Association of Metallurgical Engineers of Serbia
AMES

Scientific paper
UDC: 669.268:621.313.13-253

FAILURE ANALYSIS OF CHROMIUM PLATED ROTOR OF DOWN-HOLE DRILLING MOTORS

Meysam Zarchi *

Islamic Azad University Dezful Branch, Iran

Received 03.11.2010
Accepted 06.12.2010

Abstract

Down-hole drilling motors, so called positive displacement motors (PDM), consist of a helically shaped metallic rotor rotating within a molded stationary elastomer lined stator. The heart of the positive displacement motor is the rotor-stator. The circulation of rotor transforms the hyper pressure of hydraulic energy of drilling mud into the mechanical energy causing the motion of the drill. Rotor is usually chromium plated to resist wear and corrosion. In this study, an attempt was made to analyze the failure of a hard chromium plated rotor made of 17-4 PH stainless steel. No interlayer between the base metal and the coating was applied. Effect of various parameters on surface damages of this rotor was thoroughly studied by visual inspection, chemical analysis and metallographic examinations. The main failure mechanisms were identified as erosion due to hard particles, and chemical corrosion due to some hostile chemical elements and their compounds elements in the drilling fluid.

Key words: down-hole drilling motors; failure analysis; rotor; stator; friction; erosion

Introduction

Down-hole drilling motors, the type of motors with positive displacement motors (PDM), have two main parts: rotor and stator (Figure 1).

This motor converts the hydraulic energy of high pressure drilling fluid to mechanical energy, thereby imparts torque to the rotor, causing it to turn eccentrically. The circulation of a helically shaped rotor transforms the hyper pressure of hydraulic energy of drilling mud into the mechanical energy and finally causes the motion of the drill [1, 2]. Figure 2 represents the schematic drawing of rotor and stator showing their different profiles.

* Corresponding author: Meysam Zarchi, Sky_man1983@yahoo.com

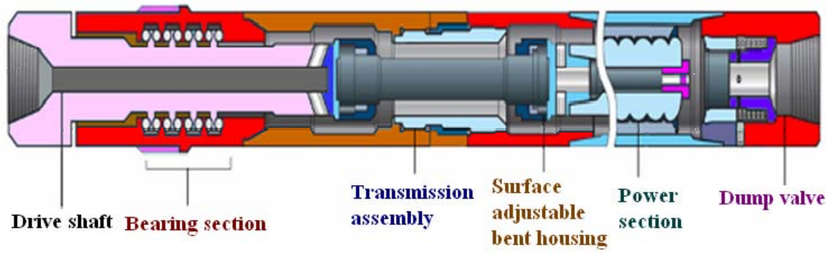

Figure 1. Schematic drawing of drilling motor (drawn by the software 'Solid Work')

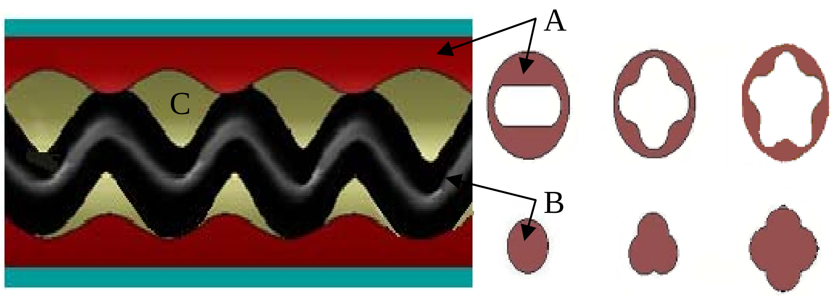

Figure 2: Schematic drawing of rotor and stator: A-profiles of stator; profiles of B-rotor; C-cavity.

Coating failure and penetration of holes into the base metal of rotor are among the main causes of rotor failure. There are more factors causing these problems, such as: kind of material the stator is made of, type of rotor coating, composition of drilling mud, temperature and working pressure. Solid particles floating in the mud, the space between rotor and stator are among other influencing factors. A rotor is often made of CK45 medium carbon steel or 17-4PH stainless steel. These materials have a good erosion resistance in different environments. Rotor is protected by a hard coating resistant to friction and has. On the other side, stator is made of some kind of elastomer which can resist friction and is able to stand the damage imposed by hydro-carbon [3, 4].

Drilling mud may be water-base, oil-base, or emulation-base. At first, drilling mud was used for drilling carriers with the purpose to bring them to the surface; however, with the development of drilling industry, the functions of drilling mud and its quality have been increased and varied [5]. In any case, the mud contains additives some of which affect the efficiency and usefulness of rotor and stator. To challenge the problems of corrosion and mechanical damage (erosion and friction) caused by drilling mud, hard chromium coating was widely used as a method of protection. Modern technological processes such as High Velocity Oxygen Fuel (HVOF) thermal spray are widely spread. Although these processes are more expensive their protection last longer when used instead of other types of coatings [6]. High hardness, good resistance to friction has made the chrome coating an applicable and desired in oil industry tools. In these cases of application coating thickness is different than chromium coating for decorative purposes [7]. Chloride in drilling mud causes holes on smooth surface of rotor and brings about rough edges acting as destruction places on the edges of stator. Cuttings caused by this mechanism on the surface of stator highly decrease the efficiency of sealing between rotor and stator and finally may stop the motor at low differential pressure. Usually the hard electroplated chromium coating is deposited along with a flat sub-layer (mostly nickel) in order to prevent direct contact of the base metal with corrosive-erosive environment, especially with that of

chloride composition, hydrogen sulfite, or carbon dioxide which may cause corrosion and mechanical damage [8]. Also, friction, mechanical stresses like stroke and distortion and influence of chemicals mentioned above may cause holes or local failure in the thin layer of the chrome coating.

Experimental

The rotor material used in this investigation was steel with hard chromium coating. In order to study the structures of rotor samples, the usual metallographic investigations have been performed by light and scanning electron microscope (SEM). SEM was used for further and more careful investigation of affected surfaces and damage of hard chrome coating.

Results and Discussion

Chemical composition of rotor is given in Table 1.

Table 1: Chemical analysis of rotor, in wt.%

C= 0.035	Cr= 17.24	Co= 0.039	Nb= 0.235	W= 0.010	P= 0.031
Si= 0.366	Ni= 3.510	Cu= 4.050	Al= 0.003	Ti= 0.011	Fe = Bal.
Mn= 0.484	Mo= 0.261	Sn= 0.030	V= 0.005	S= 0.030	

The results of the chemical analysis showed that according to AISI 630 standard this steel is of 17-4PH type which belongs to martensitic stainless steels and contains 3-5 Cu and 0.15-0.45 wt.% Nb and is hardened by copper and niobium nano-sized precipitates formed in the dendritic matrix during aging. The microstructure of this steel in aged condition is martinsitic with alpha ferrite as shown in Figure 3.

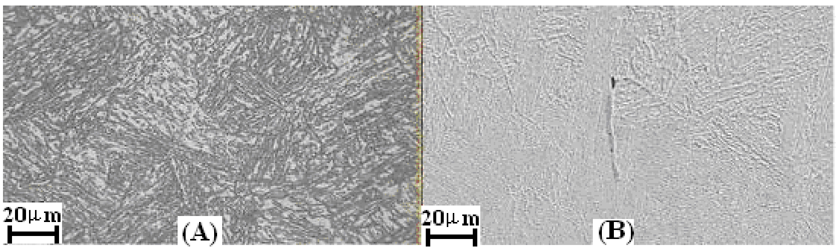

Figure 3. Microstructure of rotor; A) light microscope; B) SEM.

These hardened stainless steels were used for the first time in 1940 and since then they have been widely used for different applications especially for production of different tools due to their low distortion, high resistance against erosion and friction, excellent welding capability and relatively high hardness. Previous studies have shown that at aging temperatures above 570 ^{o}C a layered structure is formed in 17-4 PH steel which might be due to the appearance of reversed austenite or the recrystallized ferrite in the tempered martensite.

Aging in the temperature range of 480-620 ^{o}C causes an increase of strength and brittleness due to precipitation of copper-reach phase. If the temperature of aging increases above 600 ^{o}C the non-homogenous formation of copper-based precipitates in the matrix and also transformation of some martinsite occurs along martensitic plates.

The microstructure obtained by SEM and maps of elements distribution showed that the rotor coating contained chrome, whereas the sub-layer of nickel did not exist (Figure 4).

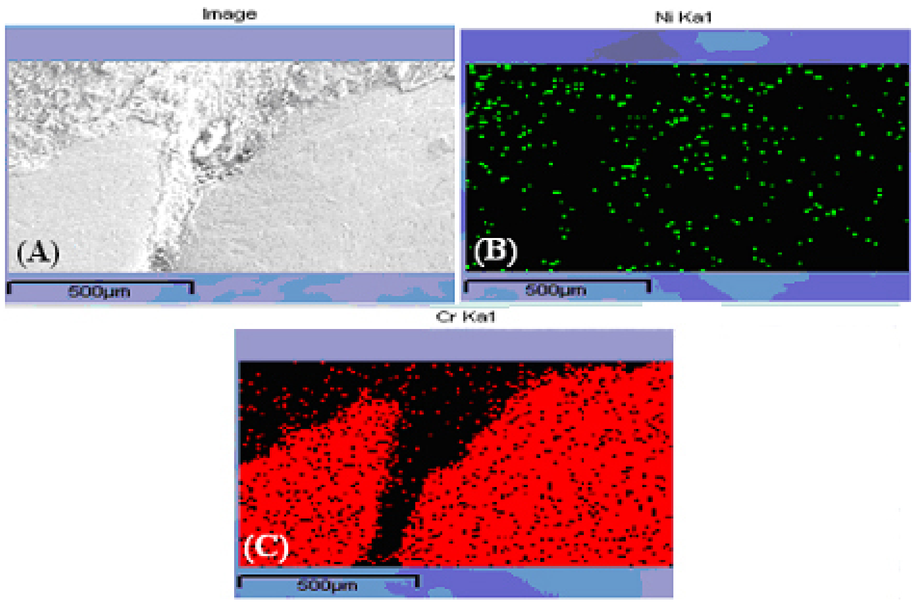

Figure 4. SEM. Microstructure of rotor. A) failed surface; B) map of nickel distribution; C) map of chrome distribution.

The coating thickness has been measured as 80 to 100 microns. On the other hand, the interspace between the coating and the base metal was not observed (Figure 5). This can be the reason for the lower hardness of the coating, i.e. less than 33-35 HRC. Also, coating was not continuous along its length since at different places of the rotor it has been broken due to the chemical corrosion and the process of formation of holes which in some cases has reached the sub-layer of the steel (Figure 6).

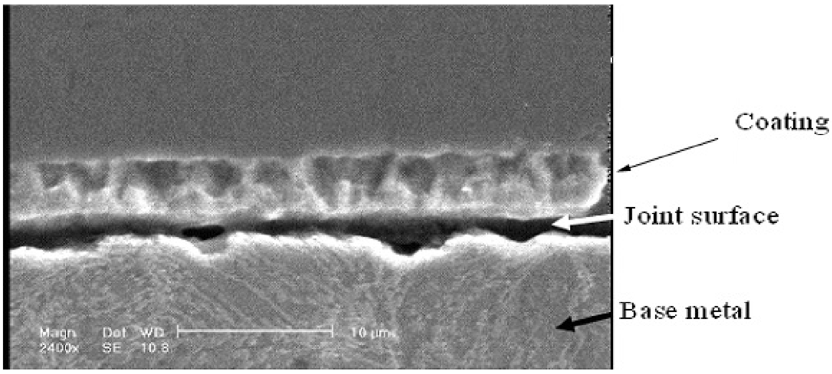

Figure 5. SEM. The cross-section of rotor with coating.

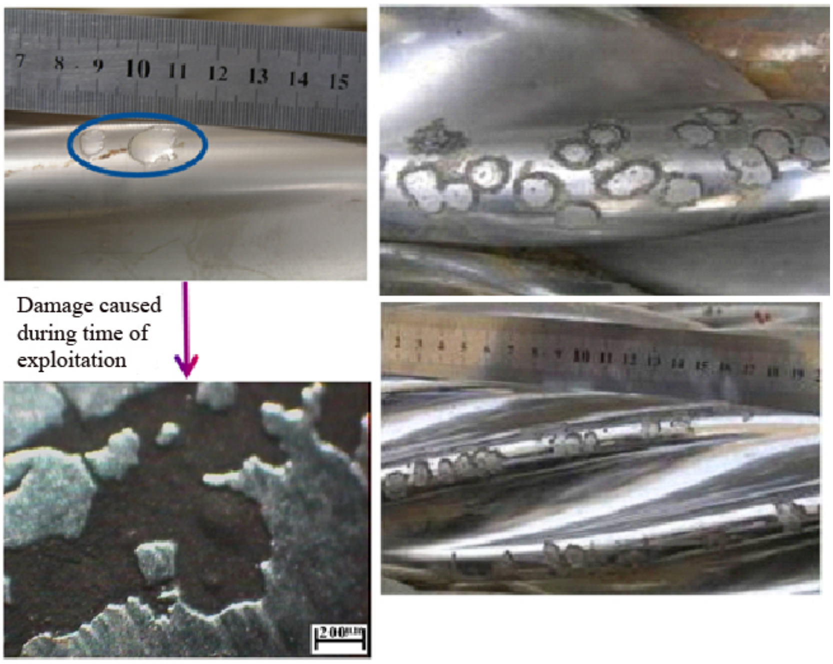

Figure 6. Macro and micrographs of the surface damage on rotor including avulsion and holes.

Formation of these holes is the result of the reaction of the steel with drilling mud containing corrosive materials like chlorides. Previous studies have shown that the hard chrome coating does not possess the necessary resistance against corrosive environments containing chloride [5]. In addition, the chemical elements and their compounds like sodium, potassium, carbon gases and hydrogen sulfide, as well as erosive particles like silica always exist in the drilling mud and their amount depends on the drilling location. It is clear that the chrome coating is always exposed to corrosive factors like these. Figure 7 shows some areas of rotor affected under the influence of friction imposed by the pressure of drilling mud or because of the collision of hard chrome coating with solid particles existing in drilling mud. Cracks appearing mainly in the radial direction may be observed.

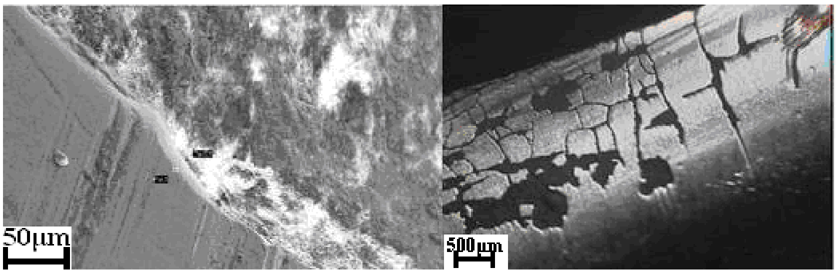

Figure 7. Cracks on coating due to friction.

Thus, two main factors affecting the surface of coating may be distinguished as:

- chemical (corrosion by chemical elements and their compounds),
- mechanical (erosion and friction attributed to solid particles in the drilling mud).

An attempt has been made to measure the size and volume fraction of corrosive particles (Figure 8).

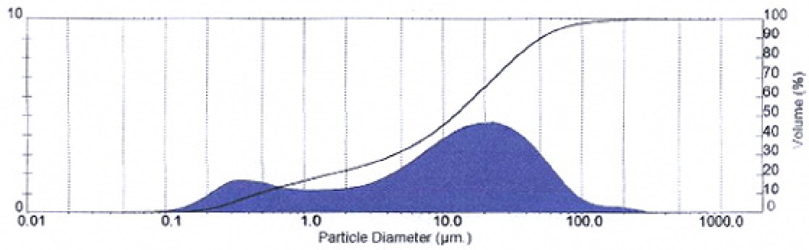

Figure 8. Distribution of the size of solid particles in drilling mud. Full line indicates the volume particles.

It may be seen that the size distribution of particles is quite irregular showing two maxima, *i.e.* one at approximately 0.3 microns (with the share of 20%) and another at approximately 20 microns (with the share of 50%), whereas particles of 300 are present in negligible amount. It may be supposed that particles with size of 20 microns are the main factor causing destruction of the rotor surface.

In order to solve this problem the coating of hard tungsten carbide was tried and its behavior examined [6]. However, on rotor with tungsten carbide coating failure in the form of pits as a result of corrosion may be seen in Figure 9.

Figure 9. Surface failure of rotor coated with WC. Friction cuttings and initiation of formation of pits into the base metal due to coating thinning.

With the prolonged time of exploitation these pits may spread into the base metal causing its failure (Figure 10). Considering the results of the tungsten carbide coating, it is clear that the degree of protection has not been improved compared to the chromium coating.

Figure 10. Surface failures of rotor coated with WC. Friction cuttings and the beginning of hole penetration into the base metal due to coating thinning. The figure on the right is enlarged detail of the left figure.

Conclusion

Results of this study indicate that:

1. There are small and big cracks on the chromium coating causing penetration of the corrosion agents into the base metal where pits are formed,
2. Two main factors affecting the surface of coating may be distinguished as: chemical (corrosion by chemical elements and their compounds), and mechanical (erosion and friction attributed to solid particles in the drilling mud),
3. Microscopic studies showed that chromium coating does not have the necessary resistance to chemical and mechanical parameters which may be found in the drilling mud. This behavior is the consequence of the poor consistency of coating with the base metal, low thickness of coating and relatively low resistance to corrosive environment,
4. The attempt with tungsten carbide as a coating did not show better results.

References

[1] R.A.R Mills, R.Gaymard,”New Applications for Wellbore Progressing Cavity Pumps”, SPE, Kudu Industries Inc Copyright 1996.

[2] E.O. Cobo, R.A. Suarez Baldo, J.B. Bessone Surface and Coatings Technology, 122 (1999) 39-43

[3] National Association of Corrosion Engineers, "Plated and Galvanized Coatings Oil Field Applications", Technical Committee Report, 1990, 1G, 290.

[4] K.M. Yin, C.M. Wang, Surface and Coatings Technology, 114 (1999) 13–223.

[5] M.Delpassand, “Mud Motor Stator Temperature Analysis Technique”, ASME Drilling Technology, 1995, Book No. H00920.

[6] J. Kawakita, S. Kuroda, T. Fukushima, T. Koda, Science and Technology of Advanced Materials, 4 (2003) 281–289.

[7] P.D.Spanos,A.M.Chevallier,N.P.PolitisandM.L.Payne.”Surface Engineering For Corrosion and Wear Resistance”. ASM Int, Metal Park, 2001, pp.871-875

[8] National Association of Corrosion Engineers, “Plated and Galvamium Coating Lost Adherence and Became Detached by Ionized Coatings for Oilfield Applications”, Technical Committee Report, 1990, 1G290.