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Effects of Cryogenic Treatment on the Microstructure, Hardness, and Wear Behavior of 1.2436 Steel

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Submitted: 19.01.2023 Revised: 12.03.2023 Accepted: 12.04.2023 doi:10.30855/gmbd.0705056

Keywords: Shallow cryogenic treatment/deep cryogenic treatment, 1.2436 steel, Hardness, Microstructure, Wear

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ABSTRACT

This study investigates the affects of cryogenic treatment on the hardness, wear resistance, and microstructure changes of 1.2436 steel. The study applied shallow at −80 °C for 6 hours and deep cryogenic treatment at −180 °C for 6 hours on quenched steel samples. In addition, the steel pieces were exposed to tempering at 300 °C for 2 hours at different stages. In the microstructure images, it was seen that the cryogenic treatment provided a more homogeneous carbide distribution in 1.2436 steel. The cryogenic treatment also substantially affected the wear resistance and hardness of 1.2436 steel. Deep cryogenic treatment provided higher hardness and wear resistance than shallow cryogenic treatment. The paramount hardness was acquired in the sample in which the tempering heat treatment was carried out between quenching and cryogenic treatment (QTDCT, 9.63% higher), and the paramount wear resistance was acquired in the piece in which the tempering heat treatment was performed after quenching and cryogenic treatment (QDCTT, 28.12% less wear rate).

Kriyojenik İşlemin 1.2436 Çeliğinin Mikro Yapısı, Sertliği ve Aşınma Davranışı Üzerindeki Etkileri

ÖZ

Bu çalışma, kriyojenik işlemin 1.2436 çeliğinin sertlik, aşınma direnci ve mikro yapı değişiklikleri üzerindeki etkilerini araştırmaktadır. Çalışmada su verilmiş çelik numunelere -80 °C'de 6 saat sığ ve -180 °C'de 6 saat derin kriyojenik işlem uygulanmıştır. Ayrıca çelik parçalar farklı aşamalarda 300 °C'de 2 saat süreyle temperleme işlemine tabi tutulmuştur. Mikroyapı görüntülerinde kriyojenik işlemin 1.2436 çelikte daha homojen bir karbür dağılımı sağladığı görülmüştür. Kriyojenik işlem aynı zamanda 1.2436 çeliğin aşınma direncini ve sertliğini de önemli ölçüde etkilemiştir. Derin kriyojenik işlem, sığ kriyojenik işleme göre daha yüksek sertlik ve aşınma direnci sağlamıştır. En yüksek sertlik, su verme ile kriyojenik işlem arasında temperleme ısıl işleminin uygulandığı numunede, en yüksek aşınma direnci ise su verme ve kriyojenik işlemden sonra temperleme ısıl işleminin uygulandığı numunede elde edilmiştir (QDCTT, %28.12 daha az aşınma oranı).

Anahtar Kelimeler: Sığ kriyojenik işlem/derin kriyojenik işlem, 1.2436 çeliği, sertlik, Mikro yapı, Aşınma

To cite this article: N. Altan Özbek, “Effects of Cryogenic Treatment on the Microstructure, Hardness, and Wear Behavior of 1.2436 Steel,” *Gazi Journal of Engineering Sciences*, vol. 9, no. 1, pp. 100-107, 2023. doi:10.30855/gmbd.0705056

1. Introduction

Metals are applied to various heat treatments to upgrade mechanical properties [1–3]. Known as complementary to traditional heat treatment, cryogenic treatment enhances metals' microstructural and mechanical properties [4–6]. High wear resistance is achieved in the material by forming very fine-grained carbide precipitates in the nucleation regions with the cryogenic treatment and converting residual austenite formed after conventional heat treatment into martensite [7–11]. The cryogenic treatment is applied by gradually cooling the material to a sub-zero temperature, keeping it at this temperature level for a certain time, and then gradually heating it to room temperature [12, 13]. Generally, two types of cryogenic processes, shallow and deep, are applied. Shallow cryogenic treatment is performed from -50°C to -100°C. A deep cryogenic process is applied between -125 ºC and -196 ºC [8, 12, 14].

Yıldız and Özbek [6] have stated that deep cryogenic treatment applied on AISI 431 martensitic stainless steel increased the hardness and yield strength of the steel sample by approximately 3.89% and 7.03%. However, it was determined that the cryogenically treated sample was worn about 62% less. Li et al.[15], in their study, they applied deep and shallow cryogenic treatment on 20CrNi2MoV steel and found that deep cryogenic treatment provided more hardness and wear resistance. Darwin et al. [16] studied the optimum cryogenic processing conditions for maximum wear resistance. Their study using SR34 steel detected that the deep cryogenic process provided better results than the shallow cryogenic process. On the other hand, Özbek et al. [17] researched the effects of deep and shallow cryogenic treatment on the hardness, wear resistance, and residual austenite phase of AISI H11 steel. Both types of cryogenic treatments reduced the residual austenite phase and improved mechanical properties. Deep cryogenic treatment provided a more remarkable recovery than shallow cryogenic treatment. Soleimany et al. [18] observed that deep cryogenic treatment on AISI H11 tool steel provides more hardness and wear resistance increase than shallow cryogenic treatment. Özbek and Özbek [7], in their study on Sverker 21 tool steel, observed that cryogenic treatment increased the hardness, wear resistance, and impact energy of steel samples. The deep cryogenic process provided better results than the shallow cryogenic process. Koneshlou et al. [19] subjected AISI H13 steel to deep and shallow cryogenic treatment and found that deep cryogenic treatment provides superior hardness, toughness, wear resistance, and tensile strength. Benselly et al. [20] reported that deep cryogenic treatment had a more plus influence on the fatigue strength of En 353 steel.

Zhirafar et al. [4] investigated the effects of tempering heat treatment temperature applied after cryogenic treatment on the mechanical properties of AISI 4340 steel. After quenching and deep cryogenic treatment for 24 hours on the steel samples, tempering heat treatments were applied at 200, 300, and 455 °C. The highest hardness was obtained at the lowest tempering temperature, and it was observed that the hardness decreased with increasing tempering temperature. Molinari et al. [21] investigated the effects of tempering and cryogenic treatment sequence after quenching on the hardness and wear resistance of AISI M2 steel. In the study, quenching + 550 °C for 2 hours double tempering (Q+T+T), quenching + double tempering + 35 hours deep cryogenic treatment (Q+T+T+C), quenching + deep cryogenic treatment + tempering (Q+C+T) and finally quenching + deep cryogenic treatment + double tempering (Q+C+T+T) heat treatments were applied. The highest hardness and the lowest wear were obtained in the sample that applied Q+T+T+C heat treatment. Baldissera and Delprete [12] applied four different heat treatment groups on 18NiCrMo5 carburized steel: case hardening + tempering (CH+T), case hardening + deep cryogenic treatment for 1 h + tempering (CH+DCT+T), case hardening + deep cryogenic treatment for 24 h + tempering (CH+DCT+T) and case hardening + tempering + deep cryogenic treatment for 24 h (CH+T+DCT). The highest tensile stress was observed in the CH+T+DCT sample, while the highest hardness was observed in the CH+DCT+T sample.

Many studies have shown that cryogenic treatment positively affects the mechanical properties of most material types. However, shallow cryogenic treatment gives better results on mechanical properties for some material types, while deep cryogenic treatment gives better results for some material types. On the other hand, tempering after cryogenic treatment is recommended because of secondary carbide precipitation [4] and residual stress reduction [22]. However, the effects of applying the tempering heat treatment before or after the cryogenic treatment on the mechanical and microstructural properties of 1.2436 steel are not yet known. For this reason, this study was carried out to close this gap in the literature. In this study, after quenching on 1.2436 steel, deep and shallow cryogenic treatments were applied for 6 hours. After the quenching process, four different heat treatment cycles were applied on the steel pieces: tempering treatment (QT), shallow cryogenic treatment+tempering (QSCTT), deep cryogenic treatment+tempering (QDCTT), tempering+deep cryogenic treatment (QTDCT), The effects of these heat treatment cycles on the microstructure, microhardness and wear resistance of 1.2436 steel were investigated

2. Material and Methods

The chemical components of 1.2436 steel are in Table 1. 1.2436 steel specimens were subjected to quenching after being kept at 920 °C for 25 minutes. Then, heat treatments were applied with different types and different sequences. Table 2 presents the heat treatments applied in the study in detail.

The samples were grouped into QT, QSCTT, QDCTT, and QTDCT. The QT samples are tempered immediately after quenching. QSCTT specimens were exposed to shallow cryogenic treatment after quenching and then tempered. The QDCTT specimens were subjected to deep cryogenic treatment after quenching and then tempered. QTDCT samples were tempered after quenching, and deep cryogenic treatment was applied.

Table 1. Chemical components of 1.2436

Element	**Cr**	**C**	**W**	**Mo**	**V**	**Si**	**Mn**
Wt.%	11.58	2.28	0.59	0.24	0.14	0.25	0.4

Table 2. Details of heat treatments

Specimen	**Heat treat details**		
QT	Quenching	-	Tempering (300 °C, two h)
QSCTT	Quenching	Shallow cryogenic treatment (-80 °C, six h)	Tempering (300 °C, two h)
QDCTT	Quenching	Deep cryogenic treatment (-180 °C, six h)	Tempering (300 °C, two h)
QTDCT	Quenching	Tempering at 300 °C for two h	Deep cryogenic treatment (-180 °C, six h)

The surfaces of the parts were sanded, polished, and etched for the microstructure photographs. Microstructure photos were taken with Quanta-FEG 250 SEM device. The hardness of the steel samples was measured as a result of applying 500 grams of load in 20 seconds. Wear experiments were carried out at a sliding distance of 900 m, load of 30 N, and speed of 0.75 m/s. TRD Wear pin-on-disk device was used.

3. Findings and Discussion

Figure 1 shows the microstructure images of 1.2436 steel using an optical microscope. Carbide grains in all samples are visible in the microstructure images. All samples have large and small sizes of carbides. Large carbides are more concentrated in certain regions in the QT sample microstructure. Carbide distribution is more homogeneous in all cryogenically treated samples. On the other hand, the carbide content is higher in the deep cryogenically treated samples (Fig. 1c, 1d). From this, it can be said that the cryogenic treatment provides carbide precipitation in 1.2436 steel and provides a more homogeneous carbide distribution. Microstructure images were taken with SEM at 5000X magnification to perform microstructural analysis more accurately. EDX confirmed it analyzes in Figure 2 that the larger carbides in the microstructure images were M_7C_3 and the smaller ones were M_3C carbides. Cementite (M_3C/Fe_3C) is a Fe-rich carbide with an orthorhombic crystal structure. M_7C_3 (Cr_7C_3) has a hexagonal crystal structure. It is a carbide rich in Cr. It is founded in steels with moderate to high-Cr content and only moderate quantities of other carbide-forming alloying elements [23]. EDX analysis of the smaller carbides in the SEM images in Figure 2 confirmed that there are M_3C carbides with more Fe than Cr and some W and Mo. EDX analysis from the larger carbides confirmed the M_7C_3 carbide with more Cr than Fe.

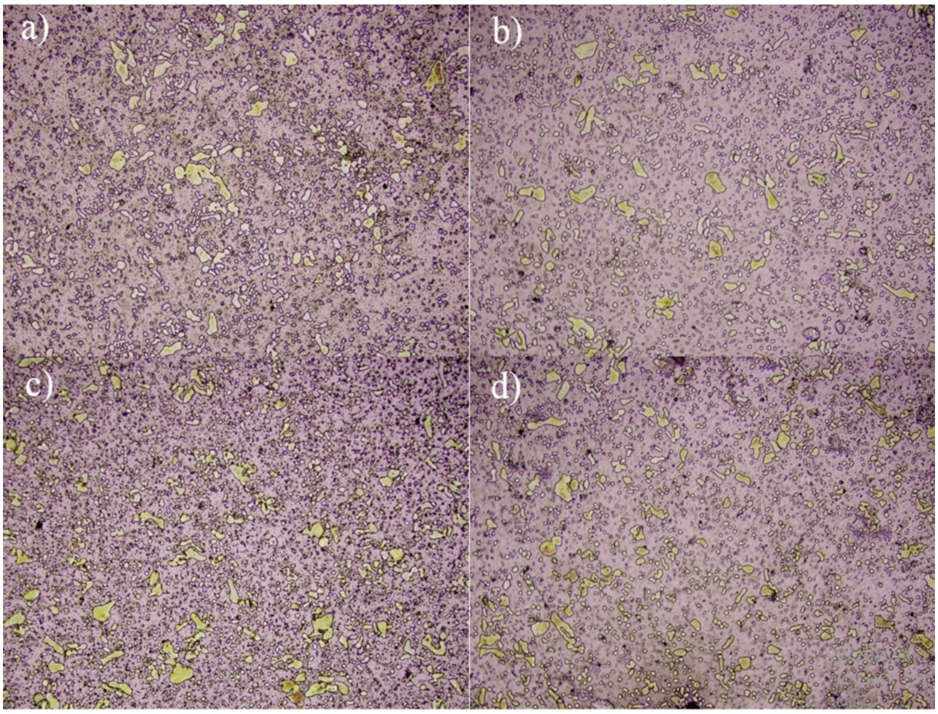

Figure 1. Optical microscope images of different heat-treated steel samples a) QT, b) QSCTT, c) QDCTT, d) QTDCT

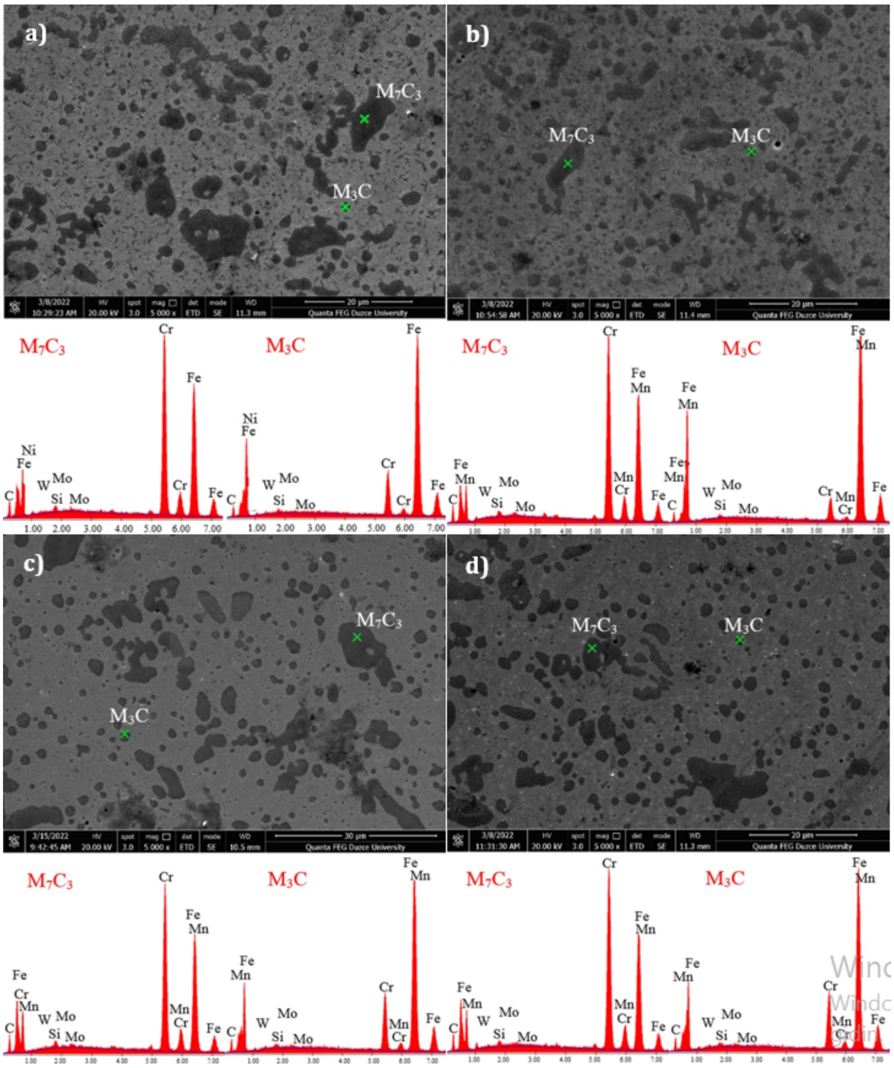

Figure 2. Microstructure of steel samples and EDX analysis of carbides a) QT, b) QSCTT, c) QDCTT, d) QTDCT

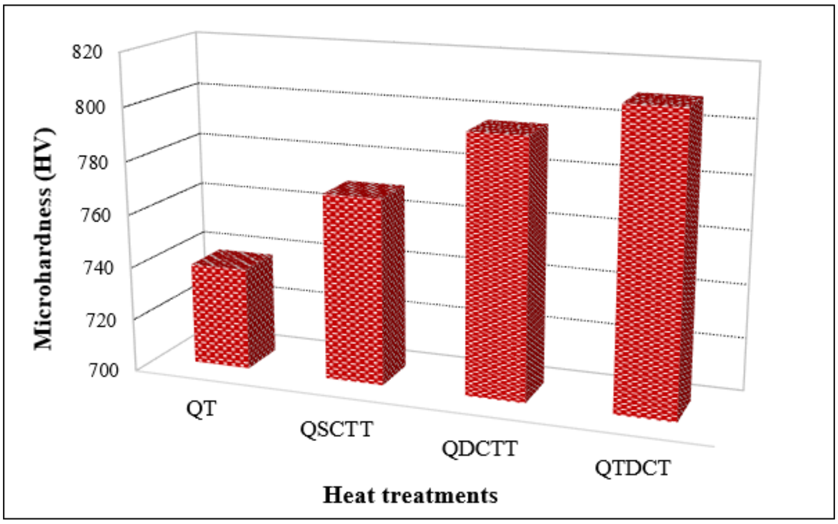

Figure 3. Microhardness change the graph of 1.2436 steel applied to different heat treatment cycles

Figure 4 shows the wear rates of 1.2436 steel specimens exposed to different heat-treatment cycles. In wear test results, it was seen that the cryogenically treated samples were less worn. This has been associated with the cryogenic treatment converting residual austenite to martensite, forming new carbide precipitates and a more uniform carbide dispersion, thereby increasing hardness and wear resistance. Deep cryogenic treatment provided a more wear resistance improvement than shallow cryogenic treatment. This is thought to be thanks to the deep cryogenic treatment providing more residual-austenite phase transformation and thus increasing the hardness. Among the deep cryogenically treated specimens, the tempered sample exhibited better abrasion performance after cryogenic treatment. The least worn sample is DCT+T. Compared to the QT sample, the QSCTT, QDCTT, and QTDCT samples were worn approximately 18.75%, 28.12%, and 21.87% less, respectively.

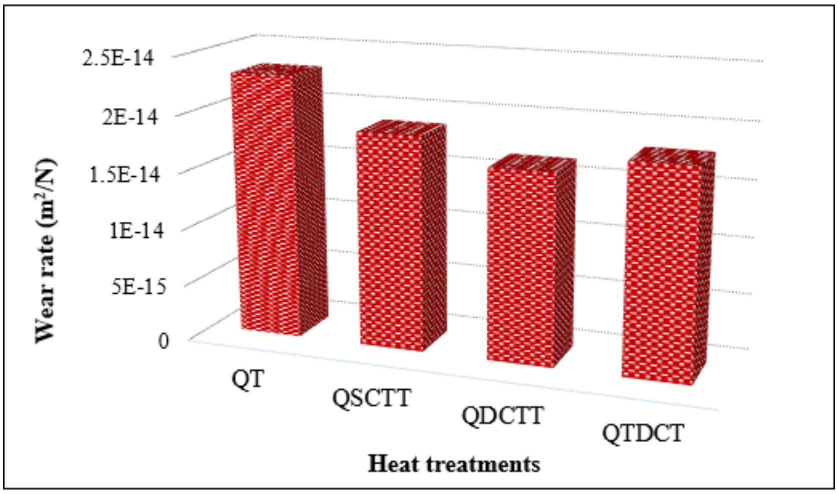

Figure 4. Wear rate change graph of 1.2436 steel applied to different heat treatment cycles

Figure 5 shows SEM images of worn surfaces of steel specimens after wear tests. It is seen that plastic deformation and adhesive delamination in the form of layers are dominant on the worn surfaces of all samples. In the adhesive delamination mechanism, flakes of material are pulled out from the surface during the test sample sliding on the disc. In addition, oxide debris was formed during wear. In general, it is seen that in all samples, wear occurs with the combination of plastic deformation and oxidation. On the other hand, it is observed that microcracks are formed in the QT sample. Wear is likely to increase further due to the rapid propagation of the first cracks formed in the early stages. The cryogenic treatment appears to play a significant role in preventing the growth of cracks, as it strengthens the microstructure by providing a smaller and more homogenous carbide distribution. In addition, this behaviour may be related to the conversion of residual austenite in the microstructure to martensite.

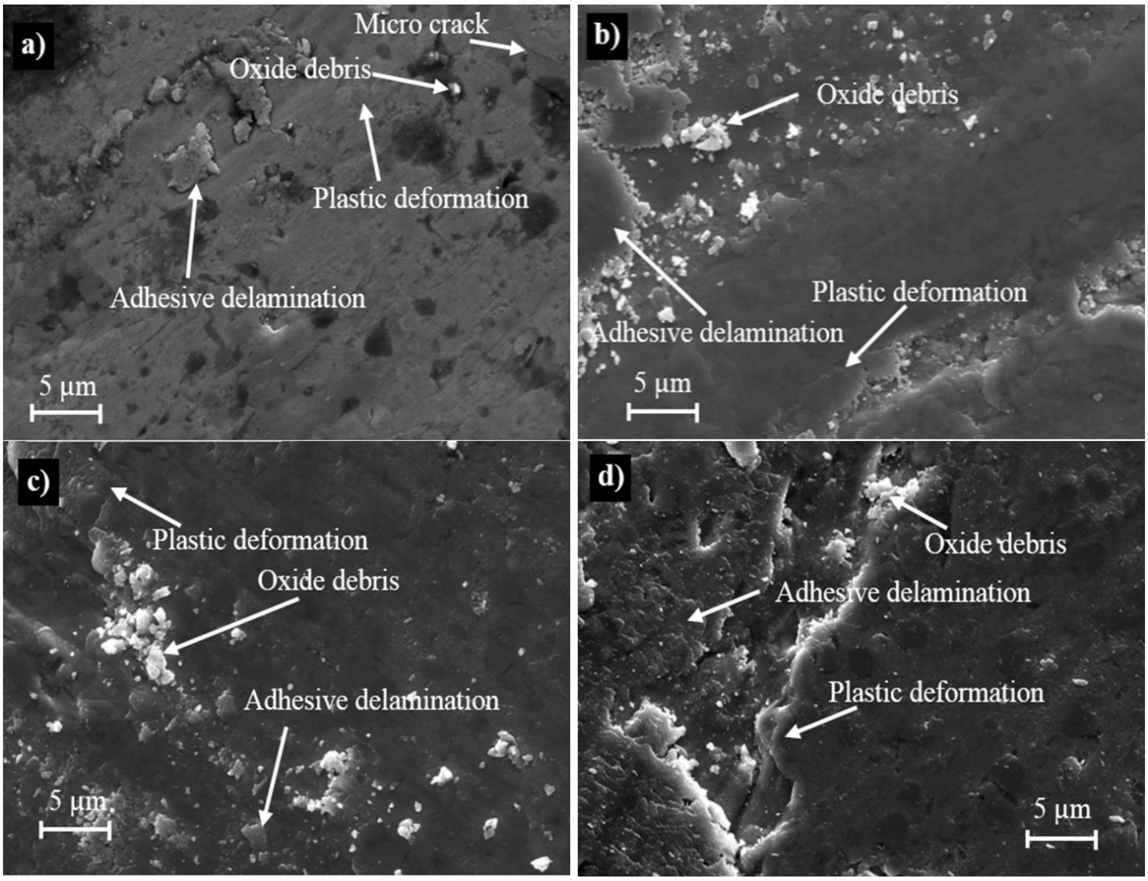

Figure 5. SEM images of worn surfaces as a result of the wear test a) QT, b) QSCTT, c) QDCTT, d) QTDCT

4. Conclusions

This study applied different treatment cycles to 1.2436 steel, including quenching+tempering, quenching + deep cryogenic treatment + tempering, quenching + shallow cryogenic treatment + tempering, quenching + tempering + deep cryogenic treatment. The effects of cryogenic treatment cycles applied under different conditions on microstructure, hardness, and wear resistance were investigated. The results obtained in the study are as follows.

- As a result of all heat-treatment cycles, M_3C and M_7C_3 carbides were formed in the steel samples. After cryogenic treatment, more carbide precipitation and more homogeneous carbide dispersion were observed in the steel samples. It was determined that the carbides in the deep cryogenic treated samples were dense than the shallow cryogenic treatment.
- The hardness of the cryogenically treated pieces is higher than the untreated samples. The deep cryogenic treatment produced a more significant increase in hardness. The greatest increase in hardness was measured in the QTDCT sample at a rate of approximately 9.63%.
- Wear tests have shown that cryogenic treatment has improved the wear resistance of 1.2436 steel. Samples with all cryogenic treatment cycles worn less than untreated samples. Both deep cryogenic treated samples wore less than shallow cryogenically treated samples. The maximal wear resistance was provided in the QDCTT specimen. Approximately 28.12% less worn compared to the QT sample.

Acknowledgments

This work is supported by Düzce University Scientific Project (2021.22.01.1177).

Conflict of Interest Statement

The author declared no conflict of interest.

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