TRIBO-CORROSION PROTECTION OF VALVES AND ROTORS USING CERMET LAYERS APPLIED WITH HVOF

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ABSTRACT

The economic viability of equipment in industrial facilities that perform organic processes depends on the capacity of auxiliary equipment, such as valves or rotors, to withstand wear of the tribo-corrosion type (combination of heat and an aqueous medium). The use of Surface Engineering Techniques such as High Velocity Oxy-Fuel (HVOF) in order to apply carbide based cermet layers and showing very positive results in decreasing tribological and corrosion mechanisms, is still industrially evaluated against the use of wear resistant bulk materials. A comparison, after a working campaign, between non-protected and HVOF treated parts is presented.

1. Introduction

The energy crisis that took place in 1973, had major repercussions in all the countries with market economies and resulted in shifts in the technology development strategies in order to achieve a more rational and efficient use of raw materials, improving manufacturing processes and the performance of the materials used in these facilities.

The bulk materials used in the design and construction of industrial equipment must withstand wear of both mechanical and chemical (or electro-chemical) types. Furthermore, if temperature is high (above 250°C, which is a temperature limit that restricts the use of water in the liquid state), other oxidation processes are activated (oxidizing atmospheres with $P(\mathrm{O_2}) \geq 10^{-4}$ MPa), as well as chemical attack by metallic or metal oxides mixtures in the form of melts.

There are many routes in order to solve design problems for parts that present wear mechanisms related to mechanical features:

a) *Increase the thickness of the material*

b) *Increase hardness*

The use of thicker walls became a common practice until the mentioned energy crisis. Current solutions used be most specialized engineering firms, are focused in the modification of materials using new alloying elements and/or heat treatments, resulting in harder materials though losing toughness. Nevertheless, an increase in hardness is not always directly related to a better tribological behavior (1)

2. Wear mechanisms: Tribo-corrosion

A system suffers mechanical wear when superficial contact with another material takes place: a force is applied and there is considerable displacement between the surfaces. If mechanical conditions or thermal variations are high, the wear may produce failure by fatigue. Another mechanism to be considered in the wear of materials in general and metals and their alloys in particular is electrochemical corrosion: water acting as solvent and addition of acid or basic products, along with dissolved oxygen and temperature, will activate the anodic dissolution of the metal.

Figure 1 presents, from a thermodynamical point of view, the equilibrium of the Fe-O-H system at constant (atmospheric) pressure and 60°C temperature for an iron concentration of 10^{-6} moles·liter^{-1} solution, known as the Proubaix diagram (2,3).

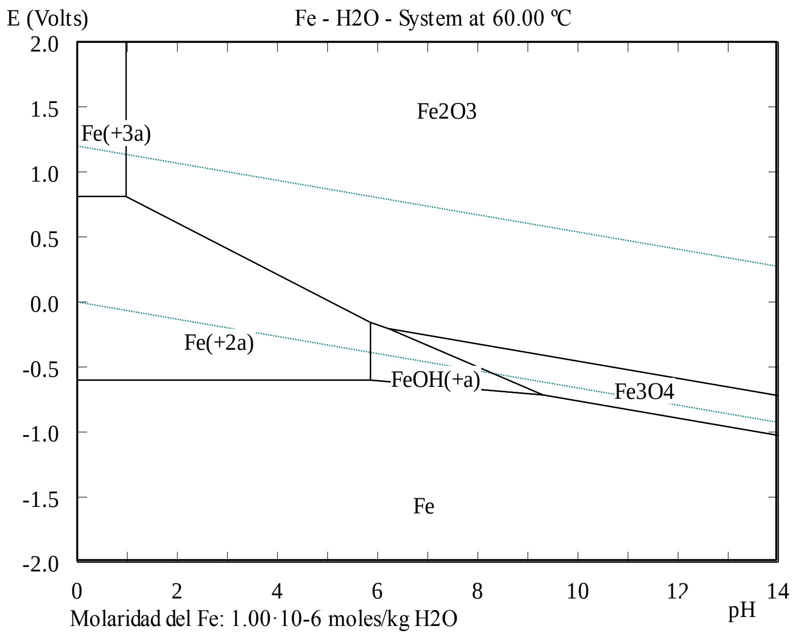

Figure 1. *Proubaix diagram at 60 °C for the Fe-O-H system (atmospheric pressure).* $Fe^{3+}(aq) = 10^{-6}$ *moles·litre*$^{-1}$.

Tribo-corrosion is defined as the combination of mechanical and electrochemical mechanisms producing wear and, consequently, acting simultaneously and aiding each other to produce the wear of the material, this is, the amount of material lost due to mechanical-electrochemical activity is higher than the sum of each of the mechanisms acting separately (4).

Consequently, tribo-corrosion is relevant in primary industry processes, and specifically on preparation-grinding-milling of raw materials and mostly evident in finishing stages that use aqueous environment. Likewise, digestion-lixiviation processes for pulps (solids in aqueous suspension) using acid, basic or oxidizing solutions also present this type of wear. As an example, food industry extracts sugar from beets using alkaline solutions at 50~70°C.

In all the previous cases, the simultaneous activity of erosive (perpendicular stress-impact), abrasive (mostly tangent stress-impact) or sliding (combination of tangent and perpendicular stress-impact) mechanisms along with electrochemical corrosion produced by local micro-anodes and cathodes will result in a considerable damage of the equipment, installations and auxiliary elements (stirrers, feeders and valves).

Two alternatives have been used recently in order to solve this type of wear:

a) *Design of devices with materials highly resistant to electrochemical wear: titanium- or tantalum-based alloys.*

b) *Manufacture of parts highly resistant to erosion, abrasion or sliding wear by raising the amount of Mn, Cr, Ni or Mo in both carbon or stainless steels.*

In most cases, the first alternative is economically unviable, turning the second one in the most frequently used practice by design-industrial facilities construction engineering firms. Furthermore, this last practice not only raises the mechanical resistance of the material by adding alloying elements but also intrinsically increases resistance to electrochemical corrosion wear.

A third alternative to solve tribo-corrosion problems is using a low cost base (bulk) material and adding a surface with the required chemical and mechanical stability. If the characteristics of the protective surface are adequate (different types of wear may or may not be reduced using HVOF coatings)(5), the chemical-physical and mechanical characteristics of the base material (which acts as support for the installation) will only demand adequate adherence of this protective layer in order to avoid wear mechanisms. Consequently, it would be detrimental if an inadequate application of the protective surface results in longitudinal (delamination of the layers) or vertical cracks which allow contact between the environment(or corrosive fluid) and the base material (4,6).

3. Experimental data

Protection of the surface using High Velocity Oxygen fuel – HVOF is one of many thermal projection techniques perfected since 1980, for surface engineering processes, in which a suspension of metallic or ceramic powders are placed over the surface of the material to be protected at a speed two or three times higher than sound and 1700~1900 °C temperatures (7) as shown in schematically in Figure 2. The combined effect of speed (high kinetic energy) and temperature results in characteristics of a surface layer that show simultaneously low porosity (less than 2%) with very good adherence to the substrate (base metal needing protection) (6,8). Piping of oil and gas industry in contact with sea water (offshore facilities) is a good example of this (9).

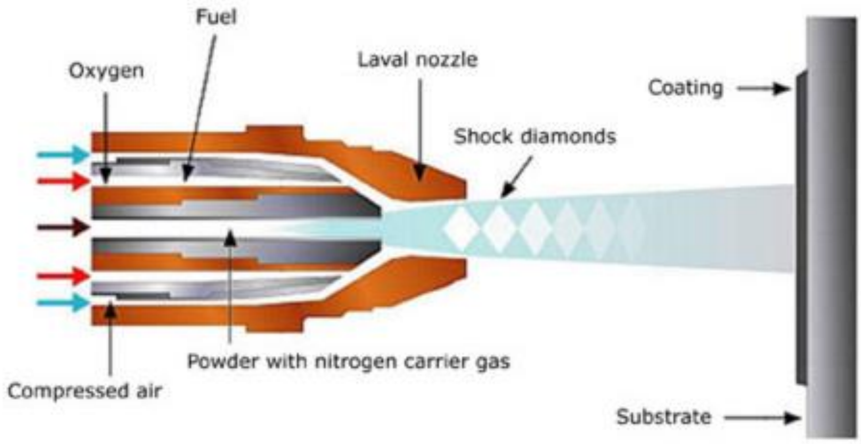

Figure 2. *HVOF process for cermet coating of surfaces*

For the sugar industry that uses beets as raw material, protective layers applied with HVOF to auxiliary equipment (valves and rotors) allows very long working periods. In this case, a low carbon ferrite-perlite steel, usually required by the construction industry and with 1.0~1.2 % Mn, is used as a base for ceramic-metal (cermet) layers: Cr or W carbides based. Table I indicates the elemental analysis of the Cr and W based cermets applied with HVOF for these equipment (10). Ni. Fe and Co act as binding metal of the carbide particles in order to form ceramic-metal composites. Though very much is known about cermets as tool materials for different applications, the characteristics of these cermet layers from a mechanical and corrosive point of view are very different. Moreover, metallic binders (Ni) must assure adherence and toughness at the surface, which may also be a function of the geometry of the part (9).

Table-I. Chemical composition for Cr and W based cermets

Cr cermet	70% Cr	9.3% C	20.5% Ni	0.2% Fe
W cermet	80% W	5.4%C	10.35% Co	4.25% Cr + Fe

After a nine month working campaign, the effect of wear in a rotating auxiliary system is shown in Figures 2 and 3. The material of the part shown in Figure 2 is a rotor structure damaged with grooves or tracks over the surface of a hot rolled steel with a ferrite-pearlite structure (0.30 % C and 1.20 % Mn). On the other hand, Figure 3 presents the surface integrity, at the end of the campaign, of the same steel with a 200 µm layer of Cr-W cermet applied with HVOF. In both situations, the material was in contact with an alkaline solution formed with different proportions of solids in suspension (siliceous clays) for a nine month period, at a temperature of 60°C.

The surface wear of the part shown in figure 3 is almost non-existent, though at 7many zones the thickness of the protecting layer has been reduced to ~100 µm (starting thickness of 200 µm).

Figure 2 *Final state after a working campaign of a rotor in a sugar production facility.*

Figure 3. *Final state of a rotor for a sugar production facility after a working campaign and protected with Cr and W cermet layers.*

4. Conclusions

HVOF projection technique is a very efficient surface treatment, especially in those cases where auxiliary equipment (rotors, valves or pumps) must be protected from wear in sugar production facilities that use beech.

The use of HVOF as protective layer is efficient in both a structural and an economic way, as it allows for the same device to be used in periods as long as 9 months, reducing the cost of maintenance stops. Parts not protected with HVOF layers can suffer damage that will make its further recovery (for example, by applying welded metal layers) impossible. In some cases, not protected parts, such as pumps may suffer perforations during the working campaign, requiring its replacement during extraction activities.

The superficial damage in different auxiliary equipment in a sugar production industry will result in energy consumption, loss of productivity due to production stops and, consequently, low economic efficiency.

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6. References

(1) St. Siegmann, O. Brandt, N. Margadant, Tribological requirements of thermally sprayed coatings for wear resistant applications, ist International Thermal Spray Conference . Thermal Spray: Surface Engineering via Applied research, Montreal, Canada, 2000
(2) Ballester, A.; Verdeja, L. F. y Sancho, J. P. (2000): Metalurgia Extractiva: Fundamentos, Síntesis, Madrid, pp. 219-223.
(3) HSC Database Chemistry. (2002). Outokumpu Research Oy, Version 5.1. Finland.
(4) Vázquez, A.; Damborenea, J.J. (2000): "Ciencia e Ingeniería de las Superficies de los Materiales Metálicos". Ed. Consejo Superior de Investigaciones Científicas, CSIC, Colección Textos Universitarios No. 31, Madrid, pp. 9-56; 473-484.
(5)Introduction to Thermal Spray Processing 2004 ASM International. All Rights Reserved., Handbook of Thermal Spray Technology 3-13
(6) Puértolas, J. A.; Ríos, R.; Castro, M.; Casals, J. M. (2010): "Tecnología de Superficies en Materiales". Ed. Síntesis, Madrid, pp. 155-173.
(7)Mohammed Yunus, J.Fazlur Rahman, An investigation towards characterization of thermally sprayed industrial coatings, (IJAEST) INTERNATIONAL JOURNAL OF ADVANCED ENGINEERING SCIENCES AND TECHNOLOGIES Vol No. 10, Issue No. 2, 275 – 284, 2011
(8) Sobolev, V.V.; Guilemany, J. M. ; Nutting, J.(2004): "High velocity oxy-fuel spraying". Maney Publishing and Institute of Metals (IOM), London, UK.
(9) Erosion - Corrosion of Cermet Coating, Magdy M. El Rayes, , Hany S. Abdo, and Khalil Abdelrazek Khalil, Int. J. Electrochem. Sci., 8 ***(2013)*** *1117 - 1137*
(10) Verdeja, L. F.; Sancho, J. P. y Ballester, A (2008): Materiales refractarios y cerámicos, Síntesis, Madrid, pp. 19-22; 343-356.