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Surface Modification Technologies for Pumps and Valves

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Introduction

Corrosion and wear often combine to increase aggressive damage in a number of industries, such as mining, mineral processing, petrochemical processing, pulp and paper production, energy production and other process industries. Corrosion and wear failures involve many synergistic mechanisms, the combined actions of which lead to their additive effects. In process industries today, reducing unscheduled maintenance or shutdowns and improving equipment reliability has become increasingly important. At the same time, managers, process reliability engineers and maintenance personnel are all looking for new ways to increase plant productivity and equipment reliability, while reducing operations cost and downtime.

Corrosion is a major cause of plant and equipment deterioration in many process industries. Closely associated is erosion and other forms of wear. The damage to pump and valve components can increase need for repair or replacement, lead to costly shutdowns, and reduce efficiency and productivity. For many services it may be possible to select specialized materials that are resistant to attack by the process conditions, but the expense of such an approach is often too high. In practice it is common to select appropriate materials that corrode slowly at a predictable uniform rate; and make design allowances for repair and/or replacement of equipment. However, a significant amount of damage may occur due to some accelerated form of localized corrosion or wear mechanism which results in failure much sooner than anticipated. Additionally, one must consider that abnormal erosive flow conditions and/or solids wear may initiate localized materials loss and equipment leakage, which may represent a bigger problem than mere uniform corrosion or wear itself.

The most demanding service environments are those where combinations of both corrosion and wear damage exist. Complicating matters is the fact that the combined effects often result in greater material losses than the individual additive effects taken alone. Severe conditions influenced by multiple causes or complex surface interactions are among the most difficult to safeguard. For improved protection of pumps and valves, modern surface engineering technologies can be utilized to reduce these destructive effects and offer an alternative to more costly materials. By application of surface modification technologies; protection of equipment surfaces can improve reliability, extend part life, and cut maintenance budgets and downtime.

Surface Engineering

Surface modification is a multi-disciplined engineering activity intended to alter the surface properties of components so their function and reliability can be improved. An effective means of mitigating damage due to corrosion and wear is to modify, or "engineer," the surface so that it can perform functions that are distinct from those required of the component bulk material. Some desirable properties and characteristics of surface-engineered pump and valve components include:

- Enhanced erosive wear and cavitation resistance
- Enhanced corrosion resistance
- Enhanced adhesive wear and galling resistance
- Reduced friction, power and energy loss
- Enhanced mechanical properties (e.g. increase hardness, fatigue strength or toughness)
- Enhanced electrical and thermal properties or protection
- Enhanced appearance, dimensional restoration and repair

Several processes currently being applied to pumps and valves for difficult services include:

- Carburizing, nitriding, carbo-nitriding, and other case hardening thermal processes
- Hardfacing or weld overlay with corrosion and/or wear resistant alloys
- Various plasma or thermal spray coating technologies
- Diffusion alloying “TMT” , Kolsterising® or other surface modification processes
- Tungsten Carbide cladding treatments to increase wear and corrosion resistance

The most obvious application of these surface modification technologies are in the area of corrosion protection and oxidation resistant coatings. For example, it is well known that refractory metals like tantalum and niobium are very resistant to many chemicals. Unfortunately, these metals are very expensive and used only when and if absolutely necessary, and then at great expense.

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Many applications are such that a thin surface coating or cladding on the part would perform just as well as a solid mass of metal would, at a relative fraction of the cost.

There are also many applications in which a harder, more wear resistant surface is desirable. Surface hardening by carburizing and other similar methods have been routinely used for years. However, newer technologies such as low temperature diffusion Kolsterising®, "TMT" inter-metallic diffusion alloying, or Conforma Clad® brazed carbide metal cladding offer properties of interest for softer corrosion resistant and other "non-hardenable" alloys that are typically used in industrial pumps and valves.

Processing Considerations

Application of coatings or surface modifications is one of the most widely used means of protecting critical parts used in industrial equipment. Surface properties can be physically, mechanically, and/or chemically enhanced by adding a new surface material or by modifying the existing surface. The bulk of the component or substrate material cannot be regarded as entirely independent of surfacing treatments since process modifications may also affect the substrate if thermal cycle exposure or mechanical stress is involved.

The process decision sequence should address several key points. The first is the need to clearly define service conditions and materials requirements based on system and equipment design, service experience and application data. This is fundamental to proper materials selection.

The second consideration is whether the choice of surface modification methods is suitable for the parts involved. This includes questions regarding part compatibility with the materials and or treatment method; which is to say, not all surfacing technologies can be applied to all materials or all part geometries. Additional questions may arise between both surfacing materials used and process compatibility, with regard to the part substrate; for example, whether stress, distortion or metallurgical changes can be tolerated due to thermal heating.

For example, an impeller must be tough and fatigue resistant yet have a surface that resists cavitation or erosive wear. For applications that require only a moderate degree of impact toughness, fatigue resistance, and wear resistance, a carbon or alloy steel may be sufficient. For more severe or corrosive conditions, however, a surface hardened corrosion resistant stainless steel or nickel alloy may have to be used. What are the available options based on service conditions and alloy requirements? Should the impeller be diffusion case hardened; or would a cladding processes or thermal spray coating be more appropriate?

Furthermore, consider the use of an austenitic stainless steel like type 316 for various sleeve or wear ring applications in corrosive service. While corrosion resistant, this is a relatively soft material and susceptible to galling and other forms of wear in many service environments and generally must be hard coated to achieve a satisfactory service life. Again, we must consider a variety of treatment options. Should the part be weld overlay, electroplated, thermally sprayed, diffusion case hardened or clad with a more wear and corrosion resistant material?

Other Technical Issues

There are a wide variety of coatings and surfacing technologies to choose from, and proper selection of a treatment method should be based upon the overall system requirements. Several technical issues must be addressed during selection of a suitable process. The materials involved, purpose and function of the coating or any part constraints, service environment concerns, processing method constraints and economics need all be considered in the selection of candidate treatments. The intended function of the "engineered" surface must be known, including factors such as life expectancy, materials compatibility and any other applicable surface effects. Then both technical and economic issues can be reviewed, based on the total life cycle and cost benefits expected; not just direct purchase price, as is so often done.

Heat may distort components or introduce stresses and material changes that are metallurgically unacceptable or damaging. For example, diffusion treatments (e.g. carburizing, nitriding, boridizing, etc.), weld overlays, and many thermal spray processes involve elevated-temperatures that might subject parts to thermal transformations and metallurgical property changes. A question regarding compatibility between both material and process arises, for example, whether high-temperature exposure can be tolerated or not. Therefore some materials or processes may not be used together due to thermal degradation which may alter material structures and reduce corrosion resistance.

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Part geometry constraints must also be considered in any surfacing technology. The part size, weight or shape may be a major processing limitation concerning treatment availability. For example, large pump casings or impellers may be bigger than the treatment equipment used preventing use of certain technologies. The complexity of a double shrouded impeller or multi-port valve may limit line-of-sight processes, and only allow for non-line-of-sight chemical deposition, surface conversion or other diffusion processing. Application thickness or treatment depth may be another constraint limiting the usefulness of some processes. In addition, imperfections or defects such as interconnected porosity and networks, micro-cracks, heat checking or other surface flaws can present problems in corrosive environments resulting in failures. These limitations may or may not be overcome by sealants or intermediate undercoat layers and must be considered in the total system review.

Finally, the environment in which the equipment is used obviously can affect the materials or treated surfaces. The modified surface layers or coatings must be compatible with the service environment, and must be able to protect the base metal substrate from attack by corrosives in the environment if present. Material selection, process costs, part distortion tendencies, and other surface treatment characteristics described above must all be considered when selecting the right surface modification technology for the parts involved.

Clad coatings, alloyed diffusion, and surface hardened diffusion transformation layers that enhance the resistance to corrosion or wear can be applied to a wide variety of materials. Potential applications include pump bodies, covers, impellers, shaft sleeves and wear rings; as well as valve bodies, balls or gates, valve stems and seats to name a few. The remainder of this article will review several advanced surface engineering developments which offer significant engineering advantages that can be used for pump and valve upgrades. While these developments have initially come from outside the industrial and biopharmaceutical communities, they can be directly applied to industrial equipment with good benefits for the manufacturer and end user.

Kolsterising®

Field complaints regarding nickel and austenitic stainless alloys have been that their usefulness is limited due to their low hardness, low resistance to galling, and accelerated erosion-corrosion in services where conditions lead to accelerated wear. Since these materials cannot be hardened by conventional heat treatment without reducing corrosion resistance, their range of application has been limited. While many austenitic stainless and nickel alloys meet the need for corrosion resistance, their relatively low hardness often results in accelerated wear and materials loss.

One unique case hardening method (See Figures 1 and 2) has overcome this problem in a commercial case hardening treatment known as Kolsterising®; which diffuses carbon into the surface of austenitic alloys to increase hardness and improve wear resistance. Since detrimental carbides or grain boundary networks are suppressed by low temperature processing, the corrosion resistance of the alloy is fully maintained. In fact, corrosion testing and independent research has shown enhanced corrosion resistance after treatment. Treated components also show improved resistance to galling, fatigue cracking, stress corrosion and cavitation damage due to high compressive stress in the near surface hardened zone layer.

Figure 1
Showing surface Kolsterising® of ball used in a ball valve.

This diffusion process is a proven method for surface hardening of austenitic stainless steels. While preferred alloys are those containing molybdenum and without ferrite (resulting in alloys with improved resistance to localized corrosion and stress corrosion); the technology shows that duplex stainless steels and certain nickel alloys may also be hardened. These enhancements offer tremendous technical advantages for highly stressed pump and valve components such

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as valve stems, balls and seats; and pump wear rings, sleeves, bushings, fasteners, impellers and other high wear parts which could benefit from the kolsterising process.

Kolsterising increases surface hardness of an austenitic stainless steel like type 316 to values of 1000 to 1200 HV (equivalent to a 70-74 HRC hardness). Treated surfaces are five times harder than that of the normal base alloys which decline with depth through the diffusion zone. Standard treatments currently offered can effectively harden surfaces to depths of 20 to 35 micrometers or more as shown in Figure 2.

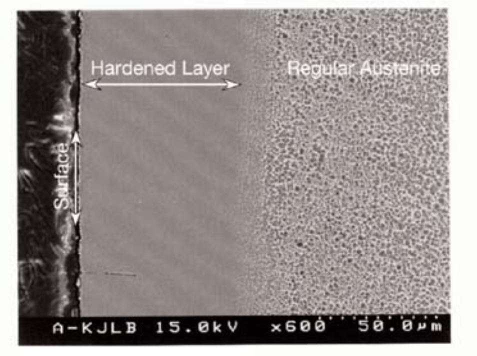

Figure 2
SEM micrograph showing Kolsterising® case hardened layer in Type 316 stainless.

Since kolsterising is a case diffusion hardening process that does not apply a coating or alter the shape of the treated part, finished machined components can be processed while maintaining full corrosion resistance and dimensional stability. Because this is a surface modification diffusion process, there is no risk of a coating failure or possibility that the engineered surface can delaminate or peel away from the substrate, resulting in excellent toughness.

Furthermore, since this is not a line-of-sight process, complex internal passages of components and other complicated shaped parts can be easily treated. The kolsterising properties offered makes an interesting and attractive materials option for many pump and valve applications.

Kolsterising® is the registered trade name of a proprietary surface carburization treatment for austenitic alloys provided by Bodycote Hardiff BV of Holland. Developed in the Netherlands over two decades ago, the technology is now being further developed in North America at operations in Boaz, Alabama and London, Ohio. More detailed information on Kolsterising® can be found by visiting their website at www.bodycote.com.

"TMT" Diffusion Alloying Conversion

Another surface modification technology for wear and corrosion resistance improvement is diffusion alloying conversion. This process develops a layer of inter-metallic (single phase) conversion compounds by the addition of elements into the surface under controlled conditions to form new "converted" surface materials that is a modification of the original surface. An example of a typical diffusion alloyed conversion surface is shown in Figure 3.

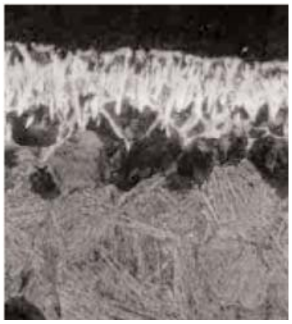

Figure 3
Microphotograph showing typical diffusion alloyed conversion coating.

Boron diffusion alloying and other similar conversion coatings offered by a number of companies (vendors like 'TMT" Turbine Metal Technology, Vapor-Kote, Surface Modifications Systems, Inc.) can treat parts to "convert" or modify the surface microstructure by a chemical alloying of the surface. Again, this represents a major breakthrough in diffusion technology processing that allows soft materials like austenitic stainless to be hardened to levels over 60 HRC with "diffusion zone" case depths of about 0.010" without loss of corrosion resistance to the base alloy.

Depending upon the base material treated, alloying compounds selected and processing methods used, surface hardness of TMT diffusion conversion coating can reach Knoop hardness levels over 1650 KHN (estimated more than 80 HRC). Since there is no direct analytic hardness conversion for measurements over 970 KHN (70 HRC converted); by way of comparison at these hardness levels an approximate correlation to scale would give quartz 820 KHN (64 HRC converted), silicon carbide 2480 KHN, and diamond 8000 KHN hardness.

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Since diffusion alloying is not restricted to line-of-sight, this surface engineering technology is ideal for use in pump and valve components where complex surfaces may be treated for exposure to corrosive and erosive environments. Adhesive wear resulting in galling damage, such as between wear rings or sleeves, is no longer a major problem for mating components. Surfaces of pump and valve components damaged from erosive or contact wear can be metallurgically modified by the addition of a special blend of materials and compounds that changes the surface.

The part is usually processed at an elevated temperature under controlled time, temperature and atmosphere conditions in a sealed chamber where the addition of elements, starting as a gas phase, react with and become a part of the converted “diffusion zone” at the surface. Elements from the component being treated combine with those added to form a new material, which again, is not a "coating", but an actual “engineered” surface conversion layer. These diffusion surface modifications can be tailored to meet the needs of the manufacturer or end user to reduce the effects of wear, erosion, galling or corrosion.

Since this process requires a thermal heating cycle, not all materials can be treated equally as previously discussed with regard to technical issues. Considerations regarding distortion, thermal transformations, and pre or post machining must be carefully evaluated prior to processing.

Infiltration Brazed Tungsten Carbide Cladding

Wear resistant overlays often crack. The thickness can be increased by applying several weld layers but these usually create highly stressed surfaces that lead to distortion and further heat check cracking. Weld variations can severely effect quality, alter wear characteristics and overlay performance. Overlays can be applied unevenly, introducing cracks between weld beads and in the worst case fail if open pathways allow for corrosion attack of the substrate.

Heat check cracking is inherent to carbide weld overlay processes. The overlay process involves intense localized heating combined with the difficulty in controlling cooling rates of the materials, subjecting surfaces to extreme thermal stress. In high wear applications, surface flaws can initiate spalling and possibly lead to failure.

As an alternative to weld overlay, infiltration brazed tungsten carbide cladding technologies offered by several vendors (e.g. Conforma Clad®, Yeardley Engineering Company) can be used to provide superior surface protection where corrosion and extreme wear are the main cause of damage. The Conforma Clad® process uses infiltration brazing to bond tungsten carbide to the base material component to form a hard yet tough and uniform protective cladding that provides superior wear against abrasion, erosion, and corrosion.

Since the infiltration brazed claddings are metallurgically bonded, they are highly resistant to flaking and spalling. Unlike thermal spray and weld overlay, brazed cladding can be applied to non line-of-sight regions such as inside diameters or other hard to reach areas. Multiple and unique cladding formulations can be engineered to protect against damage in various severe wear environments.

As shown in Figures 4 and 5 the infiltration brazing method comprises filling by capillary action with a molten filler metal combination of nickel, chrome and boron (NiCrB), a porous structure that has a melting point higher than the filler metal. While there are several methods for applying the carbide and braze in preparation for infiltration braze coating, the principle technique used to manufacture the brazed tungsten carbide cladding involves temporarily adhering a flexible pre-form “non-woven cloth” containing 85% tungsten carbide and other select metal powders to the treated surface. When heated in a vacuum furnace at temperatures in excess of the melting

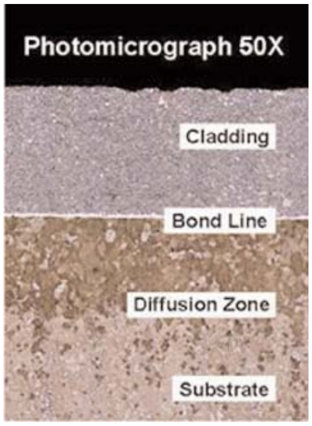

Figure 4
This photomicrograph shows how the cladding is bonded to the substrate with no interconnected porosity forming a true metallurgical bond.

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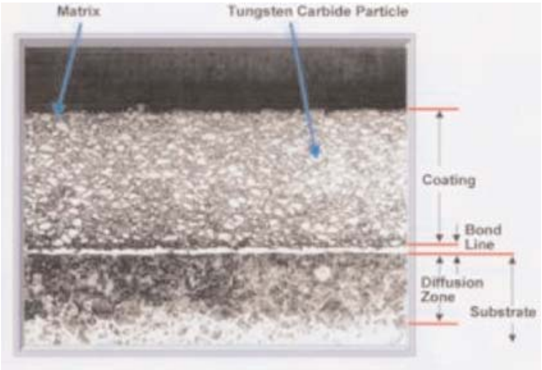


Figure 5
Photomicrograph of Infiltration Brazed Tungsten Carbide Cladding with NiCrB filler metal Matrix.

point, the NiCrB brazes to the substrate forming a matrix of NiCrB and the tungsten carbide particles with a true metallurgical bond. The result is a robust cladding that is very abrasion and corrosion resistant. The cladding is also practically crack-free due to the controlled application and cooling during the infiltration process.

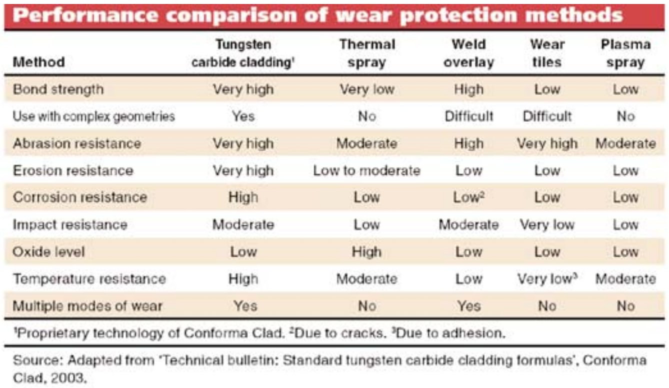
The Conforma Clad® cloth delivery system enables densely-packed tungsten carbide to be uniformly and strategically applied to complex geometries providing a superior protection barrier. As for geometry, the area to be clad must be accessible. "The resultant cladding," says Conforma Clad®, "has no interconnected porosity, is uniform in depth and loading, and is metallurgically bonded to the substrate with a bond strength in excess of 70,000 psi."

Hardness is in the range of 64-70 HRC for WC 200, 60-66 HRC for WC 210, and 56-62 HRC for WC219 Conforma Clad® coatings. These claddings are a composite of tungsten carbide particles dispersed in a nickel-based NiCrB alloy matrix. The extremely hard carbide particles have a Vickers Hardness of about 2000 DPH50g (1865 DPH50g is equivalent to 80 HRC hardness), are surrounded by a two-phase matrix (300-800 DPH50g, equivalent to 30-64 HRC). Because of the mixed structures within the cladding, direct hardness measurements are an average of the hard particles and matrix and are not representative of the individual components in the cladding. Typical cladding thicknesses are in the 0.020" - 0.060" (0.5mm-1.5mm) range. However, thinner or thicker claddings can be applied if required. The cloth is cut to shape and selectively applied to areas that need wear protection. A special adhesive holds the cloth onto almost any surface, whether vertical, inverted, or even internal. Thus, the inside of radial bearings or wear sleeves can be coated, or the internal surface of a pump casing.

Infiltration brazed cladding can be applied to most carbon alloy steels, precipitation hardened steels, high chromium irons, stainless steels and nickel based alloys. Some alloys can be heat-treated after cladding to restore mechanical properties provided they can withstand the process temperature of approximately 2000°F. Materials that cannot tolerate the elevated process temperatures cannot be clad.

Field experiences, along with standardized laboratory testing, has determined that infiltration brazed tungsten carbide cladding offers improved equipment protection and outperforms other protection methods in highly erosive, abrasive and corrosive environments. Shown in Figure 6 is a comparison of infiltration brazed tungsten carbide cladding with other wear protection methods.

More detailed information on cladding can be found by visiting these Web sites:
http://www.conformaclad.com/
http://www.yeardleyengineering.com/Tung_Carbide_Clad.htm



Performance comparison of wear protection methods

Method	Tungsten carbide cladding[1]	Thermal spray	Weld overlay	Wear tiles	Plasma spray
Bond strength	Very high	Very low	High	Low	Low
Use with complex geometries	Yes	No	Difficult	Difficult	No
Abrasion resistance	Very high	Moderate	High	Very high	Moderate
Erosion resistance	Very high	Low to moderate	Low	Low	Low
Corrosion resistance	High	Low	Low[2]	Low	Low
Impact resistance	Moderate	Low	Moderate	Very low	Low
Oxide level	Low	High	Low	Low	Low
Temperature resistance	High	Moderate	Low	Very low[3]	Moderate
Multiple modes of wear	Yes	No	Yes	No	No

[1] Proprietary technology of Conforma Clad. [2] Due to cracks. [3] Due to adhesion.

Source: Adapted from 'Technical bulletin: Standard tungsten carbide cladding formulas', Conforma Clad, 2003.

Figure 6
A comparison of infiltration brazed Tungsten carbide cladding with other wear protection methods.