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DOI: 10.21278/TOF.41102
ISSN 1333-1124
eISSN 1849-1391

ABRASION RESISTANCE OF SURFACE-MODIFIED STEELS USED FOR ARTILLERY WEAPON BARRELS

Summary

A barrel is one of the most tribologically and thermally loaded parts of artillery weapons. The influence of the salt bath nitrocarburizing and hard-chrome plating of three steels used for artillery barrels on their abrasion resistance is studied in this paper. The tested steels are 42CrMo4, 30CrNiMo8, and 36CrNiMo4 in the initial quenched and tempered state. The test results from the "dry sand/rubber wheel" method, after 700 m of wear path, showed that the hard-chrome plating of 42CrMo4 and 30CrNiMo8 steels improved their abrasion resistance. In addition, reduced abrasive wear of 42CrMo4 steel samples was also achieved by nitrocarburizing. Hard chrome-plated samples exhibited good wear resistance due to their greater hardness and bigger thickness of the compound zone in comparison with that obtained on nitrocarburized samples.

Key words: *abrasive wear, 42CrMo4, 30CrNiMo8, 36CrNiMo4, hard-chrome plating, nitrocarburizing*

1. Introduction

A barrel is the most loaded and worn part of an artillery weapon exposed to intensive wear, corrosion, mechanical and thermal loads during its service life. High flame temperature of propellants may produce combustion gasses at temperatures as high as 3700 K. Peak gas pressure may reach up to 700 MPa. The peak bore temperature of a gun may reach up to 1800 K a few milliseconds after it is fired [1, 2]. The firing process has a very strong dynamic effect on the weapon parts: most directly on the barrel, but also on the other weapon parts like the breechblock parts, the breech piece, and the recoil mechanism. A combination of wear and degradation processes affects these parts, particularly the processes of erosion, abrasion, adhesion, tribo-corrosion, together with the mechanical and thermal fatigue processes. The weapon barrel is exposed simultaneously to all previously mentioned wear and fatigue mechanisms [3]. The wear of barrel has an impact on the weapon ballistic parameters while the wear of other parts causes difficulties in the weapon function. Therefore, high wear resistance and good thermal stability of the artillery weapon barrel are particularly important for its performance and service life [4]. The standard wear resistance of these parts can be obtained by an appropriate selection of the chemical composition of the gun barrel steel combined with the selection of an optimal heat treatment procedure [5, 6] and the surface finish quality [7]. A further increase in the wear resistance and resistance to fatigue can be achieved by using the methods of surface modification and coating, e.g. by using the hard-chrome plating or nitrocarburizing processes [8].

The paper describes the procedure and compares the results of abrasive wear tests carried out on the samples made from the three grades of hardened and tempered steels, additionally surface-protected by hard-chrome plating or salt bath nitrocarburizing.

2. Experiments

The chemical composition of the three steels, i.e. 42CrMo4, 30CrNiMo8, and 36CrNiMo4, used in testing is shown in Table 1. These steels are commonly applied in the production of weapon parts. The dimensions and shape of a sample used for abrasive wear tests are shown in Fig. 1

Table 1 Chemical composition of samples

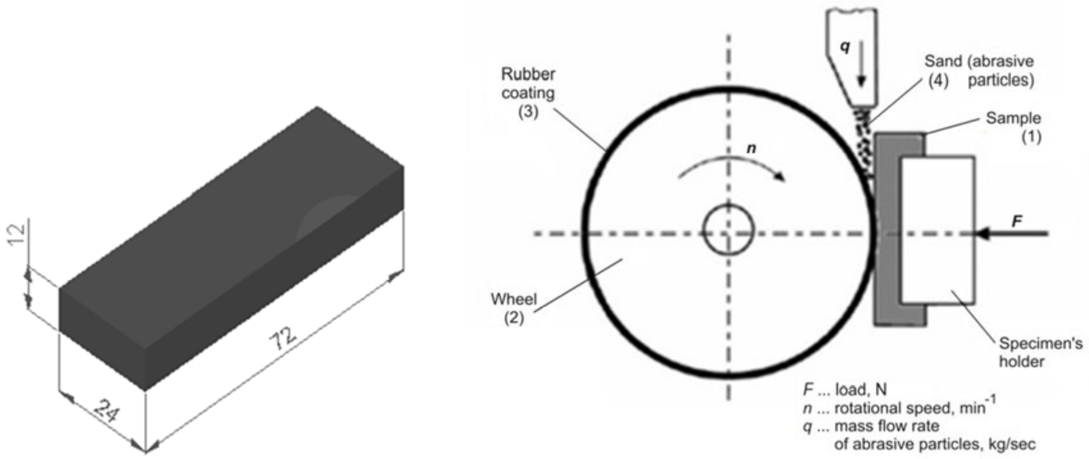
Steel grade	Chemical composition wt. %					
	C	Si	Mn	Cr	Ni	Mo
42CrMo4	0.41	0.20	0.75	1.05	-	0.23
30CrNiMo8	0.290	0.28	0.37	1.94	1.96	0.37
36CrNiMo4	0.395	0.26	0.69	0.80	0.67	0.19

The same heat treatment was carried out on all the samples. They were austenitised at 860°C for one hour and after that quenched in an oil bath at room temperature. After quenching, samples were tempered at 600°C for two hours, and then cooled in still air. The same hardness of 32 ± 2 HRC of all three steels was obtained in the tempered condition. The test plan with the number of samples made from individual tempered steel grades is listed in Table 2. An aggregate of four tempered samples of each material was nitrocarburized with the TENIFER process at 580°C for four hours and subsequently cooled in quenching oil. A similar aggregate of four samples made from each steel grade was hard-chrome plated. Hard Chrome plating was carried out in an electrolyte composed of 250 g/l CrO_3 and 2.5 g/l H_2SO_4 with a density of 35 A/dm^2. The electrolyte temperature was in the 45 to 50°C range. After a hard-chrome layer had been formed, a homogenization annealing process was conducted at 200°C/5h in order to remove hydrogen from the coating.

Table 2 Test plan with the number of tested samples per each steel grade

Steel grade	Heat treatment state	Number of manufactured and tested samples per each steel grade
42CrMo4	Quenched and tempered (Q+T)	2
30CrNiMo8	(Q+T) + nitrocarburized by the TENIFER process	4
36CrNiMo4	(Q+T) + hard-chrome plated	4

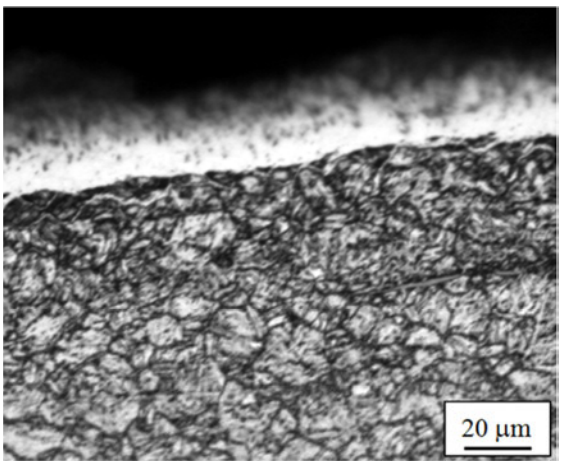
The abrasive wear of samples was investigated by the "dry sand/rubber wheel" method, in accordance with the ASTM G 65-94 standard (procedure E) (Fig. 1b). The samples were loaded with a normal force of 130 N on a total wear path of 700 m. Hardness of the rubber layer was 50 HSA. The diameter of the wheel coated with the rubber layer was 222 mm and the rotational speed was 200 rpm. Mass loss of samples was measured after 70 m, 350 m, and 700 m using a Mettler analytical balance with a measuring accuracy of ± 0.00001 grams. The worn surfaces were analysed using an Olympus light microscope with a CCD camera.



a) b)

Fig. 1 Abrasive wear testing details: a) Sample to be tested b) “rubber wheel / sample;” tribo-system

One sample for each combination of material and surface modification treatment was subsequently cut transversely using a cold procedure and was metallographically prepared. Figure 2 shows the nitrided layer of the tempered and nitrocarburized 36CrNiMo4 steel with a clearly defined compound zone and a homogeneous microstructure of the tempered martensite in the diffusion zone and the core of the sample. The structure of the compound layer is the usual structure obtained from the salt bath nitrocarburizing treatment, with a certain degree of porosity on the top of the compound zone. The effective nitriding hardness depth (NHD) of 0.23+0.05 mm was obtained on the nitrocarburized 36CrNiMo4 steel; the average thickness of the compound zone and the surface hardness were 21 μm and 600 HV1, respectively. Similar effective nitriding depth, compound zone thickness, and surface hardness were obtained with the 30CrNiMo8 steel. The effective nitriding hardness depth on the nitrocarburized 42CrMo4 steel was 0.35 + 0.05 mm. The average thickness of its compound zone was 20 μm while the surface hardness of that steel was 650 HV1.



Etched in 3% NITAL

Fig. 2 Nitrocarburized layer on the quenched and tempered 36CrNiMo4 steel

Fig. 3 shows the hard-chrome layer plated on the quenched and tempered 42CrMo4 steel. The good quality chrome layer is without porosity and cracks. Also, the layer shows good adhesion to the base material. The hard-chrome layer has the thickness from 40 to 45 µm and the surface micro hardness of about 840 HV0.1. A similar layer was produced on the 30CrNiMo8 steel. The hard-chrome layer deposited on the 36CrNiMo4 steel had a similar surface hardness but the thickness was about 40 µm.

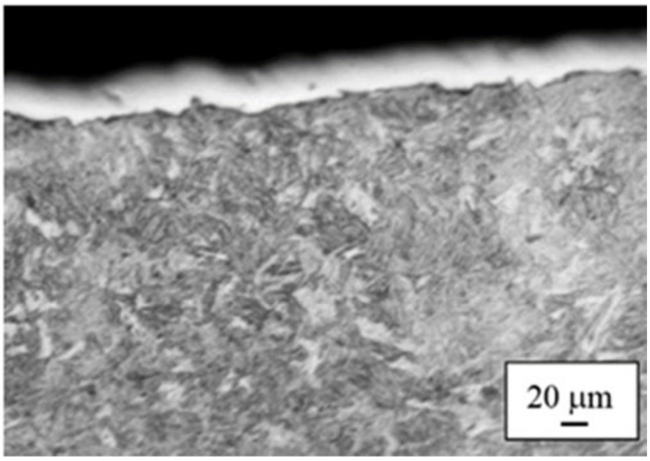


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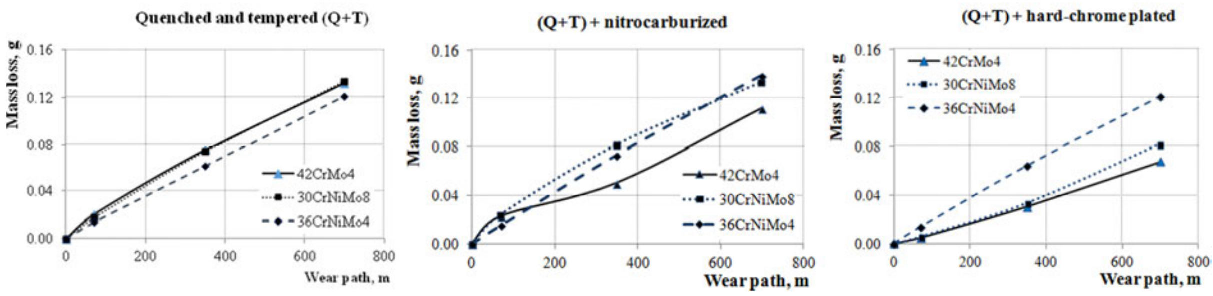
Fig. 3 Hard-chrome layer on the quenched and tempered 42CrMo4 steel

3. Results and discussion

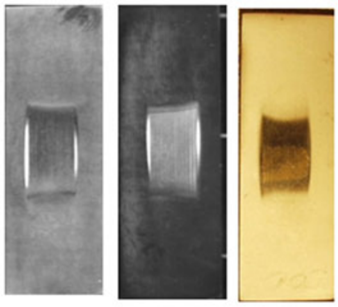
Fig. 4 shows the mass loss of all the samples tested on a wear path of 700 m during the wear testing with the "dry sand/rubber wheel" method. The diagrams in Fig. 4 show the average mass loss of the samples in four repeated tests. The values of the measured weight loss for each test case of wear normally deviate by less than 5.0 % from the mean value of the displayed mass loss.



a) b) c)

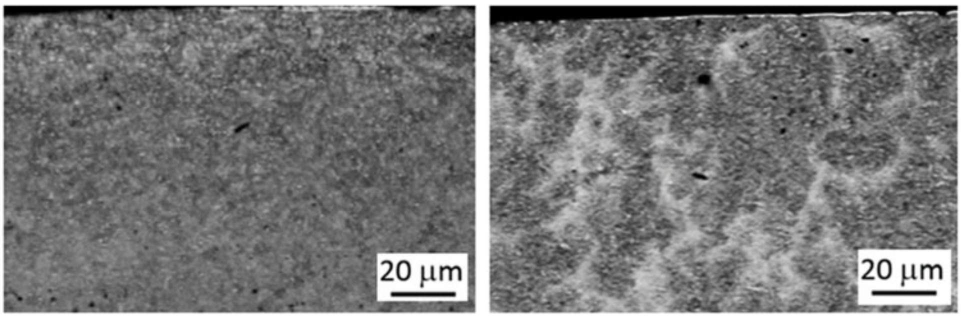
Fig. 4 Mass loss of samples during the testing of abrasive wear by the "dry sand/rubber wheel" method: a) sample with uncoated surface; b) sample with nitro carburized surface; c) sample with hard-chrome plated surface

The representative appearance of worn surface is analysed on the samples made from the 42CrMo4 steel, but a similarly worn surface is obtained on the two other tested steels, i.e. 30CrNiMo8 and 36CrNiMo4. A macroscopic appearance of worn surfaces after a wear path of 350 m is shown in Fig. 5 for all three surface conditions: uncoated surface, nitrocarburized surface, and hard-chrome plated surface. The microstructure of the worn surface layer on the same 350 m long wear path is shown in Fig. 6 for the nitrocarburized and hard-chrome plated samples. The wear path of 350 m is critical for the removal of protective nitride or hard-chrome layers.



a) b) c)

Fig. 5 Worn surfaces after the testing of abrasive wear by the "dry sand/rubber wheel" method on a 350 m long wear path of the samples made from the 42CrMo4 steel in different surface conditions: a) uncoated surface, b) nitrocarburized surface; c) hard-chrome plated surface



a) b)

Fig. 6 Optical micrograph of the surface layer at the wear track after 350 m of wear path on the quenched and tempered 42CrMo4 steel previously protected by:
a) nitrocarburizing in the TENIFER salt bath, b) hard-chrome plating (etched with 3% NITAL)

From the results of wear resistance testing, shown in Figure 4 and 5, the following can be concluded:

The 42CrMo4 and 30CrNiMo8 steels in the quenched and tempered condition showed virtually the same resistance to abrasive wear which was the lowest resistance of all surface conditions (Fig. 4a). The 36CrNiMo4 steel in the quenched and tempered condition showed up to 8% less weight loss compared with the other two steels. The aforementioned slight increase in the abrasion resistance of 36CrNiMo4 steel can be explained by its more uniform microstructure in the hardened and tempered condition (Fig. 2) compared with the microstructure of 42CrMo4 steel (Fig. 3), which shows areas of segregation and martensite grains of unequal sizes.

The nitrocarburized steels 30CrNiMo8 and 36CrNiMo4 showed no significant increase in the abrasion resistance with respect to these steels in the quenched and tempered condition. However, a significant increase in the resistance to abrasive wear of 15%, compared with the quenched and tempered condition, is achieved with the nitrocarburized steel 42CrMo4 (Fig. 4b). Such a result of wear resistance can be explained by the fact that a slightly deeper diffusion zone is achieved in the surface layer of 42CrMo4 steel than in those of 30CrNiMo8 and 36CrNiMo4 steels.

In Fig. 4b, a significantly lower mass loss can be noted in the nitrocarburized 42CrMo4 steel on the wear path section from 70 m to 350 m in relation to the mass loss of the other two steels. This phenomenon is a result of reduced wear of the nitrocarburized layer on the 42CrMo4 steel compared with the wear of the nitrocarburized layer on the other two steels. After the wear path of longer than 350 m, the nitride layer is almost completely removed and then the wear resistance is provided by the diffusion zone and the core of the sample. A partial removal of the nitride layer can be clearly seen after 350 meters of abrasive wear path, as shown in Fig. 6a.

The hard-chrome coating showed an improved wear resistance as a consequence of its greater hardness and a bigger thickness of the compound zone in comparison with the compound zone obtained on nitrocarburized samples. Also, the application of hard-chrome coating significantly increased the abrasion resistance of the 42CrMo4 and 30CrNiMo8 steel samples by 45% to 49% with respect to the uncoated samples (Fig. 4c). On the other hand, the increase in the wear resistance of the hard-chrome coated 36CrNiMo4 steel was almost negligible in comparison with the same, non-coated surface steel grade. These results can be explained by a smaller thickness of the coatings on the 36CrNiMo4 steel and, probably, its weaker adhesion to the surface of the sample. In Fig. 6b, one can see that the hard chrome coating on the 42CrMo4 steel sample is partially removed after the 350 m long wear path. Removal of the coating is evident in the mass loss diagram in Fig. 4c, where one can observe an increase in the slope of mass loss on the 42CrMo4 and 30CrNiMo8 steel samples after the 350 m long wear path.

4. Conclusion

On the basis of tests done on three different steels intended for the manufacture of weapon barrels, a possibility of increasing their resistance to abrasive wear using the procedures of surface modification and coating was confirmed. A significant improvement in abrasion resistance was achieved by the hard-chrome plating of the 42CrMo4 and 30CrNiMo8 steels. A less marked improvement in wear resistance was achieved by nitrocarburizing the 42CrMo4 steel in the TENIFER salt bath.

Analysis of the microstructures of the nitrided layer and the hard-chrome coatings showed the importance of achieving a hard protective layer of uniform thickness and homogeneous microstructure, which provides good wear resistance at room temperature, as well as in the condition of a brief exposure of the samples to the rate of fire and superheat.

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Submitted: 20.7.2016

Accepted: 07.12.2016

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