Titanium Internals in Refractory Lined Pressure Oxidation Autoclaves

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ABSTRACT

This paper provides an overview of the design considerations, manufacturing techniques, quality assurance and installation of titanium compartment walls, baffles and anchor brackets for use in metallurgical autoclaves. Hatch pioneered the use of titanium autoclave internals in 1996 at Barrick Gold Corporation's Goldstrike facility in replacement of hydraulically inefficient, maintenance intensive and voluminous refractory brick internal structures. Titanium is a proven material of choice for autoclave internals due to its service longevity in the high temperature, acidic and abrasive environment found in metallurgical autoclaves. Employing computational fluid dynamics and stress analysis, and fabrication techniques developed by W.E. Smith Engineering, Hatch has successfully implemented titanium compartment walls and baffles on a number of autoclave projects, including four of the world's largest refractory lined pressure oxidation autoclaves at the Pueblo Viejo Project in the Dominican Republic.

INTRODUCTION

This paper provides an overview of the design considerations, manufacturing techniques, quality assurance and installation of titanium compartment walls, baffles and anchor brackets for use in metallurgical autoclaves. Higher ore through-put requirements necessitating larger vessels and oxygen mass transfer have made traditional un-baffled brick compartment walls obsolete. The need for a high strength material that is resistant to the high temperature, acidic and abrasive process conditions has lead to the adaptation of titanium for autoclave internals. Design tools such as computational fluid dynamics (CFD) and finite element analysis (FEA) are employed to ensure hydraulic performance and structural stability. Advanced cutting, bending and welding techniques were employed to deliver a metallurgically unaltered, dimensionally accurate multipart product, enabling rapid site erection.

NEED FOR CHANGE

Traditionally autoclave compartment walls are constructed from refractory brick which is integral with the brick lining that protects the pressure boundary from high temperature, corrosion and abrasion. Subjected to static and dynamic fluid loads, as well as large stresses due to constrained thermal growth, these walls are typically thick (300 to 450 mm). The result is increased installation man-hours requiring specialized labour from brick layers, and the loss of internal fluid volume. Autoclaves are reaction vessels, so retention or reaction time (time to pass from vessel inlet to discharge) is a critical design parameter in the determination of vessel diameter. By replacing bulky brick walls with titanium a given autoclave’s process volume increases, thereby processing more ore per unit time or the autoclave can be made smaller to reduce capital cost. In addition, hydraulically efficient baffling can be incorporated into titanium compartment walls where the optimum geometry is difficult with brick. This improves mixing efficiency, solids suspension and oxygen mass transfer. Autoclave availability is a major factor in the profitability of all process plants. Where brick walls require scheduled shut downs for rebuild, titanium walls have a design life equal to that of the autoclave. If excessive wear occurs in a portion of the wall, the modular construction of titanium walls facilities quick rebuild while replacing only worn components.

DESIGN CONSIDERATION

Successful pressure oxidation requires mass transfer and dispersion of oxygen gas into the slurry, allowing chemical reactions which liberate precious metals. In the case of Pueblo Viejo gold, gold was liberated from sulphide ores. Slurries must also be sufficiently agitated to prevent solids from settling out. Settling can create a concrete like scale that can plug pipes and damage equipment. To accomplish gas dispersion and solids suspension, computation fluid dynamics (CFD) is used to model the gas / liquid mixing and the affects of compartment walls, baffling and agitator blade geometry. CFD is also used to select the optimal injection sites for feed slurry to reduce slurry bypass. Bypass is the shortcutting of feed ore to the discharge in a shorter time than the required retention time, which leads to reduced recovery.

From the CFD analysis, it is possible to extract baffle loads exerted by the moving slurry. For the Pueblo Viejo project these loads are extracted incrementally along the baffle length as show in Figure 1.

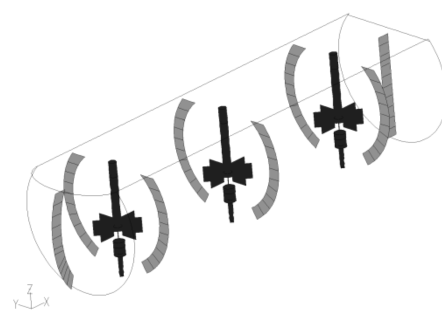

Figure 1: Compartments 1A, 1B & 1C complete with head, wall and compartment wall baffles, agitators and oxygen spargers. CFD results provide forces exerted on each baffle square.

To ensure the structural integrity of the titanium walls and baffles, finite element analysis (FEA) is conducted considering static

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liquid head, thermal affects and the dynamic fluid forces derived from the CFD analysis. While not expected during operation, the compartment walls are designed to resist the overturning moment of a full compartment adjacent to an empty one. The Pueblo Viejo autoclaves have a maximum operating temperature of 230 ^{o}C, therefore thermal growth is expected to be a major stress contributor. Across the vessel centre line, the compartment wall is 4522 mm wide and is expected to grow 8 mm from ambient to max operating temperature. To alleviate thermal stress, the design incorporates controlled gaps, slotted / oversize holes and a compressible ceramic paper lining so the expanding titanium is as unconstrained as possible. The wall geometry is modeled and meshed as a shell so that the required thickness could be determined through iteration. The analysis was considered successful when the combined equivalent stress was below the ASME Boiler and Pressure Vessel allowable stress for SA-240 Gr. 2 (UNS R50400) titanium. It is expected that the life of the wall is equal to the autoclave vessel, so an appropriate erosion allowance is added. Figure 2 shows the stress magnitude with selected wall and baffle thicknesses of 10 mm and 20 mm respectively. Deformation is exaggerated to 50x actual for clarity.

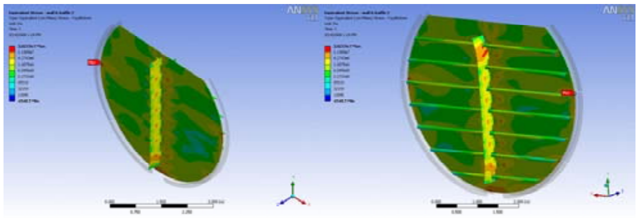

Figure 2. Mechanical (static head plus dynamic fluid forces) and thermal loads. Max stress is 30.2 MPa < 168 MPa allowable.

FABRICATION

The 10 mm Titanium Grade 2 used for the baffle walls had many challenges needed to be overcome for successful fabrication. These challenges included how to bend the 10mm Titanium Gr. 2 to a 50 mm radius, making the greatest use of the Titanium sheets, assembling the geometrically difficult parts through welding, and then final fit-up inside the autoclave.

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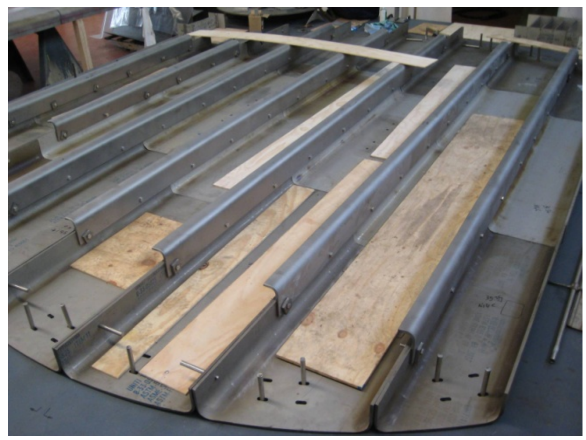
Bending the 10 mm Titanium Gr. 2 to a 50 mm radius was accomplished by experimenting with ratios of applied heat and bend radii that would allow the Titanium to bend but still maintain its properties. Due to titanium's affinity for oxygen at higher temperatures, tensile tests and hardness surveys were performed to ensure that the bending process did not alter the mechanical properties. After extensive experimentation, a range of applied heat input vs. bend radii had been established allowing relatively thick sections of titanium to be bent to tight radii. The fabricator that was chosen for this delicate bending operation did not have any previous experience bending titanium adding to the challenge. W.E. Smith (WES) approached their regular subcontract bending shop and carried out the experimentation as well as executed the end procedure in detail with them training the staff on proper handling procedure as they went. Emphasis was placed on contamination avoidance and the controlling of applied heat to the Titanium plates.

Before bending took place, due to the exact tolerances that needed to be achieved by the fabrication of the titanium anti swirl baffles and compartments walls, all the parts of the assemblies were cut off sheets of titanium by water jet cutting. The titanium plates were nested by a custom program automatically, that achieved a 98% material utilization. The CAD drawings were directly imported into the nesting program. Accuracy of the drawings was critical so they passed through four levels of checking. The driving factor allowing for such high nesting efficiency was the accuracy

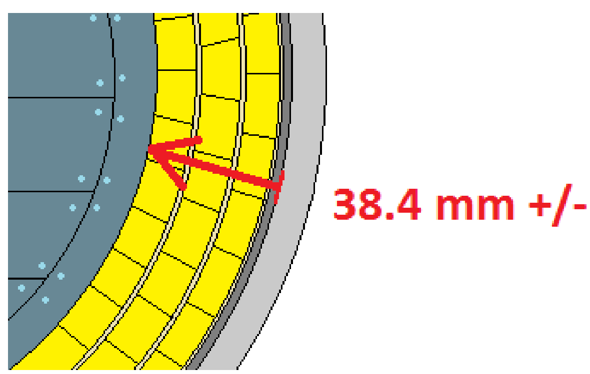


and width of the water jet used for cutting. The abrasive in the cutting medium was C and Si free with a cutting width of 0.2mm. Through lessons learnt we eventually had all the slots and bolt holes water jet cut (in lieu of punching and machining) as well, which placed an enormous importance on the bend lines and tolerances. The water jet cutting facility had approx 5 cutting types, ranging from fast with less accuracy to slow with precision and a high degree of accuracy. A speed was selected that optimized accuracy and precision with needed quality and production schedules given equal importance. Cutting duration was approximately two months. This was again driven by the bending process and the accuracy required.

Once the parts were bent and shipped to W.E. Smith the process of assembling the baffle walls and their components took place. This required the use of special propriety fixtures and jigs used in the fit-up of the titanium pieces for welding. The difficult nature of ensuring the shielding gas was constantly enveloping the weld during the welding operations was quite difficult due to the complex geometries involved. Minimal distortion was the other major requirement, and sequencing of the welding was done through rotating the welder with up to 4 different jigs at the same time. Sequencing the welding was vital to minimize distortion and allow for adequate shielding gas coverage, hence the need for multiple custom jigs and fixtures. After welding, the entire assembly was fit on another custom jig to ensure that full fit-up and stacking tolerances were not pushing the overall baffles out of tolerance.

ASSEMBLY

Fit-up of the titanium baffle and anti swirl walls inside the autoclave was a relatively easy task made difficult due to tolerances that stacked during the construction of the autoclaves. To maintain an acceptable surface for the brick lining the roundness of the vessel needed to be kept to 0.4% (44.8 mm, 22.4 mm per side) roundness. This was extremely difficult to do due to the complex fabrication sequence required to build the vessel. Once the steel achieved the 0.4% roundness tolerance the lead lining had an additional tolerance of 8 mm (4 mm per side). In addition to the lead lining tolerance, the brick lining tolerance was even more extreme, accounting for more than 24 mm (12 mm per side) of acceptable variation. This gave more than a 75 mm allowable difference in dimensions. Slight variations in the walls were preformed on site to account for these stack up tolerances and allow for proper fit-up.



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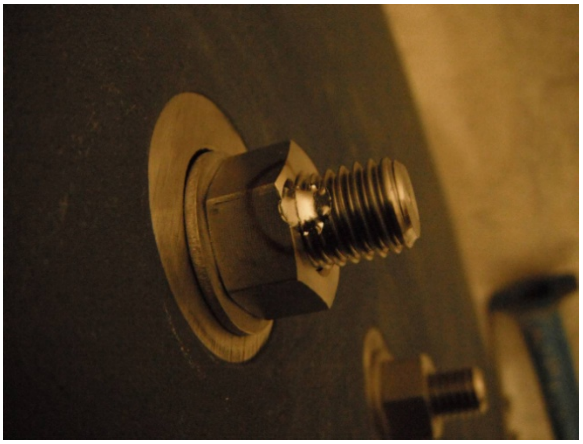
One of the issues that were encountered during the fit-up of the titanium baffle walls and the anti swirl baffles was producing contamination free tack welds. Due to the turbulent nature of the environment inside of the autoclave it is necessary to ensure that no titanium components can loosen causing damage to the autoclave internals. This is prevented by tack welding every nut and bolt inside the autoclave including the ones that hold together the titanium walls and baffles. This presented a particular challenge due to the small size of the fasteners that are being tack welded and the vast number of them in difficult locations. Also due to the space restrictive nature of the positions that these nuts and bolts need to be tack welded in additional shielding gas fixtures where impractical. Upon experimentation it was found that if the tack weld size could be controlled to 1/8" or less than a contamination free tack weld could be produced. This proved to be not only a time saver but a material saver as well, as the intended purpose of the tack weld was to discourage loosing of the nut on the bolt. The tack weld was small and was just enough to ensure that the threads were sufficiently altered and filled to prevent the nut from loosening.



CONCLUSION

Titanium is the material of choice for many critical applications in an autoclave process plant. High strength, corrosion resistance and manufacturability make titanium an ideal material for internal wall structures and baffles. To date, two (2) of Pueblo Viejo's autoclaves are in production, with the remaining two (2) scheduled for fourth quarter 2012 start-up.

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Appendix A – Photos

Pueblo Viejo AUT-150: Compartment 4 wall with compartment wall baffle installed (at centre).

Pueblo Viejo AUT-150: Reverse (discharge) side of compartment 1 wall. Stiffener rings, clamping plate and titanium hardware.

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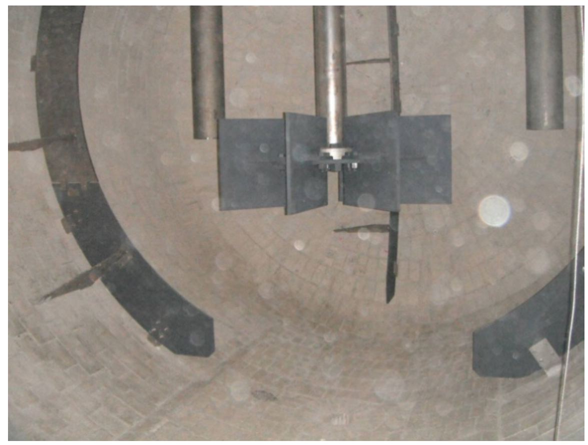
Pueblo Viejo AUT-150: Compartment call anchored by corbel brick. Ceramic paper installed for relief of thermal expansion.



Pueblo Viejo AUT-150: Compartment 1A wall baffles, anchors and agitator.

Pueblo Viejo AUT-150: Compartment 1 head baffle clamping connection between lower two (2) pieces.

Pueblo Viejo AUT-150: Reverse (discharge) side of compartment 3 wall. 'C' channels, stiffener rings and wall baffle.

Titanium Internals in Refractory Lined Pressure Oxidation Autoclaves

A discussion featuring design, fabrication, and installation of titanium walls in brick lined pressure vessels

Charles Ugarenko, Welding Technologist

October 7-10, 2012 • Atlanta, Georgia, USA

HATCH™

Introduction

- Hatch Autoclave Technology Group
- Autoclave
  - Reaction pressure vessel operating at elevated temperature and pressure used to create the necessary conditions for chemical reaction in a hydrometallurgical mineral process plant.
  - Pueblo Viejo Project:
    - 24,000 tpd
    - Process conditions: 3618 kPa(g) at 230 °C [525 PSIG at 446 °F]

Presentation Overview

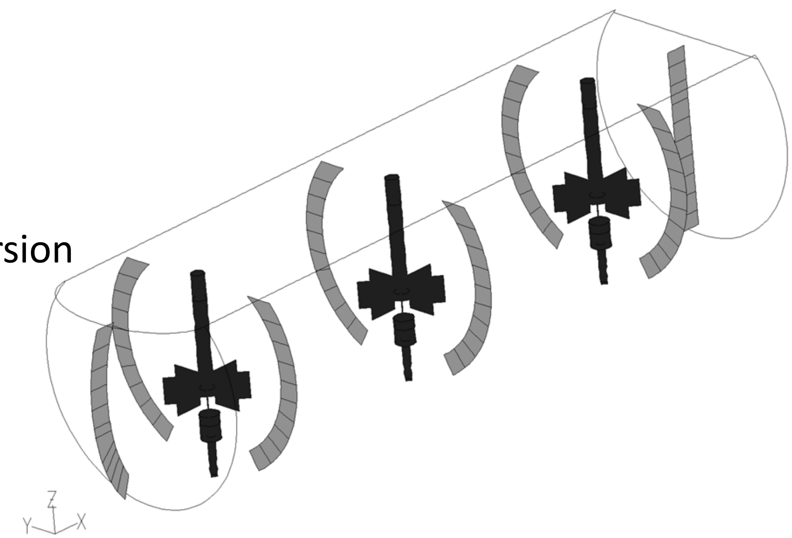
- Need for Change
- Design Considerations
- Fabrication
- Assembly
- Conclusion

Need For Change

- Past walls were made out of refractory brick
  - Very bulky, thick wall sections
  - Reduced process volume
  - Labour Intensive
  - Difficult to incorporate baffling
- New wall design needed to incorporate
  - Lighter and easier to install
  - Reduced wasted process volume
  - Better way to incorporate wall baffling
  - Less down time for maintenance and repair
  - Corrosion resistance (hot acidic environment)

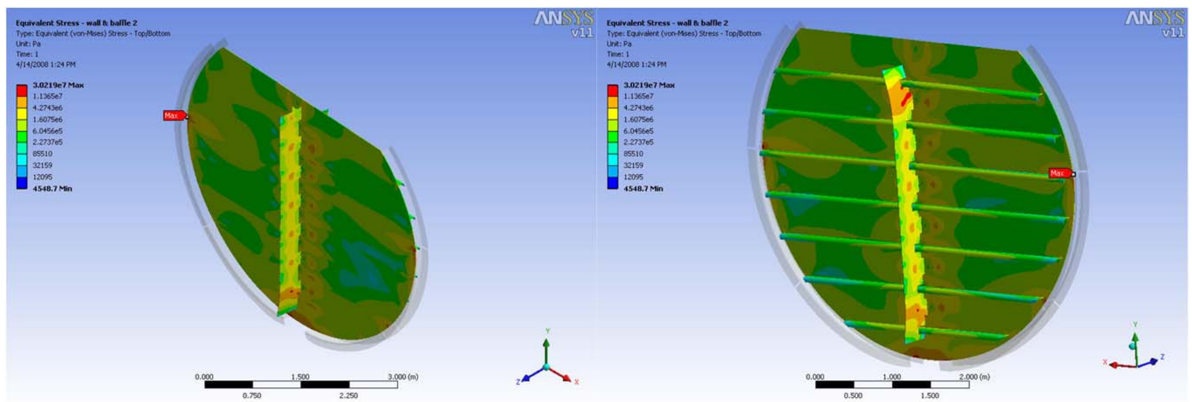
Design Considerations

- Successful pressure oxidation relies on
  - Mass transfer of oxygen into slurry
  - Retention time
- Computational Fluid Dynamics (CFD)
  - Used to model fluid behaviour and gas dispersion
  - Uniform solid suspension



Design Considerations Continued

- Finite Element Analysis (FEA)
  - Used to ensure structural integrity of compartment walls and baffles
  - Selection of nominal plate thickness
- Load Considerations
  - Static slurry head
  - Dynamic fluid forces
  - Thermal expansion



Equivalent Stress – deformation 50x

Design Consideration Continued

- Final Selection
  - Anti Swirl Baffles
    - SA 240 Grade 2 (UNS R5400)
    - 20mm Thick
  - Compartment Walls
    - SA 240 Grade 2 (UNS R5400)
    - 10mm Thick

Fabrication

- Water Jet Cutting and Material Utilization
  - Nesting program utilized 98% of the material
  - Water jet cut quality needed to be very high with a cutting width of 0.2mm
  - Accuracy of nesting an cutting was critical
- Bending Titanium
  - Correct ratio of heat vs. bend radius
  - High degree of dimensional accuracy required
  - Contamination avoidance during heating
  - Heat Control
  - Tensile Testing and hardness testing on bent sections

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Fabrication Continued

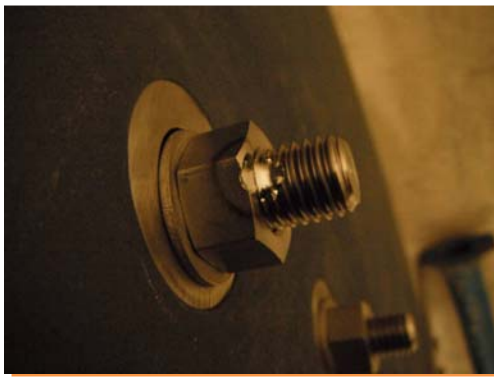
- Welding and fit-up
  - Fixturing for shielding gas coverage and dimensional accuracy
  - Welding sequence
  - Final in shop full wall assembly
- Cleanliness and Contamination Prevention
  - Shield gas fixtures
  - Glass Bead Blasting
  - Ferroxyl Testing
- Quality Assurance
  - Welding inspections
  - NDT testing of bends and weldments

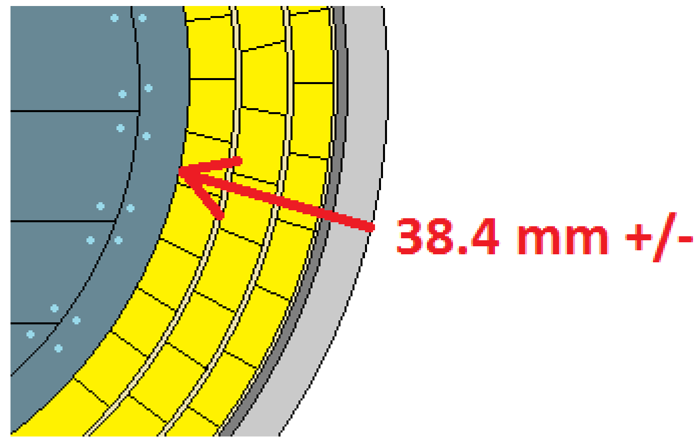
Assembly

- Easy Fit-up Sequence
  - Modular sections used to make all walls
  - Adjustable Fit-up
  - Light large sections

Assembly Continued

- Assembly Issues Encountered
  - Stacking tolerances
  - Tack welding of fasteners





Conclusion

- High Strength, Corrosion Resistance and fabricabilitiy.
- Titanium walls successfully installed in 4 autoclaves at Pueblo Viejo Mine
- 2 Autoclaves in Start up operation with 2 more scheduled to start Q4 2012