Wear protection of pump components using hard coatings

Abstract

Pump components are subject to wear, corrosion and cavitation damage in service, which reduces pump efficiency and component life and significantly increases the life cycle cost of the pump. All these degradation mechanisms are active on the surfaces of the pump components, and therefore surface coatings could be an effective way of addressing this problem. This article hopes to provide the pump user with some insight into the common commercial coating technologies available.

Wear in pumps

Pump components are subject to abrasion, erosion, cavitation and sliding wear in service. Abrasion and erosion results from abrasive particles in the medium being pumped, but even in the absence of any abrasive particles sliding (or galling) wear can occur due to unintentional contact between rotating and stationery components. Moreover these wear rates in pumps are often unexpectedly high because of the synergistic relationship between wear and corrosion; even a mildly corrosive process media can significantly increase wear rates. This is often increased even more by the high flow velocities that can be found in some high-energy pumps. As the pump components in the flow path wear, efficiency critical sealing clearances increase and vane angles change, resulting in a decrease in pump efficiency over time. Abrasion wear is also common in other areas of the pump such as product lubricated bearings and shaft sleeves, often resulting in increased vibration or leakage over time. Wear therefore reduces the service life of the pump and increases the life cycle cost significantly. There are numerous strategies to reduce the impact of wear on pump components such as specialised pump design and the use of sophisticated materials (e.g. high-alloy steels, ceramics, rubbers etc.), but surface coatings are some of the most successful and cost-effective tools for managing wear.

Surface coating technologies

Surface coatings are extensively used to protect pump components from degradation due to wear, corrosion and cavitation. These coatings have traditionally been based on nickel-chrome and cobalt-chrome alloys, but the recent development of ceramic metal composite (CMC) have further improved on the wear resistance of commercially available coating materials.

There are several coating technologies that are commonly used for applying coatings to pump components, and each has its own advantages and disadvantages. A basic understanding of the different coating processes will assist the user in selecting the right solution for a specific pump problem. The common surface coating processes are briefly described:
Thermal spray

Thermal spray coatings are produced by projecting a molten stream of particles onto the base material. On impact these particles deform and solidify to form splats, and these splats mechanically lock onto the surface. There are numerous ways of generating the stream of molten particles using an electric-arc, plasma or a combustion process. Depending on the process it is possible to produce coatings of pure metals, alloys, ceramics and ceramic metal composites (cermets), and coating thickness generally varies between 0.1 and 2 mm. The adhesion and cohesion of a thermal spray coating is purely mechanical, which has certain advantages and disadvantages. The main advantage is that there is no metallurgical compatibility issue between the substrate and the coating, and it is therefore possible to apply a wide variety of coating materials onto essentially any substrate (e.g. bronze and cast-iron). The heat input into the base materials is also limited, and it is therefore possible to apply a thermal spray coating to a heat-sensitive substrate (e.g. heat-treated HSLA steels like 4140 and martensitic stainless steel) with no risk of softening or distortion. The main disadvantage is that the adhesive and cohesive strength of a thermal spray coating is relatively low, making coatings susceptible to damage from high mechanical loads (such as point or impact loads), cyclical loads or thermal stresses.

Thermal spray coatings are commonly used for applying tungsten carbide cermet coatings onto impeller and casing wear ring surfaces, impeller inlet and outlet vane tips, anti-galling coatings onto pump shafts (e.g. to assist with assembly and disassembly on stainless steel pump components), carbide and ceramic coatings onto shaft sleeves and for the refurbishment of worn or damaged shafts. There have recently been significant material and process developments, especially the high velocity oxy-fuel (HVOF) spray process, and it is now possible to produce carbide coatings with exceptional wear (i.e. hardness of >1200 HV0.3) and corrosion (i.e. ASTM B117 > 400 hours) resistance and high toughness (i.e. tensile adhesion strength ASTM C633 > 80 MPa).

Figure 1: Microstructure of a high-quality WC-CoCr HVOF coating
Spray and fuse

The original powder flame spray processes developed towards the middle of the previous century were not able to produce coatings with sufficient density, cohesion and adhesion to make them suitable for use in corrosive or high-wear applications. To overcome these limitations a special range of nickel-chrome and cobalt-chrome alloys were developed which allowed for post-spray densification and fusing of the coating. This was made possible by the addition of alloying elements such as boron, iron and silicon, which significantly reduced the melting point of the coating alloy, making it possible to melt the coating during post-coating processing at temperatures below the melting point of the substrate. The post-coating heat treatment, which involves the heating of the part with a high-energy gas torch to approximately 950°C, results in the densification of the coating and the formation of a metallurgical bond (i.e. fusing) to the substrate. Using this technique it was possible to produce nickel-chrome alloys with a hardness of up to 60HRC, but even harder coatings were subsequently developed through the addition of tungsten carbide particles into the coating alloy. The spray and fuse process produces dense corrosion resistant coatings of between 0.5 and 1.5 mm with good wear resistance and damage tolerance. The main disadvantage of spray and fuse coatings is the fact that the coatings hardness and thickness is somewhat limited compared to other competing technologies (e.g. PTA and laser), and because of the high temperature post-coating processing there is a limitation on suitable substrate materials. This technology has been employed...
in pump application for many years, and the Colmonoy\(^1\) range of spray-fuse coatings is a well-known brand, particularly in API 610 pumps.

Figure 3: Post-spray fusing of large pump sleeve

**Plasma transferred arc hardfacing**

The plasma transferred arc (PTA) weld hardfacing process was developed to produce high quality weld overlays with relatively low heat input and very low dilution of the substrate into the weld overlay. The PTA process is essentially a hybrid process containing elements of thermal spray (i.e. powder consumable melted in a continuous plasma heat source) and welding (i.e. melting of and the formation of a metallurgical bond with the substrate). The torch manipulation is generally automated and hence can achieve uniform overlays on complex parts. The PTA process is typically used to apply relatively thick (i.e. 2-3 mm) wear and/or corrosion resistant cobalt (Stellite and Triballoy\(^2\)) and nickel (Inconel 625\(^3\)) alloys. Stellite 6 is a well know overlay in the pump and valve industry. It is also possible to apply tungsten carbide containing nickel based overlay, although the high melt-pool temperature places limitations on carbide size, volume fraction and binder alloy composition. The major disadvantage of PTA is that it is essentially a welding process with relatively high heat input into the base material compared to thermal spray and laser cladding, resulting in potential distortion.

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\(^1\)Registered trademark of Wall Colmonoy Corporation

\(^2\)Registered trademark of Kennametal Stellite Group

\(^3\)Registered trademark of Special Metals Corporation
issues and the possible need for post-weld heat treatment. Because PTA is a welding process the weldability of the base material also needs to be considered.

Figure 4: PTA welding of pump shaft sleeve

**Laser cladding**

Similar to PTA, laser cladding is a welding process that uses the concentrated light of a laser as the heat source. A powder consumable is melted by the laser in the presence of an inert gas. This consumable is then deposited onto the surface to be treated. The main advantage that laser cladding offers over PTA is that the heat input into the substrate is reduced and so the heat affected zone is smaller and there is even less dilution. There is also generally less distortion, and with laser cladding it is possible to overlay certain problematic steels, notably martensitic stainless steels. Laser cladding however has the disadvantage of significantly higher cost compared to PTA, and in many pump applications there is no compelling performance advantage.
Which is best?

So how do these processes compare, and which material and/or process will be best suited for a specific wear application? This is not always an easy question to answer, and very often there might be more than one “right” answer. It is best to consider this question with reference to two well-known coating types:

**Stellite 6.** This alloy is a well-known cobalt-chrome-tungsten alloy that combines good corrosion and wear resistance with excellent galling and sliding wear resistance. This coating material can be applied using any of the coating processes previously described, although for a spray and fuse application a modified alloy chemistry is required (generally called SF6, which contains additions of boron, iron and silicon for reasons previously explained). A thermally spayed Stellite 6 will be suitable for low-stress sliding wear applications with low to moderate abrasion or erosion wear, e.g. impeller and casing wear rings in a process medium with relatively low solid particle content. Where high mechanical or thermal stresses, or high wear rates due to high solid particle levels are expected, one of the other techniques will be more appropriate. It is important to note that PTA and laser cladding produces Stellite 6 overlays which are superior to those produced by conventional welding techniques like MMA or TIG. The latter processes are all high-energy arc welding processes that
result in a large dynamic weld pool resulting in a significant dilution of especially iron into the Stellite 6 overlay. Once the iron content of the Stellite 6 exceeds approximately 10% there is a substantial decrease in galling resistance and high temperature hardness. These arc-welding processes require the Stellite 6 overlay to be applied in multiple passes to reduce the dilution level, therefore requiring very thick (i.e. 6 mm) overlays. Both PTA and laser can achieve sufficiently low dilution in a single pass weld, thereby reducing the required overlay thickness to approximately 3 mm.

\[\text{Figure 6: Very low dilution typical of PTA Stellite 6 weld overlay}\]

\textit{Tungsten carbide based coatings.} As previously described, CMC materials are made of a mixture of very small (generally < 0.5 mm) wear resistant ceramic particles (typically tungsten carbide) in a ductile metal matrix (typically cobalt or nickel alloys), resulting in a material with the hardness comparable to that of a ceramic but with the ductility approaching that of a metal. The choice of ceramic hard phase and metal binder is largely determined by chemical compatibility (i.e. wetting). Generally the smaller the tungsten carbide particles the higher the binder fraction and therefore the harder the coating, and this is a significant differentiator between the different coating processes.
The corrosion resistance of the CMC is primarily determined by the corrosion resistance of the binder alloy, which can vary from pure metals (e.g. cobalt or nickel) with marginal corrosion resistance to complex alloys with excellent corrosion resistance.

Thermal spray is the most flexible in terms of binder alloy type, and it is possible to spray a wide variety of different carbide binder phase alloys, such as:

- WC-10Co4Cr
  - Excellent wear and moderate corrosion resistance
- WC-10Ni5Cr
  - Excellent wear and good sea-water resistance
- WC-NiCrMo (Hastelloy\textsuperscript{4} C binder)
  - Excellent wear and sea-water corrosion resistance.

With the HVOF process it is possible to spray carbide coatings with very fine carbides (i.e. average carbide size < 3 µm) and high carbide mass fraction of more than 80%. This provides superior wear resistance in the presence of fine abrasives particles. Coating thickness is however limited to approximately 0.5 mm and these coatings are not suitable for applications where the coating will be

\textsuperscript{4} Registered trademark of Haynes International
subject to high mechanical or thermal stresses. HVOF coatings are therefore commonly used in light to medium wear applications and/or where a corrosive medium is present.

Figure 8: WC-10Co4Cr coating applied with HVOF process

All the other processes have a limitation on minimum carbide size and carbide fraction because of the high processing temperature and time. Smaller carbide particles will decompose at these higher processing temperatures, resulting in the formation of unwanted hard and brittle phases in the binder alloy and a decrease in the carbide fraction. For this reason a PTA or laser carbide coating will have an average carbide size of approximately 200 µm (or 0.2 mm) and a carbide mass fraction of less than 60%. Furthermore the binder composition is limited to nickel-boron-silicon and nickel-chrome-boron-silicon alloys, with generally relatively low chrome content, therefore limiting the use of these coatings in certain corrosive environments. These processes can however produce very thick coatings (i.e. >2 mm) and they will generally be able to withstand high mechanical or thermal stress. For this reason PTA and laser clad carbide coated shaft sleeves are commonly used in slurry pump applications.
Figure 9: WC-NiBFeSi coating applied with PTA welding process

Conclusion

Although this is a brief introduction to coating technologies for protecting pump and valve components in severe service applications, it will hopefully provide the reader with some insights into selecting the right solution for a specific problem. It is clear that the pump user will benefit from developing a relationship with a knowledgeable and reputable coating service provider to assist in ensuring that the optimum coating solution is identified and correctly applied. This can result in a significant extension to the service life of pump components and improve pump efficiency over its service life, resulting in a substantial reduction in the life cycle cost of the pump.