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Research Article

THE INFLUENCE OF THE CARBURIZING PROCESS ON THE IMPACT-SLIDING WEAR BEHAVIOR OF 14NiCr14 STEEL

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ABSTRACT

Weapons depend largely on the barrel. Gunpowder combustion converts chemical energy into thermal and mechanical energy. Barrels give projectiles initial speed and flight direction, and helical grooves require fast spinning for stability while moving toward the target. Due of barrel exposure to heat, high pressures, gunpowder vapors, and external impacts, this weapon element needs extensive investigation. The study discusses carburizing for surface modification in high-pressure circumstances to improve gun barrel interior line tribology. Carburizing has been detected at a depth of 960 µm from the surface, as revealed by light-optical microscope images. The microhardness test has been performed on the sample's cross section, which has a maximal hardness of 650 ± 10 $HV_{0.05}$ close to the surface and 250 ± 5 $HV_{0.05}$ close to the interface. At room temperature (RT), this study looked at how the carburizing process affects the impact-sliding wear performance of 14NiCr14 steel, which is widely used in the barrel extensions of guns under complex loading conditions. A series of impact-sliding wear experiments were conducted on 10 mm-diameter bearing steel balls made of 52100-grade steel, for a total of 4297 loading cycles. A 2-D contact profilometer and a light optical microscope (LOM) then examined the wear tracks that had formed on the samples. The carburized steel caused a decrease in the wear rate at the impact and sliding zones of the wear track.

Keywords: Barrel extension, Depth of diffusion layer, Surface damage, Surface hardening, Steel.

1. INTRODUCTION

Gun barrels, breech mechanisms, and other sliding mechanisms experience severe wear during shooting and operations. The primary cause of barrel failure is the bore's expansion due to wear. As a result of wear damage, the tactical and technical characteristics of the weapon system, such as shot accuracy, firing range, and muzzle velocity, are diminished, thereby shortening the weapon's lifespan [1]. Some techniques for increasing material wear resistance are supported, such as using wear-resistant materials at the expense of product price, using surface technology, or using lubricants. However, in intense battle conditions, weapons' lubricating ability is restricted. Then, to increase the tribological properties of barrel material, surface technology is mentioned [2]. Barényi and Šandora [3] discuss recent trends in improving the mechanical properties of steels used for sport or army gun barrels, focusing on special conditions like high tensile strength, surface hardness, yield point, and impact value. It also discusses howitzer or cannon barrel production, heat treatment, and the electroslug remelting process for barrel quality improvement.

Since World War II, diffusion surface hardening (DSH) processes have been used to preserve barrels, but there has been renewed, active research in this area over the past decade [4]. The DSH has a hard surface on the outside and a soft, tough core. The enhancement in surface hardness directly contributes to the enhancement of wear resistance, hence leading to an improvement in the longevity of the component. Gas carburizing is a popular surface hardening method with low thermal distortion to enrich the surface layers of steel or other alloys with carbon [5, 6]. According to Arulbrittoraj et al. [7], gas-carburizing surface hardening significantly improves wear resistance at moderate temperatures with a small effect on visibility, indicating its potential for light-duty applications. Recent research has focused primarily on understanding the mechanisms of wear failure and evaluating the performance of known potential carburized steel, as opposed to the development of new coating materials. The ball-on-disc test, the impact test, the fretting wear test, and the abrasive wear test are all well-known ways to study surface failures on different substrates [1, 4, 8]. Li et al. [9] proposed a computational model for surface damage in artillery barrel chambers caused by thermochemical erosion and mechanical wear. It includes three sub-models: collision wear, melting exfoliation, and high-speed jet wear. The model predicts mechanical structures' surface damage based on contact force, temperature distribution, and the effect of melting exfoliation and collision wear on high-speed jet attack angles. But there is no

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good way to test the wear properties of carburized steel when it is subjected to a combination of impact and sliding movements at very high contact stress. Still, there needs to be a way to test the wear caused by repeated impact-sliding movements.

The utilization of carburized 14NiCr14 steel, characterized by a high level of toughness in its core, is deemed appropriate for components subjected to dynamic loading conditions [10]. Industrial materials having high resistance to impact-sliding wear have been studied increasingly. The objective of this study was to find out how long carburized 14NiCr14 steel would last under complex wear conditions. This was done by using an impact-sliding wear tester and increasing the contact loads up to 240 N in one loading cycle. For the barrel extensions of guns made of 14NiCr14 steel, it would be useful to know how well carburized 14NiCr14 steel works under dynamic loading conditions.

2. MATERIAL AND METHOD

20 mm in diameter and 10 mm in height disc samples were cut from commercially available 14NiCr14 steel. The discs were gas-carburized at 900 °C for 5 h, quenched, and then tempered at 300 °C for 1 h. The microstructure of the carburized 14NiCr14 steel was observed with a Nikon Eclipse LV150 Light Optic Microscope (LOM). The hardness measurements were performed on the cross-sections of the untreated and carburized 14NiCr14 steels with a Vickers pyramid indenter using a conventional microhardness tester (Shimadzu HVM) with a load of 50 g and a dwell time of 15 s per the ASTM E384-11 guidelines.

Researchers at Bilecik Seyh Edebali University designed a home-made impact sliding tester, shown in Fig. 1, to evaluate the impact-sliding wear performance of untreated and carburized 14NiCr14 steels. The design of the tester was patented by Chen and Nie [11]. During the experimental procedure, the application of loads onto the surfaces of both untreated and carburized 14NiCr14 steels was regulated by the utilization of a spring and a pneumatic cylinder. Prior to testing, a load cell set the maximum loads that the spring and pneumatic cylinder could provide at 40 N and 240 N, respectively. At ambient temperature (20±5 °C and 40±5% RH), impact-sliding wear tests of untreated and carburized 14NiCr14 steels were conducted against commercially available 10 mm SAE 52100 grade bearing steel balls. Two distinct regions of wear scar (impact and sliding) were examined by a 2-D surface profilometer following the impact-sliding wear test in order to calculate the quantity of wear loss. The wear rates were then calculated by dividing the volumetric wear loss by the number of loading cycles in mm^3/cycle. To ascertain the wear mechanism, LOM examinations were also performed on the worn surfaces of untreated and carburized 14NiCr14 steels. To better understand the wear mechanism in the impact-sliding tests, it was necessary to evaluate the friction coefficient of the sample-counterface system under a sliding motion. In this case, reciprocal sliding tests were carried out under an ambient condition (20±5 °C and 40±5% RH) according to the ASTM G133-05 standard using a 10 mm SAE 52100 steel ball, a sliding speed of 1.9 cm s^{-1}, a sliding distance of 60 m, a track length of 11.5 mm, and a normal load of 30 N.

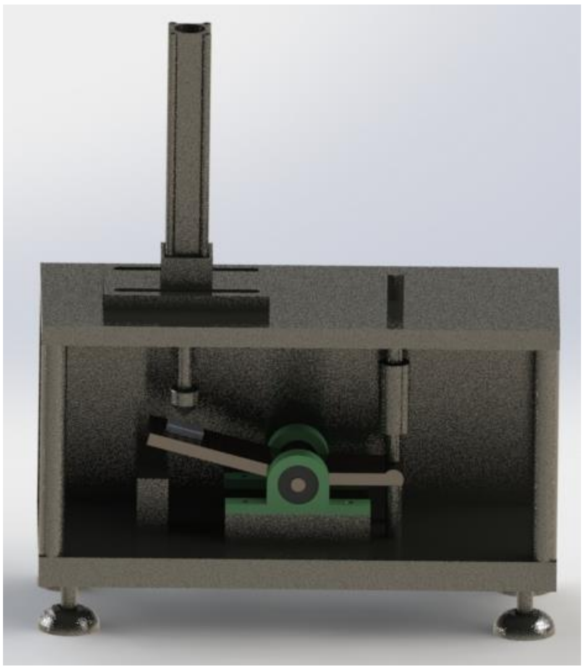

Figure 1. Schematic view of impact-sliding wear tester.

3. RESULTS AND DISCUSSION

Figure 2 exhibits the LOM microstructures of a cross-sectioned gas-carburized sample for different magnifications. After the gas carburization process, tempered martensite and sorbite primarily composed the structure of the steel (Fig. 2). The presence of eutectoid and under-eutectoid compositions in the carburized layer of 14NiCr14 steel is evident.

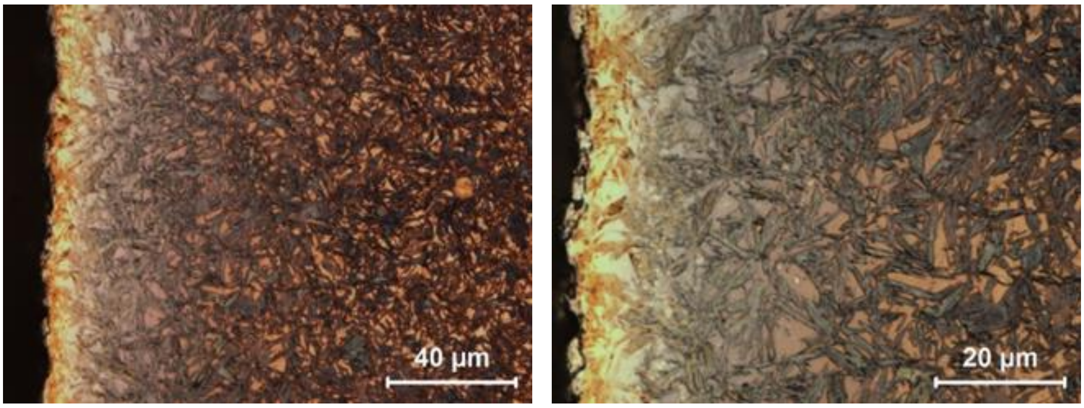

Figure 2. Cross-section LOM microstructures of the carburized 14NiCr14 steel (low and high magnifications).

The hardness values of untreated and carburized 14NiCr14 steels are plotted from the surface to the core in Figure 3. These values are shown in ascending order. The surface of the untreated 14NiCr14 steel has an average hardness of 250 ± 5 $HV_{0.05}$. The carburized 14NiCr14 steel has a maximum surface hardness value of 650 ± 10 $HV_{0.05}$. The carburizing process resulted in a hardness profile that gradually decreased. This drop in hardness demonstrates that the diffusivity of carbon is higher on the surface and gradually decreases toward the core. The surface has a higher concentration of carbon than the core does. Because the value of hardness stays the same after 960 µm have been removed from the surface of carburized steel, this demonstrates that the maximum depth at which carbon diffusion takes place is 960 µm.

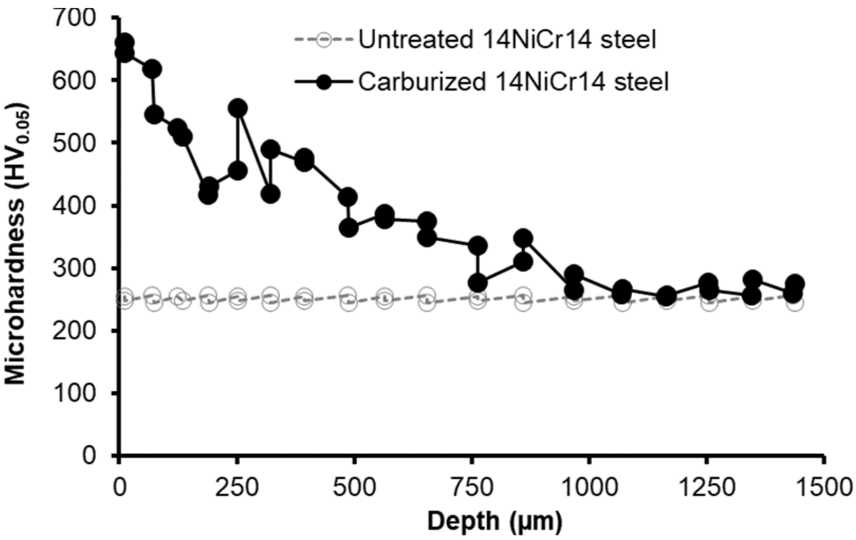

Figure 3. Microhardness values of gas-carburized 14NiCr14 steel from the surface to the core.

Figure 4a illustrates the schematic representation of a wear track, whereas Figs. 4b and c illustrate the 2-D profiles of the impact and sliding zones of the wear tracks for both untreated and carburized 14NiCr14 steels following impact-sliding wear tests. For untreated 14NiCr14 steel, the impact zone has greater depth and width than the sliding zone. However, the gas carburization process imposed shallower and narrower wear tracks in both impact and sliding zones. In the case of carburized 14NiCr14 steel, the depth of the wear track formed by the steel ball in both impact and sliding zones is less than the depth of the carburized layer (960 µm). High-case depth and surface hardness steels are more wear-resistant [12]. The relatively soft, untreated 14NiCr14 steel was more likely to yield under high cyclic loading conditions. The system's pile-up zones [13] indicated material transfer rather than wear loss. Additionally, pile-up formations were observed in the edges of the impact and sliding zones, indicating that plastic deformation played a role in the progression of wear for untreated 14NiCr14 steel, whereas the carburized layer had a much higher hardness and provided better load support; thus, very limited damage could be observed on carburized 14NiCr14 steel, and pile-up zones were not obvious after the test.

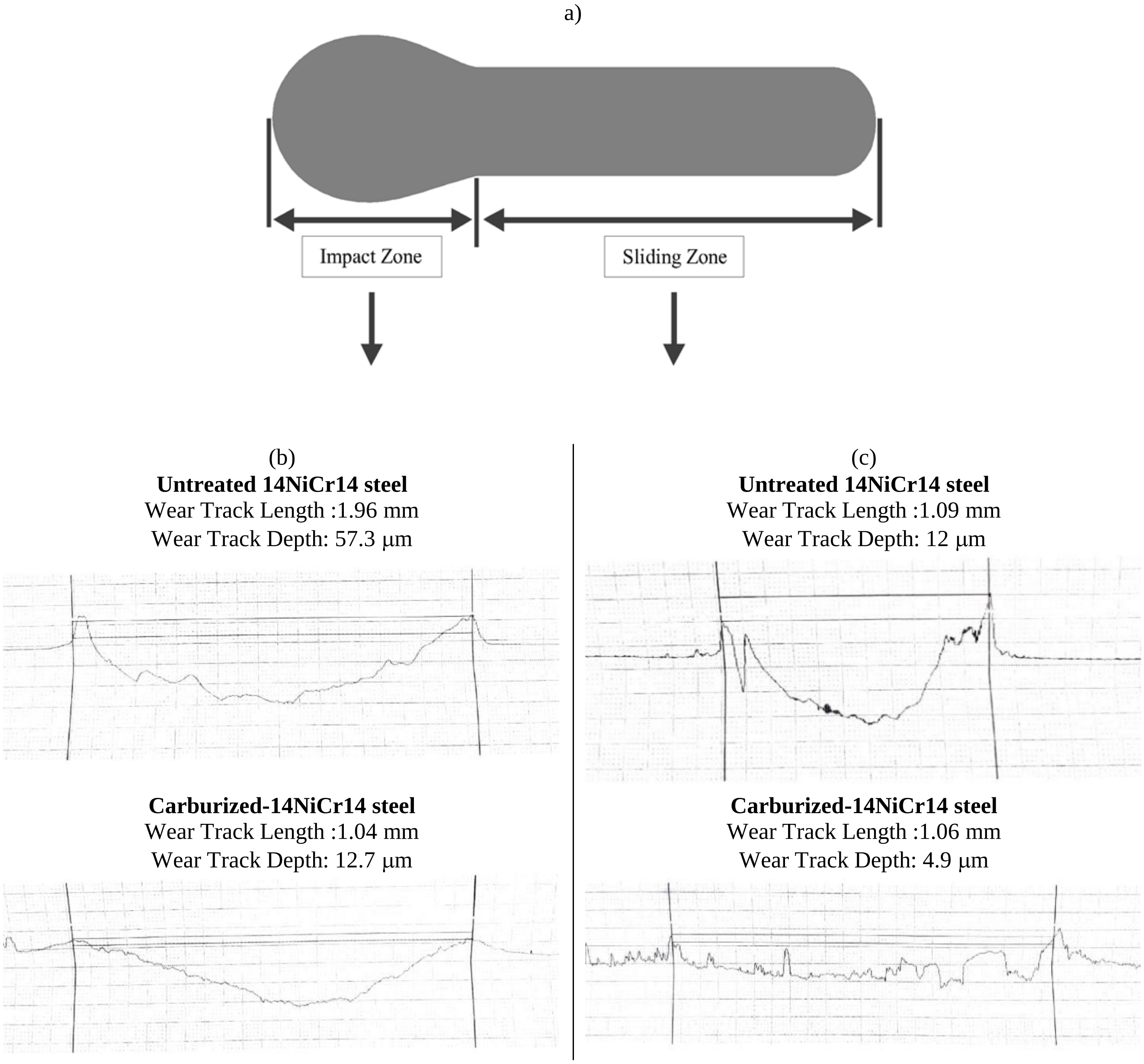

Figure 4. (a) A schematic drawing of the wear track that was made on the samples' surfaces. After impact-sliding wear tests, 2-D profiles of the untreated and carburized 14NiCr14 steels' impact (b) and sliding (c) zones.

Figure 5 depicts the wear rates of the samples' impact and sliding zones. It should be noted that gas carburization reduced the wear rate of the impact zone by 87%, while only 37% of the wear rate of the sliding zone was reduced. Gas carburization, on the other hand, reduced the total wear rate by 81%.

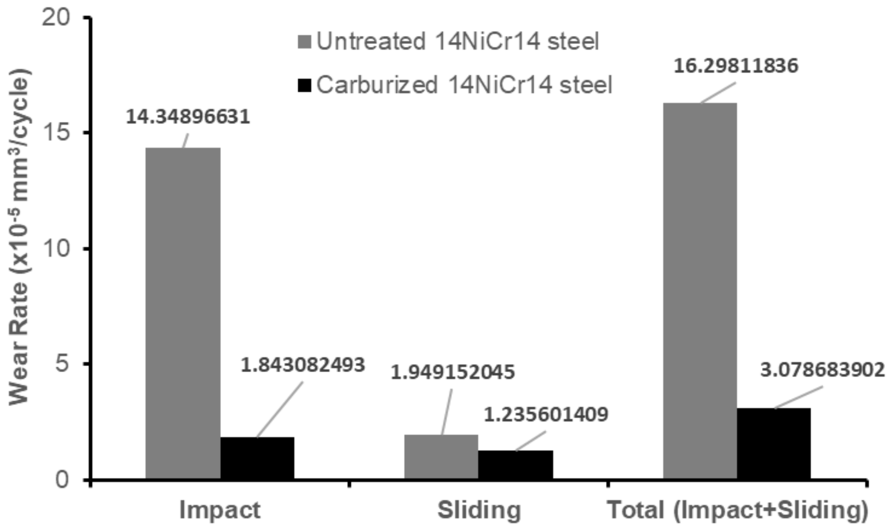

Figure 5. Wear rates of the wear tracks formed on the surfaces of the untreated and carburized 14NiCr14 steels.

The coefficient of friction (CoF) plot under reciprocal sliding tests is shown in Fig. 6. The initial phase, referred to as the running-in stage, exhibited a notable rise in CoF, whereas the subsequent phase, referred to as the steady-state stage, demonstrated a plateau after varying sliding distances of the two steels. The plateau values of untreated and carburized 14NiCr14 steels were approximately 0.63 and 0.96, respectively. The results of Fig. 6 show an increase in the CoF of the carburized 14NiCr14 steel as reported by Dobrocky et al. [14].

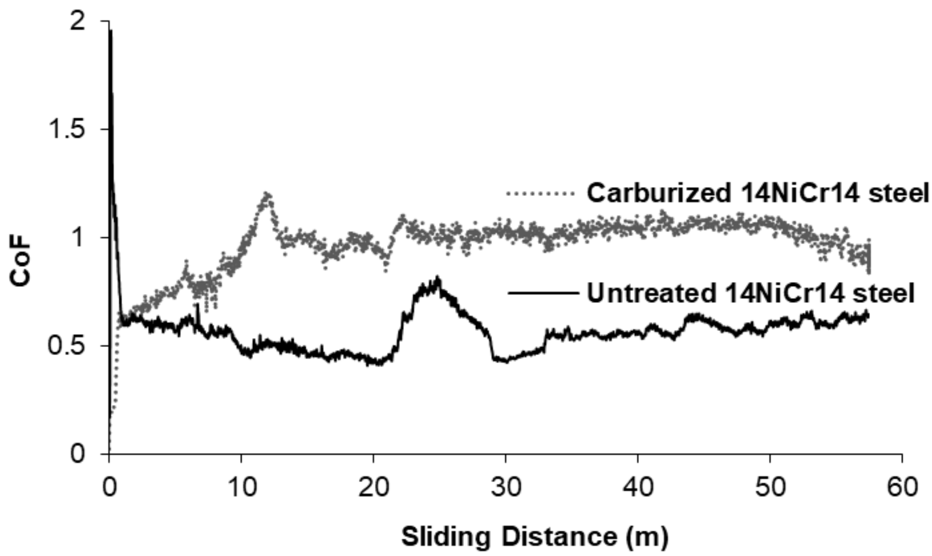

Figure 6. Trend of the CoF under reciprocal sliding tests.

LOM images of the wear tracks formed during the tests are shown in Figs. 7 and 8. The worn surfaces of the untreated 14NiCr14 steel showed severe plastic deformation, with pile-up zones at the edges of the impact and sliding zones (Fig. 2), which were larger in the impact zone than in the sliding zone. High contact pressure causes extreme wear and deep plowing and scratching of the worn surface, resulting in direct metal-to-metal contact [15]. The sliding zone of the untreated 14NiCr14 steel displayed microscale cutting and plowing processes, which were caused by abrasive wear (Figs. 7 and 8). A decrease in the CoF for untreated 14NiCr14 steel will result in an increase in the sliding amplitude, hence causing a greater extent of abrasion wear during the reciprocal sliding test. This observation aligns with the findings depicted in Fig. 6. As carburized 14NiCr14 steel was composed of a hard surface layer on a relatively soft matrix, plastic deformation occurring in the 14NiCr14 steel with high toughness in the core under an impact load could induce surface layer brittle fracture. However, the carburized layer did not detach (Figs. 7 and 8), and the rubbing of the steel ball in the sliding zone caused a combination of adhesive and oxidative damage to the carburized 14NiCr14 steel (Figs. 7 and 8). The production of the hard layer, which consisted of the carburized layer and the carbon diffusion zone beneath it, as a result of gas carburization had a significant hardening impact, as was anticipated by this formation. The carburized layer exhibited hardness values of 650 ± 10 $HV_{0.05}$, whereas untreated 14NiCr14 steel exhibited softer hardness values of 250 ± 5 $HV_{0.05}$. During impact-sliding wear tests, it was observed that the steel balls also experienced wear, as depicted in Figs. 7 and 8. The wear scars observed on the contact surfaces of balls have a direct relationship with the size of the wear tracks observed on both untreated and carburized 14NiCr14 steels. This correlation suggests that the wear of the ball is influenced by the dimensions of the contact regions. It is important to acknowledge that the quantity of wear debris that adheres to the surface of the steel ball in contact with untreated 14NiCr14 steel is significantly higher compared to the surface of the steel ball in contact with carburized 14NiCr14 steel during impact-sliding wear tests.

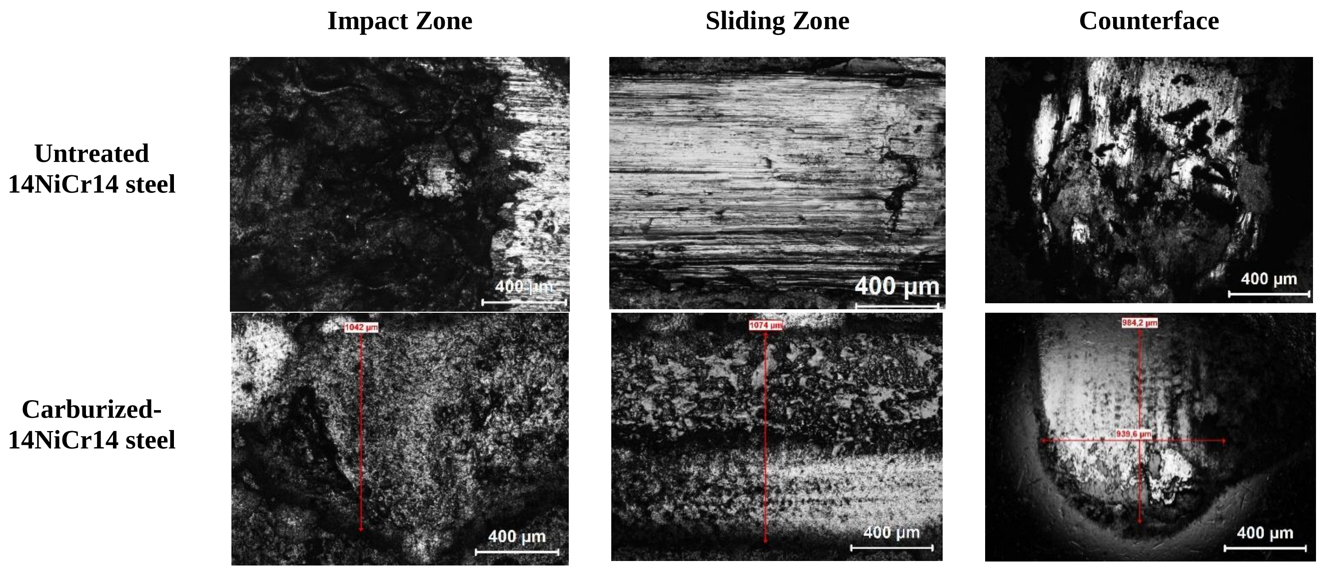

Figure 7. Low magnification LOM images showing the morphology of the wear tracks.

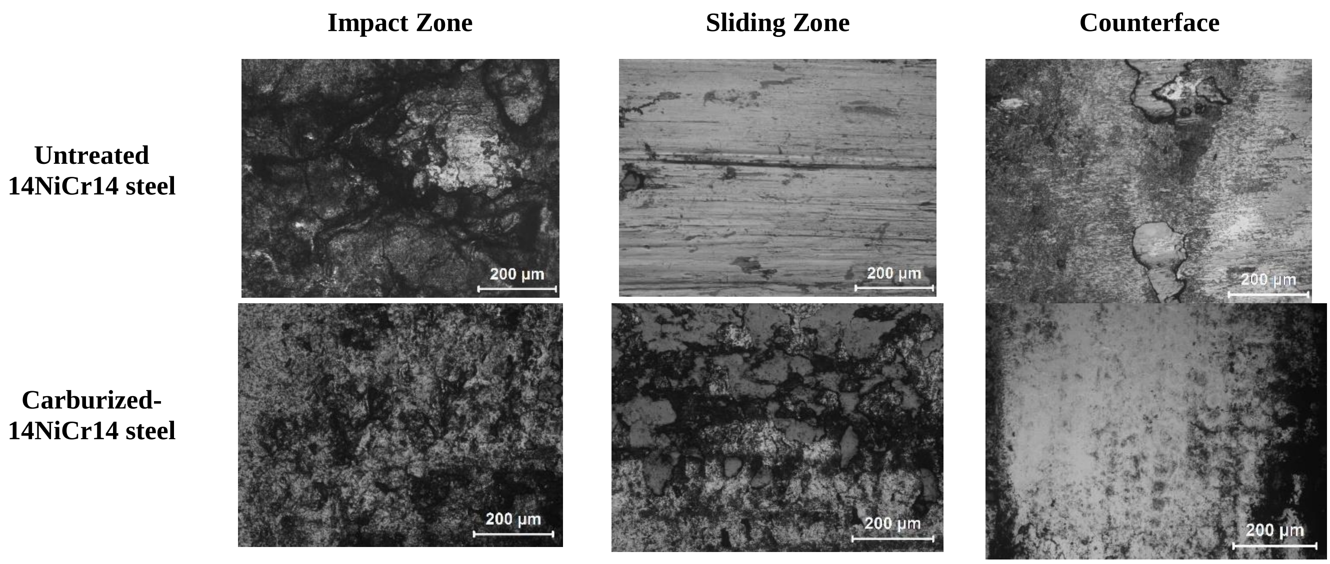

Figure 8. High magnification LOM images showing the morphology of the wear tracks.

4. CONCLUSION

The fatigue wear behavior of untreated and carburized 14NiCr14 steels was assessed under high contact stresses in an atmospheric setting using an inclined cyclic impact-sliding test, yielding successful results. The following is a concise summary of the present study's findings:

1. The plastic deformation was the main cause of the wear loss of untreated 14NiCr14 steel in the impact motion of the experiment. During the sliding motion of the experiment, abrasive wear and adhesive/oxidative damage were the main causes of wear loss in both untreated and carburized 14NiCr14 steels, respectively.
2. In the impact and sliding zones, carburized 14NiCr14 steel had an 87% and 37% reduced wear rate, respectively, compared to untreated steel under 40/240 N contact load conditions.
3. Carburized 14NiCr14 steel exhibited a decreased total wear rate, defined as the sum of the wear rates of the impact and sliding zones, indicating that it may be a viable candidate for gun barrel extensions.

SIMILARITY RATE: 15 %

AUTHOR CONTRIBUTION

Harun Mindivan: Conceptualization, methodology, writing, editing etc.
Ayşenur Eğercioğlu: Conceptualization, methodology.
Gökhan Özdemir: Methodology.
Ömer Faruk Çoşkun: Conceptualization, methodology.

All authors have read and agreed to the published version of the manuscript.

CONFLICT of INTEREST

The authors declared that they have no known conflict of interest.

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