MICROSTRUCTURE AND WEAR PROPERTIES OF 42CRMO4 STEEL PREPARED BY VARIOUS HEAT TREATMENTS METHODS

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https://doi.org/10.37904/metal.2022.4404

Abstract

42CrMo4 steels are widely used in automotive, aerospace applications and machine tools where wear resistance needs to be maintained throughout its lifetime. It is possible to change the initial microstructure of these steels with various heat treatments and improve their mechanical properties. For this purpose, the effect of different heat treatment processes on wear characteristics of 42CrMo4 quality steel was investigated in this study. After various heat treatments methods, spheroidized ferrite-perlite, tempered martensite, tempered martensite with spherical carbides microstructures were obtained in 42CrMo4 steel. Hardness measurements and the wear tests were performed with microhardness tester and reciprocating type tribometer, respectively. The microstructural features developed by the applied heat treatments were examined with an optical microscope, and the wear characteristics were studied in terms of friction coefficient, wear volume loss, and worn surfaces of samples.

Keywords: 42CrMo4 Steel, heat treatment, microstructure, hardness, wear, metallurgy

1. INTRODUCTION

Wear is a significant material failure mechanism that reduces the surface quality and cause deterioration of machining tolerance of parts working in contact. 42CrMo4 quality steels with high toughness and strength properties are widely preferred in applications involving contact deformation such as machine parts. Heat treatment is an effective method of obtaining the optimum microstructure component of the steel in order to increase its mechanical properties to the desired level. The wear behavior of a material varies mainly depending on the mechanical features of the worn surface, such as hardness and toughness, in a tribological system [1]. It is essential to identify how wear characteristics differs according to the basic steel microstructures when designing wear-resistant steel components.

Hardness provides wear resistance by reducing the depth of wear, and toughness by limiting delamination in the worn area [2]. Hardness is a structure- sensitive property that is lowest in ferrite structures formed from the austenite phase during slow cooling and highest in martensite structures transformed with rapid cooling. Advanced strength, toughness and hardness mechanical properties for a steel alloy can be achieved by the tempered martensite microstructure. The hard carbides precipitated in the martensitic matrix have wear-improving characteristics, and tempering temperature has a considerable effect on wear resistance by altering the amount of precipitation, matrix hardness, and retained austenite fraction [3]. Moderate cooling transformation phase of pearlite consists of a layered arrangement of ferrite and cementite, and the morphology and distribution of iron-carbide in it also affects the wear resistance. Perlite clusters dispersed in a ductile ferrite matrix strengthen the structure and reduce the rate of material loss during wear. Earlier researches indicate that, lamellar perlite is more resistant to fricton-induced plastic deformation in an abrasive environment than spherodized perlite [4]. Free movement of dislocations caused by the increasing intercarbide distance during the spheroidization process enhances the wear rate, and also in severe wear conditions, coarse spherical carbides can promote abrasive wear through the hard particle effect [5, 6]. However, spheroidisaiton annealing in pearlitic structure improve the machinability, impact toughness and fatigue properties of the steel, as well as providing a more homogeneous and harder texture in the hardening process to be applied later. In the martensitic structure developed with quenching after spheroidization annealing, carbides can be partially dissolved in the austenitization process. Wu et al. investigated the effect of spheroidization treatment prior to quench-tempering in GCr15 bearing steel and concluded that enhancing the initial grade of spheroidization improved hardness and wear performance [7].

The purpose of this study is to characterize the wear behavior of 42CrMo4 steel as a response of different microstructures obtained from various heat treatment methods. To examine the wear performance of the steel after heat treatments, reciprocating wear test conducted at room temperature against 100Cr6 steel ball. Examination of the microstructural evolution, elemental analysis of the wear zone, and hardness testing are also included to reveal the steel's wear behavior.

2. EXPERIMENTAL

The chemical composition of 42CrMo4 quality steel is given in **Table 1**. 42CrMo4 grade steels in the form of cylindrical slabs were processed to dimensions of 30 x 300 mm and afterwards heat treated.

Table 1 Chemical composition of 42CrMo4 steel

Elements	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Sn
Contend (wt%)	0.43	0.26	0.65	0.015	0.021	1.07	0.19	0.16	0.16	0.021	0.006

In the study, spheroidized perlite-ferrite, tempered martensite, tempered martensite with spherical carbides micostructures were obtained with different heat treatments applied to 41Cr4 steel, and the relevant samples were abbreviated as SFP, QT and SQT, respectively. 41Cr4 quality steel has a ferrite-perlite microstructure as it is cooled in air after hot rolling during the industrial production routes, so the as-received specimen abbreviated as FP. In QT sample, tempering carried at 400°C for 1 hour after quenching from austeinisation treatment at 850 °C and water was used as the quenching medium. Spheroidizing annealing treatment was applied at the subcritical temperature of 700 °C for 4 hour followed by furnace cooling with 1.96 C/min cooling rate which determined by a K-type thermocouple contact with sample surface. Similar quench-tempering process parameters with the QT sample was applied to the SQT sample that cooled to room temperature after the sphericalization process. The schematic representation of the related heat treatment processes is as in the **Figure 1**.

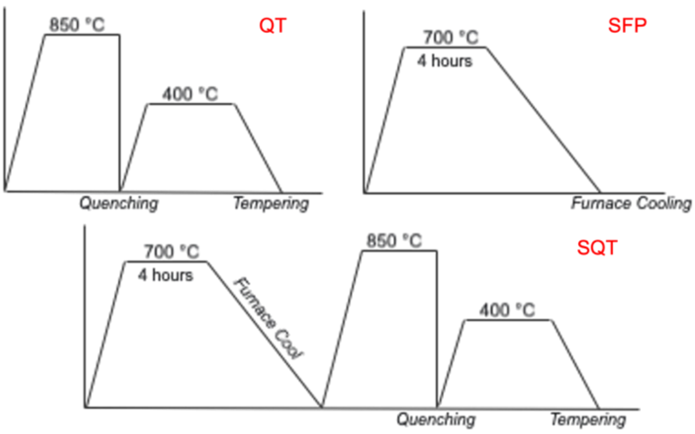


Figure 1 Schematic heat treatments illustrations

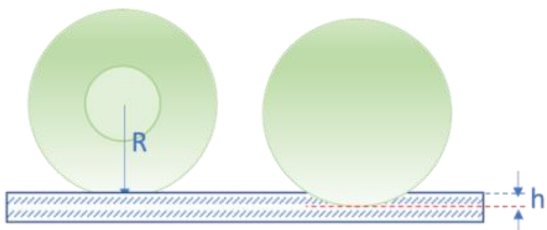


Figure 2 Ball radius and height between wear ball and surface

The hardness variation of the heat treated samples was investigated by Vickers test method (HV5), and the average of five different region's measurement values was calculated. Wear volumes and varying friction coefficients with sliding distance were measured with the laboratory scale Bruker (Tribometer) brand wear device. A reciprocating wear test was applied to the sample surfaces with a 5 mm diameter steel ball (100Cr6 steel) with a total sliding distance of 20 meters, a force load of 3.5 N and a wear path parameters of 5 mm. Wear volume was calculated based on the initial ball radius (R) and the height h (**Figure 2**) measured after wear test using the equation given in below [8].

$$W = \frac{1}{3}\pi h^2 (3R - h) \quad (1)$$

where:

W: Wear volume (mm^3)

R: Ball radius (mm)

h*: decreasing height (mm)

*h measured after wear, was calculated depending on the change in the z-axis position (Δz) of the ball at the test start and end moment.

3. RESULTS AND DISCUSSION

41Cr4 steel are in ferrite-perlite microstructure (FP sample) seen in **Figure 3a** as it is received after production. In **Figure 3b**, after the spheroidization heat treatment, spherical cementite types were dispersed in the matrix and fingerprint structure was disappeared.

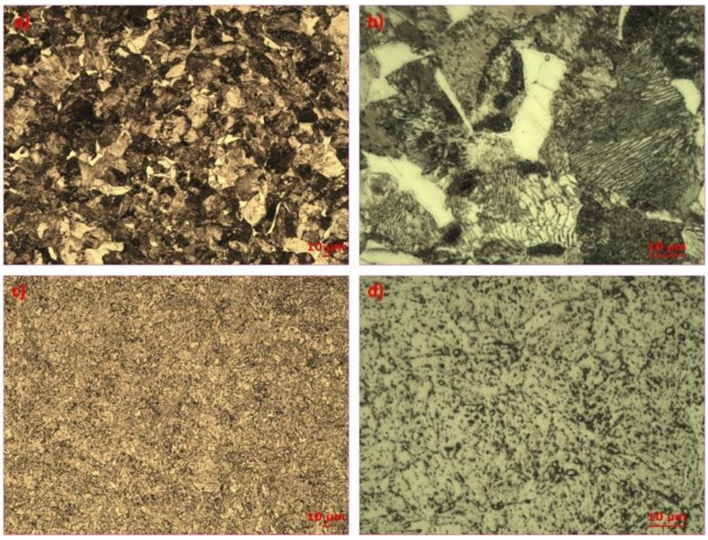


Figure 3 Ferrite-perlite microtructure a) (lower magnification) and b) (higher magnification) and spheroidized ferrite-perlite microstructure c) (lower magnification) and d) (higher magnification)

After conventional quench-tempering treatment and pre-spheroidization followed by quenching and tempering, a similar morphology, lath-type tempered martensitic microstructure is observed in QT and SQT samples as shown in **Figure 4**. In these two samples, tempering process was applied at a similar temperature (400 °C) and time in the last step, and no retained austenite phase was found in these samples since it would decompose at the relevant temperatures. Cementite (Fe_3C) and alloy carbides formed in 42CrMo4 steel are located on tempered martensite substructures and appear as black dots that can be distinguished in optical microscope photographs. The quenching and tempering process in the SQT sample starts with austenite transformation from a stable ferrite-perlite microstructure containing spheroidized carbides. About that case, the primary carbides and cementites may be partially dissolved during the austenitization process at 850 °C, while the coarse spherical carbides present in the original structure may remain undissolved. The coarser and intensive carbides observed in the SQT sample can therefore be attributed to the formation of new carbides in the structure and the coarsening of the existing carbides during the 400 °C tempering process.

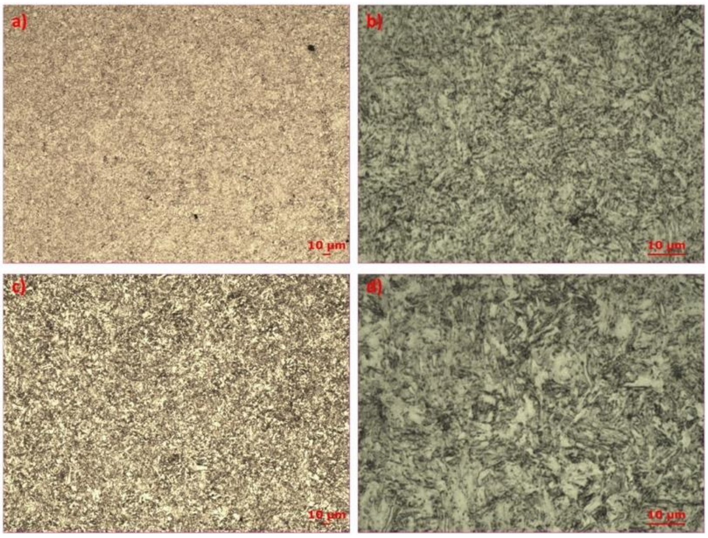


Figure 4 Quench-tempered microtructure a) (lower magnification) and b) (higher magnification) and pre-spheroidised quench-tempered microstructure c) (lower magnification) and d) (higher magnification)

The hardness values determined by the Vickers test method after the applied heat treatments are as in **Figure 5.** Conventional quench-tempering treatment applied to the ferrite-perlite initial microstructure (FP) significantly increased the hardness value. Similar hardness values are observed in SQT and QT samples treated at the same tempering time and temperature. It was observed that the pre-spheroidisation annealing applied before quenching-tempering did not cause a significant change in hardness. As compared to the FP sample, the modest drop in hardness during the spheroidization process in the SFP sample is due to morphological changes in the carbides present in the microstructures. 4 hours of holding and furnace cooling at a rate of 1.96 C/min resulted in decline in hardness of around 10%. Hidalgo et al. stated that the carbon ratio in the matrix has a significant effect on the hardness change [9]. During the spheroidisation as the carbides in the structure aggregate throughout the subcritical temperature holding period, the carbon ratio in the matrix lowers, and reduced the hardness.

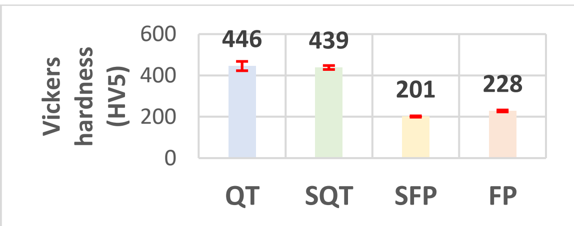


Figure 5 Variations in hardness of heat-treated samples with different methods

The variation of the coefficient of friction (COF) with time in the room temperature reciprocal wear test applied to the samples is as in **Figure 6**. The average friction coefficients of the FP, SFP, QT and SQT samples were calculated as 0.68, 0.62, 0.61 and 0.58, respectively. Even as similar results are observed, the friction coefficient values are determined for the lowest SQT and highest FP samples. It was observed that the friction coefficients of the samples, which increased with time at the beginning of the test, continued with regular fluctuations at values close to the average calculated COF values of the samples after certain sliding distances. This can be explained by the fact that the increase in surface roughness at the beginning of wear raises the coefficient of friction, but with the increase of the sliding distance, the wear track becomes flatter and the COF value altered with minimal variations. As the friction coefficient increases, the material's wear rate increases, so it can be interpretted that the SQT sample shows slightly better wear resistance [7].

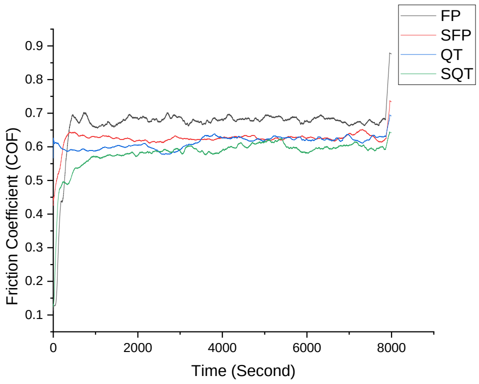


Figure 6 Variation of friction coefficients with time of different heat treatments

The wear ball volumes calculated with equation (1) at the termination of the reciprocating wear tests are shown in **Figure 7**. The contact ball exhibited the highest degree of wear ball in the quench-tempered (QT) sample and the lowest level of wear ball in spheroidized quench-tempered (SQT) sample. When the SQT and QT samples with similar hardness values are evaluated, the SQT sample with a homogeneous distribution of undissolved spherical carbides demonstrated a lower friction coefficient and 100Cr6 steel ball showed greater wear resistance in this sample. Relatively low hardness and ductility of the ferrite-perlite microstructure explains the better adhesion of the wearing particles to the surface and consequently the lower material loss. Low variations in hardness between FP and SFP lead to corresponding differences in wear loss. Ferrite-perlite microstructure including lamellar cementite caused less wear ball volume compared to that having globular cementite. Since plastic deformation of lamellar carbides requires more energy than deforming of spherical carbides in the ferrite matrix, the ferrite-pearlite sample exhibit more resistant wear behavior with abrasive steel ball [10].

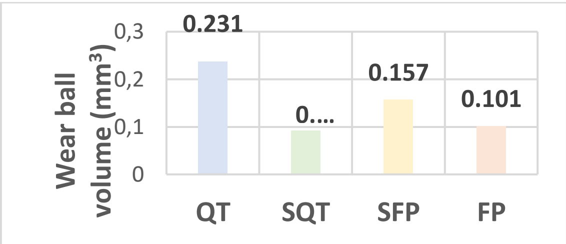
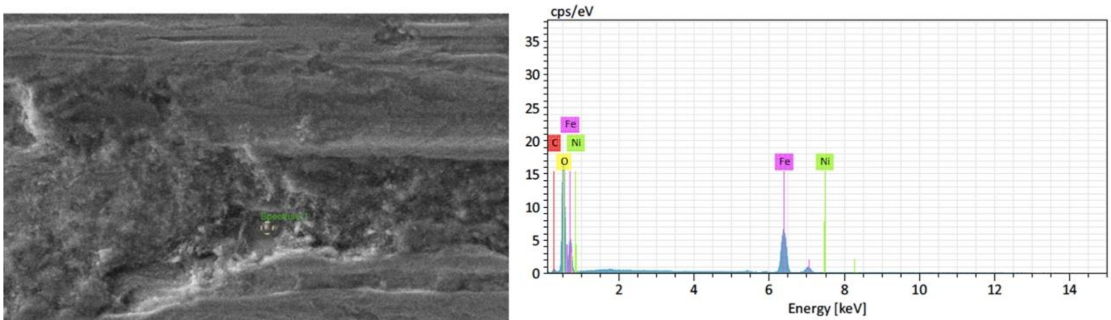


Figure 7 Calculated wear ball volumes of different heat-treated samples

The presence of a high level of the oxygen element in the point EDS analysis data (**Figure 8**) from the worn area indicates that oxidation occurs between the ball (100Cr6 steel) and the surface as a result of the locally increased temperatures during the wear process. The wear debris as a result of the fragmentation of the high hardness oxide layer could have an additional abrasive effect, leading in surface delamination and material loss. The oxide layer in the wear tracks also could prevent the welding effect that may occur between the steel ball and the sample surface, and therefore, abrasive wear behavior was observed on the surfaces rather than adhesive wear.



Spectrum	Carbon	Oxygen	Iron	Nickel
Spectrum 1	1.87	63.41	34.65	0.07

Figure 8 EDS analysis of wear debris on the wear track

4. CONCLUSION

In this study, ferrite-perlite, spheroidized perlite-ferrite, tempered martensite, tempered martensite with spherical carbides micostructures obtained for 42CrMo4 steel and hardness and wear characteristics examined. The following conclusions can be drawn:

- Spheroidization prior to quenching-tempering resulted in the dispersion of insoluble carbides in the final microstructure, with no significant change in hardness values but a decreasing in wear ball volume.
- While the lowest hardness values were observed in the spheroidized ferrite-perlite structure, a lower wear ball volume and therefore more resistance to the abrasive ball in contact was obtained in the lamellar ferrite-perlite structure.
- The friction coefficients exhibited low variation with the applied heat treatments, and the lowest COF value was observed in the SQT sample and the highest in the QT sample.
- A consistent correlation could not be established between the measured hardness, average friction coefficients and wear ball volumes for the samples.
- In the wear test against 100Cr6 steel, 42CrMo4 steel exhibited abrasive wear characteristics, as oxidative wear were observed in the wear zone.

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