Titanium Clad Autoclave Performance in Nickel Laterite Hydrometallurgy

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ABSTRACT

Titanium/steel clad has been selected as the material of construction for six pressure acid leaching autoclaves for nickel production from laterite ores. These six pressure vessels are now in production service in western Australia. Titanium provides reliable corrosion protection in the nickel laterite pressure leaching environment. Clad metal construction offers a significant cost reduction for equipment of this type in comparison to solid titanium. Clad metal construction offers superior durability and reliability in comparison with non-metal or titanium loose-lined equipment. Experiences in titanium clad equipment construction and performance are reviewed. The presentation addresses aspects of design, fabrication, and testing which are necessary to assure reliable equipment. The explosion cladding process and titanium alloy selection considerations are also discussed.

INTRODUCTION

Titanium's superior corrosion resistance is ideal for many process applications (Ref 1). Process industries choose titanium as the material of construction for piping, tanks, pressure vessels, autoclaves, and heat exchangers. When pressures and/or temperatures and size demand very thick plate, the titanium equipment can become considerably more expensive than units constructed from lower cost, lower performance materials. Titanium clad steel offers a reliable, cost effective alternative, providing durable titanium lined equipment which is lower cost than many less reliable alternatives. The explosion cladding process produces a high quality titanium-steel clad product with proven fabrication reliability and performance.

PRESSURE ACID LEACHING AUTOCLAVES

Hydrometallurgical refining of metal ore is an industry where titanium clad steel has helped to make large scale facilities economically viable. Pressure acid leaching (PAL) provides an economically viable method for reducing many metal types. Specifically, sulfuric acid pressure leaching is considered cost effective for refining nickel laterite ores, which are low grade but plentiful and easily mined (Ref 2). Autoclaves for PAL of nickel laterites operate around 250°C to 265°C (480°F to 510°F) and 5.0 MPa (725 psi), using a 5 to 7% sulfuric acid concentration. Corrosion conditions in these facilities are frequently frustrated by high chloride concentrations in the locally available process water. Today's nickel leaching autoclaves are typically 4m to 5m diameter (150 to 200 in) , 25m to 35m long (80 to 115 ft) with steel wall thickness around 80mm to 120mm (3 to 5 in). In addition to the autoclaves, several of the other vessels in the acid leach circuit operate under similar corrosion conditions. These include flash tanks, slurry tanks, and preheating equipment. Due to highly oxidizing conditions and low PH, titanium alloys (Ref 3) and refractory brick are the materials of choice for corrosion resistance. Currently accepted material options for construction for these autoclaves are solid titanium, titanium clad steel, and lead-lined steel with internal acid brick linings. Titanium clad steel construction offers many advantages over the other options.

In comparison to solid titanium:

1. Titanium clad steel can be considerably lower cost than solid titanium plate. For most titanium equipment requiring over 20mm wall thickness, clad reduces cost. The savings approach 90% for autoclaves of the size and thickness and operating temperatures for nickel leaching.
2. Fabrication costs for titanium clad steel are lower than for solid titanium in the thicknesses typical for autoclaves.

3. Components outside of the corrosion envelope, such as supports, stiffeners, agitator mounts, nozzles and external jackets can be fabricated from low cost steel.
4. Since titanium is no longer the strength component, the titanium alloy can be chosen for features other than strength, such as corrosion resistance, erosion/abrasion resistance and/or ignition resistance. The designer is no longer limited to titanium alloys contained in the Pressure Vessel Code table of allowable working stresses.
5. The titanium cladding alloy selection can be varied selectively within the autoclave to provide unique performance features in specific regions of the autoclave.

>Low cost unalloyed titanium, Grade 1, can be used in regions where general corrosion is the primary concern.

>Alloys containing palladium or ruthenium, such as Grades 11, 17, or 27, can be used where there is potential crevice corrosion.

>Abrasion resistant alloys, such as Grade 12, can be used where severe abrasion and erosion are anticipated.

>Ignition resistant alloys, such as Ti-45Nb, can be applied in regions where oxygen impingement or rubbing surfaces pose a potential ignition threat.

In comparison to lead - brick designs:

1. Titanium provides excellent corrosion and abrasion resistance in direct contact with process media at the required operating temperatures and pressures, whereas lead does not. In order to maintain wall temperatures suitably low for lead membrane containment, internal brick linings are 300 to 500mm thick (12 to 20 in.) Titanium eliminates the need for thick refractory brick linings, significantly reducing pressure vessel diameter and weight, shell thickness, welding and fabrication costs, and transportation costs. It has been reported that titanium clad autoclaves for nickel laterite conditions are approximately 30% lower cost than lead-brick alternatives (Ref. 4).
2. Maintenance costs and lost production time due to maintenance are reported to be much lower for titanium clad autoclaves.

A significant number of titanium and titanium clad pressure vessels have been fabricated for research and production autoclaving over the past 25 years. The largest of these clad autoclaves has been around 3.3m diameter x 13m long (130 x 512 in) (Ref. 5). Additionally, many large production autoclaves have employed titanium and titanium clad components in selected areas. However, until recently, no large production autoclaves have been constructed of titanium or titanium clad. During 1996 and 1997 six large titanium clad nickel laterite autoclaves were fabricated. Details on these units are presented in Table 1.

Figure 1: Titanium clad autoclave for nickel laterite pressure acid leaching. The autoclave is Titanium Grade 1 clad steel for the Murin Murin Nickel Cobalt Project. Photo provided by the autoclave fabricator, ASC Engineering, Adelaide, Australia.

Table I Australian Nickel Laterite PAL Autoclaves

Project	Owner	Quantity	Size (m)	Titanium Selected
Bulong	Preston Resources	1	4.60 ID x 31 long	Gr 17 8 mm thick
Cawse	Centaur Gold	1	4.65 ID x 27 long	Gr 11 8 mm thick
Murin Murin	Anaconda Nickel	4	4.95 ID x 35 long	Gr 1 6 mm thick

Figure 1 shows one of the Murin Murin autoclaves at the completion of fabrication. At the time of this presentation, all six autoclaves are in operation. The Cawse autoclave has been in service for over one year. At the near one-year inspection, the vessel was observed to be in excellent condition. Projected autoclave service life is in excess of 20 years.

TITANIUM CLAD EQUIPMENT MANUFACTURE

Titanium clad equipment can be reliably constructed and has proven service reliability. However, due to differences in metallurgical characteristics, thermal expansion, modulus, and other aspects, titanium clad construction is not “just another clad vessel.” Special considerations must be taken in design, fabrication, welding, and testing to insure a reliable product. Inadequate attention to proper design and fabrication techniques can result in a subsequent vessel failure.

Titanium and steel cannot be directly fusion welded to each other due to brittle intermetallic formation. Clad fabrication is typically accomplished using a batten strap technique as depicted in Figure 2. The titanium cladding is removed from the area around all edges where steel welds are to be made, typically 12mm (0.5in) inward from the steel weld prep edge. The steel base metal is prepared and welded using conventional steel fabrication procedures. The vessel is then cleaned up and prepared for titanium welding. In the batten strap technique, a filler-metal strip is inserted into the space where the titanium has been removed. The choice of filler is dependent upon proprietary fabrication preferences; commonly used materials include copper, steel, aluminum and titanium. A wider strip of titanium, the batten strap, is then placed over the weld area. The batten strap is welded along the edges with fillet welds. Large diameter nozzles are frequently fabricated from clad plate using these same procedures as for vessel fabrication. Typically, smaller diameter nozzles are lined with solid titanium or bimetallic titanium-steel sleeves. Attachments between nozzles and the vessel body are made using procedures similar to those employed on the vessel circumferential and longitudinal butt welds.

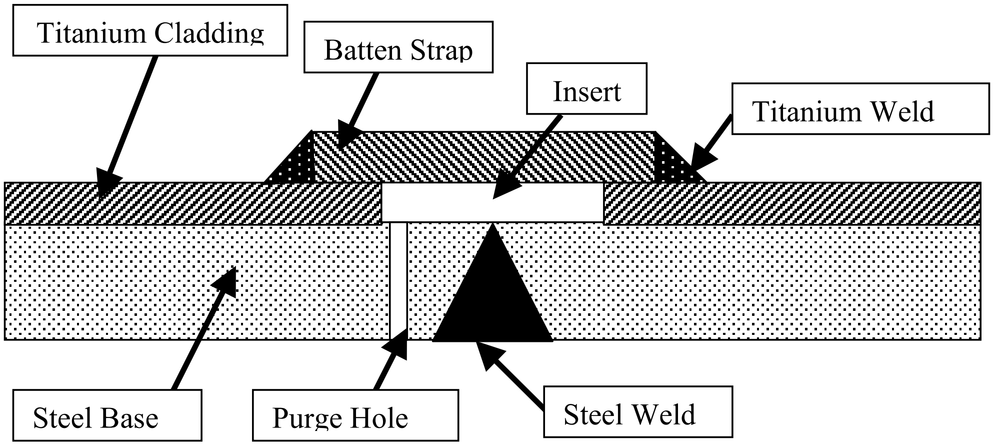

Figure 2: Schematic of titanium clad fabrication using Batten Strap method.

Although the above description is quite simple, the precise design of welds and batten straps for autoclaves is not. One critical concern results from the highly different thermal expansions of titanium and steel combined with the high operating temperatures of the equipment. The coefficient of thermal expansion (CTE) of titanium is 30% lower than that of carbon steel. Since the thickness of titanium is typically only 5% to 10% of the steel thickness, the titanium is essentially forced to move at the steel CTE rate. This strain results in a tensile stress in the titanium cladding layer. Over the main body of the autoclave, the continuous clad bond transfers the thermal expansion stresses between the two metals uniformly. In the weld region, all of the differential stress must be borne by the batten strap and the fillet welds along each edge. Incorrect design can result in stresses in the welds that exceed proper design allowables, a situation that could potentially result in catastrophic weld failure. Experience has shown that properly designed weld systems are problem free in service. It is critical that detailed stress analyses and experimental verification be performed to assure proper sizing and configuration of the batten straps and the fillet welds joining them to the clad plate surface. Specific details are typically highly protected proprietary designs of the equipment fabricators. It is not the purpose of this paper to provide a detailed discussion of vessel stress analysis and the author has minimal expertise in this area; however, for successful vessel performance the importance of this aspect of vessel design cannot be over emphasized.

Forming, fabrication, and welding all require special consideration in titanium clad vessel construction. Reference 5 specifically addresses these issues. With proper planning, training, equipment, and attention to detail, reliable high-quality titanium clad equipment can be constructed.

INSPECTION AND TESTING

Proper testing and inspection of large clad autoclaves is critical to reliable operation. The steel welds are inspected by traditional steel fabrication inspection methods. Inspection of the titanium batten strap welds requires different methods. One of the concerns with the batten strap fillet weld design is that it cannot be reliably inspected by radiography, the traditional weld inspection process. One major concern is weld root quality. Test methods vary between vessel fabricators. Surface defects can be detected by penetrant testing. Gross weld defects can be isolated by pressure testing with helium. The high pressure gas can be fed behind the weld through the inert gas purge holes; leakage can be monitored on the opposite weld surface. Hardness measurements should be taken at periodic locations to test for contaminated titanium welds.

Ambient temperature hydrostatic testing is necessary for code compliance, but it will do little to reveal defects or problems with the titanium welds and batten straps. This is a particular concern when the vessel will be operating at high temperatures, as are the autoclaves. Hot, high pressure cycle testing, simulating the operating temperatures and pressures is highly recommended for locating isolated weld defects or batten strap problems. Considering the very large amount of welding in an autoclave, some weld rework is to be anticipated. The equipment should be given a series of cycles simulating temperature and pressure service conditions with intermediate penetrant and helium leak inspections. Weld defects should be reworked, and the complete process repeated . For a number of reasons, it is preferable to perform this testing in the fabricator’s shop prior to shipment of the vessel. However, with the very large autoclaves this may not be practical; the cost of equipment and facilities for shop testing can be huge. It may be preferable to perform these tests after delivery to the site since the process steam facilities are available there to provide both heat and pressure. This can be done effectively if the fabricator and the procurement engineers work together to plan this in the pre-commissioning schedule. Testing of this type will assure correction of design, fabrication, and/or welding defects, minimizing problems in startup and subsequent operation.

TITANIUM AND STEEL ALLOY CONSIDERATIONS

All of the titanium alloys can be clad using the explosion bonding process. However, the optimum bond mechanical properties and optimum plate sizes are produced when the yield strengths of both the cladding and base metal are below 345 MPa (50,000 psi). Consequently the optimum bond strength and toughness of titanium cladding results from a combination of Titanium Grade 1, or similar, clad to a moderate strength pressure vessel steel, such as ASME SA516 Grade 70. (Titanium Grades 17, 11, and 27 exhibit similar yield strength and similar bond performance to Grade 1.) Although higher strength titanium alloys such as Grades 2 and 12, can be directly bonded to steel, the maximum sizes that can be manufactured reliably are too small for cost effective manufacture of PAL autoclaves. When cladding higher strength titanium grades in large plate sizes, it is common practice to use an interlayer metal between the alloy titanium and steel. Grade 1 titanium is the most commonly used interlayer for clad pressure vessel applications. Alternately, other alloys can be applied to the Grade 1 base using processes such as weld overlay or strip cladding. For example, in regions of a vessel requiring high erosion resistance, Grade 5 or 12 can be weld overlay deposited onto Grade 1 cladding, or wear plates can be attached to the Grade 1 cladding. Table 2 lists several of the currently available titanium alloys and highlights their specific features including cladability and relative cost of the clad product (Ref 5,9).

Table 2
SELECTED TITANIUM ALLOYS AND PERFORMANCE FEATURES (Ref. 5,9)

Gr# (*)	Basic Alloy Components	Cladability to Steel(**)	Cost (***)	Features/Motivation for Alloy (****)
1	Ti (Chem. Pure)	Direct	1.0	Low Cost, High ductility
2	Ti (less pure)	Interlayer	1.5	Low Cost , Medium Strength
3	Ti (less pure)	Interlayer	1.6	Low Cost, Higher Strength
5	Ti+6AL+4V	Interlayer	1.7	Strong & Erosion Resistant
7	Ti Gr2+0.15Pd	Interlayer	2.2	Crevice Corrosion Resistance
11	Ti Gr1+ 0.15Pd	Direct	1.7	Crevice Corrosion Resistance
12	Ti+.3Mo+.8Ni	Interlayer	1.6	Strong and Erosion Resistant
16	Ti Gr2 + .05Pd	Interlayer	1.9	Crevice Corr. Resist. Lower $
17	Ti Gr1 + .05Pd	Direct	1.3	Crevice Corr. Resist. Lower $
27	Ti Gr1 + .1Ru	Direct	1.1	Crevice Corr. Resist. Lower $
NA	Ti-45Nb	Direct	2.3	Excellent Ignition Resistance

Legend:
* ASTM B265 Grade Designation
** Readily explosion clad direct to steel, or interlayer recommended
*** Clad Metal Cost Ratio in comparison to Lowest Cost Alloy (Ti Gr 1/steel), Based upon 8mm thick titanium alloy clad onto 100mm thick steel.
**** When Alloy Composition shows “Ti Gr.# + addition”, the alloy exhibits features of the base Grade plus the features listed for the higher grade.

EXPLOSION CLAD

Explosion cladding is a solid state metal-joining process that uses explosive force to create an electron-sharing metallurgical bond between two metal components. Although the explosive detonation generates considerable heat, there is no time for heat transfer to the component metals; therefore, there is no appreciable temperature increase in the metals. Due to the absence of heating, the microstructures, mechanical properties and corrosion properties of the wrought parent components are not significantly altered during explosion bonding. There are no heat affected zones, and brittle intermetallic layers are not formed. For these reasons explosion cladding is ideally suited for bonding of virtually any combination of metal. (Ref 6,7,8). Titanium and iron are not metallurgically compatible at high temperatures. Under conditions normally used for weld overlay or hot rollbonding, titanium and steel instantly react to form brittle intermetallic compounds. Consequently, neither weld overlay or hot roll bonding is reliable for cladding of titanium direct to steel. Explosion cladding is the preferred process for manufacture of titanium clad steel.

Because of the unique safety and noise/vibration considerations, explosion cladding is performed in relatively isolated facilities by companies specializing in explosive clad manufacture. At the time of this presentation, there are three clad manufacturing companies worldwide with proven experience in the product sizes required for cost effective PAL autoclave construction. Manufacturing processes for all three are similar but specific process parameters are proprietary. Product sizes are normally limited only by the size availability of the component metals and the explosive detonation limitations of the manufacturing facility.Titanium clad plates with widths of 4.5m (176in) and lengths of 11m (430in) are commonly produced. The titanium cladding thickness typically ranges between 2mm (0.08in) and 19mm (0.75in), dependent upon the application. The steel base metal typically ranges between 12mm (0.5in) and 500mm (20in), dependent upon pressures. Additional technical information is available at www.clad-metal.com.

Titanium clad is typically produced to ASTM Specification B898. This specification provides ultrasonic testing requirements to assure high bond integrity. UT Class B, which is recommended clad plates for autoclaves, requires 100% inspection and 99% minimum sound bond area. Mechanical testing for bond strength is provided by a shear strength test.

CONCLUSION

Titanium clad solves corrosion, maintenance and environmental problems in many reactor and autoclave applications. Titanium clad construction permits autoclave designers a great deal of flexibility combined with significant cost reduction. Titanium alloys can be selectively applied in specific regions of the autoclave to maximize performance under anticipated localized environmental conditions at minimal cost. Explosion clad pressure vessel fabrication and performance have been demonstrated through three decades of experience including manufacture of six nickel laterite PAL autoclaves. With proper attention to design, fabrication methods and testing, titanium clad equipment is highly reliable, durable, and long lasting.

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