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Research Article

Effect of Cryosoaking Time on Transition in Wear Mechanism of M2 Tool Steel

N. B. Dhokey, J. V. Dandawate, and R. Rawat

Department of Metallurgical Engineering, Government College of Engineering, Pune 411005, India

Correspondence should be addressed to N. B. Dhokey; nbdhokey@yahoo.co.in

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Specimens of M2 were hardened (H) by quenching at 1200°C, triple tempered (TTT) at 400°C, and then cryogenically (C) treated at minus 185°C for varying lengths of time interval starting from 4 hours to 48 hours of cryosoaking followed by soft tempering at 100°C to relieve cold stresses (HTC). Underlying wear mechanism, hardness, and impact energy were studied and optimum cryosoaking time was established. It was felt that wear resistance of cryogenically treated material was influenced by the so-called tertiary carbides possibly produced as a result of cryogenic treatment.

1. Introduction

Cryogenic treatment has been used to improve wear resistance of materials because it enhances transformation of austenite (soft phase of iron) to martensite (hard phase of iron). It is a one-time permanent treatment process, and it affects the entire cross-section of the material. It is usually done at the end of the conventional heat treatment. Also, it is not a substitute process but rather a supplement to the conventional heat treatment process. Some literature data indicates that the lives of tool increase significantly after being submitted to subzero (below 0°C) temperatures. Accounts of 92% to 817% increase in lives of high speed steel tools have been reported. The performance of M2 high speed steel tools with cryogenic treatment (−196°C) was assessed using sliding abrasion, hardness tests, and also microstructural analysis. It was found that cryotreatment plays significant role in tool life [1]. A study on M2 tool steel has reported that cryogenic treatment not only facilitates the carbide formation and increases the carbide population and volume fraction in martensite matrix but also can make the carbide distribution more homogeneous. The increase in carbide density and volume fraction is responsible for the improvement in wear resistance [2]. The properties of HSS tools were considerably improved. The perfect combination of alloying elements and the domain of heat treatment processes conferred on this material excellent hardness and wear resistance properties besides good toughness [3]. The research on M2 tool steel by varying the cryogenic cycles has quantified the precipitated particles and verified their influence on the material properties [4]. In another study on M2 tool steel, using vacuum quenching at 1220°C and double tempering at 540°C followed by cryogenic treatment at −196°C for soaking period of 35 hours was reported. The total duration of cryoprocessing cycle was 100 hours. The lowest wear rate was obtained by quenching and double tempering followed by cryogenic treatment [5].

In the past, researchers have used arbitrarily cryosoaking time to the extent of 100 hrs to realize the effect on enhancement of wear resistance of the tool steels. However, there is limited published data on understanding wear mechanism in the context of cryogenic treatment more specifically when cryogenic soaking time is varied systematically from 4 hrs to 48 hrs. In the present work on M2 tool steel, the effect of cryosoaking time is analyzed to explore the underlying wear mechanism of M2 tool steel.

2. Experimental Work

2.1. Selection of Material. The M2 tool steel was procured from local market in the form of rod of diameters 10 mm and 15 mm length. The actual chemical composition was analyzed

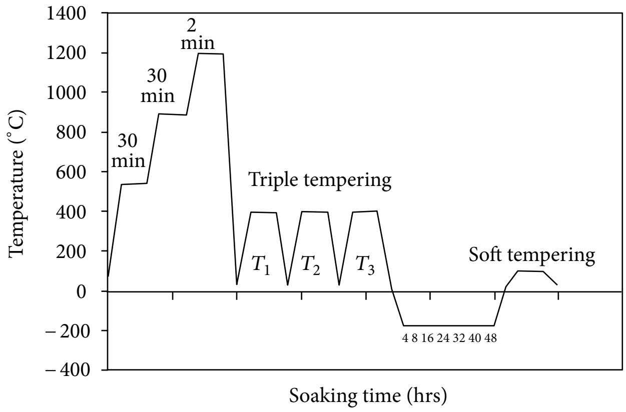

Figure 1: Schematic T-T diagram illustrates processing steps employed on M2 tool steel.

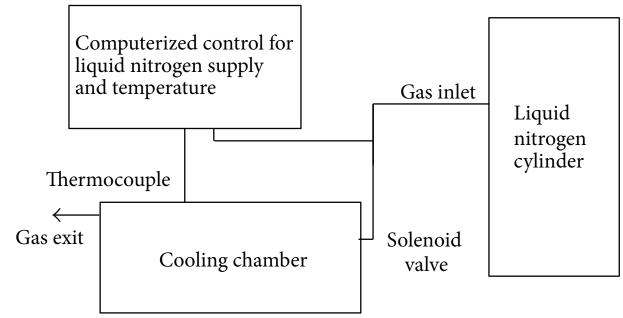

Figure 2: Schematic line diagram of Cryoprocessor used for experiments.

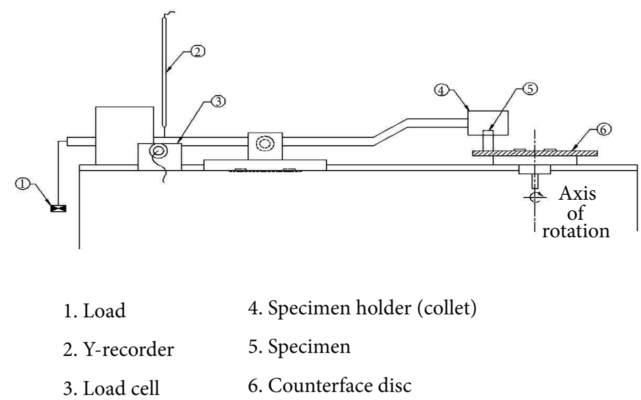

Figure 3: Schematic diagram of pin-on-disc wear testing machine.

using vacuum spectrometer as 0.91% C, 4.05% Cr, 5% Mo, 1.73% V, and 5.96% W (by wt).

2.2. Hardening and Tempering. Hardening of M2 tool steel was done in a tubular furnace (Therelek, 3.8 KW, 230 V, AC, 1600°C) with controlled heating in stages of 550°C, then 900°C for half an hour each in argon atmosphere, and finally 1200°C for 2 minutes followed by quenching in oil stirred bath. After hardening, the triple tempering (TTT) was carried out at 400°C for 2 hrs for each tempering cycle followed by air cooling to room temperature. The specimen treated in this manner was designated as HTTT (without cryogenic treatment, zero hour).

2.3. Postcryogenic Treatment. The cryogenic treatment, as shown in Figure 1, was given in a computer controlled Cryoprocessor (make: Sanmar, Mumbai, minus 185°C) to conventionally heat-treated specimens (HTTT) as described in Section 2.2. The principle of operation of Cryoprocessor is explained in Figure 2. Tool steel specimens were put in Cryoprocessor at room temperature before it started its operation, and then the temperature of the processor was brought down at a cooling rate of 3°C/min by supplying calculated gasified liquid nitrogen through solenoid valve. The cryosoaking time was varied from 4 hours to 48 hours. After regular interval of cryosoaking time, the specimens were removed from the Cryoprocessor and immediately transferred and stored in a highly insulated Thermocol box till the specimens attain the room temperature. A specimen processed in this manner, for example, for 4 hrs cryosoaking time, is designated as HTC4.

2.4. Hardness Test. Rockwell hardness machine was used for measurement of hardness on Rc scale. The flat surface was prepared by using polishing paper 1/0. A minor load of 10 Kg was first applied to seat the specimen. Then major load of 150 Kg was applied for 15 seconds, and resistance to indentation was automatically recorded on the dial gauge. An average of total nine readings on three samples was reported.

2.5. Wear Test. Pin-on-disc test machine (make: Magnum Engineers, Bangalore) was used for dry sliding wear in which stationary pin made out of M2 tool steel treated as mentioned previously was slid against counterface disc. Pin of 10 mm diameter and 15 mm height was slid on the circular rotating disc of SAE52100 for a sliding distance of 6000 m at an applied pressure of 60 N and 2.5 m/s sliding speed. The diameter of counterface disc was 170 mm with hardness of 59 HRC. The configuration of pin-on-disc is shown in Figure 3.

2.6. Metallography. As usual carefully prepared samples were first surface leveled on endless emery belt (80/0) paper. Further samples were subjected to individual polishing emery papers (1/0, 2/0, 3/0, and 4/0) so as to make surface free from scratches. Final polishing was done on velvet cloth polishing machine with intermittent application of fine suspensions of alumina to get better finish on polished surface. A freshly prepared etchant 3% by vol. Nital was used. Scanning electron microscope (make: JOEL) was used to reveal microstructures as well as to analyse features on worn surfaces.

2.7. Impact Test. Charpy impact specimen was prepared to measure the impact energy (Joules) by using digital impact test machine (make: FIE, least count 0.5J). Freshly prepared Charpy impact test specimens treated as per procedure laid down in Sections 2.2 and 2.3 were tested for impact

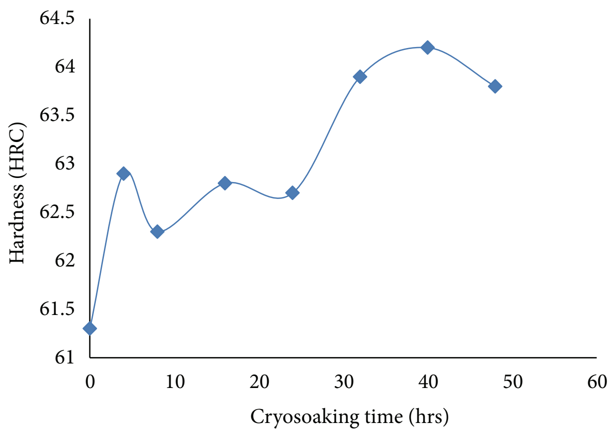

Figure 4: Hardness variation as a function of cryosoaking time.

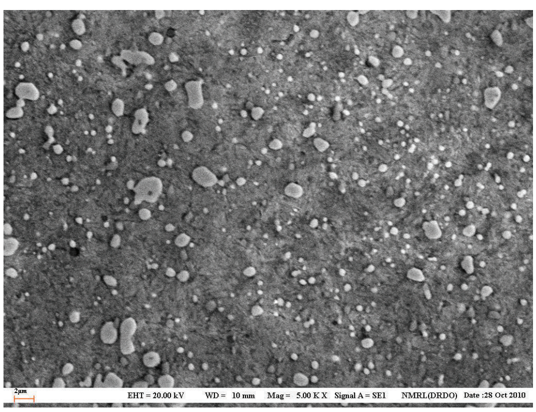

Figure 5: Microstructure shows primary and secondary carbides dispersed in tempered martensitic structure in HTTT (5000x).

toughness. Average impact energy of three samples was taken as measure of impact energy.

3. Results and Discussion

3.1. Hardness Variation. The postcryogenic treatment given to HTTT specimens is showing remarkable impact on intermittent increase in hardness with increase in cryosoaking time as evident from Figure 4. The steep rise in hardness is particularly observed initially till 4 hrs of cryosoaking and then falls gradually with subsequent increase in hardness after 24 hrs. The peak hardness is observed at 40 hrs of cryosoaking time. It may be noted that any rise in hardness could be attributed to nucleation of tertiary carbides/eta-carbide [6], and also any drop in hardness could be the results of coarsening of carbides possibly by Oswald ripening mechanism [7].

3.2. Microstructural Features. Microstructure of HTTT shows primary carbides as well as secondary carbides as shown in Figure 5. Further, cryosoaking can influence precipitation of tertiary carbides in the tempered martensitic structure as evident in Figures 6, 7, and 8. It is reported

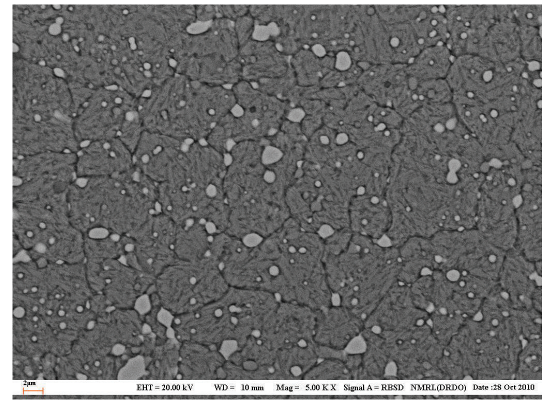

Figure 6: Microstructure of cryotreated for 4 hours shows tertiary carbides in addition to primary and secondary carbides HTC4 (5000x).

that cryogenic treatment facilitates the nanoscale carbide precipitation [6]. Besides nucleation of tertiary carbides, the possibility of coarsening of carbides cannot be ruled out with increasing cryosoaking time. It is believed that more cryosoaking (incubation) time means more time is available for conditioning of structure by way of ensuring homogenization of carbide forming alloying elements. In other words, kinetics of carbide precipitation is directly proportional to incubation/cryosoaking time and also free energy of formation which drives the precipitation mechanism. It may happen that during the precipitation of tertiary carbides, there could be coalescence of existing carbides or nucleation of new carbides and growth of existing carbides in order to bring down the surface free energy of the carbides.

3.3. Effect of Cryosoaking Time on Impact Energy. It is observed from Figure 9 that there is a gradual drop in impact energy with increase in cryosoaking time. However, for the first 32 hrs of cryosoaking time, the impact energy is almost close to the conventionally hardened and triple tempered specimen (HTTT). Figure 4 shows that hardness is highly influenced by the precipitation of tertiary carbides with increasing cryosoaking time, but cryosoaking does influence after 32 hrs.

3.4. Wear Mechanism. Wear is a complex phenomenon and governed not only by hardness but also by other influencing parameters like microstructure, process variables, and thermal properties of the sliding material and plastic instability criterion [8, 9]. It is reported that hardness in cryotreated material is one of the deciding factors but wear may be equally influenced by the microconstituents like tertiary carbides in improving wear resistance [10]. Hence drawing conclusion simply on basis of hardness may be misleading [11]. In the present work, the wear rate of cryotreated specimens is plotted as a function of cryosoaking time as shown in Figure 10. It is seen that there is a dramatic drop in wear rate observed at 4 hrs of cryosoaking time as compared to HTTT

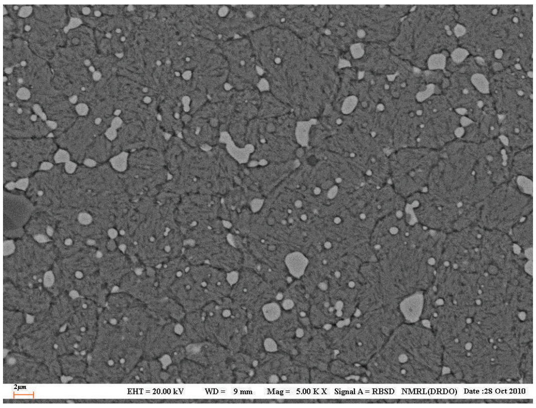

Figure 7: Microstructure of cryotreated for 16 hours shows tertiary carbides in addition to primary and secondary carbides HTC16 (5000x).

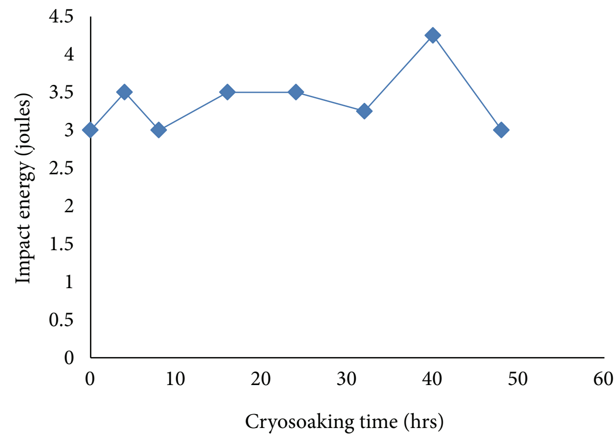

Figure 9: Variation of cryosoaking time on impact energy.

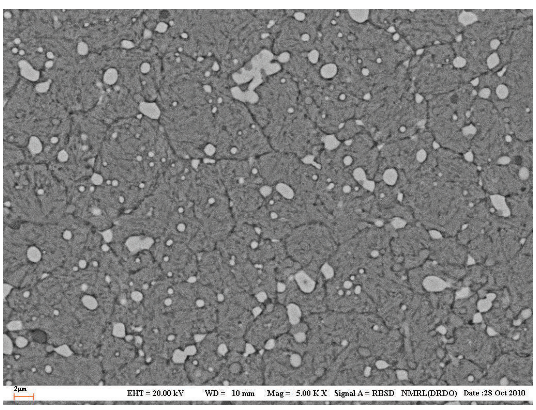

Figure 8: Microstructure of cryotreated for 48 hours shows tertiary carbides in addition to primary and secondary carbides HTC48 (5000x).

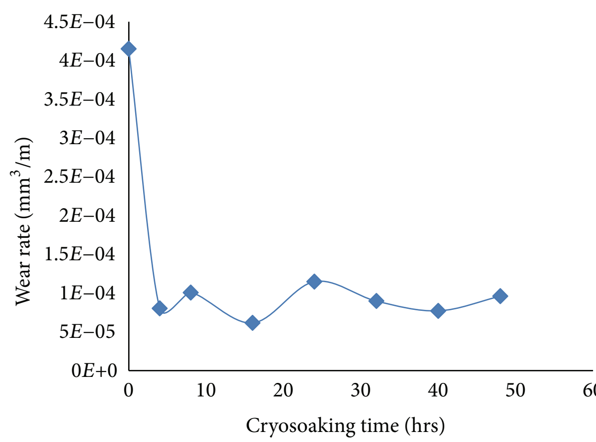

Figure 10: Wear rate variation as a function of cryosoaking time.

(control specimen), and it amounts to reduction in wear rate by 87%. Beyond this point, further drop in wear rate is not significant. Thus the wear rate curve is divided into two parts depicting mild wear and stable wear regimes [12].

3.4.1. Mild Wear Regime. The mild wear regime is seen from HTTT stage till 4 hrs of cryosoaking time and is clearly indicated in Figure 10. The worn surface of HTTT, as depicted in Figure 11, shows mild deformation marks and visible ridges along with carbides and considerable numbers of pits indicating dislodgement of wear particles in accordance with the Suh theory [13]. Increase in hardness (Figure 4) is more closely related to decrease in wear rate. The mild wear may be attributed to more generation of tertiary carbides (Figure 6). Improvement in wear resistance is seen due to uniform distribution of carbides which offer resistance to deformation during sliding. The wear in this regime is dominated by mild delamination wear mode.

3.4.2. Mild-Stable Transition Wear. Figure 12 shows mixed-mode wear consisting of partly mild deformation and partly adhesive wear mode as a result of deformation of the surface observed at 4 hrs of cryosoaking time. As compared to HTTT, the transition point is responsible for steep decrease in wear rate by 87% with consequent increase in hardness to 63 HRC (Figure 4). Thus improvement in hardness and reduction in wear rate could be attributed to increase in density of tertiary carbides.

3.4.3. Stable Wear Regime. The stable wear regime, as shown in Figure 10, is dominated in 4 hrs to 48 hrs of cryosoaking time indicating almost steady-state wear condition. Figure 13 shows stable adhesive wear mode with smooth deformed layer with intermittent tearing of the surface which results in formation of wear particle. In this case, wear is dominated by adhesive wear mode. Despite stable wear regime, hardness shows increasing trend and reaches to 64 HRC (Figure 4) which has immensely contributed the tertiary carbide density. With ultrafine nature of tertiary carbides, the material offers resistance to the flow of deforming surface and thereby reduces the wear of the surface.

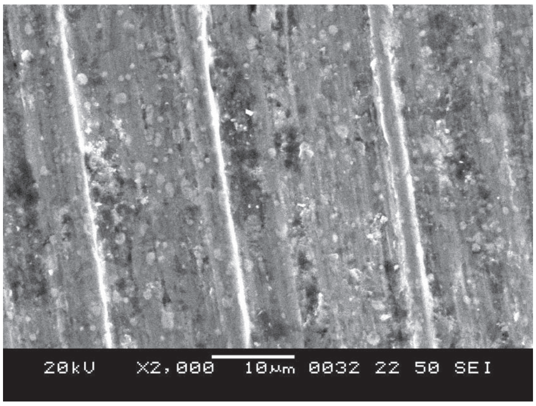

Figure 11: Worn surface of HTTT depicts deep grooving marks/ ridges along the sliding direction indicating carbides and pits due to mild delamination wear mode.

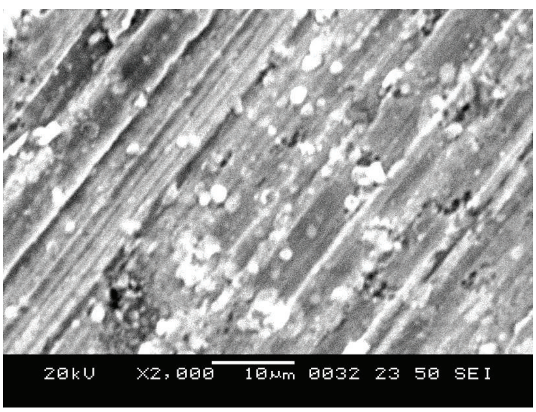

Figure 12: Worn surface of HTC (4 hrs) depicts mild-stable transition wear with shallow grooving along the sliding direction with indication of carbides and pits due to delamination wear mode.

4. Conclusions

Based on the results obtained in the present investigation, the following conclusions can be drawn.

(1) The bulk hardness of M2 HSS tool steels showed improvement in hardness as a result of cryogenic treatment.

(2) Mild-to-stable transition is observed at 4 hrs of cryosoaking time with consequent reduction in wear rate by 87%.

(3) Wear mechanism is clearly delineated into mild wear regime and stable wear regime with dominance of delamination wear mode and adhesive wear modes, respectively.

(4) In addition to primary and secondary carbides precipitation, the cryogenic treatment facilitates tertiary carbide formation which improves wear resistance remarkably.

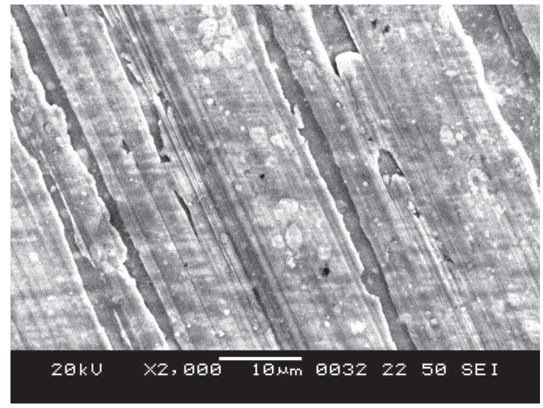

Figure 13: Worn surface of HTC (16 hrs) depicts adhesive wear mode with smooth deformed layer revealing tearing of the deformed surface as a result of grooving action with visible carbides and pits.

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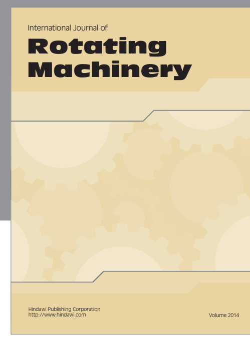

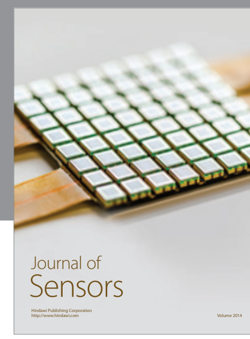

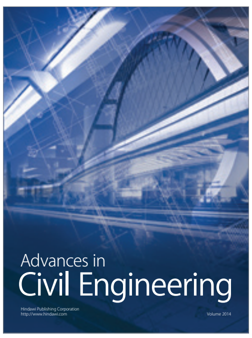

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