Assuring reliability of titanium clad equipment

Technologies for the manufacturing of high-quality reactive metal clad, and for fabricating titanium clad equipment were developed and industrialized in the 1960s. Explosion cladding has since proven to be a highly reliable, robust process for titanium clad manufacture. It is the best practice cladding process, and has been the process of choice for more than 95% of all titanium clad equipment for the past 50+ years.

Throughout these years, close cooperation between the clad manufacturers, designers, and fabricators has resulted in the evolution, and fine-tuning of technology for titanium clad equipment manufacturing. This cooperative effort has assured that delivery and performance issues with titanium clad equipment have been quite rare. When designed, constructed, and operated properly, this equipment is highly robust, which typically provides problem-free performance for 25 to 50 years or longer in chemical processing industry (CPI) processes.

For numerous commercial and technical reasons, titanium clad equipment remains a niche, non-commodity, highly diverse product-line. When a project team fails to understand the unique characteristics of titanium clad, the results can be quite painful both for themselves, and for the operations team that must work with, and maintain the equipment every day.

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Titanium clad CPI equipment

Titanium clad is broadly used in stationary CPI equipment where the titanium cladding component provides corrosion protection, while the steel- (or stainless steel-) base metal provides structural support at a much lower cost. Clad can provide significant cost reduction when compared with solid titanium construction, particularly when the overall thickness exceeds 10 to 15 mm. When titanium is the material of choice for corrosion protection, clad is used extensively in the overall construction of pressure vessels, reactors, columns, and autoclaves.

Titanium clad is broadly used in equipment of this type for the purified terephthalic acid (PTA) and related industries. Typically, the complete interior surface of these vessels is titanium clad. Figure 1 shows a large titanium clad column, and Figure 2 shows an array of reactors and heat exchangers all for a modern PTA plant. Figure 3 shows a large titanium clad, heavy-wall autoclave destined for a metals refining process. These clad vessels can range from smaller units of a few thousand liters' capacity, up to 10 m diameter behemoths exceeding 1,000 mt.

Titanium clad is also broadly used for heat exchanger tubesheets to reduce CAPEX. A clad tubesheet allows the designer to use titanium tubes for tubeside corrosion protection, while fully welding them into an otherwise fully-steel vessel on the shell-side.

Figure 4 shows a shell and tube exchanger with titanium clad tubesheets for a very high-pressure CPI application. Titanium cladding of the bonnets can also further reduce costs. When compared to a solid titanium unit, the cost reduction is enormous.

Figure 5 shows a low-pressure surface condenser with a very large tubesheet. The 30 mm-thick clad tubesheet makes fully-welded construction between the tubesheet and steel shell possible. This is not an option when solid titanium tubesheets are used. The result is a significant cost reduction for the equipment throughout its lifetime.

Figure 2: An array of titanium clad vessels and heat exchangers for a modern PTA plant. Image courtesy of COEK Engineering

Titanium clad equipment supply

The titanium clad supply team typically consists of:

• Equipment design engineer: Performs the design engineering required to meet the owner's process, and operation objectives.

• Fabricator: Performs the detailed fabrication design, and constructs the equipment.

• Clad manufacturer: Produces the clad plates in accordance with the fabricator's specified requirements. The manufacturer must have significant skills in explosion cladding, metallurgy, and welding.

The fabricator and clad manufacturer are specialists in the unique requirements of titanium clad manufacture, and construction. Significant specialized technology is required as the requirements to produce and fabricate titanium clad are very different than those required for stainless steel, and nickel alloy clad.

Today there are arguably around 25 explosion cladding operations globally, which are capable of producing stainless steel clad plates. Only a small fraction of these operations have technology to produce titanium-steel clad, and an even smaller amount have demonstrated the technology to reliably produce the large titanium clad plates needed for world-class titanium clad pressure vessels. The fabricator base is similar; there are likely fewer than five fabricators globally with proven experience in the design and fabrication of large titanium clad pressure vessels. The number of fabricators with experience in building heat exchangers with titanium clad tubesheets is a bit larger. The titanium clad plates used in the construction of all equipment shown in the five figures were manufactured by Nobelclad.

Clad equipment reliability

Diligence when selecting the designer, fabricator, and clad manufacturer goes a long way in assuring long-term equipment reliability. When design, fabrication, and clad manufacturing are performed correctly, titanium clad equipment reliability is exceptional. The rules for the design and fabrication of titanium clad are different from those of steel or titanium; they are not simply steel rules in one place, and titanium rules in another. The transition between the titanium and steel becomes considerably more complicated. Adequate training and experience in the unique niche issues of titanium clad are mandatory for reliable equipment construction.

Figure 3: A titanium clad autoclave for nickel leaching. Image courtesy of COEK Engineering.

When there are equipment integrity problems, they invariably relate back to:

Design

Inadequate considerations of the unique issues of titanium clad design.

Clad manufacturing

With titanium clad, the old axiom, 'You can build quality in, but you cannot inspect non-quality out', rules. When the clad manufacturer has strong control of his process, nonbonds are extremely rare, with typically <0.001% of the area. When the manufacturer does not have control

Figure 1: Titanium clad column for PTA. Image courtesy of COEK Engineering

or does not understand what needs to be controlled, the defect rate can be orders of magnitude greater, >5% of the area is not unusual. When the manufacturer has a strong quality culture, and not just a quality system, the assurance of a high-quality outcome is much more reliable. When the quality culture is weak, the problems can be easy to hide within the quality system rules. Vetting the capabilities and the true quality of their experience is critical in choosing a qualified clad manufacturer.

Fabrication

The primary concerns relate to the metallurgical incompatibility of titanium and steel, as well as the mechanical and physical property differences. Direct fusion welding of titanium to steel is not possible. The use of batten strip construction is mandatory. The differences in thermal expansion and elastic modulus create unique stress conditions, particularly at the welds between the titanium battens, and the titanium cladding. Commonly-used batten strip designs are well addressed in the public literature, but public information on design details, testing, and inspection is quite limited. When a piece of clad equipment leaks, failure of a poor quality titanium batten strip design or related weld is most often the cause.

Figure 4: Shell and tube exchanger with titanium clad tubesheets for a high-pressure CPI application. Image courtesy of Titan Metal Fabricators

Arguably, the greatest weakness in the clad equipment supply today is inadequate education and experience in the manufacturing process chain, particularly as the industry morphs globally, and as the old 'experts' move on. Many of the fabrication and design requirements are considered proprietary information, and are not shared by the designers and fabricators. The result is a strong need for 'experience', which is minimally available in the public literature or by doing 'what the drawings show that we did last time'. The following sections address some of these concerns.

Inspection and testing of clad plates

Titanium clad is primarily purchased to the globally-accepted American Society for Testing and Materials (ASTM) specification, B898. The primary inspection technique for bond continuity is straight beam ultrasonic inspection. B898 allows three ultrasonic testing (UT) bond quality levels. The cost difference between the three classes is not great. Quality Class A is strongly recommended for virtually all titanium clad vessel plates and tubesheets.

The standard quality acceptance criteria for clad bond strength is the shear test. The shear strength test is not mandatory, but is required when Supplementary Requirement S1 is invoked in the purchase requirements. Shear strength testing of every clad plate is highly recommended to verify clad plate quality.

A third party inspection witness of both UT, and shear testing is highly recommended until a strong quality assurance trust relationship is established between the buyer, and the producer.

Design, inspection, and testing of clad equipment

The design, fabrication, inspection, and testing of clad pressure vessel type equipment is considerably more complex than that for clad plate production. This is further complicated in that there are currently no industry-wide specifications, and/or best practice guidelines for titanium clad-fabricated equipment.

The American Society of Mechanical Engineers (ASME) Design Code provides clear requirements for the pressure-containing component of the vessel. However, Section VIII paragraph UCL, does not allow the titanium component of a titanium-steel vessel to be considered as a pressure-containing component. The result is that there are essentially no ASME Code design rules for the titanium components of a titanium clad pressure vessel. For all practical purposes, the design and fabrication rules for the titanium cladding, batten strip, and other lining components are left to be established by the owner/buyer, and/or his designee. Most experienced owner companies have established strong titanium clad equipment specifications.

Traditionally, these specifications tend to exhibit a considerable, implicit trust between the owner, designer, and fabricator, which has worked reasonably well for decades. However, with today's globalization of the titanium clad equipment construction market, and the oft-mistaken expectation that titanium clad equipment is a commodity, the absence of more explicit specifications is concerning. The end-user, who will be living with the final pressure vessel product, is encouraged to give serious consideration to this concern, and to more clearly address due diligence regarding equipment design, and in-process inspections.

Following completion of all welding, it is best practice to perform a hot cycle pressure test, followed by reinspection by non-destructive penetrant testing (PT), and leak testing. The significant differences in elastic modulus, and thermal expansion between titanium and steel can result in significant weld stresses during heat up and cool down. The procedures and criteria for these inspections are not broadly published in the literature. They tend to be proprietary to either the fabricator, the owner, or both.

For a novice in the areas of titanium clad equipment design, fabrication, and/or testing, the last several paragraphs are likely to be concerning. However, as addressed very early on in this article, throughout the past five decades, titanium clad equipment

Figure 5: A condenser for a power generation plant, with 3 mm and 5 mm titanium clad tubesheets. Image courtesy of Holtec

performance has been exceptional. Yet, this has relied heavily upon the individual skills, and experience of designers, fabricators, and clad manufacturers. As the titanium clad equipment industry evolves globally, the individuals transition or retire, and the industrial procurement systems evolve, the need for increased due diligence and standardization becomes more critical if 'problem projects' are to be avoided.

Operation and risk-based inspection (RBI)

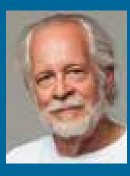
Titanium clad equipment that have been properly designed and built, have proven to be highly robust in service, but not impervious to problems. This is particularly true when there are process upsets or unplanned changes in the process over time. The persons responsible for operations and maintenance of the equipment must be aware of the equipment's limitations. Risk-based inspection programs are indeed critical.

Summary

The exceptional reliability of titanium clad equipment in CPI applications has been broadly demonstrated throughout the past half-century. When titanium clad equipment is adequately designed for the intended use, and properly fabricated using high-quality clad materials, expectations for long-term reliable service are strongly justified. From the metalworking perspective, the process technologies for explosion cladding titanium to steel, and fabrication of titanium clad are uniquely complex. When performed correctly with a strong quality system, and a strong quality culture, the end product is highly robust.

The technical details for clad manufacturing, fabrication, and design are well-established and understood, but predominantly proprietary, and narrowly held. Specification B898 covering titanium clad plate is broadly accepted globally. The specifications for design and fabrication tend to be proprietary, with no current industry-wide standards. Due diligence and thorough vetting of the designers, fabricators, and clad producers are critical components for a successful titanium clad equipment project. When all are in place, titanium clad equipment will provide highly-reliable service.

About the authors



John Banker is best known for his leadership in developing the global explosion clad industry. His degree as a metallurgist, and early experience as a member of the original explosion welding research team, proved invaluable in his ongoing 50+-year career. Banker is broadly recognized for innovation in championing the reactive metal cladding and fabrication technologies. Currently Banker continues to provide broad, technical, and consulting support to the industry focusing on the needs of the equipment developers, users, and owners.

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