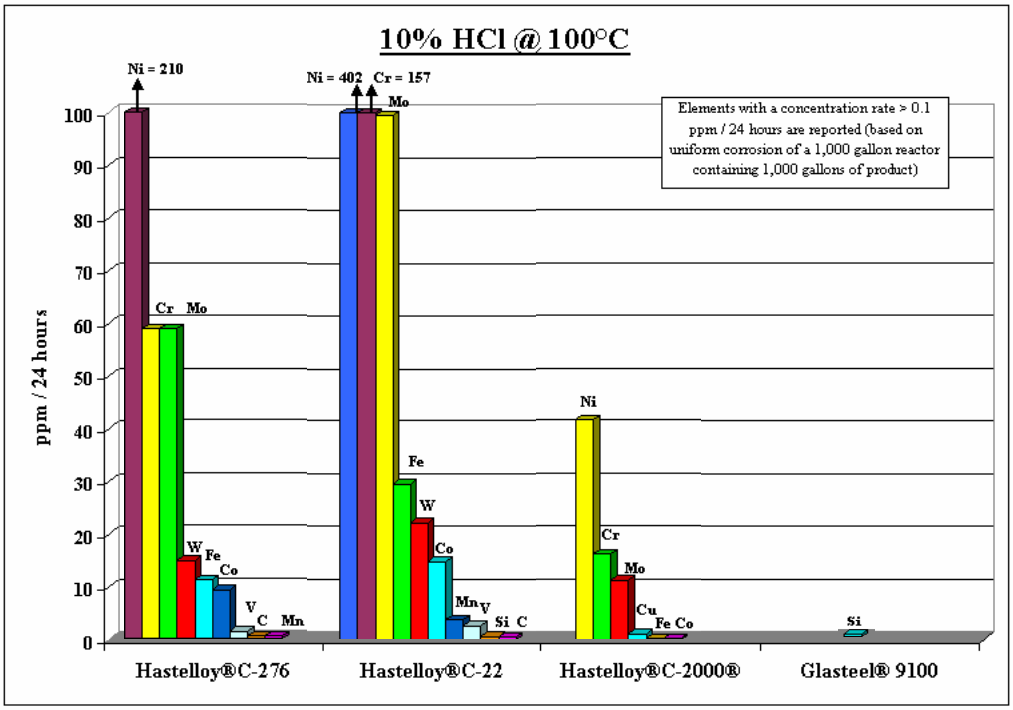
The following Isocorrosion Curves for hydrochloric acid provide a comparison of 316L stainless steel, Alloy C-276, Alloy C-22, Hastelloy C-2000® and Glasteel®:



Glasteel® does not exhibit a number of the damaging effects common in metals: intergranular corrosion, pitting, crevice corrosion, galvanic corrosion, stress-corrosion cracking, hydrogen embrittlement, etc. It also does not suffer from the permeability and cold-flow inherent with many fluoropolymers.

Essentially Inert:

Because glass is essentially inert, the normal tendency of materials to degrade or corrode is minimized. In a Glasteel® vessel there are no metal ions such as chromium, nickel or molybdenum to leach into and potentially contaminate the product. Only a very small amount of silica (less than 1.0 ppm/day based on uniform corrosion of a 1,000 gallon reactor in 10% HCl @ 100°C) leaches from the glass-lined steel surface. High-performance metal alloy vessels, on the other hand, exhibit significant leaching of metal ions.



The leaching of these extractable metals may cause undesired side reactions, which are not insignificant. They can cause fluctuations in the process reactions affecting product yields and purity, or may even cause unwanted reactions.

Exceptional Surface Quality:

The manufacturing process for Glasteel® produces an exceptionally smooth, fire-polished, low-energy surface. Typically, Glasteel® equipment has a surface finish of less than 10 micro-inches while metal equipment is often polished to 25-50 micro-inches. Achieving this or a better metal finish becomes very costly and requires polishing with rouges and pastes, often a concern to the pharmaceutical industry. In addition to the rougher surface, metals seek to reduce their high surface energy by adsorbing (i.e., the adhesion of) lower energy materials. This results in an unwanted product build-up on the wall. Because glass resists this build-up, glass-lined steel requires less cleaning, less often. Also the effective cleaning of the glass-lined surface minimizes any cross-contamination of the product and offers less fouling resistance to heat transfer.

Speaking of heat transfer, the heating and cooling rate of Glasteel® equipment is often quite similar to that of alloy equipment. The reason is the low thermal conductivity glass-lining is only approximately 0.040" – 0.080" thick as compared to the much thicker high conductivity carbon steel substrate. Therefore steam heating and water cooling of a typical organic product in a conventionally jacketed glass-lined steel reactor provides 80 to 95+% of the heat transfer in an Alloy C22 reactor with a half-pipe jacket.

Competitively Priced:

Glasteel® is extremely cost-competitive with high-performance metals. As shown below, based on 2006 market data, the price of Glasteel® equipment is lower than the price of equivalent alloy vessels, even stainless steel.

Price Relationship

Glasteel®	1.0
316L Stainless Steel	1.1 – 1.3
Alloy C-22	2.1 – 3.3

The outstanding characteristics of Glasteel® - corrosion-resistant, inert, superior surface quality, affordable—make it an ideal choice for chemical and pharmaceutical applications. Moreover, since product development is typically conducted in laboratory glassware, scale-up to pilot and full-scale production is predictable only when Glasteel® equipment is employed.

Improvements In Glasteel® Equipment Provide Longer Life Cycles:

When compared to other materials of construction, Glasteel® equipment is a unique, cost-effective material with unmatched properties. Historically this equipment is thought of as having a shorter life cycle than the alloys, mostly due to the perceived fragile nature of the lining. Current data, however, does not support this perception. Recent advancements in glass formulations have resulted in even greater resistance to corrosion and thermal shock. There also have been improvements in the substrate material and welding of this material.

Of even greater importance are the advancements in the application and fusing of the glass lining to the substrate material. The results are dramatic! In 1970 there was an average of two tantalum repair plugs applied per vessel shipped (these plugs are used to repair defects identified during glass testing). By 1980 the number of repair plugs was reduced to one per vessel. Today the installation of a repair plug is rare. Pfaudler-US has not installed a repair plug in two years!

Another previous concern with Glasteel® equipment was the tendency of the lining to spall (a spall is a small chip that may violate the integrity of the lining). Pfaudler has dedicated extra attention to this matter since the customer may have to remove the vessel from service and return it if the glass lining spalls. This, obviously, can be extremely costly to the customer. Pfaudler's attention to this matter has virtually eliminated this defect as a concern. In fact, Pfaudler-US has had no equipment returned for defective glass for any vessel bodies shipped in the last four years!

Pfaudler also closely tracks the reasons equipment is returned for reglassing (i.e., if the glass lining is compromised during use, the customers often returns the equipment for the application of a new lining). We find most of the causes of damage to the glass lining can be reduced or eliminated by using the equipment within recommended operational and maintenance practices. In order to reduce this type of damage Pfaudler offers extensive preventative maintenance training—at our facility or your's.

In any case, only approximately 1% of the total number of vessels in operation in the U.S. are returned each year for reglassing. The average time between reglass cycles for this small percentage of vessels is approximately 15 years. Although it is impossible to calculate the average life cycle of all Glasteel® equipment, if the time between reglass cycles for a small percentage of vessels is 15 years, the life cycle for all Glasteel® equipment must be a long time. In fact, data from a major user indicates the life cycle for Glasteel® equipment is slightly longer than the cycle for alloy vessels.

Another important point to consider is the equipment's pressure rating. Due to the high cost of the alloy materials, stainless and high nickel alloy vessels are typically designed with material thicknesses just sufficient for the design conditions. Because these materials can have significant corrosion rates in some acidic applications, vessels constructed from these materials may require a significant reduction in the design pressure or replacement after a short period of time. This condition does not exist with Glasteel® equipment, since the glass lining protects the pressure-containing carbon steel substrate material from product-side corrosion.

Conclusion:

From beer to food products to chemical and pharmaceutical processing, Glasteel® equipment has proved its worth in a variety of demanding applications for well over a century. Alloy equipment certainly has its place within the chemical and pharmaceutical industries for applications such as hot alkali, some fluorine-containing chemistries, hot concentrated phosphoric acid, and some materials with low specific conductivities. But only Glasteel®

equipment offers corrosion resistance similar to tantalum at a price less than stainless steel! Glasteel® equipment is a cost-effective material, provides unparalleled corrosion resistance, is essentially inert, and has superior surface quality. Recent improvements to these unique characteristics have significantly increased the equipment's life cycle, making Glasteel® the first material of choice.