Optimization of manufacturing agitator shaft with the new method of plasma: A case study from the Sarcheshmeh mine in Iran

Hamid Hajmohammadi
Research and Development Division, Sarcheshmeh Copper Complex, Kerman, Iran
Hajmohamadihamid@gmail.com

Alireza Afsahi
Research and Development Division, Sarcheshmeh Copper Complex, Kerman, Iran
Afsahi@nicico.com

Mohammadreza Bahrampour
Department of Materials Science and Engineering, Payame Noor University, Tehran, Iran
Bahrampour158@gmail.com

Abstract
Extraction of water presented in concentrated slurry of concentrating unit of Sarcheshmeh copper complex in Iran, is performed in filtration unit, in order to preparing it for melting process. agitator shaft is one of the filters components, responsible for suspending solid particles in the tank.The solid particles penetrate under the sealing ribbons and bosh around it by rounding of agitator shaft, and by accumulating there causes abrasion and corrosion of the bosh and shaft, escaping materials from reservoir, wasting of slurry and disrupting and halting the operation. By investigation of corrosion mechanism, two solutions are proposed and evaluated at present study: selecting suitable material and performing plasma nitriding heat treatment of previously used material. In order to investigate amount of abrasive corrosion of intended samples in comparison to the CK45 steel, abrasion corrosion samples and electrochemical tests were accomplished according to ASTM- G105.The surface of samples were analyzed by scanning electron microscopy and X-ray diffraction test. Observations showed new shaft, provide more proper performance at operation conditions.

Keywords: agitator shaft, plasma nitriding

Introduction

The term abrasion corrosion is related to concurrent mechanical abrasion and electrochemical corrosion. So abrasion corrosion includes all accelerated destroying due to abrasion caused by slurry movement(Banerjee, 1985). As transfer of minerals as slurry possesses a high efficiency, it is used in several mine and oil industry processes. However this method leads to many problems related to abrasion corrosion (Madsen, 1987). agitator shaft is one of the filter parts is responsible for stabilizing solid particles as suspension in the filter tank. Because of the presence of particles in the slurry and operation conditions, this equipment undergoes abrasion corrosion. The density of the abrasive particles is regarded as the most important factor affecting scratching corrosion provided by slurry (Rossi et al, 2006). Since the particles with the same sharp edges have greater densities, their resulted corrosion energy will be greater leading to deformation or cutting the particles off the metal surface (MacKenzie, 2008).

Minerals include Quartz- as the main element- and other minerals such as Feldspar, Chlorite and Calcite. According to Miller, simple carbon steels with hard surfaces has, show lower abrasion resistance in comparison to the minerals with lower hardness (Rossi et al,2006). If the hardness of the abrasive particles is higher than the metal being eroded, the rate of the corrosion will grow increasingly. But if the rate of particles hardness passes a certain value, it wont affect on the corrosion rate (ASM handbook Vol.18,1992;MacKenzie,2008). Researchers have suggested that corrosion rate is related to the hardness of the abrasive particles and if their hardness is lower than the metals, the quantity of abrasion will decrease however it never reaches to zero level (Rossi et al, 2006).

Different studies have shown that increment of hardness of steels, would be caused by fining of binit structure and ε carbides sedimentation for prevention against improper movements. So by crushing of the structure caused by increase of alloy elements, resistance to abrasion corrosion will also be enhanced in addition of enhancement in abrasion resistance (ASM handbook Vol.18,1992). Hardness enhancement is often an effective factor for increasing the alloys abrasion resistance. Then, for a piece to be resistant to abrasion , it should have appropriate hard and acceptable condition. In addition the phases presented in the substrate should have suitable properties such as lacking any sharp and needle shape edges as well as being in tiny, round and sphere like condition (Davis, 2001). As Yu and Bohel state, for industrial pieces with abrasion deficiency, employing microstructures – such as Martensite - with hard particles scattered in the soft substrate, would be more suitable (ASM handbook Vol.18, 1992; Davis, 2001). There are several methods to reduce damages caused by abrasion resistance. Since the abrasion resistance is a superficial process, using abrasive corrosion resistant metals is very suitable method for preventing damages due to abrasion corrosion. This method is the most economical solution to the most of the abrasion corrosion problems (ASM handbook Vol.18, 1992). This solution is one of the methods being considered in this study. In addition carboration, nitration, nitro carboration and induction hardening, are among the different methods for steel surface treatment. Among these methods, nitration causes the least distortion to the piece reducing any surface finishing costs.

Superficial nitration, enhances abrasion resistance and is performed through three methods of gaseous, salt bath and plasma (Skakov et al, 2015;Nishimoto et al, 2016).

In this study, because of its priorities with respect to the two other superficial hardening methods for CK45 steel, the new plasma method has been selected. Through this method, it is possible to enhance superficial hardness to 1200 without decreasing the steel core toughness.

Plasma or ionized gas is an environment full of ions and electrons made by an electrical discharge in a low pressure gas. Putting the piece as the cathode in a temperature around 500ºC, Nitrogen atoms can be penetrated in to the surface at the stage of optical discharge of plasma in a mixture of H2 and N2 (ASM handbook Vol.18, 1992). Through increasing the temperature, not only the penetration rate of nitrogen atoms into the iron crystal structure is increased, but the ability of nitrogen to react with nitriding agents present in the steel will also rise. Sedimentation of these particles is the most principal factor causing the rise of abrasion resistant of nitridated pieces.

Methodology

Chemical compositions of in alloys are presented in table 1.

Table 1. chemical compostions of tested samples.

Sample	٪C	٪Si	٪Mn	٪P	٪S	٪Cr	٪Mo	٪Ni
(CK45 steel)	0.42-0.50	≤0.40	0.5-0.8	≤0.035	≤0.03	0	0	0
(VCN200 Steel)	0.26-0.34	≤0.40	0.3-0.6	≤0.035	≤0.03	1.8-2.2	0.3-0.5	1.8-2.2

Two cubic Samples (A and B: 27×25×12mm) were prepared. Sample A was identical to Sample C undergoimg plasma nitriding process. In order to performing the test, all samples were eroded by sand paper (number 80 to 800). Some samples of CK45 were nitrided. Samples C were underwent superficial preparation and rinsed and were cleaned with acetone After drying, Samples C were kept in desiccators before transferring into the plasma nitration instrument. Then, under a heating cycle presented in table 2, Samples C were nitrated through plasma method. Samples were analyzed by phase determination (XRD) and (SEM) studies.

Tables 2. Plasma nitriding cycle for CK45 steel samples.

Operation duration (hr)	Operation temperature	Gas composition (N2/H2)
12	570-580	3/1

Then nitrated samples (CK 45 and VCN 200) were undergone abrasion test according to ASTM G 105 standard (figure 1). Slurries presented in the filtration unit of the Sarcheshmeh Copper Complex, with three concentration rate of 60% , 65% and 70% of solid particles were used for the tests. Solid particles presented in the slurry included the copper concentrates and the PH of slurries was in the range of 10 to 12(basic PH).

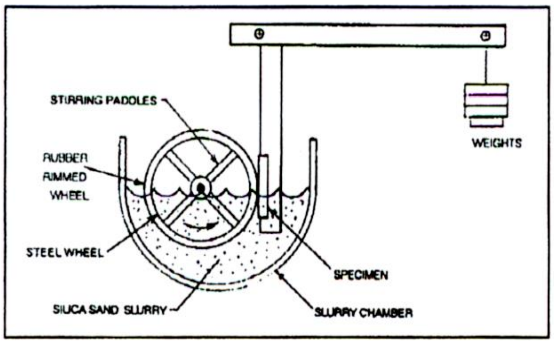

Figure 1. Scratching abrasion test apperatus according to ASTM – G105 Standard.

The composition of the slurry solid particles is presented in table 3. The hardnesses of these particles was around 1200 Vickers with the dimensions of smaller than 210 microns. Selection of such slurries was for simulating operation conditions of the agitator shaft of the filter used in Sarcheshmeh Copper Complex which operates at room temperature. In this test, the sample to be tasted is placed in the holder of the apparatus and is pressed to the rubber wheel by means of a lever with a force of 222 N, and rounding of the tire wheel with a speed of 300 m/min in presence of slurry, provides conditions for abrasion of the Specimen to take place. Three specimen were gathered from each sample and all three specimen were tested separately and weight loss of samples in different distances were measured by means of an electronic weight instrument with an accuracy of ±0.1 mg and the average result of abrasion test for each specimen was reported as abrasion rate. Abrasion rate of specimen also was obtained through potentio- dynamic method.

Table 3. Solid particles composition presenting in the abrasire slurry used for performance of scratching abrasion test.

Cu%	Fe%	S%	Cao%	Sio2%	Al2 o3 %	Mo%
۱۰.۲۹	۲۶.۱۱	۳۰.۶۹	۰.۲۶	۵	۲.۹۰	۰.۰۹۷

Results and Discussions

Analyzing the nitrided samples shows that there are two layers of coating formed on the surface. As it is shown in figure 2, the thickness of the top layer was about 8 microns. Results from XRD analyses shows the formation of nitride phases of Fe_4N and Fe_3N on the surface. Due to performing plasma operations, hardness enhances in the surface. The hardness of the nitrided sample is about 640 Vickers.

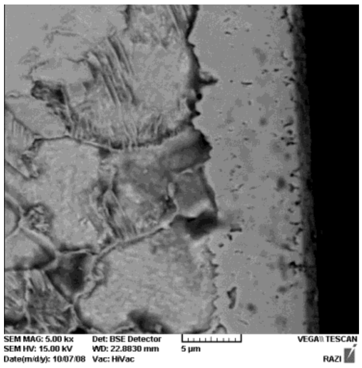

Figure 2. SEM Cross sectional photo of the nitrided layer.

Figure 3 determines that this hardness is penetrated into the depth of the piece, where penetration has occurred.

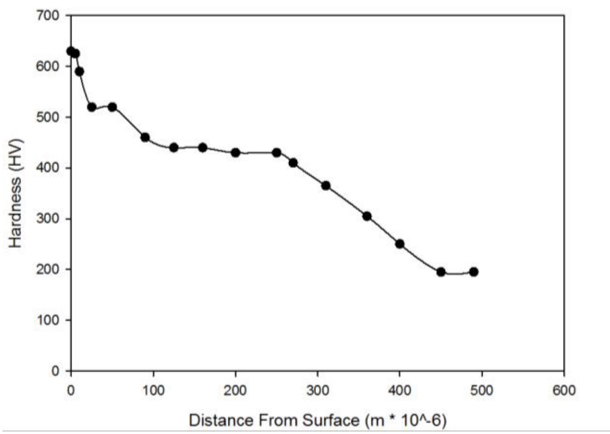

Figure 3. Variations of hardness of nitrided sample with respect to distance from the surface.

Figure 4 defines the linear analysis from the surface down to the depth of nitrided sample confirming the penetration of nitrogen to some depth of the piece. Samples A and B (without plasma operation) have the hardness rates of of 199 and 350 Vickers, respectively.

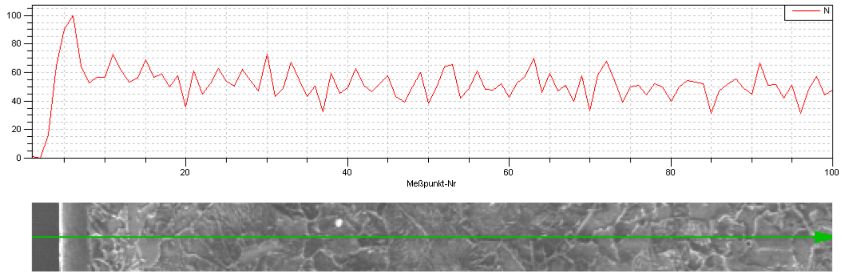

Figure 4. Linear analysis from the surface to the depth, of the nitrided sample.

Figure 5, 6 and 7 demonstrate the effect of slurry concentration on abrasion corrosion behavior of the samples. As is seen, nitrided CK45 sample, shows the least abrasion corrosion rate in all concentrations with a linear behavior. Other samples have a higher abrasion rate and by elapsing of a distance of 500 to 1000 m, weight loss of the samples increases and then reaches to a stable linear state. This happens because the particles present in the slurry change their shapes to spheres and steady hardness of these samples is continued upto the core of the piece. Sphering of solid particles presented in the slurry is due to contacting of these particles with each other and also due to contacting with reservoir walls and rubber wheel along the test process. The density of the abrasive particles is the most important factor affecting scratching abrasion of the slurry (Rossi et al, 2006). So, as the particles with the same sharp edges have higher densities, the energy released from their collusion will be higher and so causes deformation or cutting off of the particles from the surface be cause of impact (MacKenzie,2008). Comparison of figures 5 to 7, shows that, in all three samples, increasing the concentration of the slurry, will lead to rising weight loss of the samples. Misra and Finnie (ASM handbook Vol.18, 1992) observed that in scratching abrasion test of simple carbon steel (AISI 1020) with silisium carbide particles, by increasing the length of abrasion path, weight loss of the samples increases almost linearly. Results from figures 5 to 7 confirm this for all samples and concentrations.

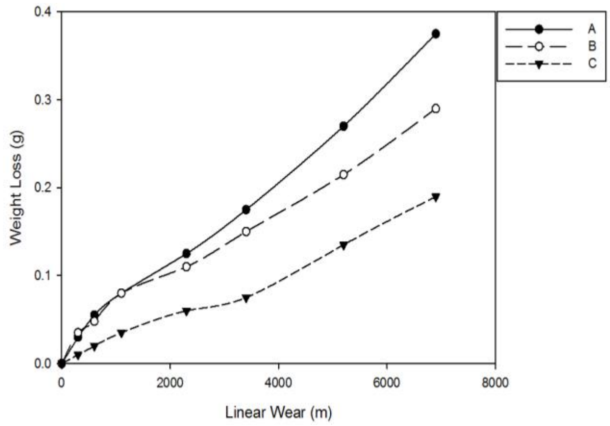

Figure 5. plot of weight loss of samples in the slurry with 60 weight percent concentration of solid particles.

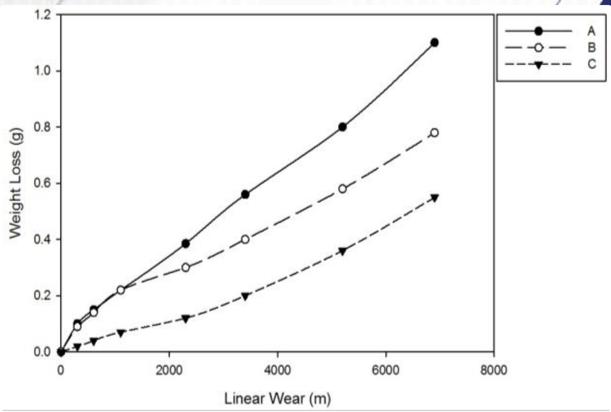

Figure 6. plot of weight loss of samples in the slurry with 65 weight percent concentration of solid particles.

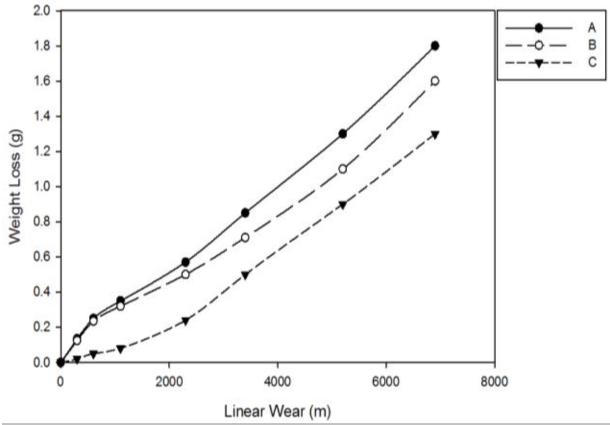

Figure 7. plot of weight loss of samples in the slurry with 70weight percent concentration of solid particles.

In figures 8 to 10, morphology of the surface affected by abrasion corrosion in seen. Depth, size and number of formed cavities on B (VCN200) Samples are smaller and less than (CK45) A Samples. This is because of existence of martenzitian micro structures for VCN200 steel inhibiting formation of long saw arves (ASM handbook Vol.18, 1992). In the case of nitrided samples, it is observed that the surfaces of the samples are worn out steadily by the effect of abrasive agents, and cavities are observed at low quantities and at high concentrations.

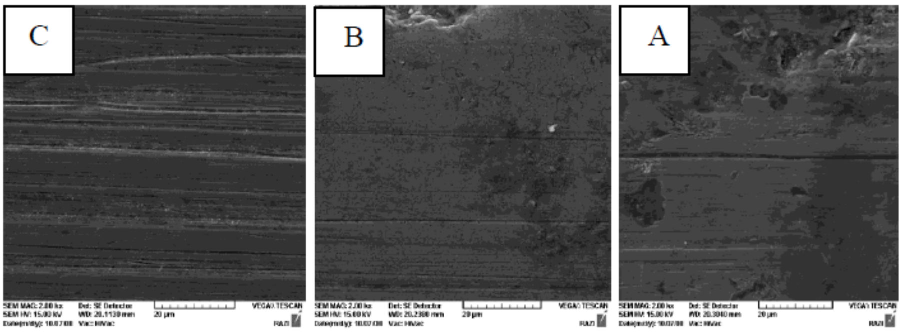

Figure 8. SEM photo from the surfaces of A, B and C samples after abrasional corrosion in the slurry containing 60 weight percent of solid materials.

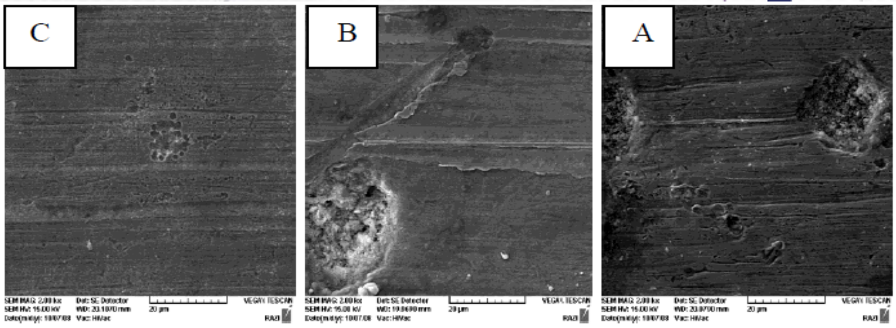

Figure 9. SEM Photo from the surfaces of A , B and C samples after Abrasional corrosion in the slurry contaning 65 weight procent of solid materials.

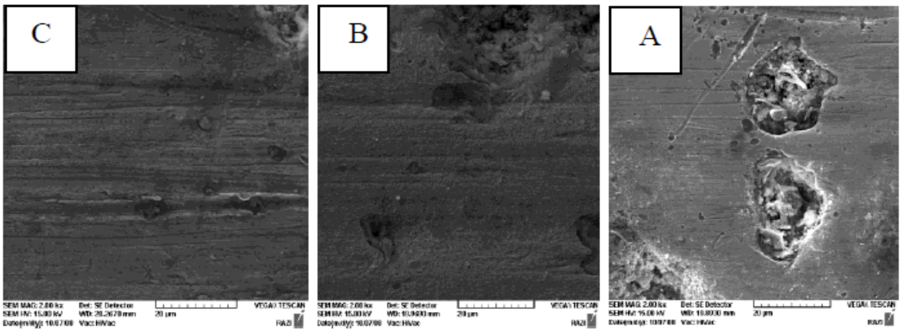

Figure 10. SEM Photo from the surfaces of A, B and C samples after Abrasional corrosion in the slurry contaning 70 weigh percent of solid materials.

These samples demonstrate lower abrasion volume which is caused by formation of combined and penetrated layer on the surface of these samples, which possess a very high hardness and adhesion to the sub layer and the substrate demonstrating less abrasion against abrasive agents (Skakov et al, 2015; Gatey et al, 2016) Several researches has shown that generally, abrasion resistance increases with nitrogen donor process.

According to figure 11, It is determined by polarization studies that the nitrided sample has the highest corrosion resistance with a corrosion current of 225 nA in a passive current limit.

Although VCN200 Sample has the most corrosion potential, its corrosion current is higher than the nitrided sample and lower than CK45 one.

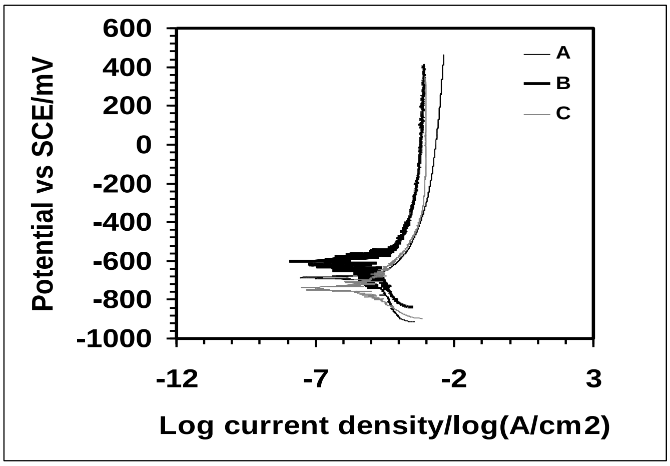

Figure 11. Plot of potentiodynamic for A, B and C samples.

The reason of the lower rate of corrosion of VCN200 Steel with respect to CK45, is the presence of Ni, Mo and Cr elements in the composition of this alloy which enhances corrosion resistance of steels (Cunat, 2004).

Conclusion

1-Nitrated CK45 Steel possess the lowest weight loss and corrosion current at the tested conditions and is the best suited one among the tested alloys.
2-The suggested material (steel VCN200), has higher abrasion and corrosion resistance in comparison to the previous material and is evaluated as being suitable.
3-Layers formed in the nitrid donation process of plasma play an important role in imparting abrasion resistance due to strong adhesion to the substrate.

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