Comparison of Dry Wear Characteristics of Two Abrasion-Resistant Steels: Q/T C1095 and 15B37H

G. Sim, K. Iqbal, Y. Wang, and K.N. Tandon

The dry reciprocating wear characteristics of two abrasion-resistant steels, C1095 and 15B37H, against an abrasive material were studied. Results showed that abrasive wear and surface fatigue were the primary wear mechanisms. The wear failure of the steels was related to frictional softening during wear.

Keywords

15B37H, abrasion, C1095, dry, reciprocating, steels, wear

1. Introduction

WEAR behavior of a material is governed by a complex, multistage process that involves many variables, such as material hardness, microstructure, kinetics, contact geometry, temperature, lubrication, and environmental conditions. The tribological behavior of a carbon steel is thus a system-dependent property. In general, wear can be described as damage to a solid surface caused by the removal or displacement of material by the mechanical action of a contacting solid, liquid, or gas. Although the terminology of wear is still being debated and basic definitions have not yet been standardized, it is widely accepted that there are four primary types of wear: adhesive wear, abrasive wear, fatigue wear, and erosive wear. Frequently, two or more mechanisms are operating simultaneously in a wear process (Ref 1-3).

It has long been generally believed that an increase in the hardness of materials improves their wear resistance. Many wear equations assume that the higher the hardness, the better the wear resistance (Ref 3-5). However, it has been shown (Ref 6, 7) that the original hardness of materials before wear cannot always express their wear resistance. Reference 8 further indicates that no simple relationship exists between original hardness and wear resistance of steels. Therefore, a new theoretical equation for wear is needed in which the dynamic changes that occur during wear are considered from the point of view of tribological metallography.

In this work, the dry wear characteristics of two abrasion-resistant steels—15B37H and C1095—under conditions of reciprocating wear have been studied through property evaluation and scanning electron microscopy (SEM) characterization of microstructure formed prior to and during wear tests. 15B37H steel is primarily used in fork tines for forklift trucks, and C1095 steel is used in wear plates for railways as well as in fork tines. Wear in these applications normally occurs in the unlubricated condition.

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2. Experimental Procedure

Detailed chemical analyses of the two steels are given in Table 1, and their microstructures are shown in Fig. 1. Different methods of heat treatment were used for the two steels: C1095 steel, austenitized at 815 °C (1500 °F) for 1 h, oil quenched, and then tempered at 315 °C (600 °F) for 1 h, resulting in a fine tempered martensitic structure with a hardness of 53 HRC (Fig. 1a); C1095 steel, austenitized at 815 °C (1500 °F) for 1 h, oil quenched, then tempered at 540 °C (1000 °F) for 1 h, resulting in a pearlitic structure with a hardness of 32 HRC (Fig. 1b); 15B37H steel, austenitized at 870 °C (1600 °F) for 1 h, oil quenched, then tempered at 455 °C (850 °F) for 1 h, resulting in a fine tempered martensitic structure with a hardness of 41 HRC (Fig. 1c); and 15B37H steel, austenitized at 870 °C (1600 °F) for 1 h, oil quenched, then tempered at 540 °C (1000 °F) for 1 h, resulting in a tempered martensitic structure with a hardness of 21 HRC (Fig. 1d).

The shape and size of the steel test specimens were chosen to provide a flat surface contact between steel test pins and an abrasive stone. The test pins were 25.0 mm long with a 6 mm square face at the ends. The square face of the pin was in sliding contact with the abrasive stone. The wear test specimens were ground and polished on a silicon carbide emery paper (200 grit size, ~0.6 μm finish) to achieve flat and similar surfaces. The abrasive material used was a silicon carbide stone with a grit size of 150. Thorough cleaning procedures were used to ensure consistency and to minimize any variation in actual experimental measurements. Immediately before and after each test, the specimens were weighed using an electronic scale with a sensitivity of 0.01 mg.

Wear tests were performed under constant-load conditions on a custom-built wear test rig (Ref 9). Parameters of the wear test are given in Table 2. Dry wear tests were performed from

Table 1 Material composition of specimens

	Composition, Wt%														
Steel	C	Mn	S	P	Si	Cu	Cr	Ni	Mo	Sn	Ca	Ti	B	Al	N
15B37H modified grade	0.3	1.31	0.006	0.016	0.2	0.28	0.27	0.22	0.02	0.01	0.001	0.04	0.0038	0.007	0.006
C1095 modified grade	0.9	0.58	0.034	0.012	0.13	0.21	0.13	0.14	0.02	0.012	...	...	...	...	...

1000 through 100,000 cycles, under a constant applied load of 20 N at room temperature. They involved a reciprocating, sliding steel pin abrading against the stationary silicon carbide abrasive stone. After the test, pins were removed to measure mass loss and were examined under an SEM to evaluate the wear processes at each stage. Microhardness data of the near-surface region of the pins were also measured as a function of depth from the worn surface for both steels.

Table 2 Wear test parameters

Cycles per minute	119
Sliding distance per cycle, mm	0.2 × 27
Contact geometry	Flat
Lubrication	Nil
Wear track length, mm	27
Contact load, N	20
Type of motion	Reciprocating
Temperature, °C (°F)	20-25 (70-75)
Relative humidity, %	45

3. Results and Discussion

For a constant-load condition, mass loss of the wearing pins is a function of the cyclic time. The composite curves, mass loss versus cycles, for all four specimens are illustrated in Fig. 2. The bottom curve (designated 385/53 HRC) depicts the wear performance of C1095 tempered martensitic steel with a hardness of 53 HRC. The other 385 curve characterizes the wear performance of the same grade of steel but with a pearlitic structure and a hardness of 32 HRC. The mass loss, up to about 5000 cycles, is initially curvilinear for both specimens; thereafter, a different wear rate takes place. The steady-state wear of the harder specimen (tempered martensite) shows a linear characteristic, which is typical for many steady-state wear regimes. Because of the reciprocating nature of the wear, some debris becomes trapped between the mating surfaces, at least initially, and a minor mass gain is observed as a dip in the data point near 5000 cycles. The wear rate of the softer specimen shows the slightly parabolic behavior that is characteristic of pearlitic steel and is attributed to work hardening of pearlite.

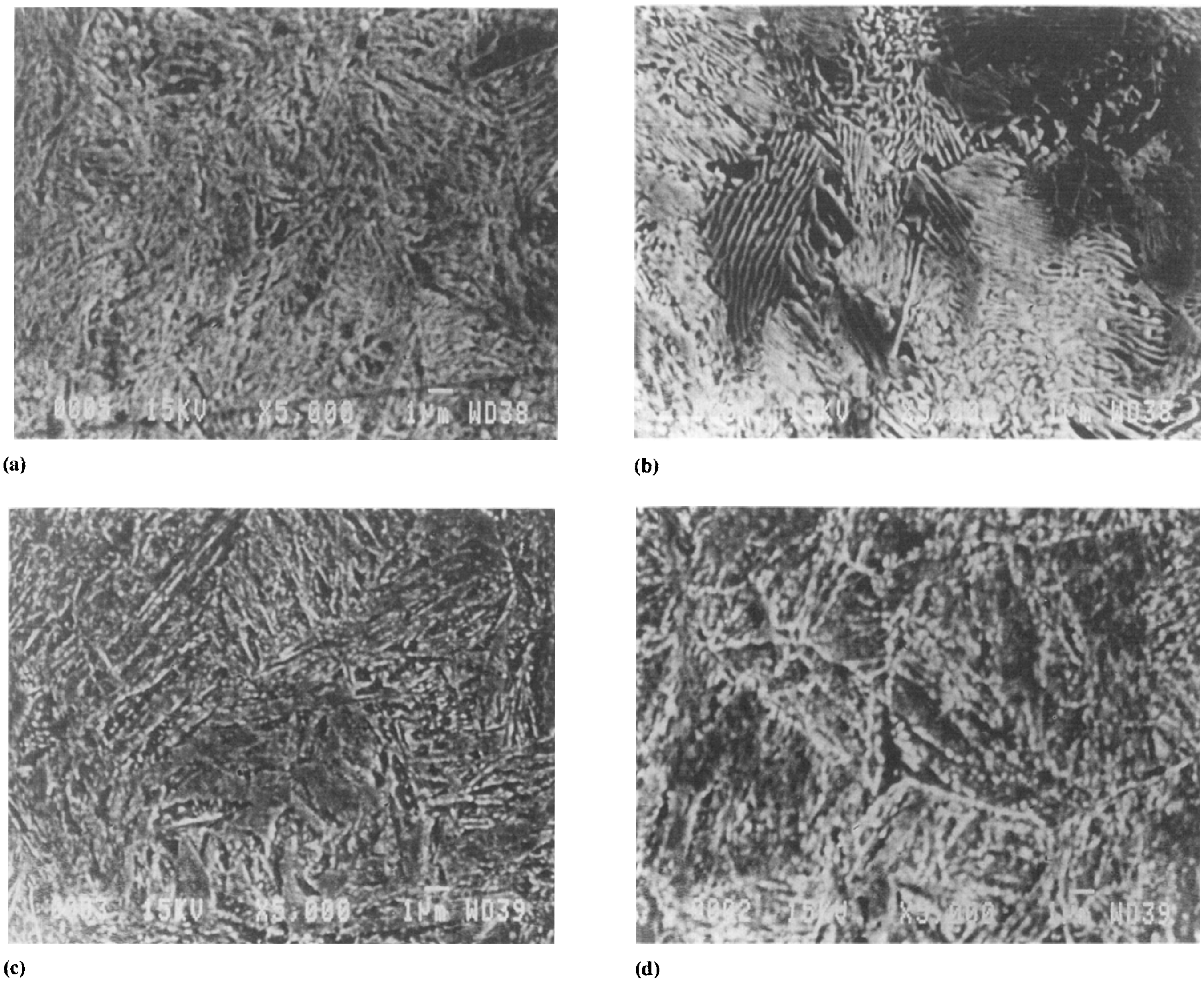


Fig. 1 Microstructures of steel specimens after heat treatment (see text). (a) C1095, 53 HRC. (b) C1095, 32 HRC. (c) 15B37H, 41 HRC. (d) 15B37H, 21 HRC

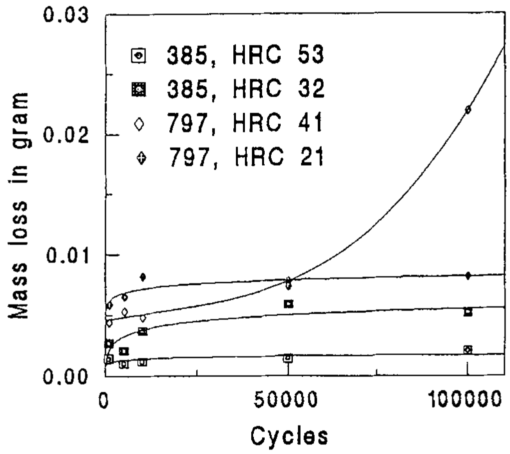


Fig. 2 Composite wear curves for all four specimens. Dry wear test; speed, 119 rev/min; load, 20 N

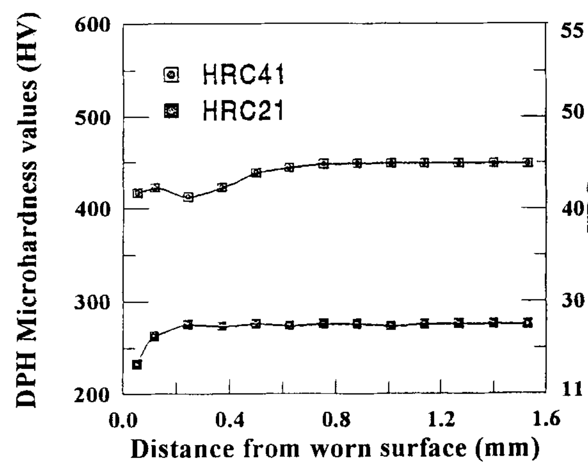


Fig. 3 DPH microhardness curves of worn surface layer of 15B37H

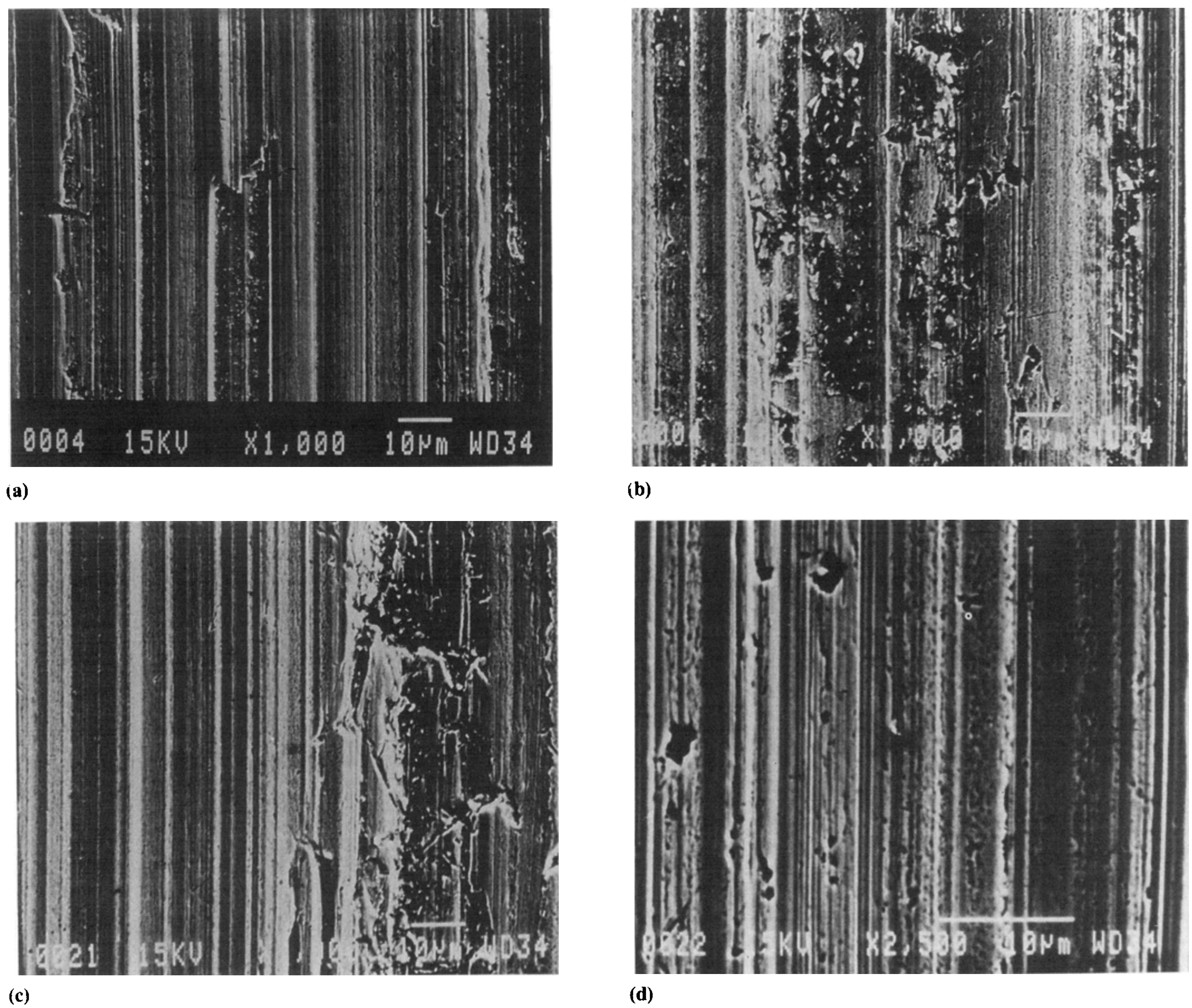
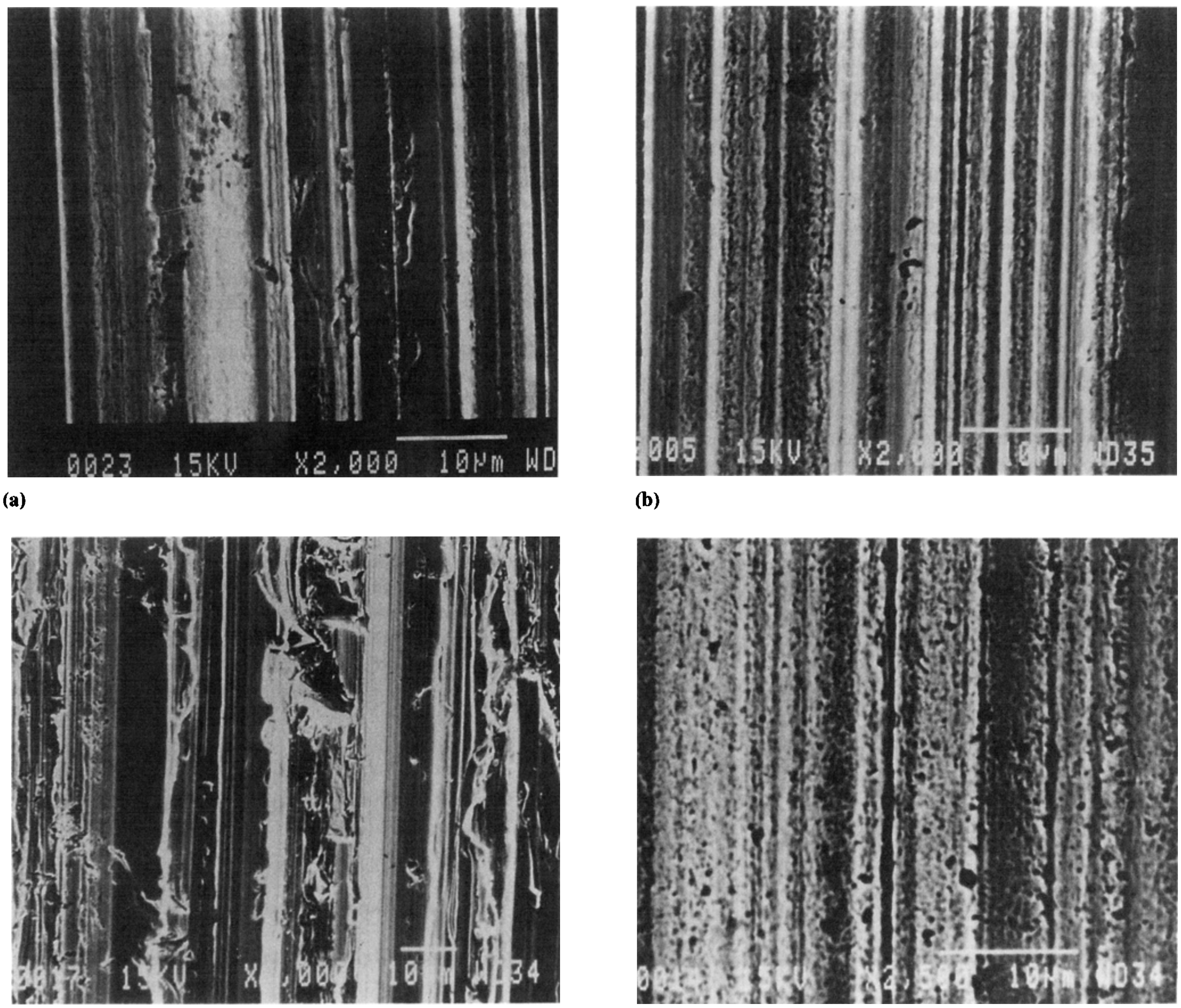


Fig. 4 Scanning electron micrographs of the wear tracks of C1095 steel pins. (a) 53 HRC, after 10,000 cycles. (b) 32 HRC, after 10,000 cycles. (c) 53 HRC, after 100,000 cycles. (d) 32 HRC, after 100,000 cycles

Wear test results of 15B37H tempered martensitic steel with a hardness of 21 HRC (designated 797/21 HRC in Fig. 2) show a steady-state wear behavior. However, 15B37H steel with a hardness of 41 HRC (797/41 HRC) exhibited different wear characteristics. The mass loss up to about 10,000 cycles is initially curvilinear for both specimens. Beyond 40,000 cycles and up to 100,000 cycles, the softer steel exhibited a higher wear resistance than the harder steel. The results show that the wear rate of steels depends little on hardness. The test results clearly identify C1095 martensitic steel with a hardness of 53 HRC as having the highest sliding wear resistance under the specified test conditions. The C1095 pearlitic steel with a hardness of 32 HRC also shows better sliding wear resistance than the 15B37H steel with a hardness of 41 HRC. This demonstrates that the wear resistance of steels is related to composition as well as microstructure. As Fig. 2 shows, the curves for 385/53 HRC, 385/32 HRC, and 797/21 HRC steels exhibit steady-state wear below 100,000 cycles. However, the curve for 797/41 HRC exhibits a rapid wear rate after a very short stage of steady-state wear. The reasons for this behavior may relate to the dynamic structural changes that occur in this steel during wear.

Figure 3 shows the microhardness distribution near the surface region of specimens 797/21 HRC and 797/41 HRC after wear test cycles. The microhardness curve of specimen 797/41 HRC has a deeper low-hardness zone near the worn surface due to frictional softening. This means that the wear failure of 797/41 HRC steel is related to the frictional softening of the steel during wear. Perhaps the frictional softening process is more important for the result because the hardness in the low-hardness zone of specimen 797/41 HRC is still higher than the hardness value of specimen 797/21 HRC before wear testing.



(c) (d)

Fig. 5 Scanning electron micrographs of the wear tracks of 15B37H steel pins. (a) 41 HRC, after 10,000 cycles. (b) 21 HRC, after 10,000 cycles. (c) 41 HRC, after 100,000 cycles. (d) 21 HRC, after 100,000 cycles

Figures 4(a) and (c) show the worn surfaces of C1095 steel pins (53 HRC) after 10,000, and 100,000 wear test cycles, respectively. The dominant wear regime is abrasion, which is characterized by the occurrence of scratches and grooves. Deep grooves in the direction of the wear track appear to be due to the ploughing action of very hard silicon carbide abrasive particles. Nucleation of cracks is also observed on the wear tracks. Figures 4(b) and (d) show the worn surfaces of C1095 steel pins (32 HRC). Examination of the wear track after 10,000 and 100,000 cycles revealed the same wear regime as the previous test specimen at a hardness of 53 HRC; that is, abrasive wear was the dominant regime.

Figures 5(a) and (c) show the worn surfaces of 15B37H steel pins (41 HRC). Abrasive wear was observed from 1000 to 100,000 cycles. The worn surfaces of 15B37H steel pins (21 HRC) are shown in Fig. 5(b) and (d). From 1000 through 100,000 cycles, abrasive wear was the primary wear mechanism. Grooves resulting from ploughing and gouging by hard particles are also present. However, a different wear surface is observed after 100,000 cycles. The wear surface shows shallow grooves and some smearing effect. Very little spalling is evident. One reason may be that perhaps some soft metal matrix was smeared on the surface of the abrasive stone, which may have weakened the abrasive effect of the stone. This type of worn surface indicates a transition in wear regime from abrasive wear to another mechanism. The near-surface hardness of the 15B37H steel pin with a hardness of 21 HRC is shown in Fig. 3.

4. Conclusions

In this study, abrasive wear and surface fatigue were found to be the primary wear mechanisms responsible for material loss in dry wear under reciprocating sliding conditions. For the four types of structural specimens, tempered martensite with a hardness of 53 HRC exhibited the greatest wear resistance. Original structural hardness cannot be taken as the sole criterion of the wear resistance of steels. Severe frictional softening will speed the wear failure of steels such as 15B37H at similar hardness levels. The wear resistance of the high-carbon steel C1095 has been found better than that of the lower-carbon alloy steel 15B37H.

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