

Hardide™ advanced CVD coatings protect against wear, erosion and corrosion

By Dr Yuri Zhuk, Technical Director, Hardide plc

Components of industrial equipment such as valves, pumps and tools often operate in extremely abrasive, erosive, corrosive and sometimes chemically aggressive environments. Wear of critical components leads to loss of performance; a worn valve can leak and an eroded pump will not provide the required pressure or productivity. This causes significant maintenance and downtime costs while parts are repaired or replaced. If component parts were more durable they would maintain optimum performance for longer and offer competitive advantage. It would also differentiate equipment from cheaper 'copycat' versions manufactured in low-cost countries and justify premium pricing. Using hard coatings like Hardide™ to protect critical components against wear, erosion and corrosion can help to achieve this and make industrial equipment more competitive.

The traditional approach for the design of critical components for demanding operating conditions has been to use hard materials like ceramic or cemented carbide to achieve high hardness and wear resistance. The down-side of using such hard bulk materials is that these materials are brittle, can crack or chip under shock loads or when deformed, they are notoriously difficult to machine, the use of some fine design features like threads or thin walls is prohibited and if the part is a complex shape or some dimensional tolerances are tight, production costs would sky-rocket.

An alternative approach became possible with the development of advanced coating technologies such as Hardide. The critical component can be machined from ordinary and cheap stainless steel and coated with a thick and tough layer of tungsten carbide to achieve a surface wear-resistance which exceeds that of a hard ceramic while retaining the steel's toughness and ability to survive shock loads and deformations. Furthermore, the design engineer can use any threads, thin walls or net-shape features to enable the component to function in the best possible way without worrying that a thin ceramic wall can fracture because the part will retain all the toughness of the substrate metal. Three key features of the Hardide coating range make this possible:

- Ability to coat uniformly complex shape items, including both internal and external surfaces.
- Sufficient thickness of the coating to provide load-bearing capacity close to cemented carbide, independently of the strength of the substrate metal. 50 microns thick Hardide coating has much greater load-bearing capacity, mechanical strength and durability in comparison to thin 3 to 4 microns coatings, which can only give "eggshell" protection ie: they break easily under load.
- Enhanced toughness, ductility, ability to withstand shock loads and part deformations without fracture.

These key features of Hardide coatings are further illustrated below.

Coating internal surfaces and complex shapes

For many coating technologies there are fundamental difficulties in coating internal surfaces or items of a complex shape. For example, spray coatings (including HVOF, plasma spray, D-gun) can only be applied to external surfaces ie: those easily accessible by the spraygun, which enables the spray torch to be kept at a distance which prevents the parts from overheating. When spray coating complex shaped items such as threads, it is difficult to avoid building a thicker coating layer on the more exposed edges while applying a thinner layer in the "shadow" between two threads and distorting the thread profile. A similar limitation exists for PVD coatings and, to some extent, for electrolytic processes such as hard chrome plating.

As a result, parts such as pump impellers, hydraulic cylinders or extrusion die cavities can not be successfully coated by these traditional methods.

The Hardide coating is applied from gas media at a low pressure by Chemical Vapour Deposition (CVD) technology. The coating is crystallised atom-by-atom from the gas phase on every hot surface in contact with the reactive gas mixture. So if the mixture is pumped through a hydraulic cylinder bore, the coating will grow uniformly inside the part. *Figure 1* (below) shows micro-photographs of Hardide coating inside a 1mm diameter hole drilled in a 5 mm thick stainless steel plate. The coating has uniform thickness all way through the hole. *Figure 2* (page 46) shows a magnified section of M5 thread with 50 microns thick Hardide coating. The coating is not only uniform on the edges and between the threads, it also accurately follows imperfections in the steel surface. This ability to uniformly coat internal as well as external surfaces and complex shaped items opens up opportunities for many new applications where hard coating was previously impossible.

Coating thickness

There are a number of coating technologies which can produce very hard but thin coatings, such as PVD or PE CVD titanium nitride and carbonitride, DLC, chrome nitride, all typically just 3 to 4 microns thick; the thickest being up to 10 microns. These coatings give excellent results in tribological applications but are so thin that a point load (eg: when a grain of sand is pressed against the coated part) can deform the substrate and "plough" through the coating. Although the coating is much harder than sand, the substrate also has to be hard enough to support the coating otherwise the thin coating will be abraded very quickly.

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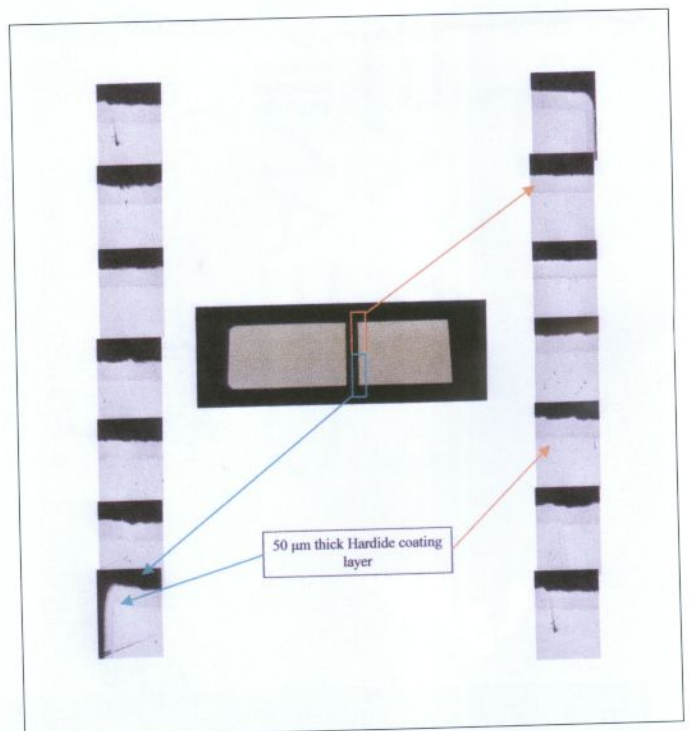


Figure 1. Hardide coating inside 1mm diameter hole in a 5mm thick steel plate. Long images on the sides are stitched together from a series of micro-photographs and show good uniformity of the 50 microns thick Hardide coating inside the full depth of the hole.

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There is an empirical rule that the coating should have a thickness of 10% of the typical abrasive particle diameter to be able resist abrasion otherwise it will behave like an eggshell, and pressure from a loaded particle will break through it easily. Coarse Arizona Road Dust (ARD) is often used in tests for modelling abrasive or erosive conditions and the ISO standard defines nominal ARD grain size as being up to 180 microns. The empirical rule would suggest that coatings with thickness >18 microns would perform better compared to thinner coatings against ARD. In testing, we compared abrasion and erosion resistance of 50 microns thick 'Hardide-T' coating against a much harder 10 microns thick coating. The tests confirmed this empirical rule and the thicker coating performed much better than the extremely hard but thin coating.

The importance of sufficient coating thickness was demonstrated during testing of an oil drilling tool application. The thick Hardide coating on a copper component resisted extremely erosive and abrasive high speed drilling mud flow. Uncoated copper, being very soft, was eroded away in a matter of seconds and yet, with the 50-100 microns thick Hardide coating, the copper parts lasted as long as the drilling tool itself. At a microscopic level when a grain of sand impacts this thick coating, the elastic deformations in the coating layer dampen the effect and spread the point load over a sufficiently big surface area of the copper substrate to prevent its plastic micro-deformations and thus protecting it against erosion.

Coating toughness and ductility

Parts of oil drilling tools, pumps or metalworking tools can experience impact or shock loads in operation. The parts can be deformed under load and if these actions cause fracture or chipping of the hard materials, it could lead to a catastrophic equipment failure. Even in normal operation, in erosive or abrasive environments, brittle hard material will suffer from micro-cracking and fatigue erosion leading to premature failure. For these reasons, toughness and ductility are very important for practical applications of hard materials. In reality, the hardness and toughness are often contradicting characteristics. Most traditional materials can be described as either hard (but brittle – like glass) or tough and ductile (but soft – like copper).

Hardide-T coating is a nano-structured material which consists of a metallic tungsten matrix with dispersed nano-particles of tungsten carbide typically between 1 and 10 nanometres in size. Nano-structured materials allow combining properties which are not compatible in macro- or micro-structured materials, like hardness and toughness. Hardide-T is a good example. It has extremely high hardness (1100-1600 Hv) and at the same time demonstrates unique toughness, crack and impact resistance. The coating can withstand 3000 microstrain deformation without any damage; this deformation will crack or chip any other thick hard coating. Hardide-T coated onto a component manufactured out of a tough alloy gives an unprecedented combination of surface wear resistance and the ability to survive impacts and shock loads. *Figure 3* shows a crater left after a shock impact on a Hardide-T-coated sample; *Figure 4* shows a coated steel ring crushed in a vice. The coating survived the impact and the deformation without cracking or chipping.

In a drilling tool application for one of the largest global oilfield services providers, the coating has increased the life of critical components three-fold. The components were operating in an extremely abrasive environment and typically failed after 60 hours due to excessive wear. After being coated with Hardide-T, the life of the parts was proven, in the lab and the field, to extend to more than 200 hours. This has enabled uninterrupted drilling for far greater periods of time and the savings in down-time and tooling costs are significant. Most of this customer's tools are now in use with Hardide-coated parts. Hardide-T appeared to be the only available solution for this application as traditional hard materials were too brittle and difficult to machine due to the complex part geometry, while other coating technologies were not able to reach the important hidden surface areas.

Other key properties include resistance to acids (including H₂S) and the absence of porosity. The highly mobile reaction products fill pores

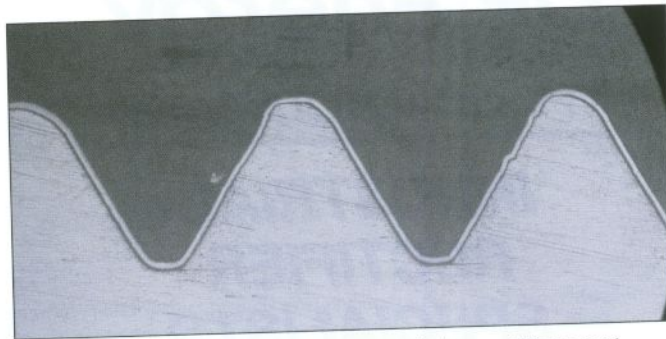


Figure 2. Hardide coating on an M5 thread shows ability to coat complex shape items uniformly; even slight imperfections in substrate are followed accurately.

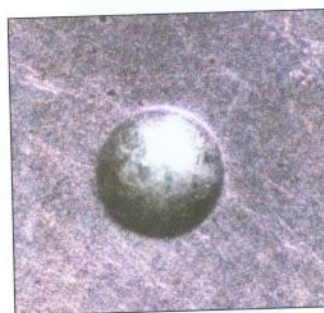


Figure 3. Micro-photograph of a crater (diameter approx. 1mm) made by impact into 50 microns thick 'Hardide-T' coating.



Figure 4. Steel test ring with a 50 microns Hardide coating crushed to test coating adhesion and toughness – no flaking or coating separation from the substrate.

and defects in the coating as it grows. The porosity measured in the coating cross-section is less than 0.05% while the coating completely covers the substrate without any through pores starting from less than 1 micron thickness. Unlike sprayed tungsten carbide, Hardide does not use cobalt which can be affected by acids; this is especially important for processing sour oil. Hardide-T was tested by Bodycote Materials Testing for resistance to aggressive media in accordance with the NACE Sulphide stress cracking test in a solution of 5% NaCl, 0.5% acetic acid, saturated with H₂S. Samples were tested in deformed conditions with coating elongation up to 3000 microstrain. During the 30 day test the uncoated control sample cracked across the full 20mm width and suffered from extensive micro-cracking and pitting while the same substrate coated with Hardide-T showed no micro or macro cracking or degradation after the same test. This confirmed the non-porous structure of Hardide-T as under 3000 micro-strain deformation any existing micro-cracks or defects would open up channels for the aggressive fluid to attack the substrate.

The zero porosity of Hardide-T is important for applications with valves where any porosity can result in gas diffusion through the coating layer leading to a potentially explosive mixture. For this reason, spray coatings are often sealed with polymeric materials to close surface porosity, but this limits their operation temperature. This sealing would still leave unsealed pores deeper in the coating layer which may open in use later. Hardide-T is produced pore-free across the whole thickness of the coating layer. The coating is used commercially on valves in the oil and gas, food manufacturing, chemical industries and cryogenics at liquid helium temperatures. In the food and chemical sectors, the use of Hardide-T has solved problems for customers where the combination of abrasive and chemically aggressive environments was causing valve failure every few days. Hardide-coated valves have now been in continuous operation in both applications for more than six months without failures.

Hardide-T is the result of many years of research and development and is now in commercial application around the world by oil and gas service companies, high-end valve and pump manufacturers. In other sectors, it is being used in the power, chemical and food manufacturing industries and in aerospace by BAE Systems on the Eurofighter Typhoon.

Hardide is processed and applied at bespoke coatings facilities by Hardide Coatings Ltd in Oxfordshire, UK. Tel: 01869 353830. www.hardide.com

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