Presented at High Performance Elastomer & Polymers for Oil & Gas Applications Conference
17-18 April 2012, Aberdeen, UK

HARDIDE CVD TUNGSTEN CARBIDE COATING EXTENDS LIFE OF ELASTOMERIC SEALS AND ENABLES HIGH TEMPERATURE SEAL DESIGN

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BIOGRAPHICAL NOTE:

Dr Yuri Zhuk is a co-founder of Hardide PLC, responsible for the company’s technology, R&D, patenting, production improvement and applications development programmes. Dr Zhuk started carrier as a scientist and later became a technology entrepreneur, gaining over 20 years of successful international technology business experience. Yuri holds an MSc (with Distinction) in Physics and a PhD degree in Plasma Physics and Chemistry from the Lomonosov Moscow State University and an MBA from the UK Open University and is the author of several patents, and scientific and technical publications.

1. ABSTRACT

Elastomeric seals in rotating or reciprocating equipment suffer from premature wear in abrasive applications and in some cases can limit the maximum operating temperatures of down-hole tools. The newly-developed Hardide CVD Tungsten Carbide coatings can help prolong seal life and increase equipment maximum operating temperatures.

The coating protects the metal shafts or plungers from scratching and scoring that can result from rotation or reciprocation and which can accelerate elastomeric seal wear rate by an order of magnitude. Traditional thermal spray WC/Co coatings contain a Cobalt binder which leaches during operation exposing hard grains of Tungsten Carbide sometimes described as “cheese-graters” and which increase the wear of elastomeric seals. The Hardide CVD coating is free from Cobalt binder and as a result the coated metal counter-surface against which the seal operates retains a good finish in operation for longer and thus is less abrasive for the seal.

Hardide coatings are also resistant to H_2S and can protect metal components from aggressive corrosive attack in sour oil and gas environments.

2. INTRODUCTION

For rotating or reciprocating equipment, seals keeping lubrication or fluids in and abrasives out of the mechanisms are critical to their operation. Abrasive or corrosive environments, high pressure or high temperature conditions can be particularly demanding for elastomeric seals.

Efforts to increase seal life have been concentrated on two approaches: improved seal design and the use of high performance seal materials. The performance and durability of seals in abrasive applications can also be improved by the use of non-abrasive hard coatings on the mating metal surfaces against which the seal is working, and optimisation of its surface finish.

In abrasive media, for example sand in water slurry, hard grains of sand can get trapped between the seal and its mating metal sealing surface and embed in the softer seal material. This seal with embedded hard sand particles will cause scratching and micro-cutting abrasive wear of the mating metal sealing surface, such as a piston or a rotating shaft. The resulting rougher abraded metal sealing surface will become much more abrasive to the seal, produce additional metal debris, increase leakage through the seal and lead to its premature failure. This failure can be prevented or at least delayed by the use of hard coatings on metal sealing surfaces which resist abrasive wear and maintain optimum surface finish of the metal.

Some advanced sealing materials, such as PTFE-based composites, often contain hard fillers, such as glass or carbon fibres, which reduce the PTFE seal wear and creep but are abrasive to metal surfaces. Use of non-abrasive hard coatings on the metal parts (shafts or pistons) working against such seals will extend the life of the metal parts as well as the life of the seals themselves.

3. SEAL WEAR MECHANISMS AFFECTED BY THE MATING SURFACE

In most cases the seals of flow control equipment or lubricated machinery operate with a lubricating fluid layer separating the seal from the mating metal part. This lubrication film reduces friction and shear loads on the seal and prevents increases in the local temperature. The film can be formed by lubricant oil, hydraulic fluids or, in the case of flow control equipment, by the product itself. Seal life depends strongly on the consistency and quality of this lubrication film.

The wear rate of an elastomeric seal can be strongly affected by the surface roughness of its metal counter-face. In the case of a rougher surface, asperities can rupture the lubrication film and wear the elastomer by micro-cutting action. Asperities lubricant-free contact also increases friction and thus seal surface temperature leading to its thermal degradation.

On the other hand, a highly polished metal surface will not retain a lubricating fluid layer under pressure. This will also increase friction and thus seal temperature and lead to premature seal degradation. Ideally, the metal surface finish should be within an optimum range between the minimum Ra required to retain the lubricant film and the maximum Ra where asperities rupture this film. PTFE-based seals also require optimum surface finish limited both by the maximum and the minimum values dictated by the PTFE material transfer mechanism.

Testing of an UHMWPE wear rate against metal surfaces with different roughness in [1] shows that the polymer wear rate increases exponentially with the surface roughness.

The effect of the metal counter-body material and finish are especially significant for seals operating in abrasive and corrosive media. Grains of sand or other abrasive particles can become embedded in soft elastomeric seals between the seal and the metal surface. These hard grains will scratch the mating metal surface producing additional hard debris and increasing metal surface roughness which then accelerates the seal wear. Hardening the metal surface can reduce its wear rate but to achieve a significant protective effect the metal surface should be harder than the abrasive material.

Metal corrosion leads to an increase in surface roughness and also produces debris of solid corrosion products such as iron oxides, which leads to increased micro-cutting abrasive wear of the seal. The combined action of mechanical abrasive or fretting wear and corrosive media can significantly accelerate the surface degradation.

For seal life it is important that the hard coating is non-abrasive, and remains non-abrasive during the part life. These seal-friendly qualities of the coatings depend on the following key factors:

- The initial surface finish of the new part. This depends on the coating machinability and the finishing techniques used;
- Micro-structure of the coating material – which defines how well the surface finish can be retained in abrasive conditions;
- Hardness of the coating - its ability to resist abrasive wear;
- Load-bearing capacity of the coating sufficient to withstand local point loads from abrasive grains embedded into the seal;
- Coating corrosion resistance and resistance to chemically aggressive media such as acids.

4. USE OF HARD COATINGS TO EXTEND THE SEAL LIFE

There are a number of traditional hard coatings and surface treatments commercially available such as Plasma and thermal spray coatings, Hard Chrome plating, PVD (Physical Vapor Deposition) and CVD (Chemical Vapour Deposition) coatings, Nitriding and Boronizing. However, each of these processes has limitations. In particular, the traditional PVD and CVD processes produce very thin coatings of less than 5 microns [4; 5; 6] which cannot resist abrasive or erosive conditions and need a hard substrate to provide load-bearing capacity. Nitriding, Boronizing and other diffusion surface treatments of most steels can achieve hardness less than 10 GPa, usually 7…8 GPa – which is not sufficient to resist abrasion by sand, the most ubiquitous abrasive material. Most of these treatments do not protect the substrate from chemically aggressive media.

Two of these mature coating technologies are often used to harden metal parts working against seals: Hard Chrome plating and spray WC/Co coatings.

Chrome plating is still widely used in abrasive applications and is considered a seal-friendly coating, but this process uses highly toxic and carcinogenic Hexavalent Chromium salts, which are under pressure from REACH and OSHA environmental, and health and safety regulations.

Spray coatings like HVOF WC/Co are considered as an alternative to Chrome but they are not suitable for internal surfaces, are difficult and expensive to finish post-coating and can be very abrasive for mating parts (including seals).

There is a CVD Tungsten Carbide Hardide coating technology which is used in abrasive and corrosive environments and is seal-friendly. The coating, typically 50 microns thick, is resistant to wear, erosion, aggressive and corrosive chemicals. The CVD coating is applied from the gas phase and can uniformly coat complex shaped parts and internal surfaces and normally requires minimum post-coat finishing. It has proven successful in applications including downhole tools, valves and pumps handling abrasive and chemically aggressive fluids.

These two coatings (HVOF WC/Co and Hardide) and their effect on the seal life in abrasive and corrosive applications are reviewed below.

4.1. USE OF SPRAY COATINGS AGAINST SEALS

Spray coatings are widely used on oil and gas tools, and aircraft components, including applications where the coated surfaces are working against seals. Hard spray coatings typically consist of extremely hard grains (WC Tungsten Carbide) in a soft metal binder (usually 9…12 wt% of Cobalt). As deposited, the spray coatings are very rough and require grinding to achieve a finish acceptable for applications against seals. These finishing operations can only be performed on simple geometries e.g. cylinders and require several stages to achieve a good finish.

Meanwhile the soft Cobalt binder is chemically similar to Iron and is prone to corrosion. The exposure of the coating surface to corrosive or acidic media results in Cobalt leaching. In abrasive and erosive environments, the soft metal binder is preferentially lost from the coating surface resulting in a non-uniform wear creating hard WC asperities. In [2] testing showed that preferential binder wear plays a significant role in the wear of Tungsten Carbide coatings and their surface degradation. In particular, the thermal spray coating containing Cobalt binder showed severe surface degradation. Cobalt binder wear or corrosion gradually leads to loss of hard grains of Tungsten Carbide – as shown on Fig.1 below. Hard WC grains protruding from the surface due to Cobalt leaching and also the pits left in the surface after loss of WC grains can make such a hard coating surface highly abrasive for the seals, or in fact even for the metal mating surface. Some engineers described the surface shown on Fig.1 as a “cheese-grater for seals”.

The following detailed study of the spray coating surface finish effect on the seal life of an aircraft shock strut assembly is presented in [3]:

“In two separate instances a 757 main landing gear inner cylinder and a 737 nose landing gear inner cylinder suffered seal failure shortly after being put into service with thermal sprayed tungsten carbide on the diameter that mates with the seal. The 757 had only completed 936 cycles and the 737 had completed 855 cycles. The 757 cylinder surface finish was 0.325 µm Ra while the 737 had a range of 0.225 to 0.30 µm. PTFE seals from the 757 had severe pock mark damage and abrasive wear on the crown of the seal, typical of friction induced stress cracking which suggests that the seals had been mated against a rough surface. In the case of the 737, a hydraulic fluid sample analysis showed that 5 µm-sized particles of tungsten carbide had been suspended in the hydraulic fluid, turning it into an abrasive cutting media. The Teflon seal also had tungsten carbide particles embedded in the surface.”

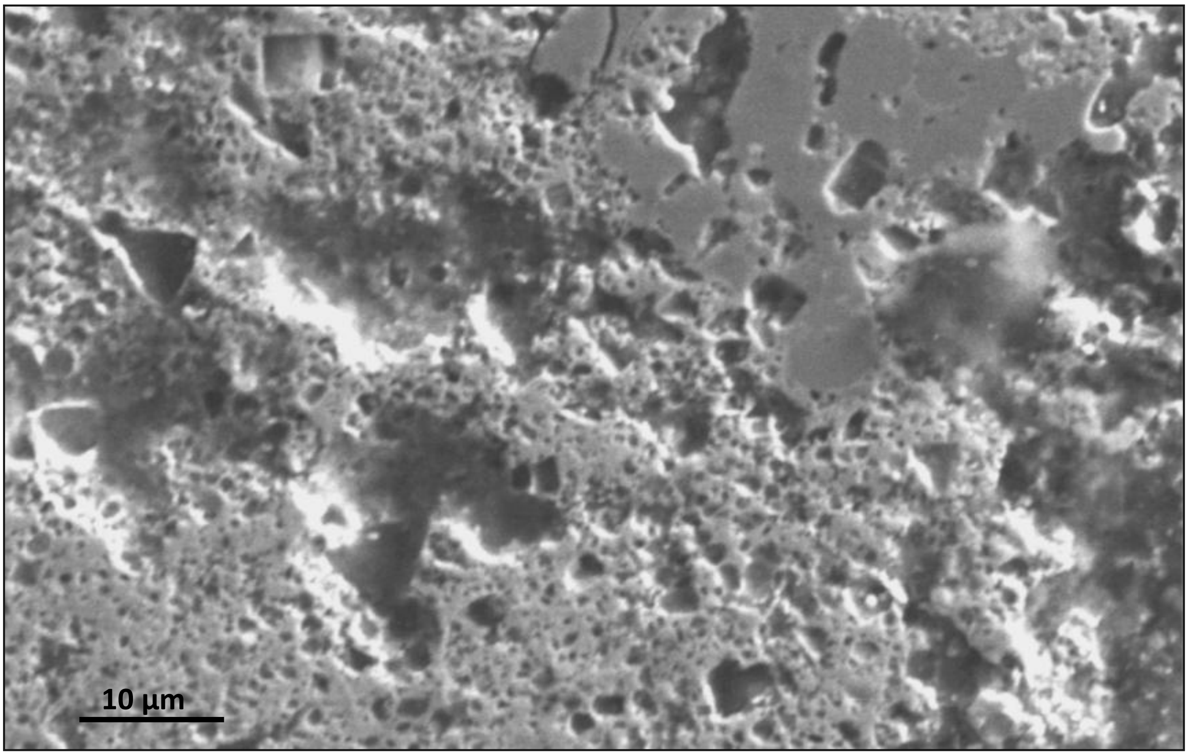

Fig.1. HVOF WC/CoCr coating surface after exposure to seawater.

4.2. USE OF HARDIDE COATINGS AGAINST SEALS, PACKING AND IN BEARINGS

Hardide™ is a new family of CVD Tungsten Carbide coatings used to increase the life of critical parts operating in abrasive, erosive and chemically aggressive environments.

The Hardide-T coating has enhanced hardness of 1100-1600 Hv combined with excellent toughness, crack and impact resistance. The coating is typically 50 microns thick – exceptionally thick for CVD – and withstands 3000 microstrain deformations without any damage. This deformation will crack or chip most other thick, hard coatings. Hardide-T is up to 12 times more abrasion resistant than Hard Chrome, the erosion rate by Alumina in gas jet is half that of WC cladding.

Hardide-A coating was developed as a replacement for Hard Chrome plating. It matches the thickness and hardness of Hard Cr and outperforms Cr in corrosion protection and some mechanical properties.

The gas-phase CVD process enables the uniform coating of internal surfaces and complex shapes such as valves and pump cylinders. Hardide is produced in a low-temperature CVD process at 500^{o}C which allows the coating of a wide range of metals, including all grades of stainless steel, most alloy steels, Ni-, Cu-, and Co-alloys, and Titanium.

Pore-free Hardide is resistant to acids and aggressive media including H_2S. The coatings are used in high-value industries where optimal part life plays an economic and/or performance critical role such as oil and gas exploration and production, aviation and general industrial pumps and valves.

4.2.1. EXAMPLES OF HARDIDE COATING’S PERFORMANCE AGAINST SEALS

Due to the Hardide coating’s hardness, wear and erosion resistance, it can increase the life of critical metal parts by a factor of x3 and, in some applications, by an order of magnitude. The coating has been tested in several applications where the coated parts are working against elastomeric seals and packing in abrasive media. These tests showed that the Hardide coating retained its surface finish and, in many cases, even improved the finish due to being polished by the seal. It was also found that the coating is seal-friendly and reduces wear of the seal and of the mating soft metal parts, such as brass bushing. Some examples:

- Hardide coated rotor of a progressive cavity pump working against an elastomeric stator: after 192 hours of accelerated testing pumping sand/water slurry, the rotor surface finish has improved significantly: from 0.6 microns Ra down to 0.25 microns, and in some areas even to 0.12 microns Ra – as shown on Fig.2 below. This ability of the coating to maintain and even improve surface finish helps reduce the elastomeric stator wear.
- Hardide coated hydraulic actuator plunger working against PTFE-based seals in reciprocating motion shown no signs of the metal part wear after 25,000 cycles, no leakage detected; after initial work-in period there is no noticeable seal wear debris;

- Hardide-coated washpipe working as a conduit for drilling mud in a rotating contact with packing seals: after a full test run the coating wear was measured at just 12 microns (representing 20% of the coating thickness). The coating finish in areas mating against the packing had actually improved, as shown on Fig.3 below these areas became shiny. The coating protected the washpipe surface from corrosion while the uncoated ID showed heavy rust. The customer noticed reduced wear of the packing.
- Brass bushing of a heavy-loaded rotating part used in sand/water slurry showed wear reduced by 50-65% when working against Hardide-coated parts. The tested Hardide-coated pin and bushing are shown on Fig.4 below;
- Hardide coating of mud-driven hydraulic cylinders of oil drilling tools reduced wear of the elastomeric seals;
- Packing and seals of the positive displacement pumps handling abrasive viscous fluids at a pressure up to 2,800psi lasted significantly longer when the pump plungers and cylinders were coated with Hardide.

These tests demonstrate that the coating finish is important to reduce the seal wear, although the optimum roughness range can be different for different applications. For example finish of 0.2…0.3 microns Ra worked well in abrasive slurry applications and drilling mud. Hydraulic parts working in clean hydraulic fluid against PTFE-based seals would require a better finish of 0.1…0.15 microns Ra, in some cases Rz surface finish characteristic is also important, which measures ten-point height of irregularities. Meanwhile, in all applications, the ability of the coated metal surface to maintain the optimum finish for as long as possible was key to it remaining seal-friendly. The Hardide coating achieved this.

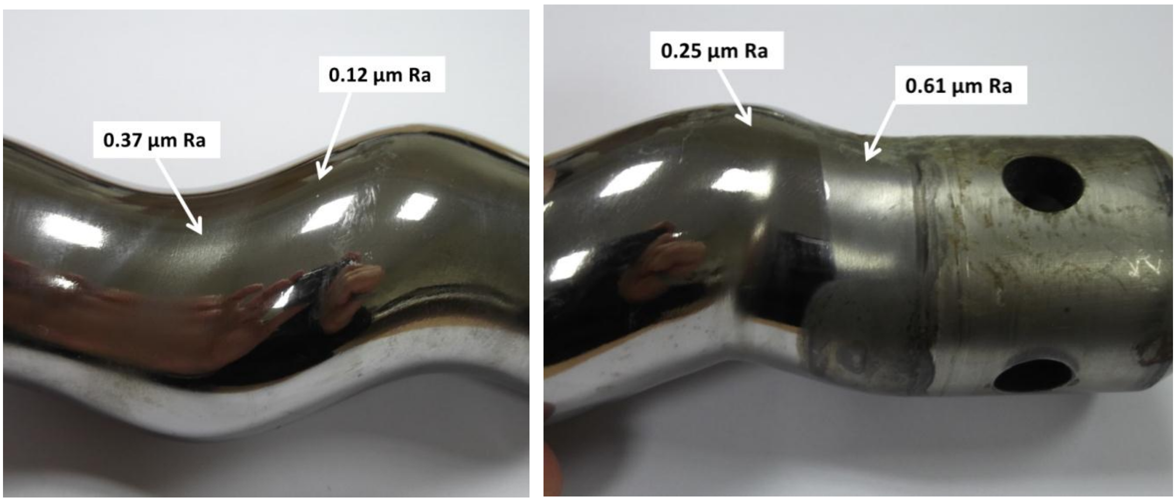

Fig.2. Progressive cavity pump rotor with Hardide coating after 192 hours testing in sand/water slurry: the coating Ra finish improved from initial 0.61 µm (see right – the dull coated area was outside the contact with the stator and retained original finish) to 0.25 µm, and in some areas even to 0.12 µm (see left).

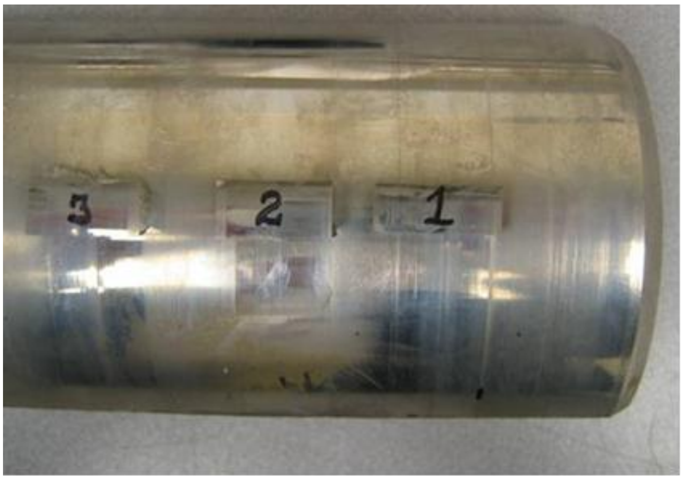

Fig.3. Washpipe coated with Hardide-T after field testing: areas in contact with the packing seals became shiny, surface finish improved. The coating wear measured at approximately 12 microns – or 20% of the coating thickness. The coating protected the washpipe from corrosion in service: the uncoated internal surface of the pipe has a thick rust layer.

Fig. 4. Rotating pin after 50,000 cycles of abrasion tests in sand/water slurry under high load: the coating reduced pin wear rate by a factor of x70 - as compared to standard case hardened pin. The uncoated brass bushing wear was also cut by a factor of 2.5 thanks to the Hardide coating's non-abrasive properties.

4.2.2. HARDIDE COATING TESTED ON METAL-METAL BEARINGS

The Hardide coating has been successfully tested on metal hybrid hydrodynamic/hydrostatic radial and thrust bearings (as shown in Fig.5) used by Alfred Conhagen, Inc. in eight-stage and six-stage high-performance centrifugal pumps designed for high temperature refinery service. At the product temperature of 450^{o}F (230^{o}C) both the octane and diesel have poor lubricity. In both applications, entrained solids and thermal growth of the close clearance components were the main concerns. In the diesel application, there was pipe scale and some coke fines, and the octane pump occasionally had catalyst carryover which can quickly destroy fine clearances.

The Hardide-coated bearings have been in service for three years during which time they have experienced some moderate-to-severe solid ingestion, yet the coated bearing surfaces remain in excellent working condition with a number of parts showing no signs of wear at all, and also no galling or cracking of the coated surfaces. In one case, a customer suffered a system upset and introduced a large amount of ceramic bead catalyst to the pumpage and destroyed all of the eight-stage pump internals except the Hardide-coated components, which were then re-used in the refurbished pump.

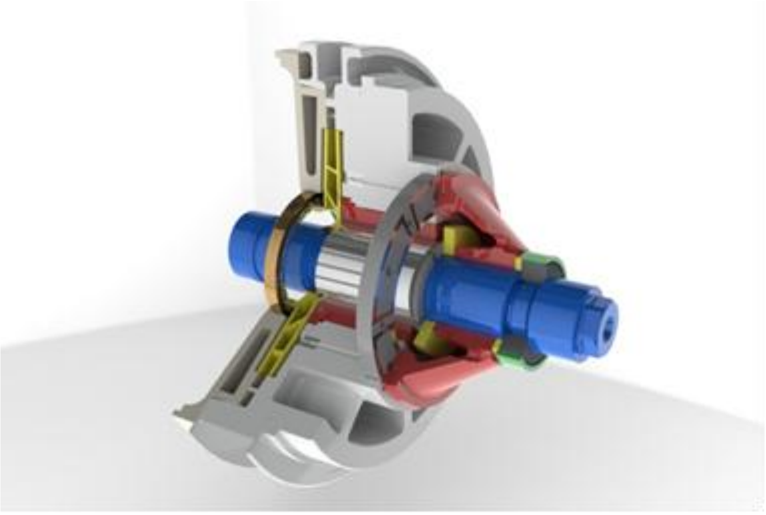

Fig. 5. FHR Non-Drive End Bearings.

The key factor for this application success was that the Hardide coating was applied to the bearing sleeves machined out of 410 stainless steel, which matches the coefficient of thermal expansion (CTE) of other bearing parts to maintain close clearance over a range of temperature. Cemented carbide sleeves, having a much lower CTE than the steel shaft, would not expand to the same degree as the steel shaft when the pump temperature rises and the bearing may then seize. The Hardide coating provided sufficient wear resistance to last more than three years in the presence of abrasive solids. It also prevented bearing galling against the steel shaft.

A similar principle can be used to design high temperature seals and bearings operating in abrasive media. Hardide coatings can be used up to 400ºC in air and oxidizing media. Considerably higher temperatures can be tolerated in an inert atmosphere. At temperatures above 200…250ºC the use of elastomeric seals would be restricted. The metal/metal seals can be designed where one part is made of uncoated metal and another of the same metal with Hardide coating. Use of the same material for both parts would allow them to expand and contract in a concerted way when the temperature changes, thereby maintaining the designed clearance. And Hardide coating on one of the parts would prevent galling which can be particularly severe when both mating surfaces are made of the same material. In abrasive applications, both parts of the metal/metal seal can be coated with Hardide to protect them from abrasive wear.

5. KEY PROPERTIES OF HARDIDE COATINGS

5.1. WEAR AND EROSION RESISTANCE

Hardness, wear and erosion resistance are the key characteristics of Hardide™ which have been extensively tested in the laboratory and proven in industrial environments. Abrasion resistance tests performed in accordance with the modified ASTM G65 standard using wet Silica sand abrasive show that the Hardide wear resistance is x400 times better than that of Inconel 625 alloy. In other words, the exposure to abrasive conditions which would wear out 400 microns thickness of Inconel will result in wear of just 1 micron of the Hardide-T coating. This illustrates the difference that can be made by the use of a hard coating: 400 microns wear could result in significant leaks in a hydraulic system, slack or loss of performance of mechanisms, while wear of just 1 micron would not have any noticeable effect in most applications.

Other tests to the ASTM G65 standard Procedures A and B showed that the Hardide wear rate is 40 times lower than abrasion resistant steel AR-500, 12 times lower than Hard Chrome and four times lower than thermal spray WC.

Hardide coating erosion resistance was tested in accordance with ASTM G76-95. Hardide's erosion rate was 0.017-0.019 mm^3/g which is significantly better than the erosion rate of the tested types of cemented carbide, white iron, Hard Chrome and chrome carbide weld overlay. Hardide outperformed steel in this test by a factor of x3, and also outperformed cemented carbide by a factor of x2. The Hardide erosion rate remained almost constant with the angle variation. Hardide also significantly outperformed various currently used hard materials in a sand/water erosion test.

Hardide's wear and erosion resistance are superior to other tested materials despite the fact that some of them have higher hardness. This enhanced performance can be explained by Hardide's excellent toughness and fatigue resistance. Brittle micro-cracking including Hertzian ring cracks and cone cracks leading to material loss via chipping are the typical mechanisms of wear and erosion of hard materials like flame-spray tungsten carbide or Hard Chrome. A tougher material will better resist this degradation – as demonstrated by the Hardide coating.

5.2. RESISTANCE TO CORROSION AND CHEMICALLY AGGRESSIVE MEDIA

Metal surface corrosion or chemical attack can produce hard debris or Iron Oxides, roughen the surface and greatly accelerate the wear of seals. Some corrosion-resistant materials become prone to corrosion when working against a seal as constant abrasion removes the protective passive layer (Chrome Oxides on stainless steel surface). The combination of abrasion and corrosion can be particularly severe.

The Hardide coating's corrosion performance was benchmarked against other coatings. Independent salt spray tests were commissioned on mild steel plates coated with Hardide, as well as commercially sourced Hard Chrome plating and HVOF coating to compare their corrosion protective properties. The 480 hour tests were conducted in accordance with ASTM B117-07, a Neutral Salt Spray Test. Fig.6 shows samples of each of the three coatings after testing. The Hard Chrome plated samples were badly corroded and removed from test after just 288 hours exposure. HVOF-coated samples showed heavy rust stains, the coating cracked due to the intensive corrosion of the steel plate beneath. The Hardide samples showed only light staining. Unlike various paints and soft anti-corrosion coatings, Hardide offers the additional benefit of enhanced wear and erosion resistance.

In the unsealed thermal spray coatings, the Cobalt metal binder is prone to corrosion. Hardide coating does not contain Cobalt metal binder, so the coating itself was not affected by corrosion during the salt spray testing. As Hardide coating is free from through-porosity it effectively protects the mild steel substrate from the corrosion attack without the need to seal the coating.

Further neutral salt spray tests of Hardide-A type coating show no corrosion after 750 hours.

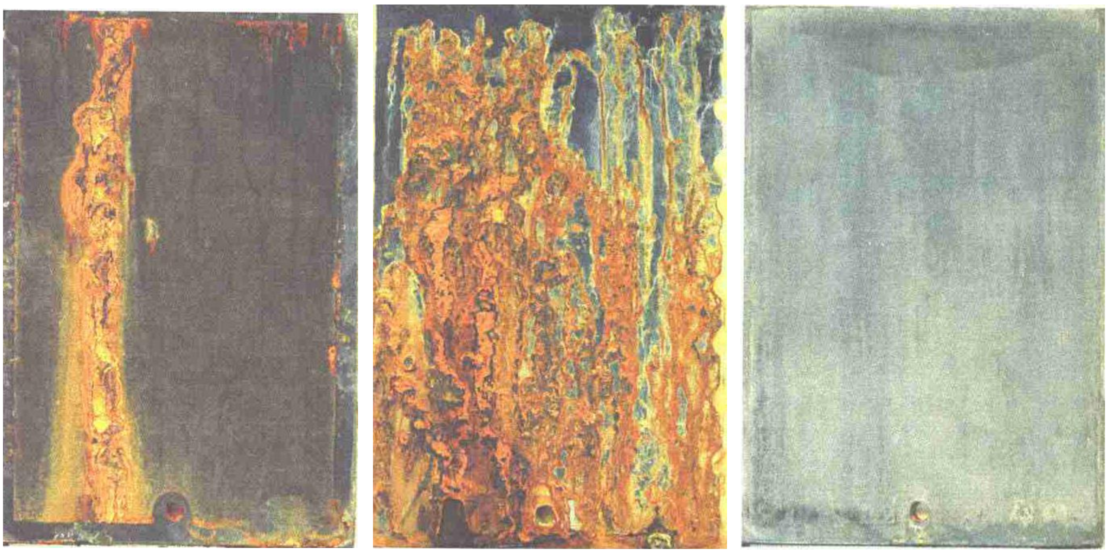

Fig.6. Samples of three different coatings after salt spray corrosion tests: left - HVOF after 480 hours; centre – Hard Chrome after 288 hours; right – Hardide coating after 480 hours.

Hardide was tested by Bodycote Materials Testing [7] for resistance to Sulphide Stress Cracking in accordance with the NACE test TM0177-2005 / ASTM G39 – Method B (1 bar H_2S) in a solution of 5% NaCl, 0.5% Acetic acid, saturated with H_2S. Samples of 17-4PH and 316L stainless steels as well as Inconel 625 were tested in 4-point bent beam stress conditions strained to 0.2%, 0.25% and 0.3%. Fig.7 shows two samples of 17-4 PH stainless steel after the 30 day test: the top dark plate is a control uncoated sample which cracked in half, metallography shown extensive micro-cracking and pitting. The bottom lighter sample was coated with Hardide and after the same test shows no cracking or degradation at all.

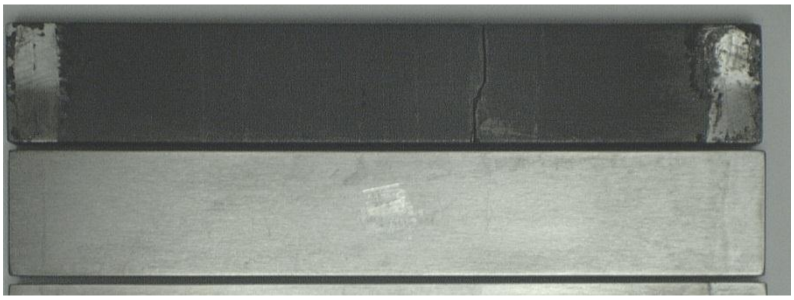

Fig.7. Stressed faces of Uncoated (top) and Hardide-coated (bottom) samples of 17-4 PH stainless steel after 30 days Sulphide stress cracking test (photo from report [7]).

Similar results were observed on Hardide-coated 316L stainless steel and Inconel 625 specimens, strained to 0.2%, 0.25% and 0.3%. The Hardide coating prevented stress corrosion cracking of these samples. None of the coated samples displayed any evidence of coating cracking, degradation or de-lamination after the 720 hr exposure period.

Due to its deposition mechanism, Hardide is free from through-porosity from a thickness of less than 1 micron. Pore-free coatings have high chemical resistance [8] and protect the substrate from attacks by aggressive media. Traditionally used coatings like flame-spray or Hard Chrome have micro-pores and micro-cracks which can open when deformed under load and allow the solution to attack the substrate.

Hardide is particularly effective at protecting against mineral acids, including HCl, Nitric and Sulphuric acids. It can even resist Aqua Regia at room temperature; particularly notable as this mixture of hydrochloric and nitric acids is capable of dissolving noble gold.

The Hardide coating was tested alongside a WC/Co detonation coating for resistance to 20% Nitric acid for 113 hours. The Hardide sample became yellowish in colour due to slight surface oxidation, meanwhile its dimensions did not change, the weight loss was not measurable – less than 0.001 g and its surface roughness remained the same as before testing - 0.10 micron Ra - which all indicate that the coating had not been attacked. In the same test, the detonation coated sample changed colour to dark grey, while the acid solution became rose coloured due to Cobalt leaching from the sample. The weight loss of the WC/Co sample after 46 hours 40 min was approx. 0.3 g. The roughness of the detonation sample before testing was 0.10 microns Ra. After testing, this increased to 0.41 microns Ra due to metal binder leaching. As a result of the increase in roughness, the detonation coating can become extremely abrasive for seals and packing when exposed to aggressive media.

5.3. ABILITY TO COAT INTERNAL SURFACES AND COMPLEX SHAPES

Hardide coatings are deposited by CVD technology from the gas-phase. This allows uniform coating of complex shapes and internal surfaces. This is important for applications with parts like actuator threads, hydraulic cylinders, valves and pumps. Fig.8 shows examples of complex shape parts with Hardide coating. Thanks to the uniformity of the Hardide coating it can be polished to a good finish, normally grinding is not required to achieve a finish of 0.2…0.3 microns Ra. Due to its uniform structure, Hardide retains its finish which prevents the wear of counterparts made of softer metals or elastomeric materials.

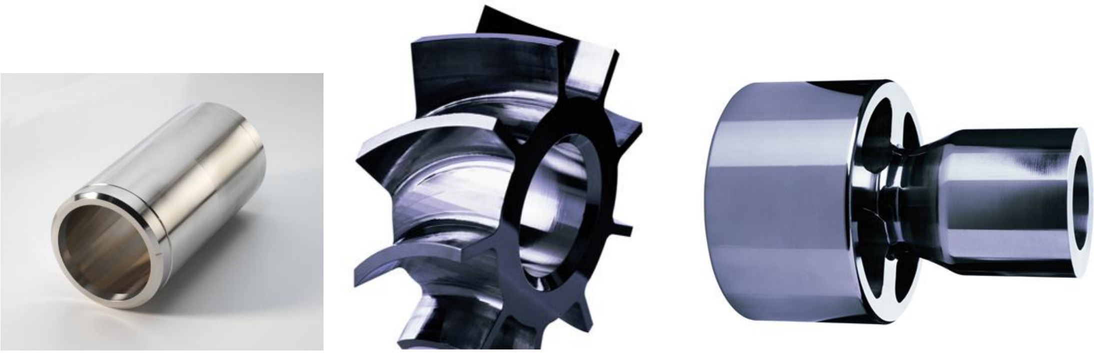

Fig.8. Examples of complex shape parts with Hardide coating: a pump cylinder ID coated (left), down-hole tool parts: a turbine (centre) and a flow diverter (right).

5.4. PORE-FREE COATING

Due to the deposition mechanism, Hardide coatings are free from through-porosity from a thickness of less than 1 micron. The coating is crystallised from the gas-phase atom-by-atom; the highly mobile reaction products fill micro-pores and defects in the coating as it grows. The porosity, measured as the difference between theoretical and actual material density, is less than 0.04%.

Traditionally used coatings like flame-spray or Hard Chrome usually have micro-pores and micro-cracks which may open when the substrate deforms under load and which allows the solution to attack the substrate. In contrast, the Hardide coating has exceptionally low porosity as applied and does not require additional sealing in most applications.

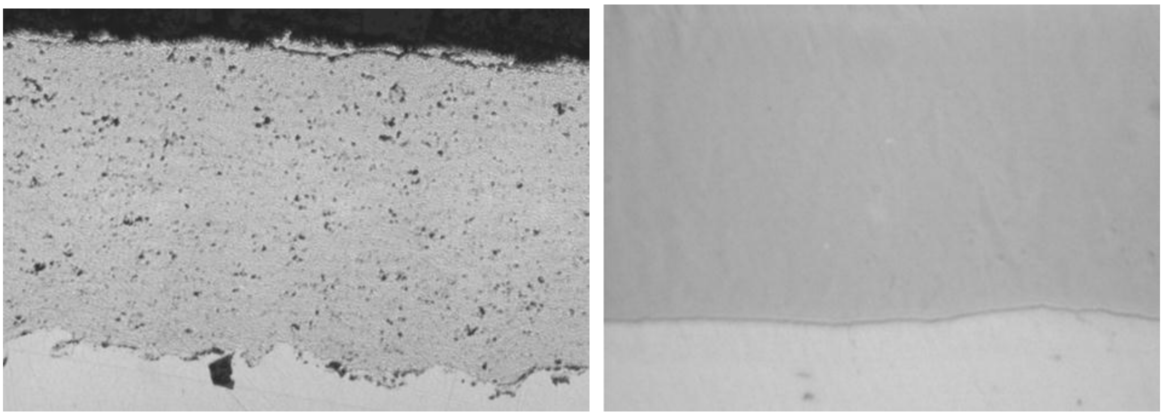

Fig. 9 Porosity measurements in coatings metallurgical cross sections: Left – HVOF WC/Co has 2.55% porosity (dark spots), Right – Hardide coating has 0% porosity.

6. SUMMARY AND CONCLUSIONS

The nano-structured Hardide coatings have been extensively tested in applications where coated metal parts are working against seals made of elastomers, PTFE and other polymers. In most cases, the coating has proven to be seal-friendly and has protected the metal parts from abrasive wear while also reducing the wear of the seals. This is due to the good finish of Hardide coatings, their uniform structure, and the uniform wear pattern of the coatings that allow the coated parts to maintain an optimum finish for longer, even in the most abrasive conditions. Excellent resistance to corrosive and chemically aggressive media is also an important contributing factor.

Hardide coatings enable the design of high temperature metal-metal seals and bearings, where all the bearing parts can be made of the same material and thus will expand and contract in concert when the temperature changes. Coating one or both components of such high temperature metal-metal seals or bearings would prevent galling and wear of the parts in abrasive conditions.

Hardide coatings offer a combination of protective properties, including wear and erosion resistance, protection against aggressive chemicals and corrosion. The coatings have enhanced toughness, impact and crack resistance - qualities essential in many critical industrial applications. The coating can be applied to a broad range of substrate materials. The ability to coat internal surfaces and complex shapes opens new potential applications for hard coatings with critical parts. Being pore-free, the coating protects the substrate from attacks by aggressive media.

These properties are realised in various applications including downhole tools, pumps and valves operating in oil and gas facilities, food manufacturing, refineries, cryogenic equipment and power generation. Typically, the coating triples the operational life of critical parts in abrasive conditions.

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