JMEPEG (1999) 8:711-715

Improvement in High Stress Abrasive Wear Property of Steel by Hardfacing

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(Submitted 5 August 1999; in revised form 30 August 1999)

High stress abrasive wear behavior of mild steel, medium carbon steel, and hardfacing alloy has been studied to ascertain the extent of improvement in the wear properties after hardfacing of steel. High stress abrasive wear tests were carried out by sliding the specimen against the abrasive media consisting of silicon carbide particles, rigidly bonded on paper base and mounted on disk. Maximum wear was found in the case of mild steel followed by a medium carbon alloy steel and a hardfacing alloy. Different compositions of steels and constituent phases present led to different wear rates of the specimen. The extent of improvement in wear performance of steel due to hardfacing is quite appreciable (twice compared to mild steel). Microstructural examination of the wear surface has been carried out to understand the wear mechanism.

Keywords hard facing surfaces, mild steel, surface tribology, tribology, wear

1. Introduction

In engineering industries, abrasive wear is probably the most significant cause of mechanical damage of equipment components coming in contact with abrasive/erosive bodies. Hard abrasive particles penetrate the components and cause damage in the form of material loss. The quality of the machine components prone to wear and tear depends on their surface characteristics, which include surface roughness, microstructure, and hardness. Hence surface deterioration is an important phenomenon for service life of components in many engineering applications (Ref 1, 2). The components of machines working under severe conditions, like a fluid pump handling slurry, the soil engaging part of the earth-moving machinery, and various agricultural implements, should be made of material that will be primarily able to withstand the adverse conditions of wear and tear (Ref 3). Steel is the most commonly used material for fabrication of these components. However, no specific composition and microstructure has been recommended for such application; this may be due to the fact that systematic studies on abrasive wear behavior of such steels are very limited. To overcome the various types of wear problems of the steel, hardfacing has emerged as an important process that improves the surface properties like hardness and wear resistance of the component. It can also be used for upgrading the inferior quality steel/material, which encounters severe wear and to restore the components for further use.

Hardfacing can be broadly defined as the application of wear resistant material on the surface of the components by weld overlay or thermal spray (Ref 2). The conventional methods of hardfacing include oxyacetylene gas welding, tungsten inert gas welding, submerge arc welding, and plasma transferred welding. Hardfacing by any open arc welding process is less expensive and can be applied to the critical part of the machine components prone to severe wear. In the present study hardfacing has been carried out on a mild steel specimen, and the abrasive wear of mild steel overlayed with hardfacing material has been compared with that of mild steel and medium carbon alloy steel.

2. Experimental Procedure

2.1 Specimen Preparation

Hardfacing was carried out by the open arc welding process using a welding machine (ESAB India Ltd., Calcutta, India) and hardfacing electrodes supplied by EWAC Alloys Ltd (Eutectic Corp., USA). Arc was established in between the substrate steel and hardfacing electrode (length, 330 mm; diameter, 4 mm: current, 150 to 170 A). The arc was moved over the substrate steel (mild steel), and melting and fusion of the electrode occurred followed by overlaying the weld deposit on the mild steel surface. A uniform layer (approximately 1.5

Table 1 Chemical composition and hardness of material

			Composition, wt%					
Specimen No.	**Material**	**Hardness, HV**	**C**	**Mn**	**Si**	**Cr**	**Mo**	**Fe**
1	Mild steel	162	0.32	…	0.35	…	…	bal
2	Medium carbon alloy steel	254	0.4	0.2	0.4	0.2	0.02	bal
3	Hardfacing material	705	0.50	0.30	0.45	6.0	…	bal

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mm thick) was deposited on the surface of mild steel. Before deposition of the overlaying material, the substrate was thoroughly cleaned to remove the oxide layer and to provide good bonding between the substrate and hardfacing material. Two types of steels and one hardfacing material have been selected for the study. Table 1 gives the chemical composition and hardness of the steels and hardfacing alloy.

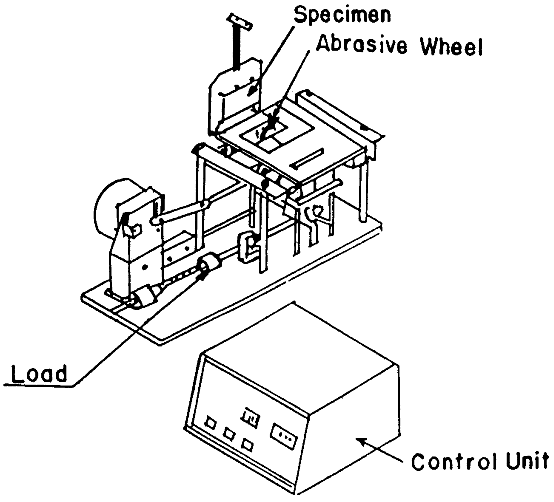

Fig. 1 Suga abrasion tester

The specimens (4 by 6 by 6 mm) of the hardfacing material, medium carbon alloy steel, and substrate, that is, mild steel were prepared for microstructural examination using a standard metallographic technique. The polished samples were etched with 2% nital solution. For high stress abrasion test, the specimens of 35 by 45 by 4 mm were prepared following the similar process as used for making specimens for microstructural examination except etching. In order to have good surface contact with the abrasive media, all the specimens were ground to a roughness value of 0.1 µm.

2.3 *Abrasive Wear Test*

High stress abrasion tests were conducted on a metallographically polished sample using an abrasion tester, model NUS-1 (Suga Test Instruments Co., Ltd., Tokyo, Japan). Figure 1 shows a schematic diagram of the test apparatus. In this test, the specimens were slid against a wheel on which abrasive paper (SiC) was rigidly fixed. This SiC-abrasive paper acted as an

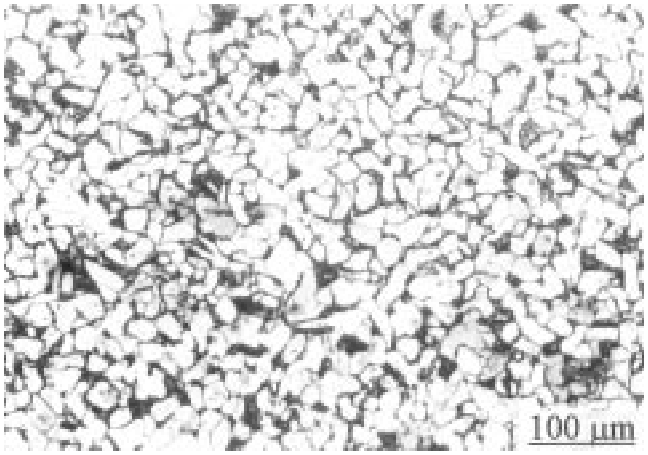

Fig. 2 Microstructure of mild steel

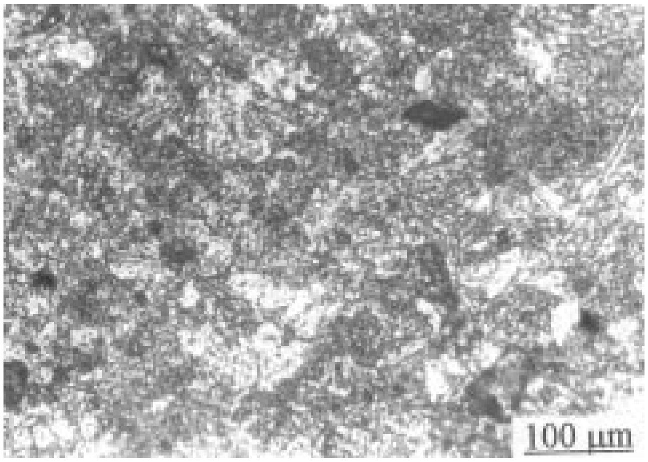

Fig. 3 Microstructure of medium carbon alloy steel

Fig. 4 Microstructure of overlaying material

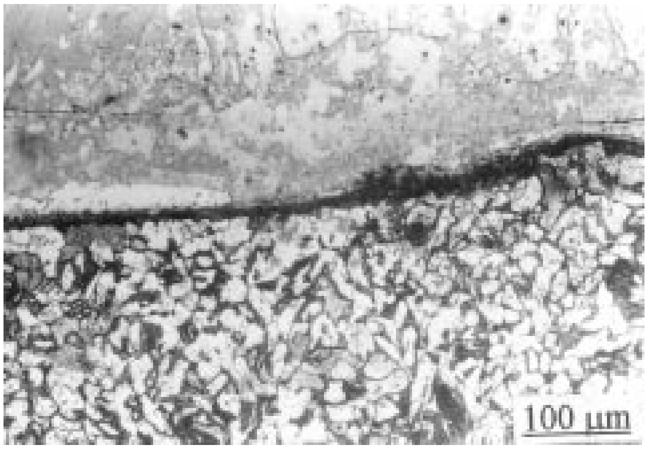

Fig. 5 Microstructure showing interface between overlaying material and mild steel

abrasive medium, and the average abrasive particle size was 53 μm. During the test, the specimen underwent reciprocating movement against the abrasive media. The load was applied by the cantilever mechanism. The abrasive wheel rotated slowly to facilitate the exposure of fresh abrasive particles to the specimen. The wheel on which the abrasive media was fixed completed one revolution on its own axis during 400 strokes of the specimen. After each 400 strokes, the specimen traveled a distance of 26 m. The specimens were thoroughly cleaned by acetone and weighed on a microbalance, capable of weighing 10^{-5} g before and after the test. The wear rate was calculated following a weight loss measurement technique. Abrasion tests were conducted at a fixed load of 7 N for various sliding distances (26 to 182 m) using the same abrasive media.

2.4 Microscopic Observation

The microstructure of each specimen (polished and etched) was observed using the optical microscope. For the wear surface observations, the tested specimens were cut to the size of 10 by 15 by 4 mm from the worn region and observed under a scanning electron microscope (SEM). Prior to SEM examinations, the specimens were gold sputtered for better resolution.

3. Results and Discussion

3.1 Material and Microstructure

The abrasive wear characteristics of the material are strongly governed by its microstructure. Figure 2 shows the microstructure of the mild steel. It is evident from this figure that the microstructure consists of a pearlitic phase in the matrix of ferrite. The ferrito-pearlitic microstructure with elongated ferrite grains of mild steel plate indicates that the steels are in hot worked condition. The steel contains around 35% pearlite and 68% ferrite. This is in good agreement with the theoretically calculated volume fraction of the phases using the lever rule from iron-carbon phase diagram (Ref 4-6).

Figure 3 shows the microstructure of a medium carbon alloy steel. It consists of tempered martensitic structure with fine carbides in ferrite matrix. The medium carbon alloy steel contains only 0.2% Cr and 0.02% Mo with 0.4% C. However, in the present investigation, the structure was noted to be tempered martensitic. This implies that the steel was received in the quenched and tempered condition. During quenching after austenization, the steel, generally, gave full martensitic structure (over-saturated solution of carbon in iron with tetragonal crystal structure). This was initially transformed into ε-carbide ($Fe_{2.3}C$), which in due course, transformed into cementite, that is, Fe_3C and distributed into the transformed martensite (ferrite body-centered cubic structure). The carbides were in the nanometer size range.

Figure 4 shows the microstructure of hardfacing material on mild steel substrate. It is evident from Fig. 4 that the overlaying material gives a fine dendritic structure, wherein the dendrites are of ferrite and the interdendritic region are of primary and secondary carbide (Ref 5). This is due to the presence of high chromium in the overlaying material and solidification of the overlayed alloy on the steel substrate. Figure 5 shows the bonding between the substrate steel and overlaying material. It is evident from Fig. 5 that the bond between substrate and hardfacing material is reasonably good, and the nature of the bonding is fusion. It is noted that the interface regions are free from any porosities, defects, and segregation.

3.2 Abrasive Wear Behavior of the Material

Figure 6 shows the wear rate as a function of sliding distance for different specimens at a fixed load of 7 N. It is noted that the wear rates of an overlayed material are lower than that of mild steel and medium carbon alloy steel. The wear rate at the later stage is considered to be the stable wear rate. The initial wear rate of a material is significantly high, which is termed as run-in wear. At the beginning of wear, the contact area between the abrasive particle and the asperities on that specimen surface is relatively low, that is, fewer abrasives are in contact with the specimen surface, and the whole load is shared by a small number of abrasives. This may have caused a higher amount of effective stress on the individual abrasives and on the asperities of the specimen, which led to more plastic deformation of the asperities and more material removal in this stage, that is, run-in wear. But at the same time, the number of wear grooves formed were less because of fewer abrasive particles taking part in material removal. As a result, the overall effect of high stress and fewer abrasives may cause stable wear rate. In this investigation, however, tests were conducted using the same abrasive. Because of this fact, as the sliding distance progressed, the cutting efficiency of the abrasive media reduced, hence exhibiting reduction in the wear rate. The cutting efficiency of abrasives reduced the progress of sliding distance, which may have been because of the chances of blunting and detachment of the abrasive from its surface. Additionally, some of the material also transferred into the interabrasive particles regions of the abrasive media (logging) or at the tip of the abrasive particles (capping). These factors further reduce the cutting efficiency of the abrasive media (Ref 2, 6, 7).

During abrasion, material is generally removed by cutting or ploughing by the abrasive particles. It is quite obvious that the total energy is not spent on cutting or ploughing. A part of the energy is spent on plastic deformation of the wear surface. This type of deformation causes work hardening of the subsurface and may have led to reduction in wear rate. However, after a specific sliding distance, the effect of all the previously mentioned factors stabilized and caused stable wear rate at the later stage.

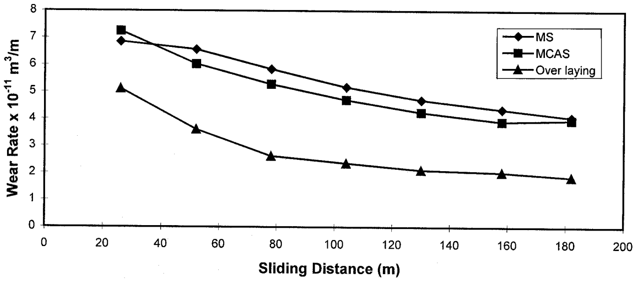

Fig. 6 Abrasive wear rate of mild steel, medium carbon alloy steel, and overlaying material as a function of sliding distance

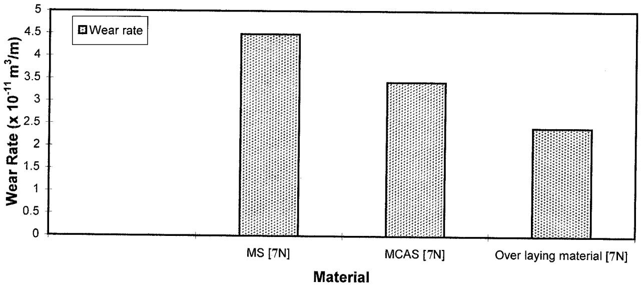

Fig. 7 Abrasive wear rate of mild steel, medium carbon alloy steel, and overlaying material at a sliding distance of 182 m

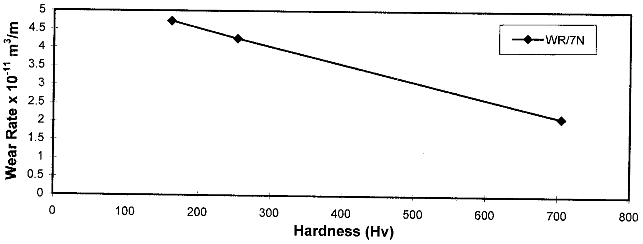

Fig. 8 Abrasive wear response of material as a function of hardness

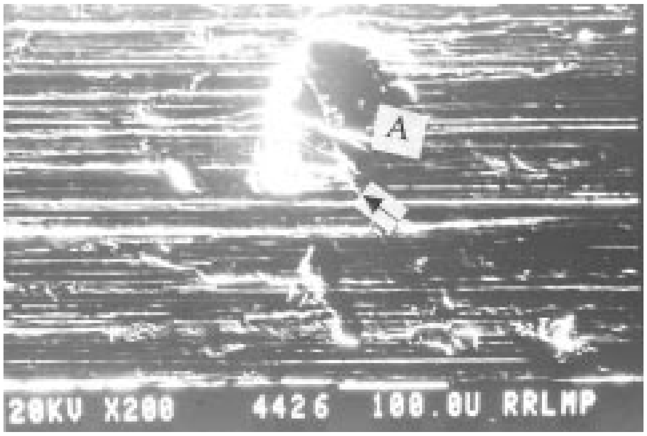

Fig. 9 Wear surface of mild steel

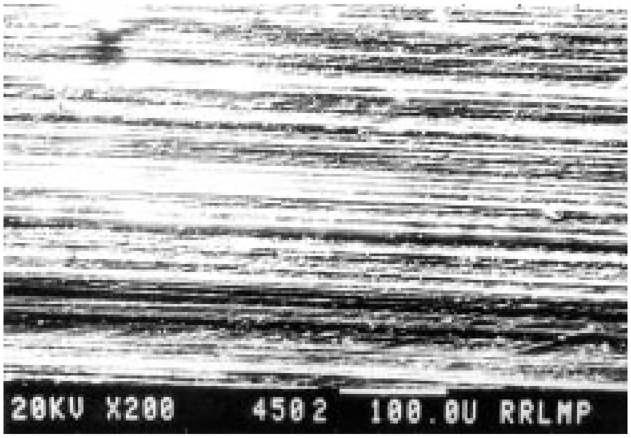

Fig. 10 Wear surface of medium carbon alloy steel

Figure 7 shows the wear rate of mild steel, medium carbon alloy steel, and overlaying material after the sliding distance of 182 m and at the fixed load of 7 N. It is evident from the figure that the overlaying material exhibits a minimum wear rate, which is approximately half of the wear rate of the mild steel. The wear rate of a medium carbon alloy steel falls in between the wear rate of a mild steel and hardfaced steel.

Hardness of the materials plays an important role in determining the wear characteristics. For pure metal and single phase material, wear is generally inversely proportional to the hardness. However for the multiphase alloy, the microstructure also contributes a significant effect on the wear of the material (Ref 8, 9). Hardness of mild steel is 162 HV, and the hardness of the medium carbon alloy steel is 254 HV. The difference in the wear rate may be primarily due to the hardness difference. The stable wear rate of different materials at a 7 N load is plotted as a function of their hardness in Fig. 8. Note that the wear rate decreases with an increase in hardness value.

It is evident from Fig. 8 that the wear rate follows a linear relationship with hardness in the present case. This is in good agreement with earlier reports (Ref 1, 2, 4, 7). The abrasive particles under load penetrate into the surface of the material, and due to reciprocating motion, the penetrated particles cause damage of the specimen surface by cutting or ploughing. The harder the surface, the lesser the extent of penetration and damage as well. In this case wear is due to ploughing, wedging, or cutting. As a result, formation of grooves occurs on the wear surface.

The mechanism of wear may vary with the material. The micrographs of wear surface of the specimens, that is, mild steel and medium carbon alloy steel at a load of 7 N are shown in Fig. 9 and 10, respectively. Wear surface of the mild steel (Fig. 9) shows deeper and wider grooves as compared to that of an alloy steel (Fig. 10). Damaged regions in large fraction can also be seen on the wear surfaces. The wear grooves of the medium carbon alloy steel are more continuous and shallower than that of the mild steel. Apart from this, the flaky materials along the wear tracks (arrow marked) are noted to be more in mild steel (Fig. 9) as compared to the medium carbon alloy steel (Fig. 10). This suggests that the ploughing action is more dominant in mild steel. In some places, the abrasive particles become detached from the abrasive media and are subsequently entrapped on the wear surface (see A in Fig. 9). This may be due to the lower hardness of the mild steel.

After some time, the entrapped particles become activated and roll over the specimen causing deep scratches and changing of wear tracks (arrow marked). The wear rate of hardfaced material is very low compared to the mild steel and the medium carbon alloy steel. Hardness of the hardfacing layer is 705 HV. Abrasive particles are not able to penetrate into the surface due to high hardness of the specimen. If particles are detached from the abrasive media they just roll over the specimen surface without causing any significant damage. The wear surface of overlaying material shown in Fig. 11 depicts these facts. The wear grooves in the hardfacing material are more continuous than that of the mild steel and the medium carbon alloy steel. Additionally, the grooves are finer and shallower than that of

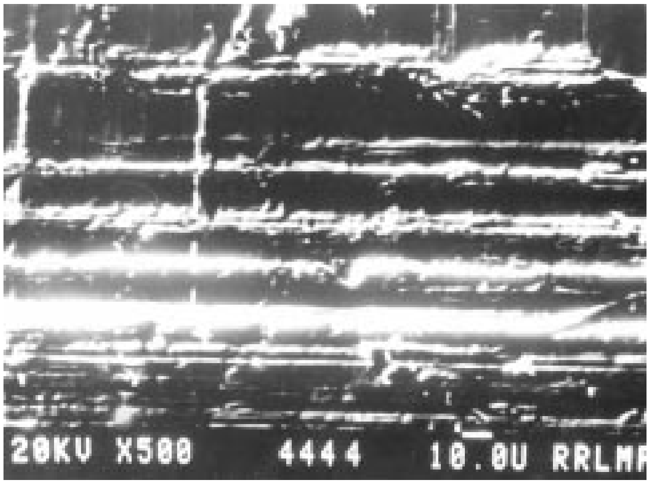

Fig. 11 Wear surface of overlaying material

other two materials. Furthermore, a lesser amount of flaky material has been noted along the wear track. This signifies that the cutting type of wear mechanism is dominating on the hardfaced steel. The overlaying material contains a larger amount of carbides and more alloying element as compared to mild steel and medium carbon alloy steel because of high chromium content. Because of the high alloying content, the hardness of the overlaying material also becomes significantly high as compared to that of mild steel and medium carbon alloy steel. Additionally, the primary and secondary carbides protect the surface from excess wear.

4. Conclusions and Recommendations

The wear rate of the hardfacing alloy is lower than that of uncoated mild steel and medium carbon alloy steel. The maximum wear rate was observed in mild steel followed by medium carbon alloy steel. The hardfacing alloy exhibited a minimum wear rate due to maximum hardness and the finer microstructure containing a larger amount of hard carbide. The wear is noted to decrease with an increase in sliding distance. This may be due to blunting, capping, and logging of abrasives and work hardening of the subsurface. After a specific sliding distance a stable wear rate was achieved. The nature of wear grooves depends on the hardness of the material. When hardness is lower, the ploughing type of mechanism predominates. When the material is ductile as in the case of mild steel, the grooves are deeper and wider. In the case of higher hardness, that is, for a hardfacing alloy, the cutting type of mechanism predominates. The wear rate was found to decrease linearly with an increase in material hardness.

It may also be concluded that hardfacing is very effective and a techno-economic solution to the wear problem of the material. The cost of the overlaying material per unit area may be higher than that of steels, but when these are applied only on the critical area of the component, the increase in the cost may be insignificant when considering the improvement in its performance. Apart from these hardfaced components, the components can be reused after overlaying the worn part of the component again. Thus, hardfacing had a greater opportunity to improve and to restore the performance of wear resistant components in the most economic way. Therefore, use of the hardfacing is a much more attractive solution than to change the material composition and heat treatment.

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