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Low Stress Abrasive Wear Behavior of a Hardfaced Steel

R. Dasgupta, B.K. Prasad, A.K. Jha, O.P. Modi, S. Das, and A.H. Yegneswaran

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A plain carbon steel was overlayed with a wear-resistant hardfacing alloy by manual arc welding. Low stress abrasive wear tests were conducted with an ASTM rubber wheel abrasion tester using crushed silica sand as the abrasive medium. The wear rate decreased with sliding distance, and there was an overall improvement in the abrasive wear resistance as a result of overlaying. The wear behavior of the samples has been discussed in terms of microstructural features while the examination of wear surface and subsurface regions provides insight into the wear mechanisms.

Keywords abrasion, hardfacing, steel, wear, wear mechanism

1. Introduction

Improvement in surface properties of materials can be achieved through a number of surface engineering techniques (Ref 1-5), and a proper choice has to be made between cost effectiveness and application before choosing a particular method or material. One important aim of modifying a surface is to attain a wear or corrosion resistant material only on the surface without affecting the bulk characteristics. The thickness of the coating can be varied from micron to millimeter levels depending upon the method chosen and its sophistication (Ref 6-7). As bulk properties of materials are of secondary importance due to wear or corrosion characteristics, surface modification can be applied even on low cost substrates; the technique becomes less expensive than designing the entire component using improved strategic materials.

One of the least expensive methods of modifying the surface of engineering components is by overlaying or hardfacing. This method is particularly advantageous where relatively thick coatings are required, and it has found extensive applications in areas where dimensional tolerances are not very stringent (Ref 8-9).

The effects of overlaying a plain carbon steel on its low stress abrasive wear properties are presented. Tests were carried out under the conditions of varying loads and traversal distances. The mechanisms of material removal were analyzed through the scanning electron microscopy (SEM) examination of the tested samples.

2. Experimental

2.1 Materials

A plain carbon (0.18% C, 0.40% Mn, 0.10% Si, remainder Fe) steel was overlayed with a rutile type (Fe-base) hardfacing (0.50% C, 0.30% Mn, 0.45% Si, 6.5% Cr, remainder Fe) alloy by manual arc welding ≤3000 to 3500 μm thickness.

R. Dasgupta, B.K. Prasad, A.K. Jha, O.P. Modi, S. Das, and **A.H. Yegneswaran,** Regional Research Laboratory (C.S.I.R.), Bhopal 462 026, India.

2.2 Wear Tests

Low stress abrasive wear tests were carried out on metallographically polished hardfaced specimens. The steel without overlaying was also subjected to identical tests for comparison. The test apparatus was a Falex rubber wheel abrasion tester (RWAT) as per ASTM G 65-81 specifications (Ref 10). A schematic view of the apparatus is shown in Fig. 1. Silica sand particles of size 212 to 300 μm were used as the abrasive medium. The silica particles were allowed to fall through a funnel between the rotating rubber wheel and sample. The rubber wheel was rotated at 273 revolutions per minute (rpm), and static loads were applied on the sample through a cantilever mechanism. Tests were carried out at 22, 49, and 67 N loads.

Weight loss measurements were made at regular test intervals of 2 min corresponding to a linear traversal distance of 392 m. Wear rate (m^3/m) was calculated by weight loss technique. Tests were carried out until a steady state wear rate was attained. Samples were thoroughly cleaned with acetone and flowing water before weighing in each case. Fresh samples were used for each load.

2.3 Microscopy

Transverse sections of the overlayed samples were metallographically polished and etched in 0.1 Nital solution for microstructural examination.

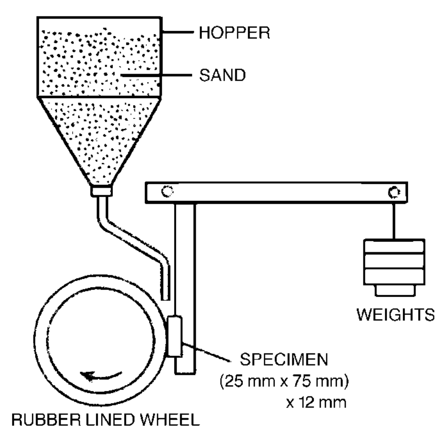
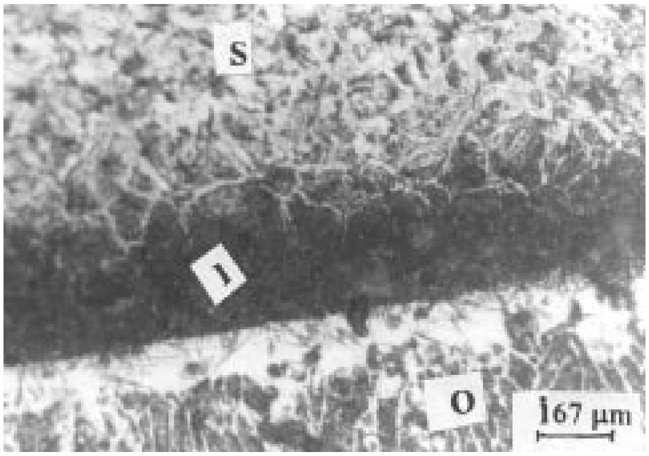


Fig. 1 A schematic view of the RWAT, three-body abrasion tester

The abraded surfaces of typical samples were examined using SEM to assess the nature and extent of wear induced damage due to abrasion. Transverse sections of the abraded specimens (after the wear tests) were also metallographically polished and etched to study subsurface changes. Hardness was measured on the tranverse section of the abraded surface, progressively downward from the worn surface to the bulk at regular distances.



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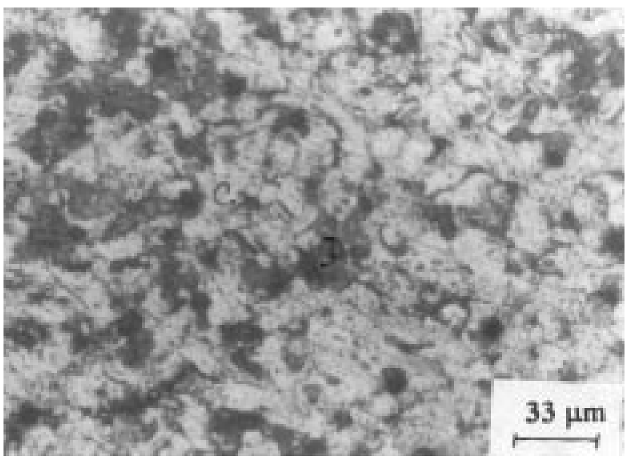

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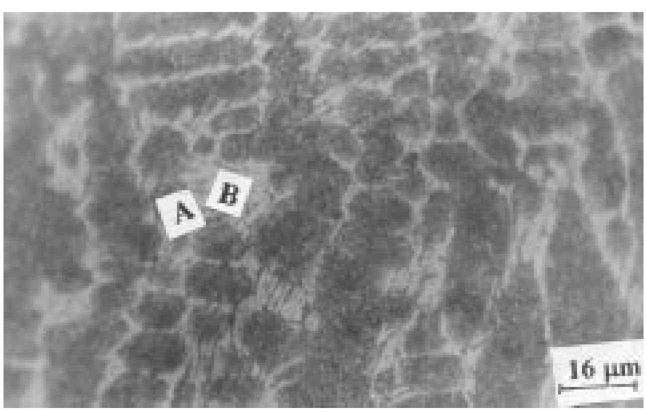


(c)

Fig. 2 (a) Transverse section of overlayed steel showing bonding, I, between substrate, S, and overlay, O. (b) Microstructural features of the steel. (c) Microstructural features of the overlay showing chromium carbides, A, in the interface and austenite plus carbide, B, in the interdendritic regions

3. Results

3.1 Microscopic Features

Figure 2(a) shows the transverse section of the overlayed steel indicating good bonding (I) between the substrate (S) and overlay (O). Microstructural features of the substrate (Fig. 2b) exhibit ferrite and pearlite while those of the overlay (Fig. 2c) consist of chromium containing carbides (A) in the dendrites and austenite plus carbide (B) in the interdendritic regions (Ref 11, 12).

3.2 Wear Behavior

Figure 3 is a plot of the variation of wear rate (m^3/m) with the distance traversed. Steady state wear is attained after an initial running in period. A comparison of steady state wear rate of the overlay and substrate shows that overlaying has appreciably improved the wear behavior at all loads. The degree of improvement varies from 50 to 60% (Fig. 4).

Minimum wear rate is observed at the intermediate load of 49 N for the overlay as well as the substrates. Further, in the case of steel substrate, the wear rates at 22 N and 49 N are not much different while there is an appreciable increase in the wear rate as a result of increasing the load to 67 N. In the case of the overlay, there is not much variation of wear rate with load.

3.3 Wear Surface Studies

The worn surface of steel samples at different loads are shown in Fig. 5. The worn surface is characterized by deep continuous grooves and some pitting at 22 and 49 N loads (Fig. 5a and b). At 67 N load, surface damage is severe, and peeling off is shown (Fig. 5c).

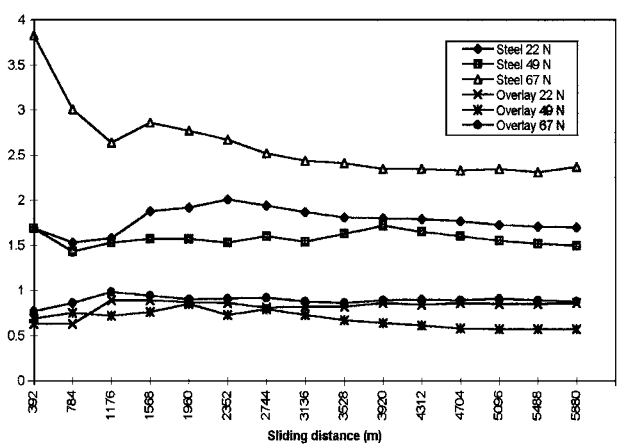


Fig. 3 Variation of abrasive wear rate with distance

In the case of hardfacing alloy, the worn surface exhibits shallow grooves with pitting, and there is no appreciable change in the nature of the grooves at high loads (Fig. 6). However, the amount of pitting is greater at higher loads.

3.4 Subsurface Studies

Figure 7 shows the transverse sections of the abraded steel substrate. The affected region observed in the micrograph indicates coarser microstructure as compared to the unaffected (bulk) region. The length of the affected region increases with the applied load. Loosely attached regions in the process of being separated from the bulk are observed at 49 and 67 N load (Fig. 7a and c, marked by arrow), which is not observed at 22 N load (Fig. 7a). Microcracking is observed along the sliding direction. The thickness of the affected regions increases with load while microcracks are observed mostly along the sliding direction (Fig. 7b, marked by arrow).

The transverse section of the overlayed steel shows microcracking below the wear surface perpendicular and along the sliding direction (Fig. 8a). Thin layers of damaged regions are also shown attached to the bulk. (Fig. 8b, marked by arrow).

From the plot of hardening as a function of distance from the worn surface (Fig. 9), it is shown that there is little effect of hardness with load for both steel and hardfacing alloy. In the case of steel, hardness levels of ~300 HV were observed at ≤170 μm from the worn surface. In the case of the hardfacing alloy, there is no appreciable subsurface hardening because the hardness values observed are in the hardness range of the hardfacing alloys (Ref 13).

4. Discussion

The wear response of samples varies depending on the hardness of the surface to be abraded. The improvement in wear resistance of overlayed samples compared to that of the substrate materials is due to the higher hardness of the overlayed samples. The increase in wear resistance at longer traversal distances in the case of the steel substrate (Fig. 3) is due to subsurface hardening (Fig. 9). The presence of microcracks in the bulk portion of the overlay below the wear surface suggests that the material underwent microcracking (Fig. 8). Accordingly, the wear rate initially increased with distance (Fig. 3). The steady state wear condition indicates a counterbalancing effect of the generation of work-hardened layer and its removal. Further, the maximum wear resistance at 49 N (Fig. 3) could be due to the generation of a relatively more stable layer at the load. Moreover, the nature of the loosely attached portions in the steels is indicative of debris in the form of long machining chips which arise due to the ductile nature of the

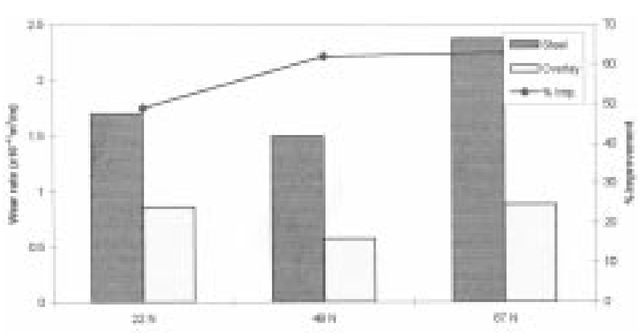
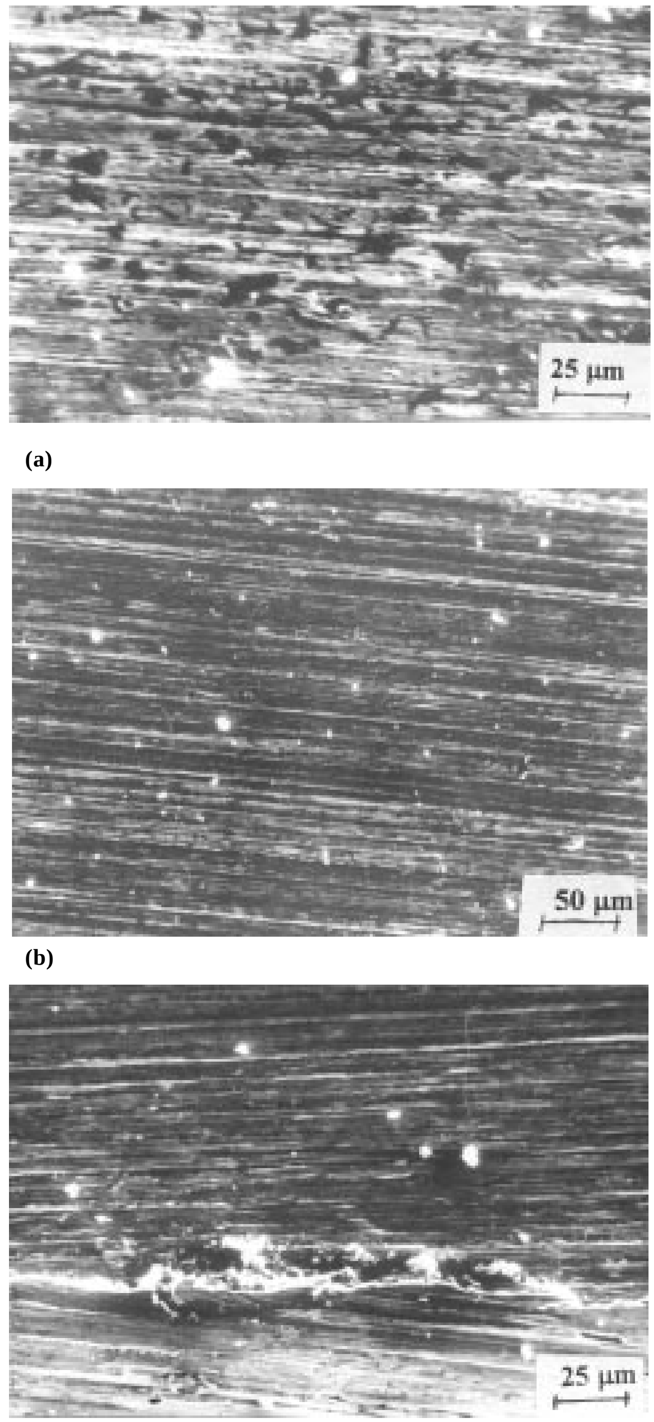


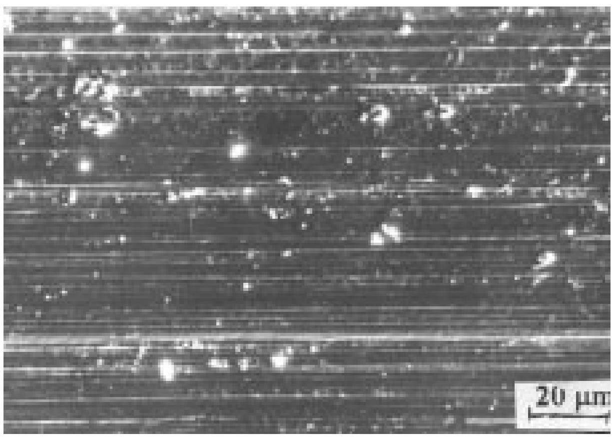
Fig. 4 Steady-state wear rate and corresponding percentage improvement



(a) (b) (c)

Fig. 5 Wear surface of steel substrate at applied loads of (a) 22 N, (b) 49 N, and (c) 67 N. Arrow indicates severely damaged regions.

(a)



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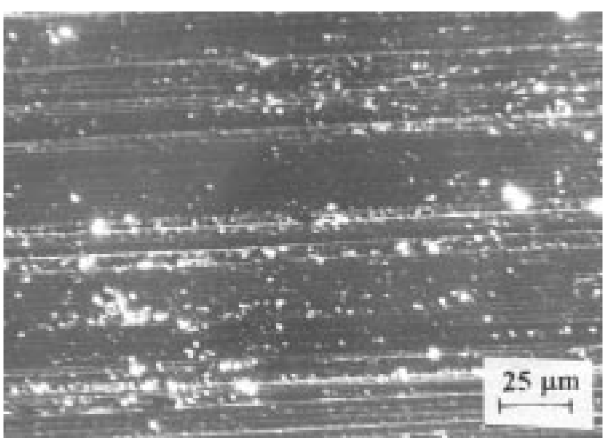
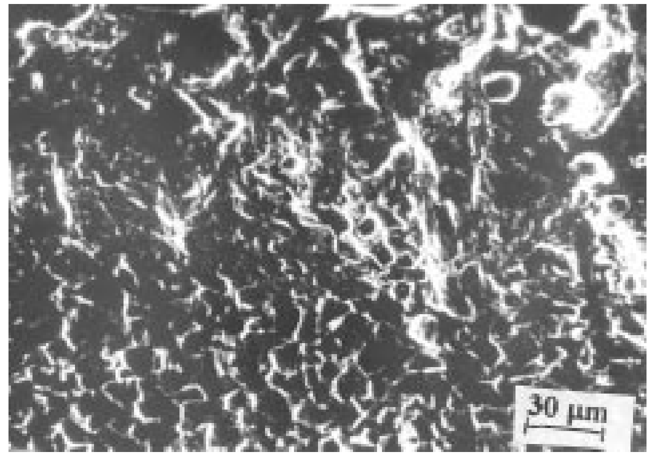
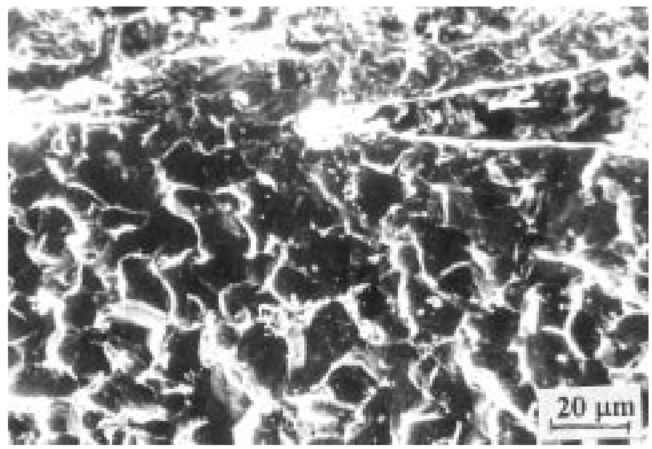


(c)

Fig. 6 Wear surfaces of the overlayed samples at the applied loads of (a) 22 N, (b) 49 N, and (c) 67 N



(a)



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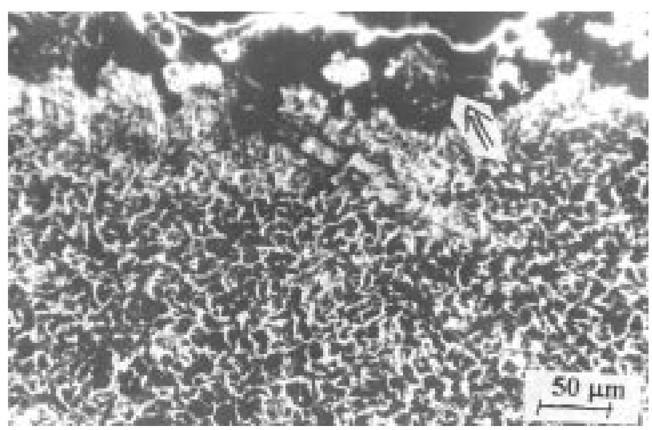
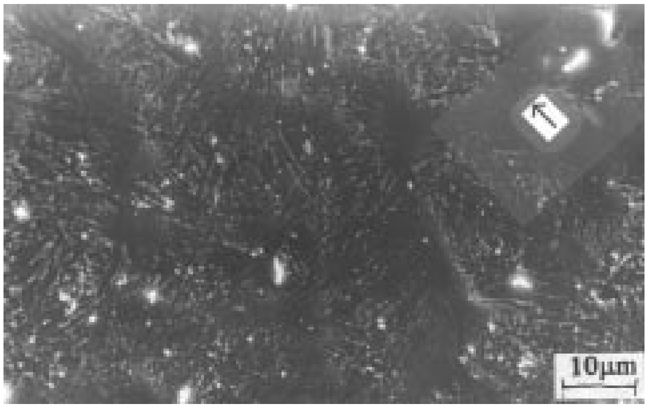


(c)

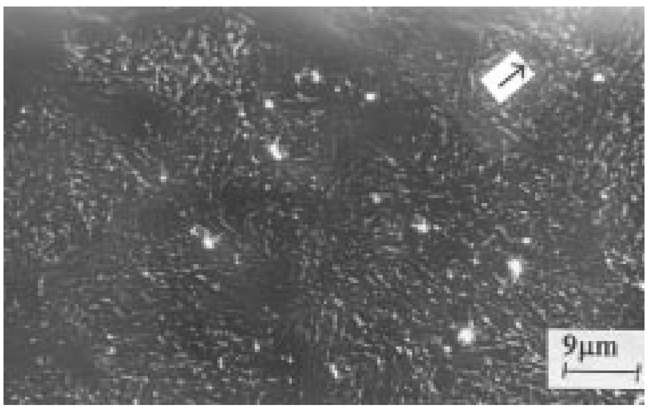
Fig. 7 Transverse sections of the abraded steel substrate at the applied loads of (a) 22 N, (b) 49 N, and (c) 67 N. Regions loosely attached to the bulk are indicated by an arrow in (c).

specimen (Ref 14-17). In contrast, the loosely affected regions in overlayed samples are smaller and fragmented which is only evident at the highest load (Fig. 8c) and indicative of the brittle nature of the overlay (Ref 18-19).

The extent of wear-induced work hardening was found to be considerably greater in a softer steel than in a harder steel during abrasion; in fact softening of the nearest vicinity of wear surface (in subsurface regions) of a harder steel was observed



(a)



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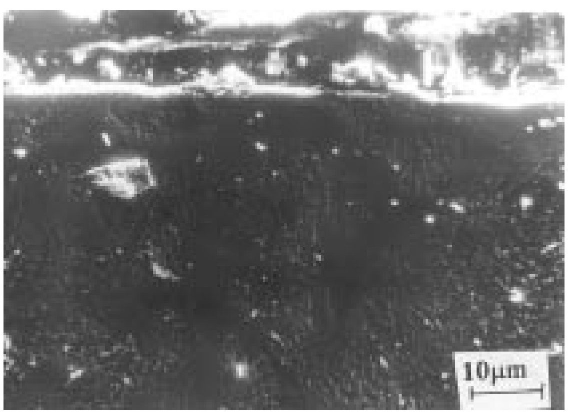

(c)

Fig. 8 Transverse sections of the abraded overlayed sample at (a) 22 N, (b) 49 N, and (c) 67 N. Arrow indicates microcracks.

(Ref 20-22). In subsurface work hardening of the softer steel, the greater deformability of the softer steel allows thicker regions to be attached to the bulk of which removal leads to micropitting and higher wear rates (Ref 20, 21, 23-26). Removal of the regions is caused when the thickness of the affected layer exceeds a specific limit. The layer forms on the mating surface of the specimens as a result of wear-induced subsurface deformation, grows in thickness in due course of wear, and gets removed subsequently through microcracking after attaining a thickness beyond a limit. The process of formation and removal of the layer goes on continually during wear and controls the wear behavior of materials accordingly. The advantage of the transfer layer in terms of improved wear resistance can be realized as long as the layer is stable and adheres firmly with the bulk. Wear loss increases in the remaining cases, that is, in the event of the formation of a premature transfer layer and the removal of the layer after attaining more thickness than optimum.

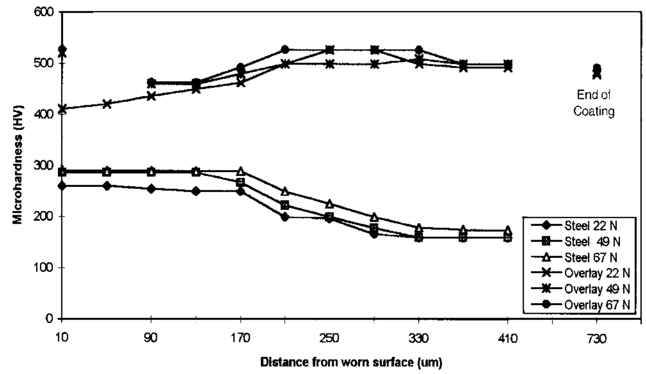

Fig. 9 Subsurface hardening of steel and hardfacing alloy (overlay)

5. Concluding Remarks

Overlaying improves the abrasive wear behavior of the steel substrate regardless of the test condition. The wear response of the specimens is affected by the distance traversed and the applied load. Various factors controlling the wear characteristics of the samples are observed to be their bulk hardness, subsurface work hardening and formation and stability of a wear-induced transfer layer and its subsequent removal through microcracking. The effectiveness altered with the changing wear conditions. The specimens' wear behavior also agreed with the nature of the wear surfaces and subsurface regions. As far as operating wear mechanisms are concerned, microploughing and micropitting (along with less microcracking) is principally responsible for causing material loss in the softer steel substrate at lower loads; the contribution of micropitting reduced as the applied load increased. The harder overlay material, however, experienced abrasion mainly through micromachining.

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