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A STUDY ON THE EROSION CHARACTERISTICS OF THE MICROPULSED PLASMA NITRIDED BARREL OF A RIFLE

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This study evaluates the erosion characteristics of the nitrided barrel of a rifle. The surface of wear sensor was enhanced by micropulsed plasma nitriding and postoxidation technology. Three types of wear sensors were used to compare the effect of surface treatment such as nitriding and postoxidation as well as without surface treatment. The surface of each sensor had an indent pressed by a Vickers microhardness indenter. The wear was measured by the change of depth of the indent. The cross section of the sensor was analyzed by an optical microscope and SEM after firing 400 rounds.

The results show that the porous nitriding and postoxidation of magnetite treated sensor represents the best anti-erosion characteristics in the free flight zone. However, in the center zone, peeling of the oxide layer occurs under the surface of each treated sensor by the tangential cracks.

1. INTRODUCTION

In the case of small arms, it is known that the primary factors in deterioration of the performance of the barrel are the erosion due to high temperature as well as high pressure propellant gas and the scoring caused by the bullet traveling at high speeds. In order to solve the problem of deteriorating performance of the barrel now in use, the free flight zone which is the part of the barrel that is most prone to wear, is treated with hard chrome coatings. The hard chrome coating however has a few problems. The coating degrades thermodynamically in high temperature environments. The coating is subject to erosion and deterioration of the hardness due to micro cracks in the coating layer. The coating thickness is not uniform because the electrical conductivity is not uniform. The friction coefficient is relatively high and the anti-corrosion characteristics are not so good. [1–3] There is the method of depositing the hard chrome coating by a PVD process[4], but there exists a technical problem of using the method in a barrel 5.56 mm in diameter. There is also a method of using a material with better anti-erosion and anti-wear characteristics than the hard chrome coating but it has a problem of high cost. Therefore in this study, to develop a method to replace the hard chrome coating used in the barrel of small arms, we used the nitriding and postoxidation treatment on the surface of the barrel, which has

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good anti-erosion characteristics, using the bipolar micropulsed technology. To assess the improvement in anti-erosion characteristics in the barrel, we used three kinds of specimens such as a barrel without surface treatment and a barrel with nitriding and postoxidation treatment. The erosion by the propellant gas was analyzed and compared among them. We would like to find out which specimen has the best anti-erosion characteristics and to present the best treatment for improving the anti-erosion characteristics of a small arms barrel.

2. EXPERIMENT

2.1 Surface Treatment of Erosion Wear Sensor

In this study we made a wear sensor to monitor the erosion characteristics. The material for the sensor is a Cr-Mo-V alloy used in the barrel of small arms according to the MIL S-115957 standard. The sensor was heat treated at 850°C for 1 hour and then oil quenched, and tempered for 2 hours at 600°C to get the hardness of 26~32 HRc.

Table 1. Preparation for the wear sensor

surface treatment specimen	Nitriding		Oxidation
	Dense	Porous	
A			
DNO	●		●
PNO		●	●

There were 3 kinds of surface treatment for the sensor, which is stated in Table 1, including as-received. Before the surface treatment, the sensor was polished until emery paper #2000 so the surface roughness was 0.2 µm Ra equally.

The surface treatment process is stated in Table 2, and to obtain a porous compound layer, 3% N_2O was added to control the structure of the compound. The equipment used for the nitriding and postoxidation treatment was the plasma nitriding system made by Ruebig in Austria, and the power was 240 kW of the bipolar micropulsed type.

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Table 2. The process of surface treatment

cases			gas pressure (l/hr)				T (°C)	V(s/e) (V)	P (mbar)	Pulse (on/off)	Time (hr)
			Ar	H_2	N_2	N_2O					
Nitriding	porous	sputtering		40	2		570	500/750	0.95		0.5
		nitriding		30	115	5	580	500/550	3		7
	dense	sputtering	10	80	4.5		500	350/680	2.2	80/75	0.5
		nitriding		100	30		525	480/535	3.95	90/95	20
Oxidation			H_2O , 510°C, 2H r								

2.2 Experimental system

Figure 1(a) shows the experiment apparatus to analyze the erosion characteristics by propellant gas. A caliber 5.56 mm barrel and a regular M193 bullet was used. The center zone of the barrel was kept at 260 ~320°C using an externally wrapped heater to get the thermal condition for continuously fired 400 rounds. The temperature of the barrel was measured by inserting the thermocouple 1 mm into the bore. The free flight zone was kept at ambient temperature.

The wear sensor (Fig. 1(b)) was made into a rod type of radius 5.5 mm, and put under surface treatment according to Table 2. Also on the surface of the wear sensor, we made an indent by a micro hardness tester with 1000 gf to measure the wear. The sensors were inserted in the center zone, 27 cm away from the free flight zone and the cartridge chamber. Sealing tape was used to prevent gas leakage. 400 single rounds were fired.

After the firing 400 single rounds, the sensor was analyzed using an optical microscope to determine the anti-erosion characteristics such as preservation of the oxide layer and the nitride-oxide layer, the presence of cracks and their propagation in depth, and the peeling of the surface.

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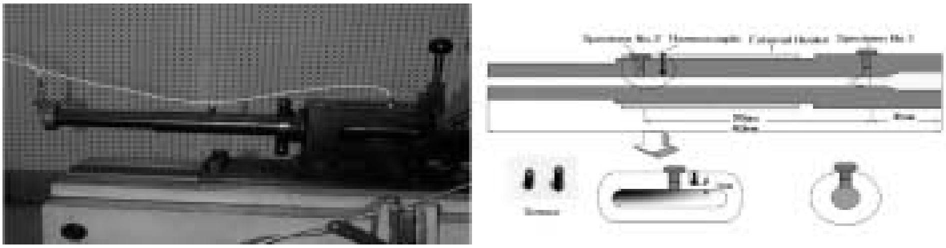

Fig. 1. Experimental system, (a) Test barrel (left), (b) Schematic diagram (right).

The change of the size of the indent on the surface was analyzed to determine the amount of wear according to the different surface treatments. The amount of wear can be determined by the change in size of the indent. The difference in the size of the indent before and after firing allows us to calculate the amount of wear and the wear rate using equation $dw=(D_1-D_2)/2\tan\phi$.[5–7]

3. RESULTS AND DISCUSSION

3.1 Micro-structure analysis

According to the XRD results shown in Figure 2, the oxide layers are all single phased magnetite regardless of the denseness or porousness of the compound structure.

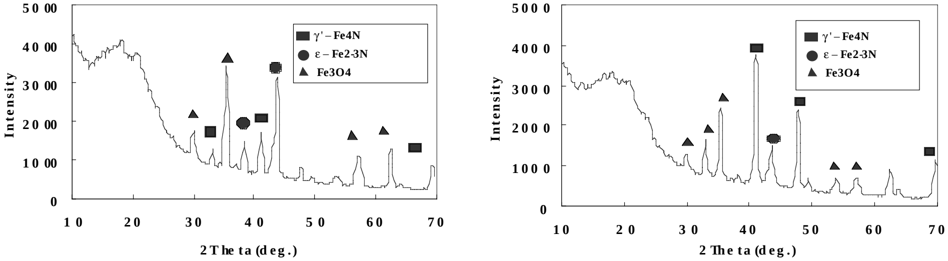

Fig. 2. XRD analysis of each sensor, (a) Dense (left), (b) Porous (right).

Figure 3 shows the result of the SEM analysis taken after nitriding and postoxidation treatment of the barrel material. In both cases magnetite layers are formed on the surface shown in the images as the white layers, and the compound layer is maintained dense or porous. The nitride layer is about 10 μm, and the oxide layer is about 3 μm. Especially in the case of (b), the boundary between the nitride layer and the oxide layer is not as clear as (a). This is because the oxide layer was formed after filling in the porous nitride layer.

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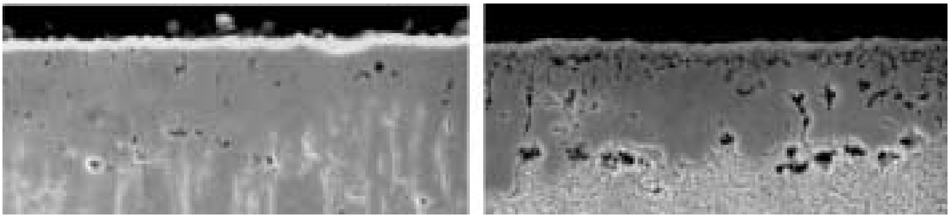

Fig. 3. Cross sectional image of each sensor, (a) Dense (left), (b) Porous (right).

3.2 Erosion characteristics analysis

The change of the size of an indent on the surface of the sensor is analyzed using an optical microscope after the firing every hundred rounds. However the cross section is observed after firing 400 rounds to check the change of the crack propagation and whether the compound layer is preserved or not.

3.2.1 Erosion characteristics according to surface treatment

Figure 4–Figure 6 show the surface and cross section of the sensor in the free flight zone (FFZ) of the barrel according to surface treatment. Figure 4 shows images of the barrel material used in the present. It shows that the size of the indent decreases considerably, and the amount of wear after firing 400 rounds is 2.67 μm. Also as can be seen in the picture, the cracks are propagated into the depth.

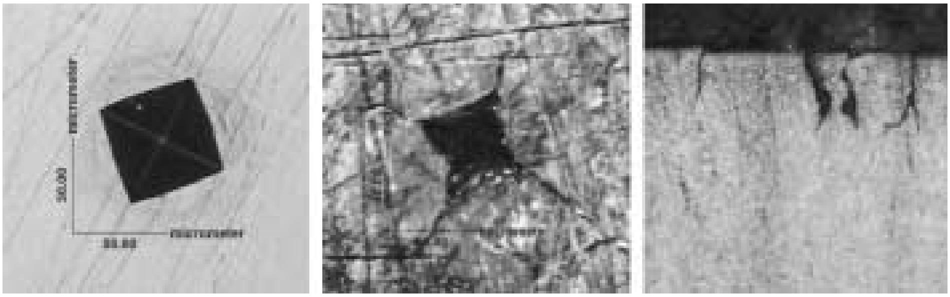

Fig. 4. Surface and cross sectional images of the barrel material (FFZ).

Figure 5 shows the sensor with magnetite oxidation after dense nitriding treatment (DNO). The amount of wear after firing 400 rounds is measured to be 2.06 μm by observing the change in the size of the indent. This is a 23% decrease in the amount of wear compared to the barrel in present use. From the cross section we can see that the cracks developed into the depth, but preservation of the compound layer is satisfactory.

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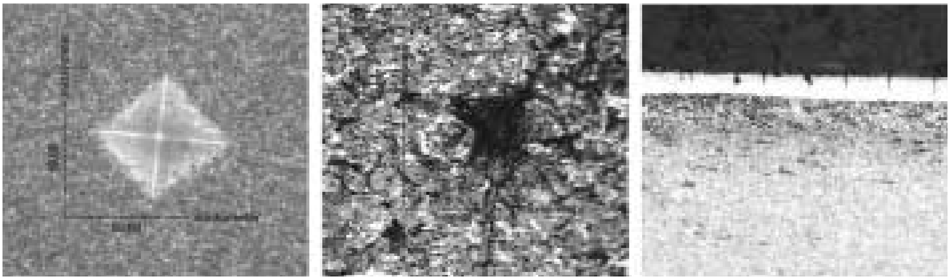

Fig. 5. Surface and cross sectional images of DNO sensor (FFZ).

Figure 6 shows the sensor with magnetite oxidation after porous nitriding treatment (PNO). The change in the size of the indent is difficult to measure acurately because of the porousness, but the amount of wear after firing 400 rounds is about 1.97 μm. This is a 26.1% decrease in the erosion compared to the barrel used in the present. From the cross sectional pictures, we can see that the cracks are shorter compared to the DNO and the preservation of the compound is also excellent.

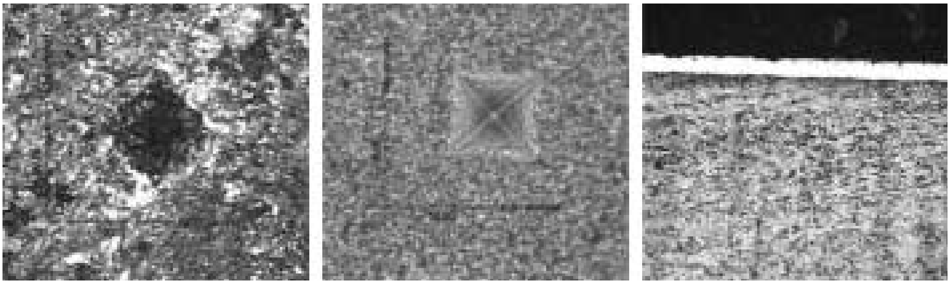

Fig. 6. Surface and cross sectional images of PNO sensor (FFZ).

Figure 7–Figure 9 show the surface and cross section of the sensors from the center zone (CZ) of the barrel. Figure 7 represents the barrel material used in the present and the amount of wear after firing 400 rounds is 1.83 μm. However as opposed to the free flight zone, there isn't any surface crack or crack propagation into the depth.

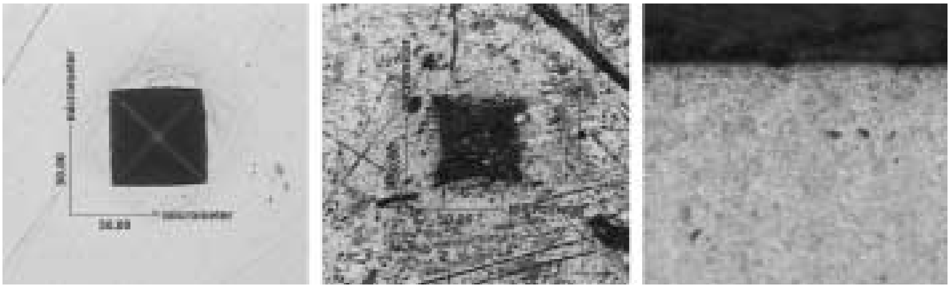

Fig. 7. Surface and cross sectional images of the barrel material (CZ).

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Figure 8 shows the sensor with magnetite oxidation after dense nitriding treatment of the compound layer. According to the cross sectional image, tangential cracks under the surface are more severe than the cracks across the boundary between the nitriding layer and the oxidation layer, thus resulting in the peeling of the oxidation layer. This is the result from the fact that the oxidation layer can not withstand the shear stress from the moving bullet. However the preservation of the core material is satisfactory and there is not any damage to the material.

Figure 9 shows the sensor with magnetite oxidation after pourous nitriding treatment of the compound layer. Analysis of the cross sectional image shows that, like the DNO treated sensor, there exist tangential cracks under the surface resulting in peeling of the oxidation layer, but the compound layer is preserved. In both Figure 8 and Figure 9, it is difficult to analyze the remains of the indent. However, roughly analyzed, the anti-erosion characteristics are improved compared to the barrel in present use.

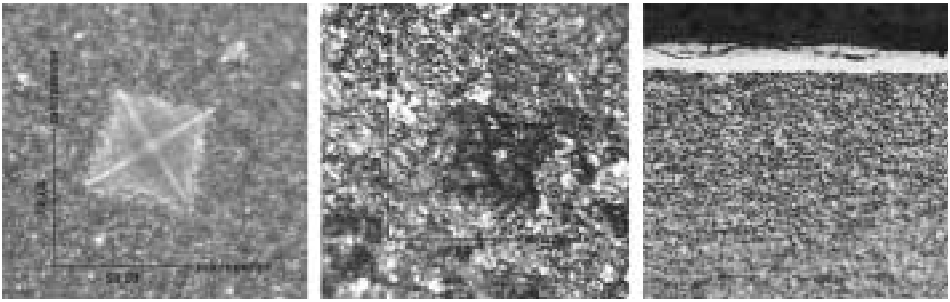

Fig. 8. Surface and cross sectional images of DNO sensor (CZ).

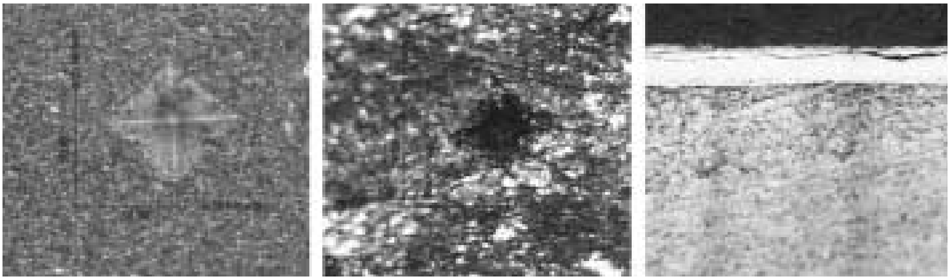

Fig. 9. Surface and cross sectional images of PNO sensor (CZ).

3.2.2 Measurement of the erosion from the propellant gas

Before the firing experiment a micro hardness tester was used to make indents on the surface of each sensor. The amount of wear is calculated by computing the difference of the depth of each indent by measuring the change of diameter of each indent after firing 200 rounds, and after firing 400 rounds. The results are shown in Figure 10. They show graphically the amount of wear in the free flight zone and in the center zone. As shown in the graph, the amount of wear in each sensor increases more or less linearly as a function

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of rounds fired. In the free flight zone, the PNO treated sensor shows the best anti-erosion characteristics with 1.98 µm of wear. Also, in the center zone, the PNO treated sensor shows the best anti-erosion characteristics with 1.22 µm of wear. Comparing the amount of wear in the free flight zone and the center zone, it is clear that the amount of wear is larger in the free flight zone. This shows that erosion resulting from the propellant gas is larger in the free flight zone compared with the center zone. This result seems natural since the pressure in the free flight zone is about double that of the center zone.

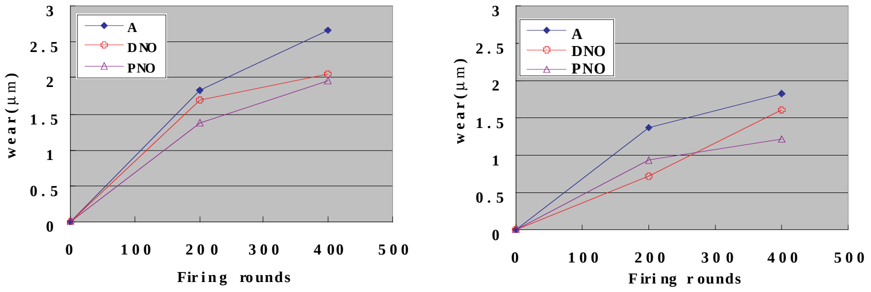

Fig. 10. The amount of wear of each sensor, (a) Free flight zone, (b) Center zone.

4. CONCLUSIONS

The surface of wear sensor was put under nitriding and postoxidation treatment after controlling the compound layer densely or porously using the micropulsed plasma nitriding technology. The sensor was inserted into the free flight zone and the center zone. The erosion characteristics by the propellant gas were measured and the following conclusions were obtained.

1) In the free flight zone, oxidation after porous nitriding treatment shows the best anti-erosion characteristics and the preservation status of the compound layer.
2) In the center zone of the barrel, there are no big differences in the anti-erosion characteristics for the different surface treatments. However, there is peeling of the oxide layer by tangential cracks under the surface resulting from shear stress.
3) Comparing the environment between the free flight zone and the center zone of the barrel, the pressure from the propellant gas is the dominant factor in determining the erosion characteristics.
4) Regardless of the surface treatment, the wear increases linearly as a function of the rounds fired.
5) The peeling of the oxide layer which occurs in the center zone of the barrel, needs to be studied further for validating the micropulsed plasma nitriding technology.

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