DetaClad™ (Explosion Cladding) & DetaPipe™ - Clad Solutions for Nitric Acid and Nitrates

M.Ahlavadi, Global Director of Chemical Applications at NobelClad, Perpignan, France

ABSTRACT

Super-ferritic alloys, Superalloys (Ni-based), and Reactive metals (Ti, Zr, Ta) are widely used in the chemical and fertilizer industries to contain corrosive media. These alloys exhibit exceptional corrosion resistance in various aggressive environments, even at elevated temperatures, thanks to advancements in cladding techniques.

Explosion cladding, pioneered in the 1960s and industrialized as DetaClad™, remains a reliable manufacturing technology. NobelClad has successfully explosion-clad super-ferritic 470LI, boasting corrosion resistance comparable to austenitic grade 316L, making it suitable for Urea Exchangers. In Urea and Nitric Acid plants, NobelClad's solutions, utilizing reactive metals like Titanium, Zirconium, and recently Tantalum alloy, enhance performance in heavy-wall pressure vessels and heat exchangers.

In piping systems, NobelClad's DetaPipe™ solution, available in sizes from 1" to 30", provides a cost- effective alternative to solid construction and is more durable than loose lining. DetaPipe™ has been tested at extreme temperatures and pressures, offering a viable option for replacing existing SS304L Ammonium Nitrate Pipe Reactors with Zr DetaPipe™ solutions.

Keywords: Urea, Nitric acid, Sulfuric acid, Ammonium Nitrate

INTRODUCTION

The EXW occurrence was discovered during World War II and developed into an actual metallurgical process in the 1960s. The industry further standardized it in the following decades. The technology has been developed into a robust and reliable manufacturing process in subsequent years. EXW products are used extensively worldwide to manufacture corrosion-resistant process equipment and other composite metal applications. The cladding metal alloy can be selected for optimum corrosion, mechanical, electrical, and magnetic performance. The base metal alloy can be specified to optimize strength, fabricability, and cost. The high-strength, durable explosion weld makes the construction of chemical, oil and gas, power generation, and mining equipment possible, exhibiting the beneficial features of both metals. NobelClad remains at the forefront of new developments with its proprietary explosion cladding technology and product, DetaClad™.

OVERVIEW OF THE DETACLAD™ EXPLOSION WELDING PROCESS

Figure 1 shows the production of plates and tube sheets with Explosion welding done in three main steps: Pre-bond operations include raw material inspection, surface preparation, and assembly (steps 1 to 3). The actual explosion welding (step 4) is based on the use of the energy of an explosive to produce a collision between two or more metals across the entire surface of the plate. At the collision point, metals are submitted under very high pressure. The post- bond activities (steps 5 and 6) consist mainly of flattening operations, NDE, and mechanical tests. A 100% automatic ultrasonic testing inspection is done for all DetaClad™ products, and shear strength testing is the most common mechanical test. Still, we perform many tests depending on specification, design, and operating considerations.

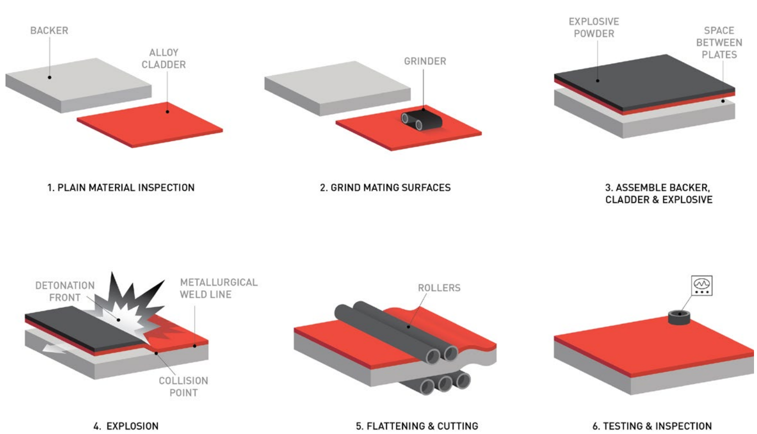


Figure 1:
NobelClad DetaClad™ Explosion Welding Process

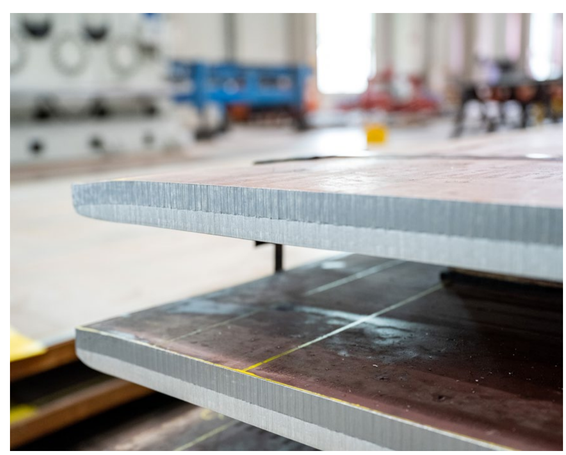


Figure 2:
NobelClad DetaClad™ Plates

Figure 3 depicts what is known as the "explosion welding window." It indirectly shows the optimum energy needed to generate a metallurgical bond in the solid-state without melting. This is typically evident by the formation of "waves" at the interface between the metals impacting each other. Vacuum chambers are limited to lower energy parameters, which leads to a straight interface, while excess energy will lead to the melting of the cladding layer. Factors like collision velocity, dynamic angle of collision, and stand-off distance play an essential role in explosion cladding progress. For elastic-plastic deformation, jetting, and energy losses, sufficient kinetic energy is required. The impact pressure at the contact point must be sufficiently large to produce fluid-like behavior. The actual magnitude of this pressure depends on the strength of the metals to be welded, the volumetric strain, and the internal energy. When two metal systems are projected together at a high velocity, a directional plastic flow of metal occurs at the interface, named surface jetting. No interaction will appear at the interface if the relative velocity and the resulting pressure between the surfaces are low. The jet velocity must be sufficiently high to provide the desired scouring action. To assist the scouring action and to ensure wave generation, a hump is necessary. For this reason, the collision point velocity or weld propagation velocity must be less than the sonic velocity of the parent plate.

Although EXW has reached a commercial scale in many parts of the world, the techniques, development of the proper explosives, parameter optimization, and know-how are truly mastered by only a handful of companies.

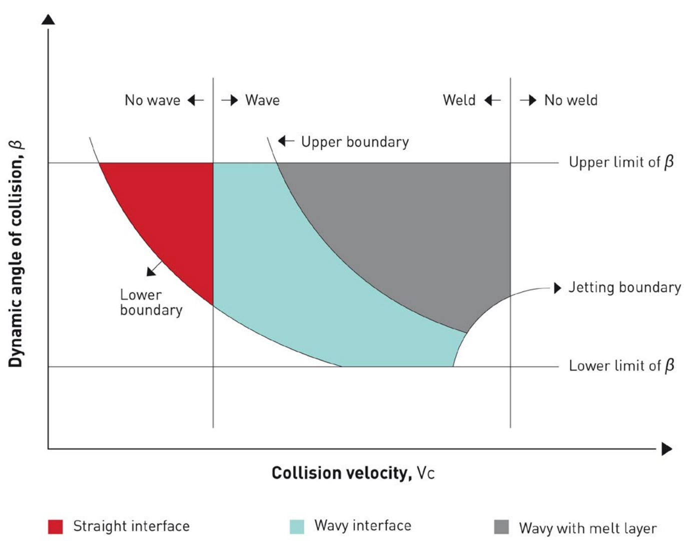


Figure 3:
Significance of Explosion Cladding Window

RECENTS ADVANCEMENTS IN SUPER-FERRITIC STAINLESS STEEL CLAD

Explosion Cladding of 470LI Super-Ferritic Stainless-Steel Overview

The study's objective was to investigate an explosive cladding process in which a new 470LI super-ferritic stainless steel, an understudy of Casale SA, is explosion welded on SA516-70 carbon steel.

Super-ferritic stainless steels are characterized by structure and properties similar to those of more common ferritic alloys, with the advantage of higher chromium (Cr) and molybdenum (Mo) levels aimed to increase high-temperature resistance and corrosion behavior in aggressive environments, such as seawater. Such steels have a Cr content ranging from 21 wt% to 24 wt% and very low carbon and nitrogen levels (C+N < 0.015 wt%). Prices are at record highs with the increasing worldwide demand for nickel (Ni) and Mo. Ni and Mo content are considered at reasonable levels to make such super-ferritic stainless steels, resulting in cost-savings. Also, it is challenging to perform weld overlay of such steels. Therefore, an alternative to put this in use is the explosion welding method.

Chemical Composition of Comparable Stainless Steels, wt%

ALLOY	C	N	CR	NI	TI	NB	MB
304	≤ 0.07	≤ 0.11	17.5 - 19.5	8.0 - 10.5	-	-	-
316L	≤ 0.03	≤ 0.11	16.5 - 18.5	10.0 - 13.0	-	-	2.0 - 2.5
470LI	< 0.03	-	22.0 - 25.0	<0.5	< 1	< 1	< 0.5

Corrosion Resistance Considerations

The Intergranular corrosion resistance behavior of super-ferritic stainless steel is comparable to that of austenitic materials. The corrosion rate as a function of the immersion time in HNO3, according to the Huey test, is reported in Figure 4.

The AISI 470LI shows the slowest corrosion rate, while the AISI 316L steel shows a higher corrosion rate. Such a phenomenon, well described in literature, can be attributed to the presence of molybdenum that promotes the precipitation of the sub-microscopic phase that dissolves rapidly in HNO3.

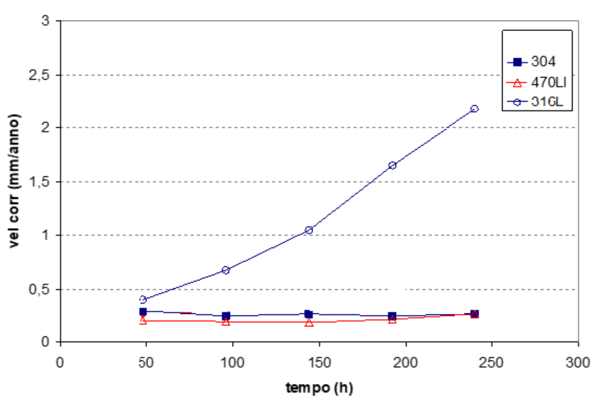


Figure 4:
Huey Test

Testing Program

NobelClad ran a testing program with Casale SA to determine the feasibility of cladding 470LI on a Carbon Steel Substrate (SA 516 Gr. 55). All the EXW parameters were carefully chosen, and cladding was performed successfully. After that, a series of destructive (Shear Test, RAM Tensile Test, Bend Test) and non-destructive (UT as per SA263Cl1 and Macrographs) tests were performed on the “master plate” produced. The outcome of the test is shared below.

Metallography of the Macro Specimen

Continuous waves can be seen in Figure 5. These continuous waves are the sign of strong bonds produced by the explosion welding process and are further proved with destructive test results. This indicated that the EXW conditions chosen fell within the parameters established by the “window” shown and explained previously in Figure 4. However, the formation of some crests may indicate that we may be near the “Upper Boundary” and thus reaching a high-energy regime.

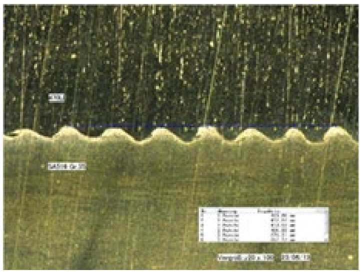
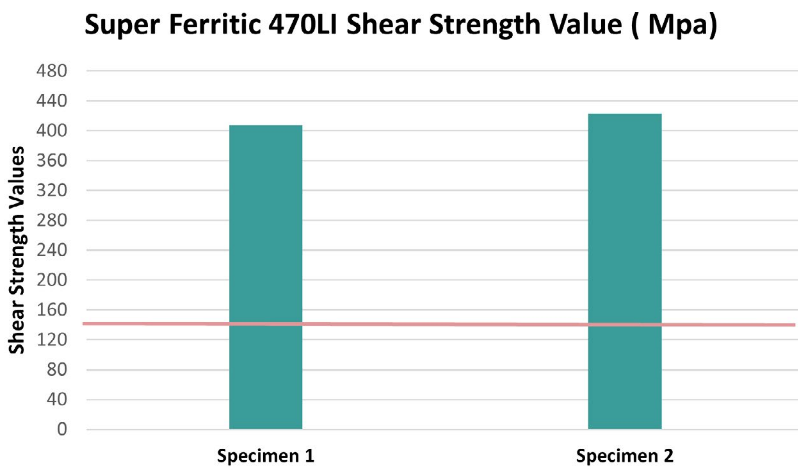


Figure 5:
Macrograph SA 516 Gr 55 substrate with 470LI

Shear Test Results as per ASTM A264

Bond shear strength is considered the best measure of quality for clad plates. The unique DetaClad™ Explosion Welding technology reliably provides exceptionally high bond strength and quality clad plates. DetaClad™ explosion welds typically exhibit shear strengths exceeding that of the weaker component metal and frequently fail away from the interface in the parent metal, as shown below.



Shear Strength Value Test Results of 470LI Stainless Steel Clad on SA 516 Gr. 55 Carbon Steel

PLATE / JOB NO.	CONDITION	SPECIMEN	SECTION (MM²)		FORCE (N)	RESULT (MPA)
			A (MM)	B (MM)		
20198.01.001	as clad	1	25.50	4.55	47,200	407
20198.01.001	as clad	2	25.46	4.55	49,000	423

Figure 6:
Specimen 1 sheared off in the interface

Figure 7:
Specimen 2 sheared off in the 470LI

RAM Tensile Test

Much data has been published on the features of explosion clad plates' bond shear strength. In contrast, minimal data on the tensile strength of explosion welded interfaces (tested in the through-thickness direction) has been presented. Generally, it is relatively easy to perform shear strength tests on clad plates; however, since cladding layers are typically thin, it is challenging to perform through-thickness tensile tests. We went further and completed the RAM tensile test on the 470LI specimen (Figure 8); the results exceeded the expectations.

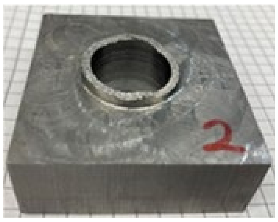


Figure 8:
RAM Tensile Specimen

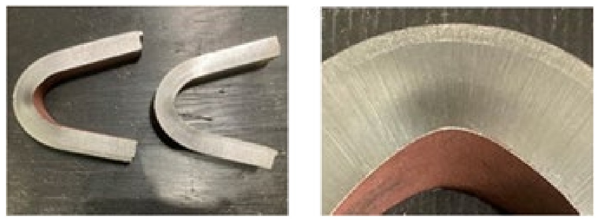


Figure 9:
Bend Test Specimens with No PT Indications

RAM Tensile Test Data

PLATE / JOB NO.	CONDITION	SPECIMEN	OUTSIDE DIAMETER (MM)	INSIDE DIAMETER (MM)	SECTION (MM^2)	FORCE (N)	TENSILE STRENGTH (MPA)
20198.01.001	as Clad	R2	23.00	18.89	135.15	75,800	561

Conclusion

- Super-ferritic 470LI can be successfully explosion cladded on Carbon Steel substrate.
- The clad tensile strength exceeded the shear strength for 100% of the materials tested.
- The tensile strength of the explosion weld
    - Exceeds the tensile strength of the steel base metal and
    - Meets the base metal minimum tensile strength requirement.
- With its high chromium content (24%), this offers such excellent corrosion resistance that it is comparable to the austenitic grade 316L. Also, this alloy provides optimum forming and welding properties due to mixed Ti/Nb stabilization.
- More applications could be envisioned for Urea and Nitric Acid Heat Exchangers.

RECENT ADVANCEMENTS IN CLADDING & USAGE OF CLAD TANTALUM PLATES

Over the last six decades, NobelClad has been supplying its DetaClad™ plates and tube sheets with Titanium and zirconium corrosion-resistant clad layers. Equipment such as Urea Strippers, Cooler Condensers, and Tail Gas Heaters have been manufactured with material supplied with DetaClad™ technology and have been running successfully in operation for three to four decades.

More recent developments have been in the Tantalum metal space. Tantalum is the ideal metal for most severe corrosion situations. It offers a superior technical choice in installations where glass-lined equipment is subject to mechanical damage or thermal shock failures. The high cost of tantalum has traditionally been a significant impediment to its broad use in large pressure vessels. Tantalum/steel explosion clad offers a commercially viable alternative. The tantalum cladding surface provides all the benefits of wrought tantalum; the steel base metal is low-cost and readily fabricable.

Manufacturing procedures for large tantalum-clad pressure vessels have been developed and used to fabricate several large tantalum-clad reactors and columns that use Copper as an interlayer between carbon steel and tantalum. NobelClad, with its DetaClad™ plates, has been at the forefront of these new developments, which include techniques to cost-effectively increase clad plate size by over 100% while using a thin tantalum cladder of 1mm starting thickness. NobelClad and Tantec GmbH optimized procedures for forming large heads without tantalum damage, specifically for accurately confirming tantalum thickness after equipment fabrication and to perform tantalum splice welds. These advancements make possible the construction of large tantalum equipment in severe corrosion environments typically limited to glass or brick-lined construction.

In one of the recent developments, NobelClad has successfully cladded tantalum directly onto carbon steel with shear strength values measured at 230 MPa (Figure 10). Tantec GmbH will manufacture equipment with this Tantalum DetaClad™ in Germany, today's world's largest tantalum-clad vessel producer.

Considering Tantalum's excellent corrosion-resistant properties, we believe this development could pave the way for cost-effective usage in nitric acid and nitrate applications.

Figure 10:
Direct Ta Clad plate: 708-TA. R05252 [1 mm] + Gr. 70 N-ST[P355NH/NL2] [80 mm]

DETAPIPE™

Pipe reactors in ammonium nitrate plants suffer short lifetimes due to severe corrosion and erosion.

NobelClad has recently launched a revolutionary reactive metal clad product known as DetaPipe™. Unlike conventional mechanically lined pipes, DetaPipe™ is manufactured utilizing a proprietary process developed by the company. The product is made to B31.3 specifications, which assists the piping engineer when designing a piping system. NobelClad has performed extensive "gripping force"-like tests, similar to the concepts used in the oil and gas industry standard API 5L. In addition to those tests, spools have been cycled up to and beyond 200 bar and 225°C.

Figures 11 and 12 show a DetaPipe™, a pipe spool clad with zirconium. The pipe spool, from flange face to flange face, is fully clad with zirconium inside carbon steel. This pipe spool can also be clad with titanium or tantalum. DetaPipe™ can be fabricated with either ANSI flanges, compact flanges, or seal ring hubs. DetaPipe™ is currently being offered in straight lengths up to 9-m and elbows.

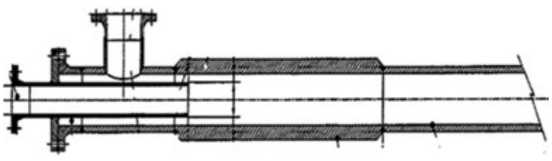


Figure 11:
Before insertion of DetaPipe™

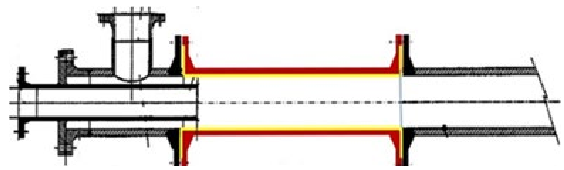


Figure 12:
After insertion of DetaPipe™

A new solution from NobelClad could provide a unique opportunity to address the problem faced by licensors and end- users in the pipe reactors of ammonium nitrate plants (reference High-Pressure Piping System Comparisons below). The NobelClad solution offers higher safety and reliability standards and less downtime and maintenance, leading to an attractive payback time. A tantalum DetaPipe™ spool has been in operation for 15 months at a site in the USA for a Chlor-Alkali application (Figure 13).

Figure 13:
Tantalum DetaPipe™ Spool

High-Pressure Piping System Comparisons

FEATURE	DETAPIPE™	SOLID PIPING	LOOSE LINED
Efficient thermal heat transfer	+	+	-
Tolerance to Thermal Expansion Differences (between liner and pipe) • Carbon Steel – 14 ppm/°C • Zirconium – 7 ppm/°C • PTFE – 150 ppm/°C	+	+	-
Ability to Heat Trace Systems	+	+	-
Vacuum Rated	+	+	-
Abrasion / Erosion Resistance	+	+	-
Availability in large diameter / long lengths (for high pressure)	+	-	+
Cost	$$	$$$	$

RESOURCES

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DetaPipe 221 specification

NobelClad solution for Ammonium Nitrate Pipe Reactors.