TITANIUM FABRICATION CORP.

Titanium, Zirconium, and Tantalum Clad Construction

General Considerations

In many applications, particularly for large pressure vessels designed for high temperature and pressure, titanium or zirconium clad steel construction can be very economical compared to solid construction. Tantalum cost is so high that clad construction is the only economic alternative for most process equipment. Also, tantalum is not recognized by at least the ASME Code as a structural material, which would limit its application even if the economics of solid construction were favorable.

Clad should be more economical than solid construction where wall thickness is in excess of 3/4 to 1-1/4 inches in titanium and 5/8 to 3/4 inch in zirconium.

With titanium or zirconium, a minimum lining thickness of 2 mm (0.078") is usually specified based on concern for iron contamination from the backer material due to welding heat or burn through if the weldor is careless. Use of a thinner liner is certainly feasible with careful welding process selection and welding parameters chosen to minimize penetration, but the cost saving is so minimal that this practice has largely been discontinued.

Tantalum is typically used in thickness of 1.0 mm (.040 inches). Due to high cost and higher melting temperatures, tantalum clad often utilizes a copper interlayer which carries away heat and minimizes the risk of weld contamination even with very thin liners.

Clad construction becomes relatively more expensive if there are more details like nozzles and penetrations that require significant detailed fabrication work. Cladding can be very low cost for large uninterrupted surfaces.
Solid construction may be superior where there is a requirement for a smooth interior surface since the normal detail of clad batten strip construction results in an uneven surface.

Thermal expansion should be considered and shear stress calculated. Titanium has a thermal expansion coefficient of about 85% of carbon steel, the usual backing material for vessels, which helps to minimize problems. Zirconium's expansion coefficient is only about 56% of that of steel, so thermal expansion differences may be more of a concern.

Although not common practice, titanium palladium, titanium ruthenium, or titanium niobium grades can be clad over titanium backing material. Application in selective areas where there is concern for liquid level or crevice corrosion, ignition hazard, and other local problems are typical applications. Tantalum has also been used selectively as a cladding on titanium. Direct welding is feasible with all of these reactive metals.

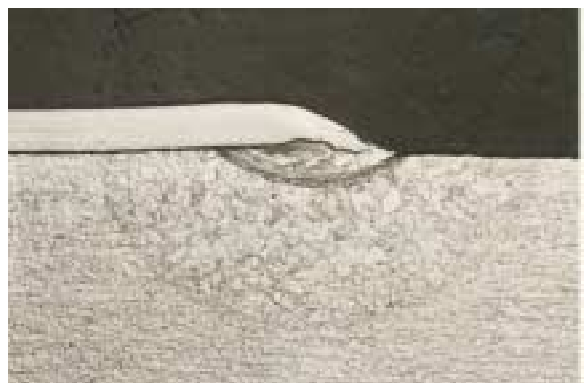

Fig. 1 Tantalum (0.5 mm, .020") Welded to Titanium

Titanium is sometimes used to clad copper for use in electrical systems like cathodes for production of electrolytic copper. The bond provides a long lasting, conductive path between the titanium corrosion layer and the copper current carrier.

Design Considerations

Simplicity is the most important consideration in clad lining design. Design to minimize welding is always a good idea with reactive metals and is doubly important for clad construction.

Avoid hard spots, particularly where there is a change is section or direction or applied stress that can cause differential movement. Keep welds out of corners. Use generous radii particularly where a liner is installed in a corner.

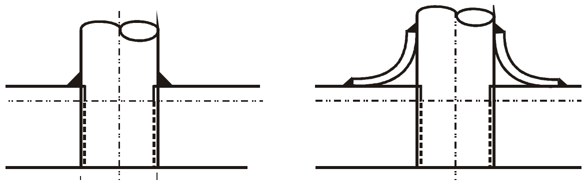

Fig. 2 Fillet Details for Attachments

An unstressed attachment will take stress from the stressed member, sometimes subjecting the fillet welds to unanticipated loads. Where the attachment may deflect under load, it should be designed to be certain that the attachment or sealing welds around them will not be subject to high or cyclic stress. For example, if a solid titanium pin or bar is mechanically fastened to the steel backing material, it may be better to seal to the liner using a formed (radiused) covering sheet than to try to weld the liner directly to the pin or bar. Consider risk of movement of either the liner or the bar in deciding how to handle the detail.

Advantages Of Clad Construction

The main reason for clad construction is economy.

Cladding also allows application of titanium or zirconium at temperatures in excess of their design allowable in code construction.

Disadvantages Of Clad Construction

There is an inherent structural weakness in the fillet welds used to make joints in the liner itself. The biggest drawback is that a failure of one of these welds releases corrosive compounds throughout the backing material. This can lead to undetected corrosion. Further, fluid contaminants behind a lining make high quality repairs very difficult if not impossible.
Loose linings are not generally suitable under vacuum.

Clad construction is inherently complex compared to solid construction, particularly in structures with many nozzles, attachments, or complex internals.

At least in titanium, clad equipment may be heavier than solid construction, which can increase the cost of foundations and supports, and may be a consideration in certain weight critical applications on offshore platforms, for example.

The exterior of a clad vessel may require painting and field touch up as well as continuing maintenance of the paint system.

Loose Lining

The least expensive method of cladding is to apply a loose lining of titanium or zirconium sheet to a completed steel vessel. Typically, 2 mm (.078”) sheet is precut and positioned on the interior surface. Joints between adjacent sheets are made by either overlapping adjacent sheets or placing a cover strip along the joint, fillet welding to seal the surface of the sheet. Next, nozzle linings and any cladding of details are completed and welded to the sheet in the same manner.
Plate, typically 5 mm (0.1875”) is sometimes used for the main shell lining to provide greater resistance to damage during maintenance or just to be more conservative.

Titanium cladding material is generally selected from grade 1, 11, 17, or 27 to take advantage of higher ductility of these low strength grades to allow manual forming (often just a rubber mallet) for closer fit at details. Zirconium Alloy 702 is typically used for clad applications.

By careful fitting of the liner it is normally not necessary to employ a stays. Use of retaining pins and stays can lead to more problems than they solve because they create hard points and additional welding. Where stays are needed the typical approach is to drill and tap through the sheet, then install a small bolt, which is then fillet welded to the sheet surface. Heavier linings or a replaceable sacrificial protective plate can be used in areas where erosion or mechanical damage are anticipated.

Explosive Clad

Titanium, zirconium, and tantalum can be bonded to a less expensive backing material such as carbon steel by explosive bonding. For most pressure vessel construction cladding material is selected from grade 1, 11, 17, or 27 to take advantage of higher ductility. Grade 2 and 7 have been used, but there is an increased risk of shear cracking during bonding. While not necessarily detrimental to final integrity, the presence of any form of crack is a concern.

Explosive Cladding Process

A few very specialized vendors practice the explosive bonding process. Most material is made to order, although some stock of titanium clad on carbon steel for tubesheet applications is maintained.

In the explosive cladding process, the material to be clad (called the backer material) which is typically at least ¾ inch thick, is prepared by sandblasting and cleaning. The cladding material, sometimes called the “prime” is placed over the backer on a pattern of spacer-supports which provide an accurate stand-off between the materials to be joined. The explosive material is placed over the prime. The explosive is usually detonated from at the center of one end of the plate, at a weld if a welded prime is utilized, so the detonation front move parallel to the weld..

As the detonation front moves outward, the prime is accelerated onto the backer. At the interface, the energy dissipates creating a jet of material from the surface of both pieces. The jet carries surface contaminants and oxides with it and the explosive energy creates a near atomic level contact between the two materials.

Nature of the Bond

The bond that results is a metallurgical-mechanical bond. Strength is developed from both a mechanical interlocking of the mating surfaces and from metallurgical bonding. The rate of energy application in the explosive bonding process is high enough that the brittle inter-metallic compounds that form in normal fusion welding of reactive metals are minimized.

Bond Mechanical Properties

Properties of titanium and zirconium explosively bonded to SA-516-70 carbon steel are typically as follows:

	Titanium	Zirconium
Shear Strength	35-45,000 psi	35-45,000 psi
Tensile Strength	30,000 psi	30,000 psi

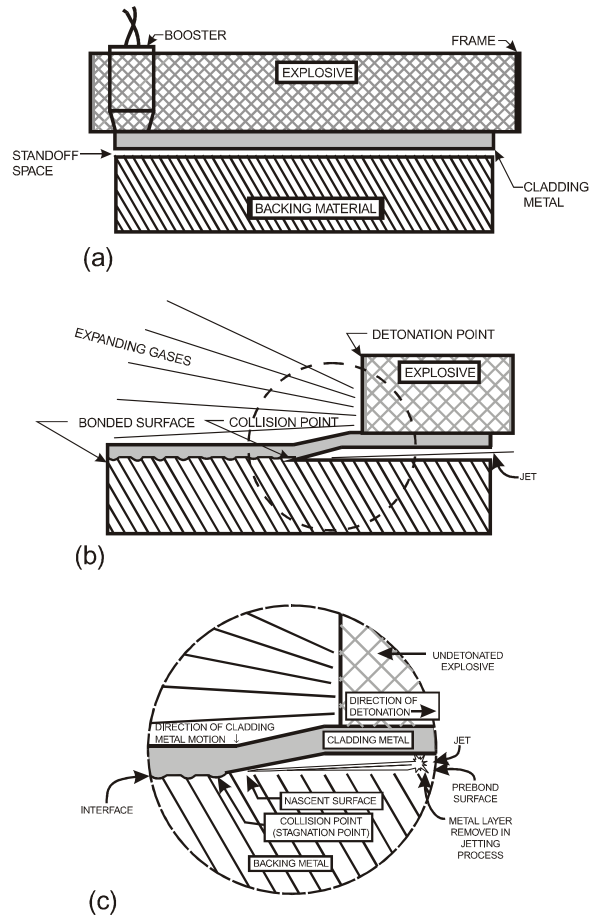

Fig. 3 Explosive Bonding Process
(taken from ASM Handbook)

Fig. 4 Titanium to Carbon Steel Explosive Bond
Photo courtesy Clad Metal Products

Fig 5 Explosive Clad Shear Test Specimen

Photo courtesy Clad Metal

Products

Testing the Bond

The most common test of bond properties is the shear test. Side bends also provide a good indication of bond quality, although they are not commonly used in North American specifications for clad plate. A shear specimen is machined from rectangular material and load applied to the cladding parallel to the bond.

Fig. 6 Explosive Clad Side Bend Test Specimen

Photo courtesy Clad Metal Products

Photo courtesy Clad Metal Products

Fig. 7 Explosive Clad Ram Tensile Specimen

While rarely utilized, bond tensile strength can be determined by machining the prime in a small diameter circle just through the bond line and boring a concentric flat bottom hole through the backer material just into the prime. A small ring of the bond area left in between. Testing is accomplished using a flat rod pushing on the prime against a retaining ring supporting the backing. Bond tensile strength is based on the area of the ring.

Special Considerations

Avoid putting the bond line in to the corrosive medium. While this sounds simple enough, the use of clad material as a structural transition is fairly common. Galvanic corrosion may be a problem. Also, because the bond line has tiny fissures, corrosive liquids or vapors can easily penetrate the joint leading to failure. If this type application is to be successful, the bond line should be protected with a barrier coating.

Limits on Forming of Clad

The shear strength of explosive bonded material may limit the minimum bend radius. Shear stresses can be calculated depending on the backer and cladding material thickness and cold bending limited to induce no more than 50%of the shear strength at the bond line.

Explosive Clad Size Limits

The backer thickness is usually at least 1/2" to minimize the deformation and subsequent straightening required to produce an adequate product.

Clad plate size is limited by the size of the liner (prime) sheet or plate. Since plate is typically produced at 96 to 102 inches in width, and about 2 inches per side is lost in the process, material clad with 5 mm (0.1875 inch) or thicker plate is limited to 90 to 92" in width. With welded primes, titanium clad plates up to 190" wide and 400" long have been produced.

To get past the width limit in sheet gages, like the most common 2 mm (0.078 inch), since 1975 Titanium Fabrication Corporation has supplied the cladding vendors with double width sheets produced by welding. A special precision machined edge preparation and two-sided welding procedure were employed to produce water clear x-ray quality in the welds while retaining the flatness required for the bonding process. The forces inherent in the bonding process preclude welding across the direction of the explosion front, so sizes are limited to the available length of sheet or plate. Titanium Fabrication has supplied 2 mm (0.078") sheets up to 148" x 192", although a more typical prime size is 96" x 148". Similarly, titanium plates can be assembled with a width of 192", which will yield roughly 190" in width.

Clad Joining Detail

The normal method of joining clad plates is to use the Batten Strip detail as indicated in Fig. 8. The titanium (or zirconium) cladding material is stripped back from the area of the backer steel and weld preparations made on the steel following procedures similar to those for normal steel. The only differences are that the weld root may be shifted away from the clad side to reduce the width of the batten strip required and that the titanium surface will be protected from grinding and welding sparks using a protective coating or a covering. Normally, all the steel work is completed before titanium or zirconium work is started.

Once the steel welding is completed, radiographed, and accepted, the vessel is thoroughly cleaned.

Where the base material requires thermal stress relief, prepare the vessel without batten strips. Protect the titanium or zirconium with anti-oxidant. Complete the stress relief at the lowest temperature allowed. Clean the vessel and joint areas.

The vessel may be moved to a clean area of the shop, or openings may be covered and the inside of the vessel used as a clean environment itself.

Following final visual inspection, filler strips (which can be copper, titanium or even steel) are fitted along each weld and are then covered by titanium batten strips which are tack welded in place. The batten strips are sealed along the edges with masking tape, and the spaces purged from the back with argon (or helium, or mixtures). Tape is carefully stripped back from a short section of the area to be welding, and the fillet weld completed following normal titanium welding practice. Heat input should be controlled and efforts to minimize residual welding stress employed. The welds should be carefully inspected visually in process, and may then be tested with liquid penetrants, by gas leak detection (halogen) or using air and soap solutions on the surface.

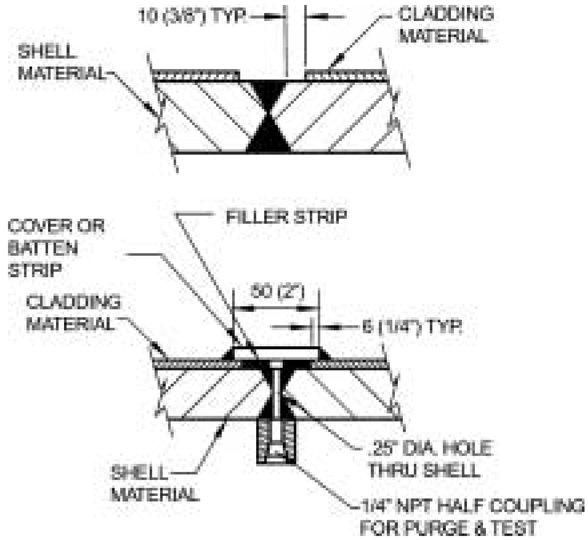

Fig. 8 Typical Clad Joining Detail

Procedures for joining loose linings are similar, except that it is common to overlap one sheet over the adjacent one to reduce welding.

There are cases where a combination of solid construction, explosive clad and loose lining may be best. For example, a heat exchanger may use explosive clad material for the tubesheet, explosive clad for channel shell, solid material for the channel divider plate and loose lining for nozzles, and flat channel covers.

Clad Tubesheets and Tubeplates

Tubesheet and tubeplates are one of the most common applications for clad material. The design allows direct welding of the steel backing material to the shell or adjacent structure.

The recommended minimum cladding thickness for tube seal welding is 9 mm (3/8"), although liners as thin as 3 mm (1/8") have been employed with success.

Explosively clad material is superior to loose lining for tubesheets. Loose tubesheet linings suffer radial shrinkage as tubes are welded. This produces high shear stress on the tube wall and in severe cases can lead to distortion of the tube wall and separation of the liner. If tubes are rolled hard into a loose liner, there is a tendency to push the liner away from the backer as the tube expands longitudinally, allowing adjacent tubes to expand into the space between the backer and the liner as well. To minimize the risk and problem, use a step rolling sequence that rolls the tubes hard into the backer, without expansion in the area of the liner. That way longitudinal tube expansion has no effect on the liner. A second step, preferably following a gas leak test of the rolled joints, rolls the tube into light contact with the liner. A rolling sequence for the light rolling should be selected that first establishes an intermittent pattern across the entire tubesheet face. Use of external restraint may be useful until enough tubes are rolled to restrain the liner. With explosive clad materials, the tubes can usually be rolled hard along the full length because the bond has sufficient tensile strength to overcome the tendency of the lining to separate. However, with very light ligaments, or where the bond quality is compromised, the procedure suggested for loose linings should be considered.

There is the possibility of a small amount of non-bond in explosive clad sheets. The producers will supply material meeting a 95% or even 99% bonding guarantee based on ultrasonic inspection over a certain grid pattern. In general, as long as the non-bond area is not too large, it is not detrimental to service. However, as tubes are rolled hard in separated non-bond areas, they can expand into the space adding a load further separate the bond.

Titanium Fabrication Corporation always recommends seal welding with clad tubesheets to reduce the risk of leakage in to the space between the liner and backer material (although there are reportedly more clad tubesheets without seal welding). If there is a desire for a groove in the liner, increased thickness of 12 mm to 15 mm (½ to 5/8 inch) is typical. By rolling before welding, oxygen is excluded from the weld root by the tight contact between the tube wall and the liner, so that no gas purge is needed. The exception will be where loose liners are used which have a thickness under 6 to 9 mm (1/4" to 3/8").

Fabricators and end users should plan for the possibility of greater non-bond areas and have a back-up plan to deal with it. The easiest is to just leave enough time in the schedule for replacement of material. A better approach may be to work with the supplier to see if the material can be used in a part of the structure where the non-bond area will have no impact on serviceability. Finally, a common sense approach which considers the importance of bond integrity on the actual performance of the equipment should be applied.

Fig. 9 Titanium Clad SA-516-70 Carbon Steel Reactor Component for Production of PTA

Fig.10 Titanium Clad Carbon Steel Reactor, 1/8" Grade 1 on SA-516-70 for Production of Organic Chemicals.

Contact Titanium Fabrication Corporation for further information and for help in designing titanium, zirconium, or tantalum clad equipment.