WHITE PAPER

PROCESS VESSEL CORROSION: CLADDING OPTIONS

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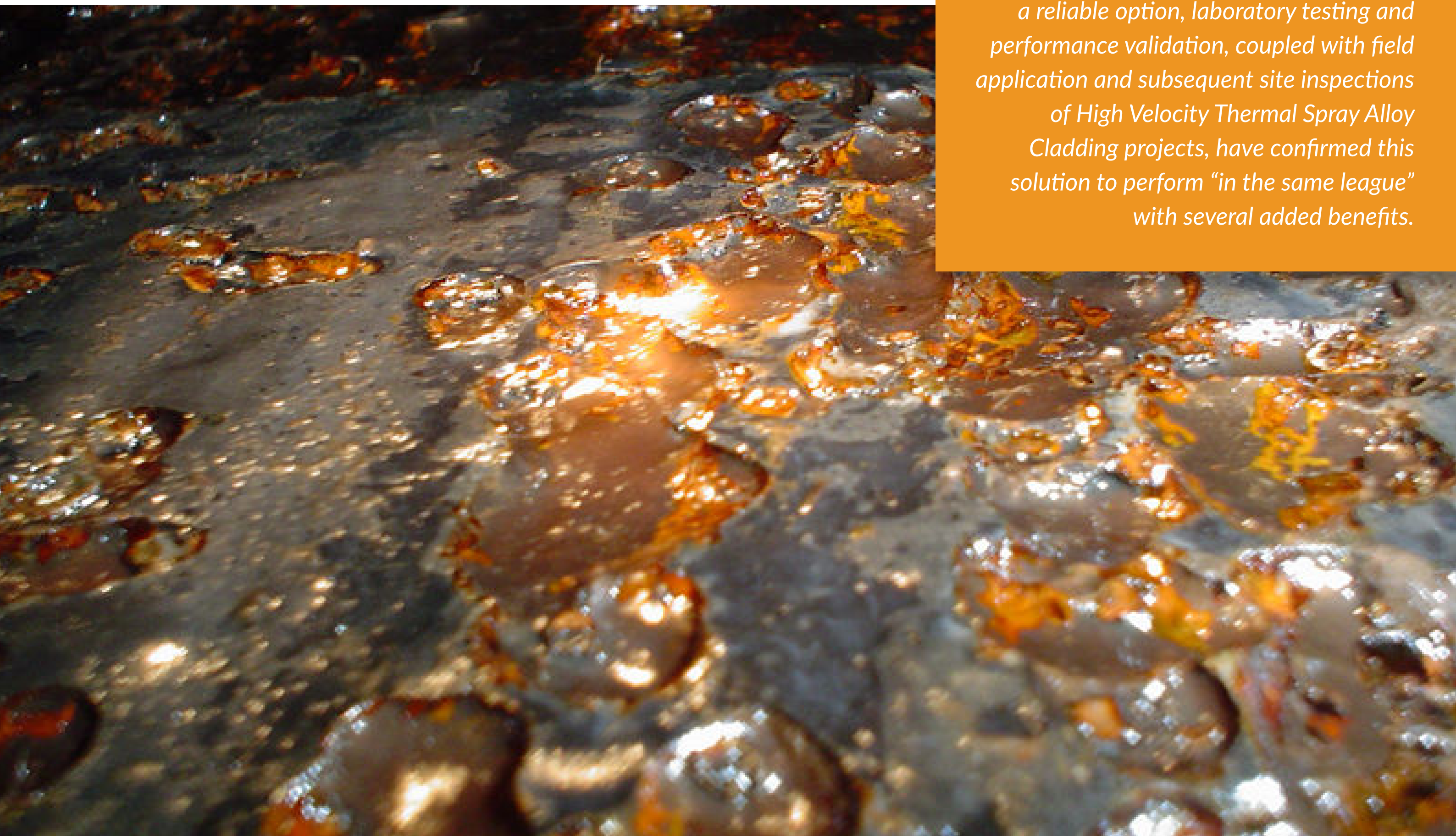
When faced with metal wastage, asset owners and operators have viable options available to them in addressing the corrosion mechanisms with a CRA barrier. The technique used to apply this CRA will mainly be determined by the shutdown time available to carry out the application.

While weld metal overlay continues to be a reliable option, laboratory testing and performance validation, coupled with field application and subsequent site inspections of High Velocity Thermal Spray Alloy Cladding projects, have confirmed this solution to perform "in the same league" with several added benefits.



1. MAINTAINING UPTIMES

Mission critical equipment, including process vessels, towers and columns play a major part in maintaining the uptimes and levels of production of oil and gas plants worldwide. Media being processed inside these vessels can be corrosive in nature.

For example, several potential aggressive corrosion mechanisms exist in amine process equipment, in the lower section of a regenerator, where carbon steel surfaces not wetted by the amine solution may be attacked by water vapor condensation and the formation of carbonic acid.

Acid-gas ratio, choice of amine, contaminants, two-phase flow, flashing, high velocities, vessel design and insulation are all factors at play.

2. THE COST OF CORROSION

Corrosion ultimately leads to metal wastage and shell thickness loss. Plant and process shutdowns caused by issues with these critical assets can quickly run up losses of tens of millions of dollars.

According to the US Department of Energy's Energy Assurance Daily, there were over 1700 refinery shutdowns from 2009 to 2012 with 23% of them caused by maintenance.

The duration of a shutdown can range from a couple of hours to weeks. A shutdown is a disruption in the refining process. An unplanned shutdown can cost companies millions due to production lost.

3. FITNESS FOR SERVICE

Once it is evident that the vessel is losing its thickness due to corrosion, the countdown begins. If the vessel wall thickness wastage has exceeded its minimum corrosion allowance, options available for the operators become significantly narrowed down to major mechanical repairs or replacement of the equipment. If intervention takes place before this time, or, if Fitness for Service (FFS) evaluations deliver a favourable result, where the vessel still maintains its operational integrity, there are several options on the market that can be considered.

4. EVALUATING ALTERNATIVES: WELDING

Welding has become an industry solution, for both rebuilding areas of wall thickness with the parent metal alloy and in providing a reliable corrosion resistant alloy (CRA) barrier. It is adopted, due to the fact that it can be applied if the vessel is below its corrosion allowance. Weld overlay will not only produce a corrosion barrier, it will also restore lost wall thickness for pressure retention.

4.1 Bond Strength

The bond produced between the base metal and welding is metallurgical and strong if applied correctly. Welding is also resistant to mechanical damage and shock. Moreover, it can be repaired if there is localised damage, if appropriately skilled welders are readily available.

For these reasons, multiple asset owners and operators rely on welding to protect their vessels from further corrosion. As with most technologies, weld application is not without its downsides.

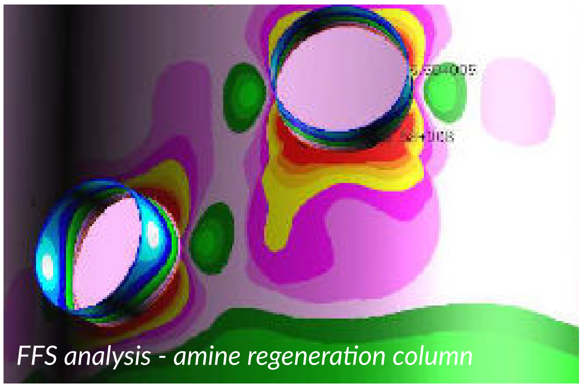
One major issue, although rare in occurrence, is the catastrophic distortion of the shell due to overheating during the welding process. A high degree of stress gets added, especially on thinner vessels. In vertical columns, welding causes shrinkage of approximately 1%. In a 5m diameter column this would mean a 50cm shrinkage – a significant level of distortion.

4.2 Application Time and Costs

There is also a question of time and costs. Welding is a relatively slow process with an application of 1 – 1.5m^2 per welding head/shift and can also cause additional delays in bringing the asset back into service.

High-temperature preheat turns the working conditions inside the vessel from very uncomfortable to impossible. The additional time of Post Weld Heat Treatment (PWHT) to stress relieve Heat Affected Zones (HAZ), if mandatory, may generally make the solution non-viable. Temper bead welding has been offered in place of PWHT, but that technique is difficult to execute and lends itself toward reliable automation.

Another time-consuming exercise is the removal and reinstallation of support rings and downcomers. This alone can double the duration of the project. It is also worth mentioning that welding is only as good as your chosen process and procedure, technician, and quality program.



FFS analysis - amine regeneration column

Welding repair

Welding repair application

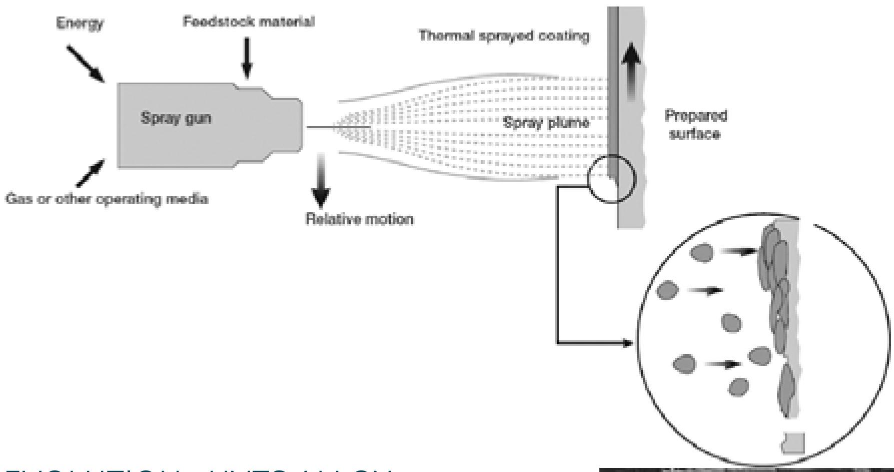
Welding repair

> At times, a limited available turnaround critical path time or an unexpected discovery scope, calls for an alternative to welding.

5. EVALUATING ALTERNATIVES: THERMAL SPRAY

Thermal spray technology has been utilized for the application of CRA since the 1980s, spraying metals widely used in the welding process. However, it was quickly noted that the thermal spray process itself can negatively affect the condition of the material being sprayed. The resulting cladding, when using traditional metal alloys and commercially available thermal spray equipment, was permeable.

This permeability coupled with internal stress and a lower bond strength with the base metal creates a path for corrosion and premature failure. These early failures resulted in a understandable and rather universal distrust of early iterations of commercially available thermal spray technology. At the same time, this evoked a great question. Is it possible to eliminate the permeability, porosity and internal stress of the thermal-spray applied coating and improve bond strength?



6. THERMAL SPRAY EVOLUTION - HVTS ALLOY CLADDING

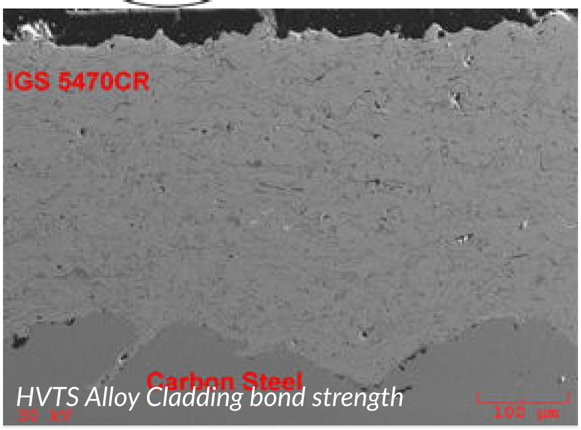
Engineers and material scientists have successfully developed a solution to this problem by redesigning both the equipment used to apply the metal cladding, the process technology and the alloy of the feedstock material.

6.1 Material

The thermal spray application process is aggressive from a thermal and kinetic perspective. It is expected that detrimental material segregation or degradation can occur to a material during thermal spray application. This makes unmodified wrought alloys such as an unmodified Hastelloy C-276 material unsuitable for application by means of thermal spray process. Several mitigating technologies are applied by IGS to prevent this. These include alloy composition modification and procedural control in order to achieve and effective uncompromised barrier.

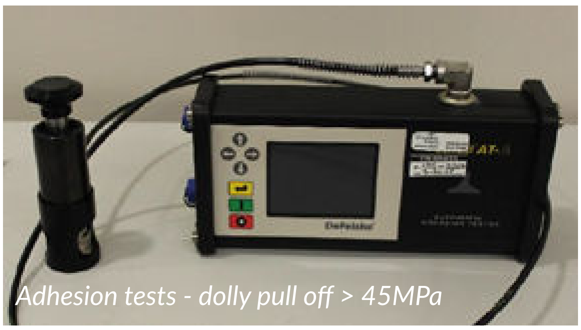
6.2 True High Velocity

The atomization velocity is a critical success factor in thermal spray cladding for critical equipment liquid and gas corrosion environments. For thermal spray cladding applied with a wire feed stock, a high velocity process is defined where the material atomization occurs in a super-sonic gas stream (gas stream velocity equal to or greater than Mach 1) which results in specific particle characteristic critical to achieve a impermeable barrier.



HVTS Alloy Cladding bond strength

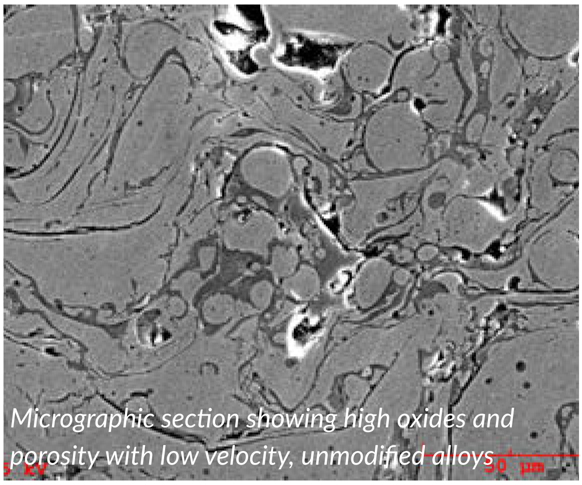
Adhesion tests -Epoxy failure before cladding



Adhesion tests - dolly pull off > 45MPa

6.3 Creating an Impermeable Protection

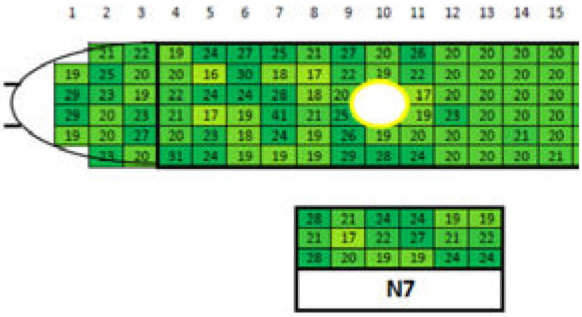
As particles are ejected from the thermal spray torch at high temperature and velocity, they are exposed to air with a high nitrogen and oxygen content. The molten particles are inclined to rapidly oxidize in flight. On deposition, oxide bands are formed in layers along with the metal splats. These oxide structures constitute permeable pathways through the applied thermal spray and are to be avoided in any application, especially where corrosion is present. Chemical and process controls are employed by IGS to significantly inhibit in flight oxide formation.



Micrographic section showing high oxides and porosity with low velocity, unmodified alloys

6.4 Bond Strength

The problem of bond strength, both between the applied metal particles and the substrate was solved by increasing velocity and improving the quality of the substrate surface preparation. When the molten metal particles hit the substrate with a suitable profile at speeds close to supersonic, they splat like a pancake and embedded metal into the substrate forming tight bonds. The particles themselves do not have a perfectly smooth microstructure, this feature promotes good intersplat adhesion. Multiple additional overlapping passes of the thermal spray torch then create a 500 micron thick cladding with excellent adhesion throughout. ASTM adhesion pull off tests measure bond strengths of 30 - 60MPa.



7. QUALITY ASSURANCE AND CONTROL

Several workshop thermal spray vendors ventured into on-site mission critical asset applications and their inconsistent results have arguably damaged the reputation of "thermal-spray applied cladding" as a whole.

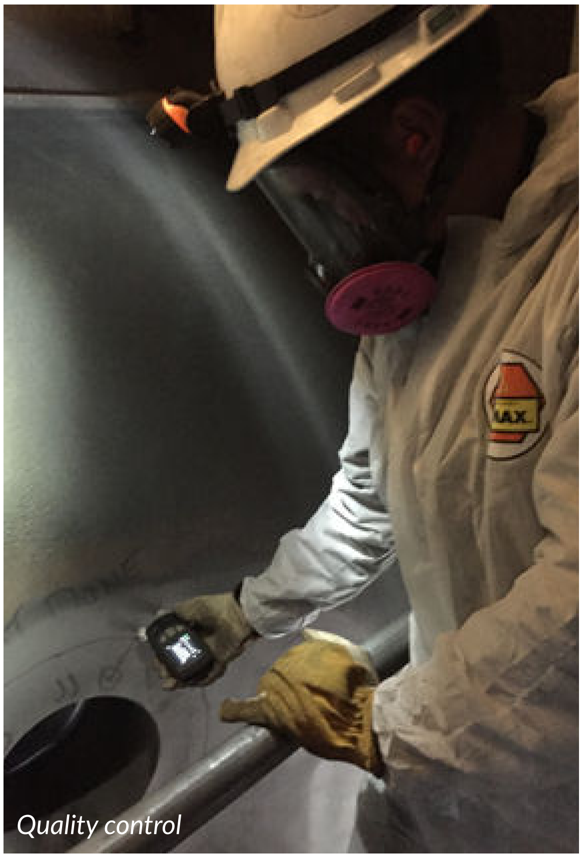
Welding, however, has been successfully applied for decades as an engineered solution, with relevant Quality Control requirements for both the technician/operator (welder), the welding process and the welding alloy.

As a result, there are multiple procedures, standard practices and controls that a client can follow to ensure the application is successful.

High Velocity Thermal Spray Alloy Cladding, on the other hand, is relatively new. Consequently, IGS had to develop engineering standards with multiple quality control systems, governing equipment, materials, process, procedures, performance qualification and manpower training adopted from the template of the welding industry, to ensure their applications would not follow the "thermal spray" experience of the past.

Iain Hall, IGS CTO, commented: *"With IGS high velocity thermal spray applied alloy cladding (HVTS) our customers enjoy all the benefits of weld overlay without some of the drawbacks.*

Our application time is significantly faster, at 3-6m^2 per head/shift. HVTS does not cause any stress or distortion, there is no need for PWHT or to reinstall support rings/downcomers."


Quality control

8. CASE STUDY – AMINE REGENERATION COLUMN

At an amine regeneration column in Qatar, there were clear indications that metal thinning was taking place, but when the turnaround came and it was mapped out, the problem was found to be more severe. With only two to three weeks of turnaround time left, a very significant part of the shell was found to be below its corrosion allowance. Following a comprehensive FFS, it was determined that although the vessel was below its minimum thickness in some areas, there was enough residual strength for it to be able to continue to operate if it could be preserved in that condition.

This vessel had to operate for another four years before the next turnaround. The only technology that was available to get this vessel back into serviceable shape before the plant could go back online, was weld overlay.


Amine regeneration column

8.1 Weld Overlay Issues

However, weld overlay would have required circumferential bands to be welded. Due to the sour service conditions of the vessel, post weld heat treatement would be required with the likelihood that the vessel would need to be stabilized with cranes during the operation. This would have extended the turnaround by two to three weeks.

The facility owners became aware of high velocity thermal spray cladding technology. Within the space of four to five days the area was cladded and protected. The vessel was promptly put back into service without any extension to the turnaround. The cost savings associated with the speed of application, production savings and the vessel life cycle were significant.


Before

8.2 Before and after 4 years in service

After two years, there was an opportunity for inspection during a short turnaround. The corrosion condition had essentially been frozen. Inspection after four years in service further confirmed that the cladding was performing as expected, stopping any attack to the shell.

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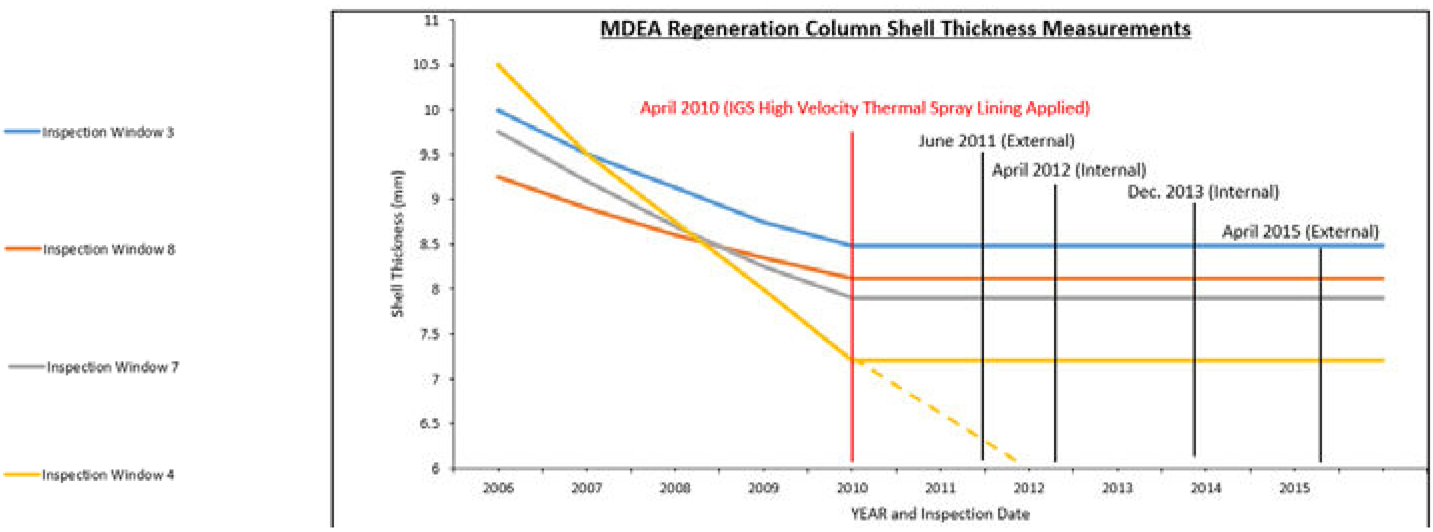
After 4 years in service

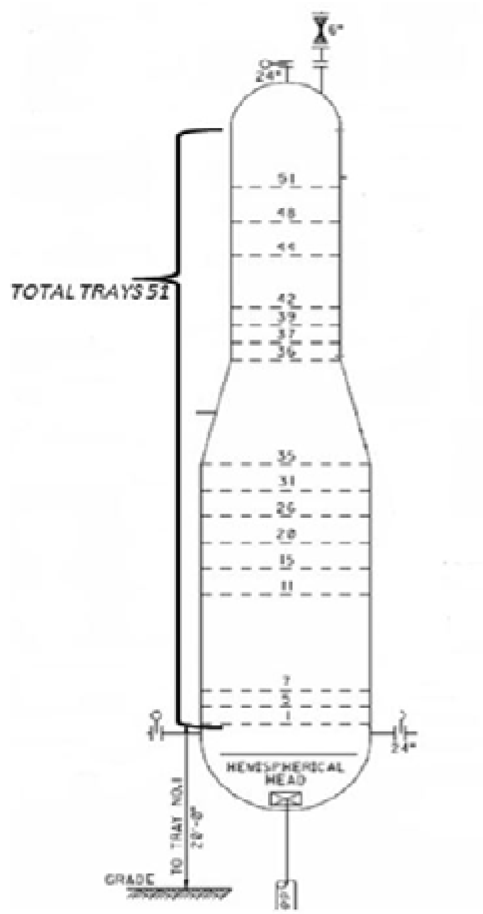


9. CASE STUDY – DE-ETHANIZER COLUMN

The de-ethanizer column was placed in service in 1975. T&I inspection in 2013 was completed for the bottom section. In total, 722 cracks were found in ring supports of 51 trays.

The majority of these cracks were found at tray ring support welds. These cracks were confirmed to be caused by Sulfide Stress Cracking (SSC) at previously weld-repaired locations that had high hardness levels.

Advanced UT inspection revealed the second significant point of the investigation in identifying hydrogen-induced cracking blisters in the top and bottom heads of the column as well as the 24” piping of the bottom product cycle.

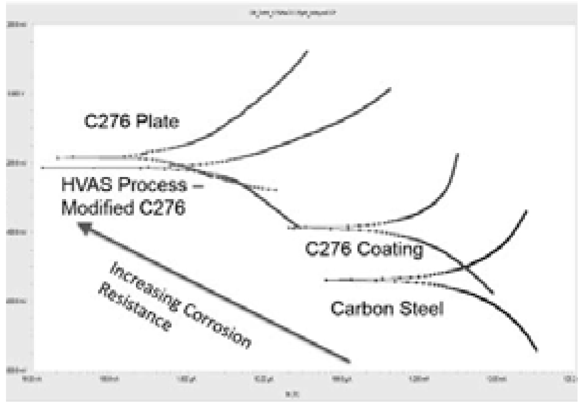


9.1 Vessel Repair Alternatives

A risk matrix was developed to consider different alternatives for the vessel repair. Due to the internal weld geometries and the large surface areas (the vessel was ~5 meters across and 70 metres tall), the thermal spray method was deemed the most feasible of the CRA options.

A corrosion test cell, with a computerized potentiostat scan and Tafel analysis of the results to determine effective corrosion rates, demonstrated that the twin wire arc spray applied standard alloy material exhibited deleterious performance due to an inability to effectively shield the carbon steel substrate.

However, a specifically modified NiCrMoW-XX alloy and high velocity thermal spray process resulted in a corrosion performance similar to wrought UNS N10276 plate.



9.2 IGS HVTS Application

As a result, a modified NiCrMoW cladding was applied with the IGS high velocity thermal spray process. In July 2014, the vessel was taken out of service and cleaned with an approved hydro blasting procedure for a T&I.

An inspection was conducted by a combined vendor and client technical team to determine the integrity of the applied coating.

No indications of SSC or corrosive coating delamination were observed. The vessel was returned to service with continued internal and external monitoring.

10. HVTS ALLOY CLADDING EXPERIENCE IN MANY INDUSTRIES

The Oil and Gas experience in determining the fitness-for-service of high velocity thermal spray applied cladding is used as a good indicator of its reliability.

Other application areas include boilers found in the Power industry, including pulverised coal, biomass and waste to energy, as well as other mission-critical assets in heavy industries, including Pulp and Paper, Mineral Processing, Agrochemical, Chemical and Petrochemical industries.

	IGS High-Velocity Thermal Spray (HVTS)	Weld Overlay (WOL)	Organic Coating (Non-Metallic)
Corrosion Resistance	Yes (1)	Yes	Yes (temperature and organic material dependent)
Erosion Resistance	Yes	Medium (depending on alloy)	Temperature and organic material dependent
Typical Alloys Utilized	Modified 625 alloy, C-276 hastelloy and monel alloys	316, 625, 622, 52, monel, hastelloy with Fe dilution	NA
Bond	Mechanical and chemical (>35 MPa)	Metallurgical	Mechanical and chemical (>15 MPa)
Typical Thickness Spec.	500 microns nominal	2-3mm (dilution issue below 2mm)	
PWHT Requirement	No	Yes (required for most application or HAZ becomes week corrosion resistance area)	No
Dillution into Base Material	No	Yes	No
HAZ	No	Yes	No
Stress/Distortion of Base Material	No	Yes	No
Application Speed	3-6 m^2/shift/machine	0,5-2 m^2/shift/machine	5-10m^2/shift/gun + VARIABLE curing time
Repairability	Blast prep, build up and/or reapply locally	Blast prep, grind and reweld if not cracked/contaminated locally possible	Blast, surface preparation and re-application
Replacement/Removal	Possible aggressive blast removal	Grind-out for removal	Locally impossible agresive blast removal
Durability	Metallic cladding - mechanically tough and temperature resistant	Metallic cladding - mechanically tough	Organic coating - fragile and susceptible to damage mechanically or by heat
Steam Out Resistance	Yes	Yes	No
Thermal Resistance	Metallic cladding - high temperature capability (>500˚C)	Metallic cladding - high temperature capability (>500˚C)	Organic coating - low immersion temperature capability (typically <90˚C)
Curing Requirements	Metallic cladding - no cure	Metallic cladding - no cure	Organic coating - chemical reation required to cure organic systems (Cure rate dependent upon environmental conditions)
Application Requirements	Metallic cladding - minimum environmental controls required	Metallic cladding - minimum environmental controls required	Organic coating - strict environmental controls required (Temperature, humidity, surface salts, amine bloom, solvent release etc.)
External Inspection Capability	Yes	Yes	No

CONCLUSION

When faced with metal wastage, asset owners and operators have viable options available to them in addressing the corrosion mechanisms with a CRA barrier. The technique used to apply this CRA will mainly be determined by the shutdown time available to carry out the application.

While weld metal overlay continues to be a reliable option, laboratory testing and performance validation, coupled with field application and subsequent site inspections of High Velocity Thermal Spray Alloy Cladding projects, have confirmed this solution to perform "in the same league" with several added benefits.

When selecting "thermal spray" to apply the CRA, however, one needs to be aware of the vendor-to-vendor differences in the design and application of such protection systems. Suitable references, operator experience, the correct process and material technologies and performance test reports need to be thoroughly reviewed to ensure the applied CRA barrier will perform as expected.

info@integratedglobal.com