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RESEARCH ARTICLE

Electrodeposition of hard chromium on the interior surface of infantry rifle barrels: an experimental investigation

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Abstract

The objective of this study was to enhance the properties of the inner surface of a rifle barrel. The substrate utilized in this investigation was produced through the cold forging technique using 42CrMo4 material, measuring 260 mm in length and 5.56 mm in diameter. Electrolytic hard chromium plating was employed to create a durable metal layer on the inner surface of the substrate. A peristaltic pump was utilized to eliminate gases, such as hydrogen and oxygen, which evolved at the cathode and anode during the process. An anode material comprising a steel rod coated with a 93% Pb-7% Sn alloy, possessing a diameter of 2.35 mm, was employed in the coating experiments. Vickers hardness testing was performed to measure the hardness of both the substrate and the coating layer. The coating thickness ranged approximately between 23 µm to 30 µm. Hardness analysis conducted at various points indicated a proportional decline in coating microhardness with increasing coating thickness. Following the electrolytic hard chrome plating process, the inner surface hardness of the barrel reached approximately 1143 HV0.025.

1. Introduction

Infantry rifles are engineering products with a large global commercial market. These products, which are used by the security and law enforcement forces of various countries, have a certain lifespan as with all engineering products. One of the critical components of infantry rifles that determine their lifespan is the barrel 1. The inner parts of the barrels, in other words the rifling surfaces, are under thermal, chemical and mechanical effects due to their role in infantry rifle systems 2. Due to corrosion and abrasion caused by the aforementioned effects, material loss occurs on the rifling surfaces of the barrels and the accuracy performance and lifetime of the barrels decrease 3. In order to increase the service life of barrels, two methods come to the forefront as the use of materials that are more resistant to the thermal, chemical and mechanical effects that occur during the use of these products in the production of the weapon system or the application of coating applications 4.

Some examples of different materials used to increase the service life of barrels are ceramic matrix/metal matrix composite 5, cobalt-based alloy 6, and Si_3N_4 7. Among these materials, composites are not widely used in the production of barrels due to the problems that may arise from the differences in properties such as elasticity and thermal expansion coefficient between the matrix and reinforcement, cobalt-based alloy cost and Si_3N_4 cost and poor production capability. Due to these limitations, low alloy steel is widely used in barrel production.

On the other hand, some of the surface treatments that can be used to increase the life of barrels made of low alloy steel can be listed as follows: physical vapor deposition, chemical vapor deposition explosive bonding, thermal spray, electrolytic hard chrome plating 8. Among these methods, chemical vapor deposition, thermal spray, explosive bonding, and physical vapor deposition have not gained widespread use due to the undesirable metallurgical changes in low-alloy steel material due to the relatively high temperatures at which they are carried out, and due to the problems encountered in the application of these methods to the inner parts of barrels with an inner diameter of 5.56 mm and 7.62 mm. Therefore, electrolytic hard chrome plating is widely used in the tribological improvement of the rifling surfaces of infantry rifle barrels due to its hardness above 1000 HV, chemical inertness and ease of application 14.

In this study, it was aimed to improve the rifling surface of a 5.56 mm inner diameter infantry rifle barrel produced by cold forging method from 42CrMo4 low alloy steel material by electrolytic hard chrome plating method. In this context, the inner surface of the barrel was electrolytically hard chromium plated by forced circulation method, and the thickness and microhardness distribution of the obtained coating along the length of the barrel was characterized.

2. Materials and Methods

The chemical composition of 42CrMo4 low alloy steel material supplied from ABS- Acciaierie Bertoli Safau S.p.A. (Italy) was verified by optical emission spectrography (Arun Technology, Artus 8, UK). The data obtained as a result of the test are compiled in Table 2. For the determination of the initial microhardness of the test material, a square specimen with a cross section of 10 mm x 10 mm and a height of 10 mm was cut and mounted. Sanding was carried out using 320, 600 and 1200 sandpapers. Polishing was carried out in two stages using 6 µm and 1 µm sized diamond abrasive particle suspension. The sample was etched with 2% nital solution. Vickers microhardness measurement (EMCOTEST DuraScan G5,

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Austria) was performed with a load of 0.025 kg using Vickers indenter tip. A barrel of 260 mm in length and 5.56 mm in diameter, produced by the cold forging method from the validated material.

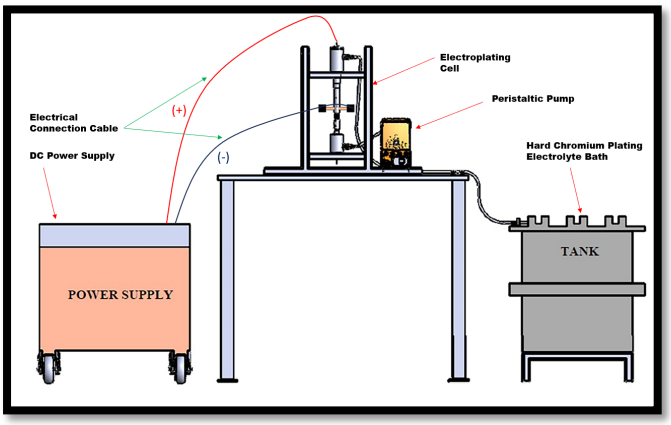

Figure 1. Electrolytic hard chromium plating setup

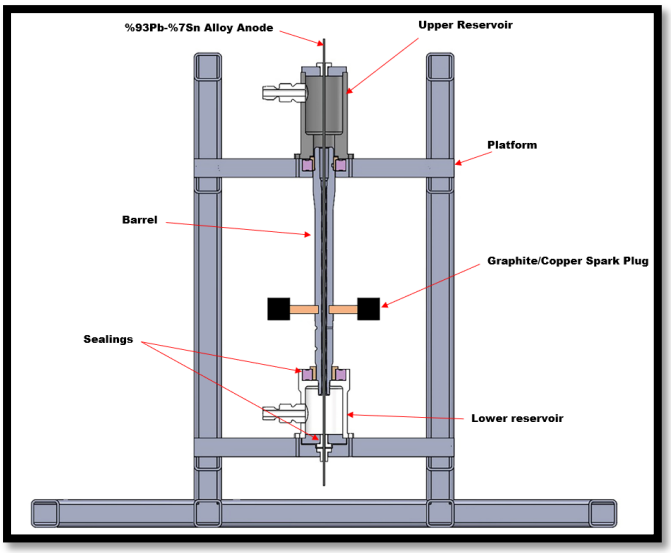

Figure 2. Electroplating cell

The inner surface of the barrel was electrolytically hard chrome plated after hot alkaline degreasing and electrolytic chromic acid etching. The electrolytic chromic acid etching and electrolytic hard chrome plating processes were carried out using chromic acid, sulfuric acid and proprietary additives in the plating setup shown in Figure 1 and Figure 2. The process parameters used in electrolytic chromic acid etching and electrolytic hard chrome plating processes are shown in

Table ***1***.

In the hard chrome plating process, a 93% Pb-7% Sn alloy coated steel wire with a final diameter of 2.35 mm was positioned at the center of the barrel as the anode. In the plating setup, a peristaltic pump (Bimetron, PSA-M-600, Turkey) was used to circulate the electrolyte to remove the oxygen and hydrogen gases formed on the anode and cathode surfaces during plating. Electrical connection to the barrel was carried out with graphite reinforced copper spark plugs. After coating, the barrel was rinsed with pure water and dried. The barrel was immersed in an oil bath to create a protective film layer to protect it until the characterization process.

In order to examine the coating thickness and coating hardness along the length of the barrel, samples were taken from five different areas of the barrel as shown in Figure 3. The samples were mounted for sanding and polishing. Coating thickness measurements of the samples were performed with an Olympus GX-53 metallurgical microscope using Stream Essentials program. Microhardness measurements were performed by applying a 0.025 kg load with a Vickers indenter tip.

Table 1. Process parameters of electroplating.

Parameter	Value
Chromic acid concentration	300 gr/L
Sulfuric acid concentration	3 gr/L
Catalyst concentration	55 mL/L
Temperatıre	55°C
Etching current density	15 A/dm^2
Etching time	5 min
Plating current density	35 A/dm^2
Plating time	30 min
Electrolyte flow rate	700 mL/min

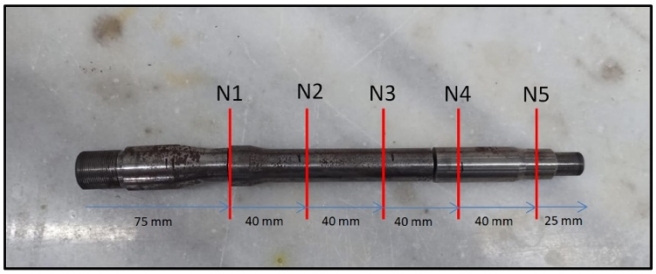

Figure 3. Cross-sectional sampling areas along the barrel length and sample codes

3. Results and Discussion

Initial microhardness of barrel material is shown in Figure 4. As can be seen in Figure 4 barrel materials initial hardness is 299,5±10 $HV_{0,025}$. Micrographs of Vickers microhardness measurements of the hard chromium coating along the length of the barrel rifling surface are shown in Figure 5. The coating thicknesses and coating microhardness variation along the barrel length can be seen in Figure 6 and Figure 7, respectively.

Figure 6 shows that the highest coating microhardness was determined as 1143±18 $HV_{0.025}$ in the sample N5 and the lowest coating microhardness was determined as 986±9 $HV_{0.025}$ in the sample N4. As shown in Figure 7, the lowest coating thickness was 23.38±0,7 µm for sample N5 and the highest coating thickness was 30.10±1,3 µm for sample N4.

Table 2. Chemical composition of supplied low alloy 42CrMo4 steel (in wt%) 15.

Element	C	Si	Mn	P	S	Cr	Mo	Fe
DIN EN 10083-3 – 42CrMo4	0,38-0,45	Max. 0,40	0,60-0,90	Max. 0,025	Max. 0,035	0,90-1,20	0,15-0,30	Balance
Measured Values	0,45	0,14	0,57	0,003	0,005	1,12	0,17	Balance

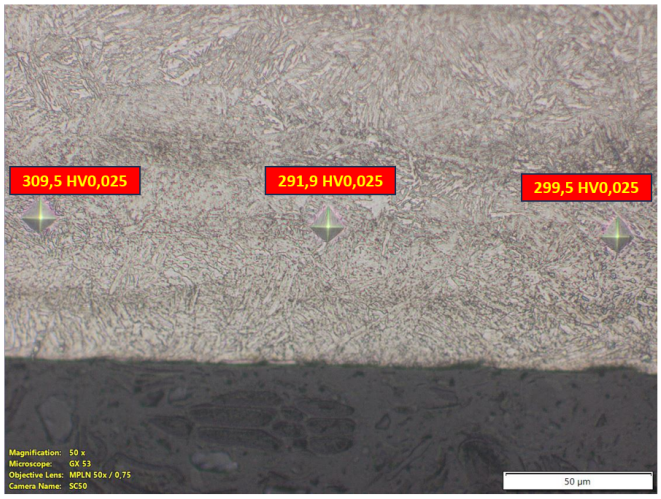

Figure 4. Initial microhardness of low alloy 42CrMo4 steel barrel material

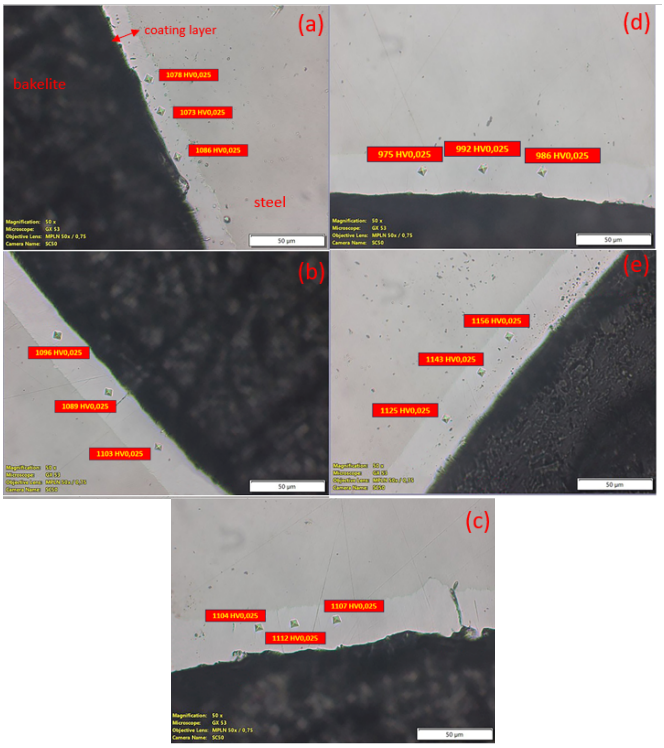

Figure 5. Microhardness measurements along the barrel length; (a) N1, (b) N2, (c) N3, (d) N4, (e) N5 sample

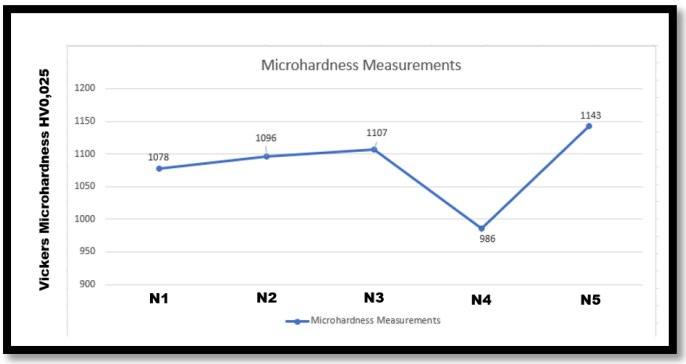

Figure 6. Coating microhardness distribution along the barrel length

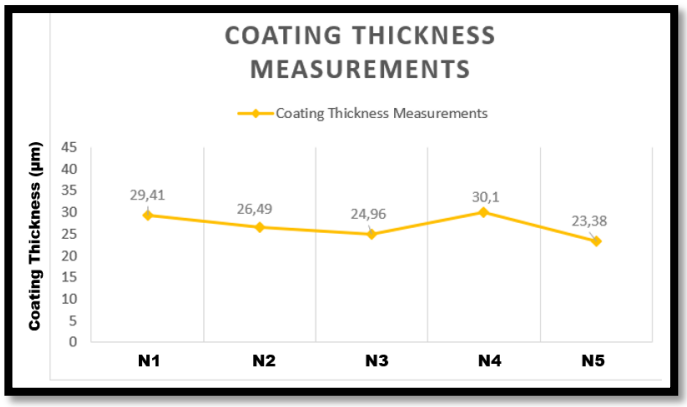

Figure 7. Coating thickness variation along the barrel length

As can be seen in Figure 6 and Figure 7, the coating microhardness value decreases with the increase in coating thickness. As stated by Schlesinger and Paunovic, in electrolytic hard chromium plating, the coating rate increases by keeping the current density constant and decreasing the temperature 16. With the increase in the coating speed, the coating thickness also increases. As the electrolyte enters the inner surface of the barrel from the N5 region, the temperature decreases as it moves towards the N1 region. Therefore, there is an increase in the coating thickness from the N5 region to the N1 region.

As a result of their study, Wahl and Gebauer revealed that at constant current density, the coating microhardness reaches a peak value in a certain temperature range and a decrease in hardness occurs below or above this range 17. Therefore, a decrease in the microhardness values observed due to the cooling that occurred in the movement of the electrolyte from the N5 region to the N1 region.

In the microhardness and coating thickness measurements, the N4 region acts contrary to the general behavior. The reason for this can be interpreted as the electrical connection to the barrel was made from this region. Regional overheating that may occur due to electrical contact is among the factors affecting coating microhardness and thickness.

4. Conclusions

The barrel inner surface hardness, which was initially 299.5±10 $HV_{0.025}$, was increased to between 986±9 $HV_{0.025}$ and 1143±18 $HV_{0.025}$ by electrolytic hard chromium plating method by forming a hard chromium layer between 23.38±0,7 µm and 30.10±1,3 µm along the length of the barrel. The coating layer increased the resistance of the inner surface of the barrel against thermal, chemical and mechanical effects. A decrease in the coating microhardness and an increase in the coating thickness were observed due to the cooling of the electrolyte in the direction along the barrel length. The N4 region is contrary to the general trend of the results. This is due to the fact that the cathode electrical connection was carried out from this region.

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