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Whitepaper on Clad Metal Repairs

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Abstract

Clad metal materials are widely used in industrial applications due to their enhanced mechanical properties and corrosion resistance. However, damage can occur to the cladding due to various factors, necessitating a repair. This whitepaper offers specific guidance based on tests performed in Tricor's shop by welders experienced in welding of Titanium and executing these types of repairs. The expertise of the welder and proper procedures are assumed and not reviewed in the context of this paper, although it cannot be emphasized enough how important these factors are in the fabrication of reactive metals like Titanium.

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1. Introduction to Explosion Cladding

Explosion cladding is a solid-state welding process that bonds two dissimilar metals through the force of a controlled explosion. This method is commonly used for creating bimetallic materials such as titanium-clad carbon steel. The bonding interface exhibits a wave-like structure, ensuring a strong mechanical and metallurgical bond.

1.1 Components of Explosion-Clad Materials

- **Cladding Material:** A high value, corrosion resistant alloy like titanium.
- **Backer Material:** Often carbon steel, lowering cost and providing the mechanical properties needed for pressure containment.
- **Bonding Interface:** Characterized by wave amplitude ranging from 0.012" to 0.0175".

Figure 1: The explosion cladding process

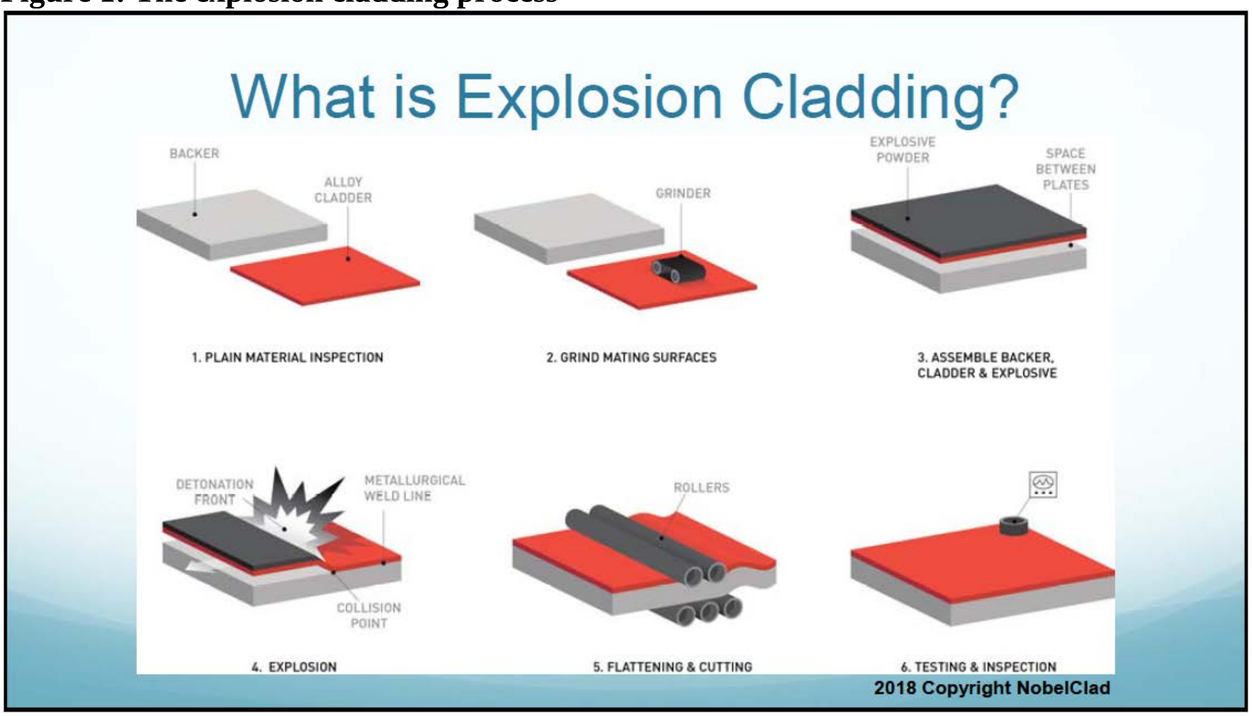
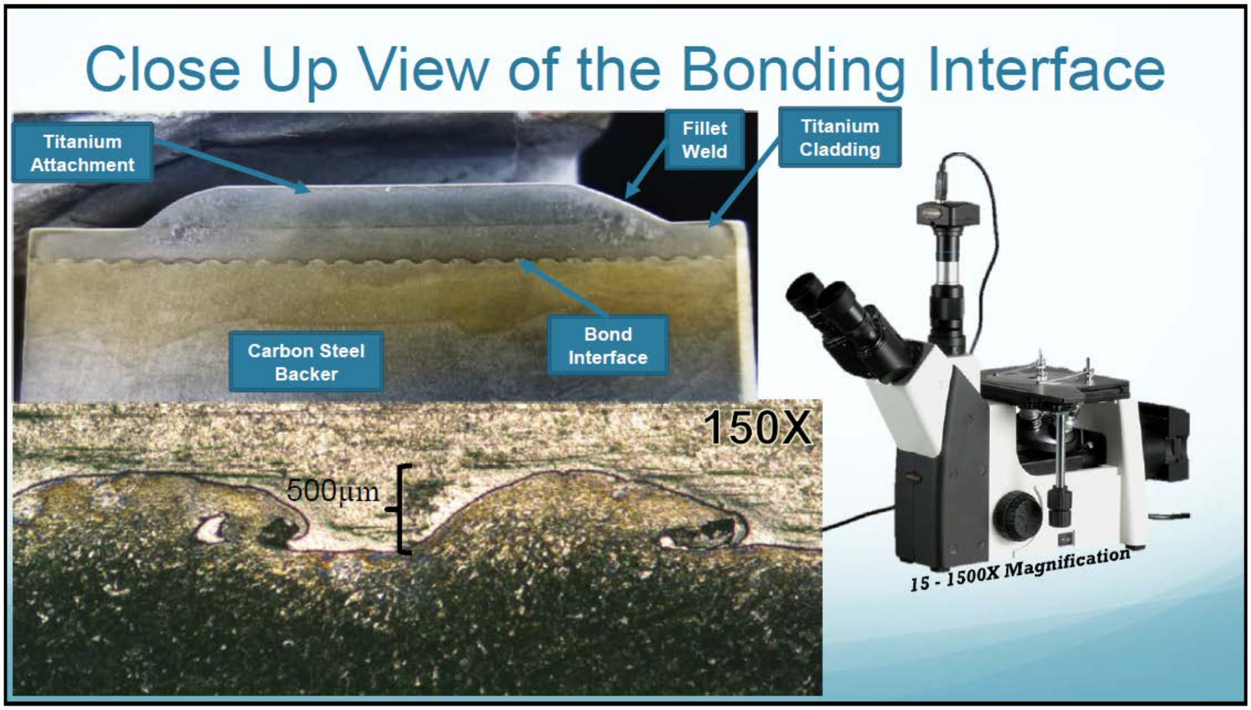


Figure 2: Close-up view of bonding interface



2. Challenges in Clad Metal Repairs

Vessels with clad linings sometimes experience degradation due to a variety of causes:

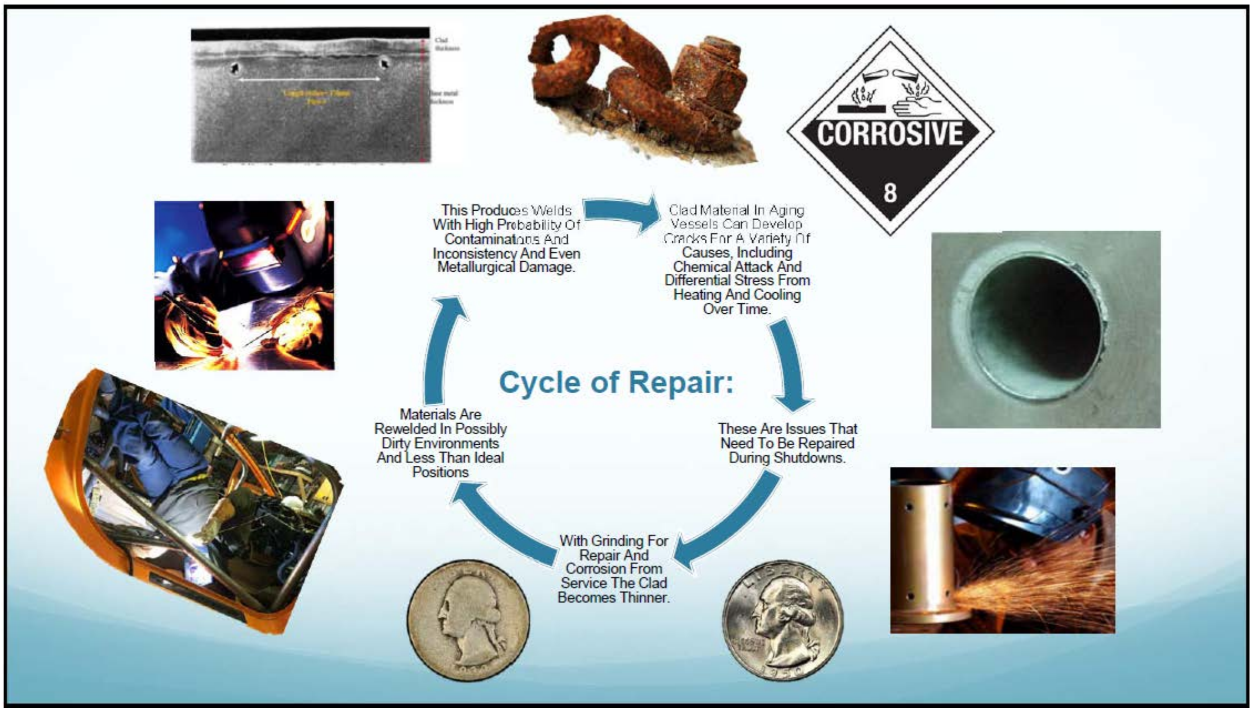
- **Chemical attack** leading to corrosion.
- **Induced stresses** from differential thermal growth during heating and cooling cycles.
- **Mechanical damage** from impacts by solids in the process or damage during confined space entries.

The clad layer can have a reduced thickness as compared to the original design over time due to erosion, abrasion, or corrosion during operation. Also, if this is not the first repair, grinding of material is generally necessary during a repair, which also thins the clad layer.

2.1 Repair Environment Issues

- Repairs are often conducted in less-than-ideal conditions, increasing the risk of weld contamination.
- Clad thinning through grinding and corrosion raises concerns about structural integrity.

Figure 3: Cycle of Repair



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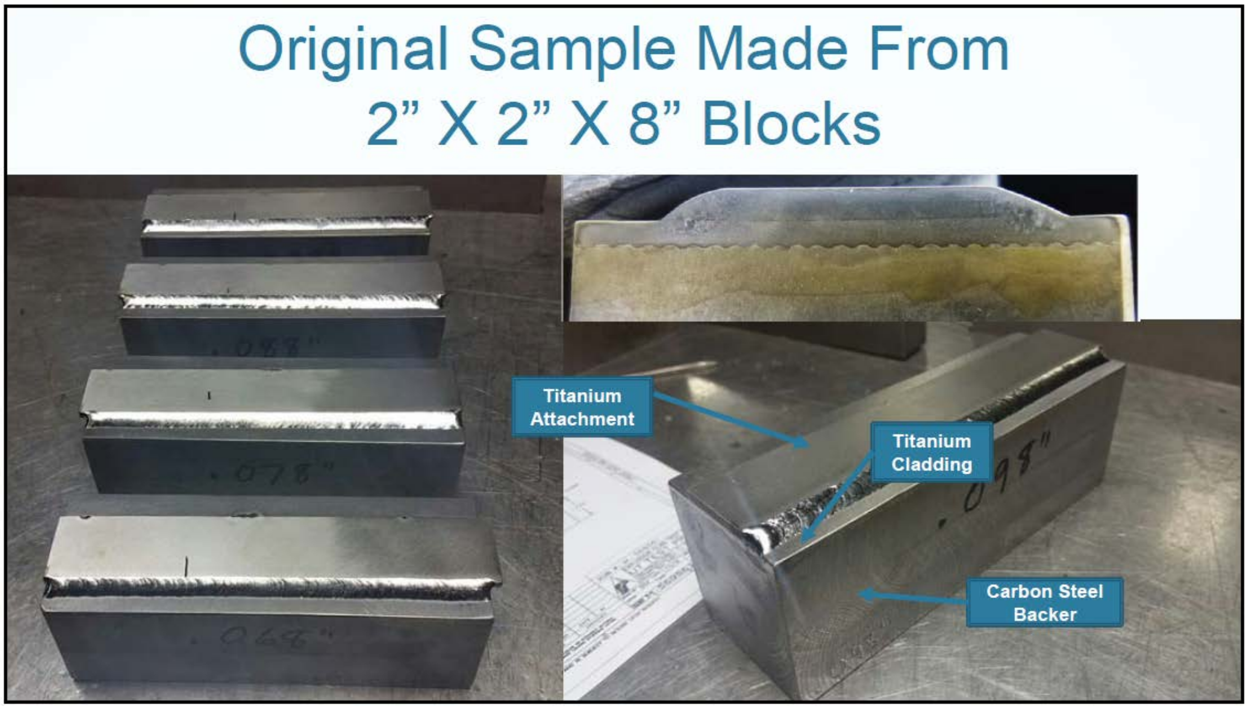
3. Clad Metal Repairs With Varying Clad Thicknesses

To explore this issue doing repairs on clad equipment where the chicness is reduced from design, trials were performed in Tricor's shop by experienced welders using proven methods on 2" x 2" x 8" blocks with cladding on one 2" x 8" face. The various cladding thicknesses tested were: 0.098" (original design), 0.088", 0.078", and 0.068", 0.058", 0.048", 0.038" and 0.028". Stereoscopic images of the heat affected zone from welding on the repair patch were taken. The weld area and repair patch were evaluated with a Sci Aps XRF PMI gun to look for Fe contamination. That work is summarized here.

Figure 4: Test Blocks



Trials were conducted using the Miller MaxStar 350 with the following conditions:

3.1 First Pass Welding Parameters

- **Wire Diameter:** 1/16"
- **Initial Temperature:** 72°F
- **Peak Amperage:** 130A
- **Pulse Frequency:** 3 PPS
- **Average Travel Speed:** 6.95 IPM
- **Final Thickness:** 0.098" to 0.068"
- **Finish Temperature:** varied from 82 to 85°F

3.2 Second Pass Welding Parameters

- **Wire Diameter:** 3/32"
- **Initial Temperature:** 75°F
- **Peak Amperage:** 155A
- **Pulse Frequency:** 3 PPS
- **Average Travel Speed:** 5.975 IPM
- **Final Thickness:** 0.098" to 0.068"
- **Finish Temperature:** 90°F for all blocks

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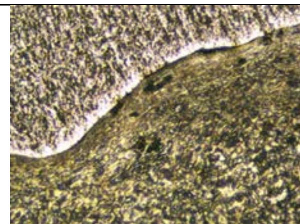
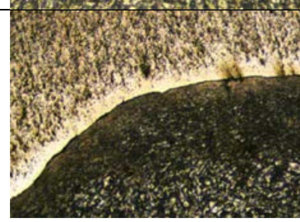
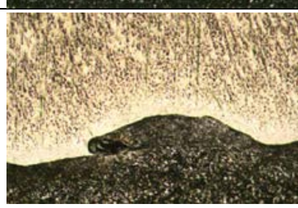
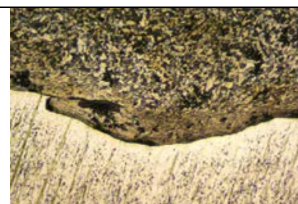
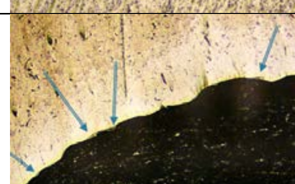
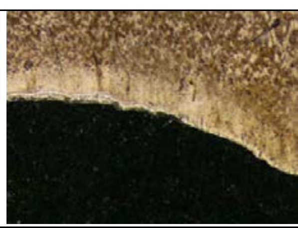
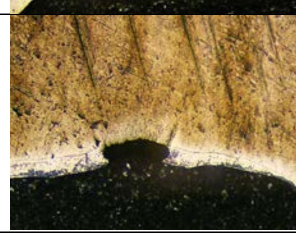
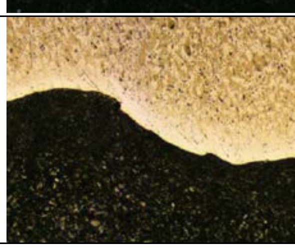
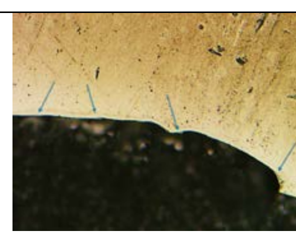
4. Summary of Results

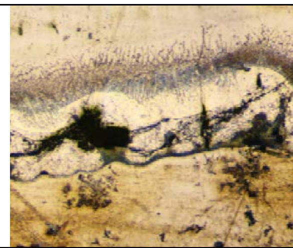
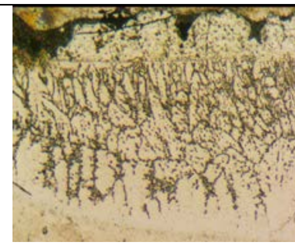
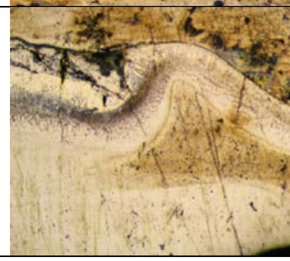
Two assessments were made of the clad blocks and repair areas after the welding was concluded. First, the cladding bond was observed with a stereoscope looking for any indication of disbonding of the clad, as well as the development of any intermetallics at the clad boundary. Next, the heat affected zone of the clad material was checked with a PMI gun for iron contamination.

The thumbnail images at various magnifications give some sense of the progressive deterioration of the clad/substrate bond interface as a function of cladding thickness at the time of welding with the described procedure:

Clad Thickness	After Repair
0.098"	
0.088"	
0.078"	
0.068"	
0.058"	
0.048"	
0.038"	

0.028”	

Clad Thickness	150X	300X	1500X
0.098”			
0.088”			
0.078”			
0.068”			
0.058”			
0.048”			

0.038”			
0.028”			

The below PMI testing results clearly show that contamination using this weld set-up became an issue when the cladding thickness decreased below 0.048”. This assessment method was not as sensitive as the visual assessments done utilizing the stereoscopic images.

Figure 5: XRF PMI Testing Results on Clad material

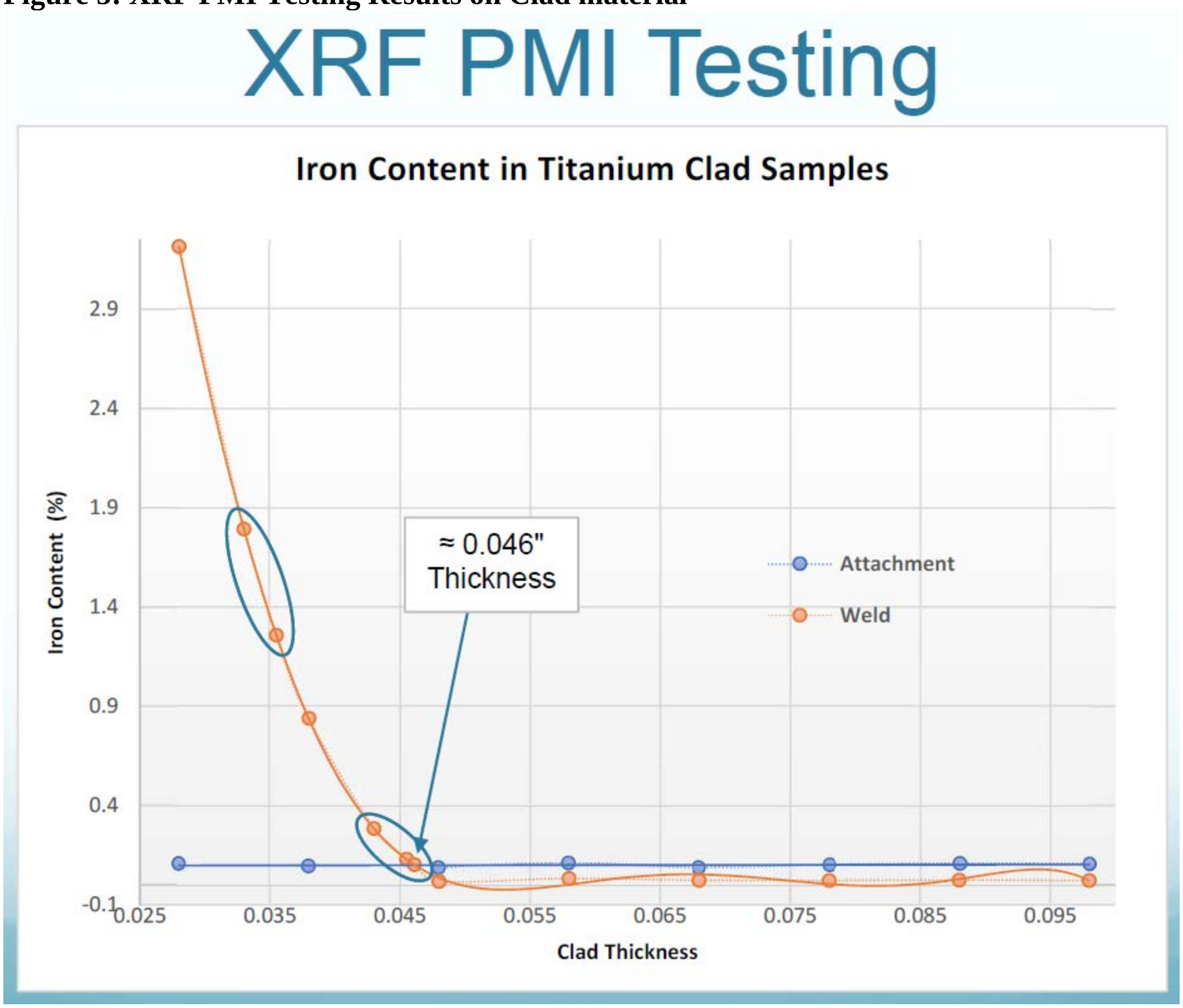


Figure 6: Clad thickness versus contamination risk.

Clad Thickness (inches)	Contamination	Intermetallic Formation	XRF PMI Analysis	Suitability
0.098”	No	No	No	Suitable
0.088”	No	No	No	Suitable
0.078”	No	No	No	Suitable
0.068”	Possible	Questionable	No	Risky
0.058”	Yes	Yes	No	Not Recommended
0.048”	Yes	Yes	No	Not Recommended
0.038”	Yes	Yes	Yes	Not Recommended
0.028”	Yes	Yes	Yes	Not Recommended

5. Key Findings and Best Practices

- Welding on clad material thinner than 0.078” is **highly risky** due to contamination risks.
- Repairs to metal cladding of any thickness can be risky with too much heat input.
- Skilled welders and stringent procedural controls are essential for successful clad metal

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6. Opportunities for Future Work

This work utilized 2 passes with an 1/8” fillet. Several smaller stringer beads could be used to minimize heat input.

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7. Conclusion

The results of this study highlight the importance of maintaining adequate clad thickness for reliable repairs. Companies should establish strict guidelines for the minimum allowable clad thickness and ensure welding is performed by experienced professionals. By implementing best practices, industries can extend the service life of clad metal structures while maintaining safety and performance.

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