Wear behavior of hardfacings on rotary tiller blades

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Abstract

A rotary tiller is a mechanized agricultural implement popularly used to save time, human effort and fuel in preparation of soil bed. However, under complex abrasive environments, tiller blades are subjected to extreme surface wear, particularly in dry sand, which considerably affects its service life. The aim of this study was to improve the service life of the tiller blade in order to cut the idle time required to replace the blade periodically during cultivation. The aim was carried out by means of hard-facing, where the effect of the hard facings on the extent of wear and the wear characteristics of the tiller blades were examined. The influence of Cr is studied by hard facing of leading edge of tiller blades made of high tensile steel by gas tungsten arc welding using four different electrodes. The comparison of hard faced blades with un-hard faced (standard) blade was made through field and laboratory test. A field test was conducted on a 50 acre area of rice field after combine harvesting. During field test, rice stubbles were present and the condition of soil was dry and sandy. Different positions were selected for the test blades in the tiller to collect the meaningful data. The average wear rate of the un-hard faced blade was found as 7.08 gm/acre, while those of 5HCr, 7.5HCr, 12HCr and 8HCr hard facings were 5.02, 4.3 2.84 and 4.22 gm/acre respectively as indicated by field test results. A significant improvement was observed in the wear protection provided by hard facings over the un-hard faced blade.

Keywords: Rotary tiller; Gas tungsten arc welding; Pin-on-disk; Abrasive wear

1. Introduction

Abrasive wear is a major cause for the premature failure of many agricultural ground tools especially engaged in some dry land agricultural areas. Heavy agricultural equipment operators and farmers always faced with the frequent

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labor, equipment downtime and reinstating costs of worn out earth engaging components. The tillage capacity of the worn out tools decreases whereas the fuel penalty increases [1].

A rotary tiller is a motorized cultivator which conjugates many conventional tillage operations of such as disc plough, cultivator and mould board plough simultaneously to merely a single tillage. The rotary tiller is one of the most efficient equipment among the soil bed preparation agricultural tools which saves lot of operating time and human effort. It also helps to improve the organic health of soil as it incorporates the rice stubbles after harvesting [2].

Despite the fact that the rotary tillers have become world famous for preparation of seedbed in fields, under pulsating loads its blades are subjected to high abrasive wear and fatigue, which may confine its use in certain applications. Generally, the life span of tiller blade is predicted by wear. As this wear inflate the total cost of agricultural production, many heat treatment processes are often carried out to lengthen the service life of tiller blades. Under aggressive field environments, sufficient abrasive wear protection may not be provided solely by heat treatment. Still, even after heat treatment, high abrasive wear is observed, ensuing in frequent blade replacement during tillage [3].

Surface modification techniques have emerged as an alternative processes to curb wear resulted from abrasive action of soil particles. These modification methods improve the surface properties like hardness and wear resistance of tiller blades. A pertinent review of the literature has revealed that very few researchers have provided some techniques to enhance the abrasive wear resistance of earth engaging tools in agricultural sector such as surface coatings by Karoonboonyanan et al. [3], Kang et al. [2] and hard facing by Bayhan [4]. Dasgupta et al. [5] stated that when abrasion conditions become too severe for ground engaging tools, or when the cost of equipment downtime requires more frequent parts replacement, then the expense of using hard facing technique can be justified and at the same time the technique becomes less expensive than designing the entire component using improved strategic materials.

In this case study hard facing was selected as a surface modification technique. Gas Tungsten Arc Welding (GTAW) process was selected to deposit the weld overlays. The aim of this case study was to ascertain the wear behavior of rotary tiller blades hard faced with four different commercial hard facing alloys and comparing these with the standard heat treated tiller blades under laboratory and field conditions of operation. The wear rates as observed from laboratory and the field test can then be used to predict the service lives of tiller blades.

2. Experimentation

2.1. Substrate and Hardfacing Alloys

The chemical composition of rotary tiller blades made from high tensile steel (EN-14B) is given in Table 1. EN-14B offers good combination of mechanical properties which are required to exhibit excellent resistance to pulsating loads as necessitated by tiller blades during field operation. EN-14B is carbon manganese steel with carbon maximum upto 0.3%. The tiller blades obtained a hardness of 436 HV after oil quenching from a temperature of 780-810°C and tempered at 430-500°C [2]. The leading edges of tiller blades have been covered with four different hardfacing electrodes to increase their hardness as shown in Figure 1 (a) before grinding (b) after grinding. These hardfacing alloys are designated according to the percentage of chromium present in the composition as 5HCr, 8HCr, 12HCr, 7.5HCr with 5, 8, 12 and 7.5 percent of Cr respectively. After deposition of 5HCr, 8HCr, 12HCr, 7.5HCr hardfacing alloys on substrate with GTAW process provided the hardness as 576, 667, 713 and 654 HV respectively. The first reason for these hardfacing alloys being chosen is that they provide high resistance to wear and second one is that they are comparatively economical on the market.

| Grade | % ELEMENTS |
|-------|-------------|
| EN-14B | C | Mn | Si | S | P | Al | Cu | Cr | Mo | Ni | Pb | V | W |
|       | 0.29 | 1.33 | 0.22 | 0.021 | 0.022 | 0.02 | 0.23 | 0.41 | 0.04 | 0.12 | 0.001 | 0.02 | 0.03 |
Figure 1 Leading edges of the tiller blades hardfaced with 5HCr, 8HCr, 12HCr, 7.5HCr (a) before grinding (b) after grinding

Table 2 Welding parameters used in the test

| Parameters                              | Hardfacing Alloys | 5HCr | 8HCr | 12HCr | 7.5HCr |
|-----------------------------------------|-------------------|------|------|-------|--------|
| Electrode diameter (mm)                 |                   | 4    | 4    | 4     | 4      |
| Arc voltage (V)                         |                   | 240  | 240  | 240   | 240    |
| Welding current (AC/DC) Amp             |                   | 169/AC | 144/DC+1 | 125/DC+1 | 155/DC+1 |
| Welding speed (mm/min)                  |                   | 62-65 | 75-80 | 125-130 | 65-70  |
| Gas Flow Rate (LPM)                     |                   | 15   | 10   | 10    | 10     |
| Deposition rate (kg/h)                  |                   | 3.4  | 4.2  | 3.8   | 4.7    |
| Gas Pressure (kg/cm²)                   |                   | 2.5  | 2.5  | 2.5   | 2.5    |
| Type of Gas                             |                   | Argon | Argon | Argon | Argon  |
| Tungsten electrode diameter(mm)         |                   | 2.4  | 2.4  | 2.4   | 2.4    |

Table 3 Chemical composition of four hardfacing alloys by wt.%

| Hardfacing electrode | Chemical composition (wt.%) of hardfacing alloys |
|----------------------|-----------------------------------------------|
|                      | C    | Si   | Mn   | Cr   | Mo  | P  | S   | V   | Fe   |
| 5HCr                 | 0.7  | 0.45 | 0.4  | 5    | 0.8 | -  | -   | 0.7 | Balance |
| 8HCr                 | 0.4  | 0.5  | 0.6  | 8    | 0.5 | -  | -   | -   | Balance |
| 12HCr                | 0.8  | 0.01 | 0.48 | 12   | -   | 0.021 | 0.03 | 0.6 | Balance |
| 7.5HCr               | 0.5  | 0.6  | 0.1  | 7.5  | 0.4 | -  | 0.03 | -   | Balance |

The typical welding parameters used in the present study are given in Table 2. These parameters were kept within the range as specified by the manufacturers and the sizes of the electrodes used were of 4 mm diameter size. The hardfacing alloys with high content of chromium were selected since the high chromium content exhibits the minimum abrasive wear rate as stated by Kumar et al. [6]. The major characteristic feature offered by manufacturers
of these hardfacing alloys is that they are used for overlaying to enhance the abrasive wear resistance of such as excavator bucket teeth, tillage tools and mining tools. For each composition of weld overlays, a weld deposit up to 2 to 3 mm thickness has been made on leading edges of blades as shown in Figure 1. This thickness was achieved by depositing hardfacing electrodes in number of passes where the desired thickness was not achieved in single pass.

A good inter-pass temperature control was maintained as a means of avoiding cracking in the hardfaced layers. The chemical compositions of the four electrodes are given in Table 3. Care has been taken to avoid any transverse oscillation of the electrode throughout the process to deposit stringer beads which controls the dilution rate within limits as specified by Selvi et al. [7].

2.2. Test Methods

2.2.1 Laboratory Procedure

![Figure 2 (a) Schematic of hardfaced specimen (b) Pin-on-disk wear test apparatus as per ASTM G99-95 standards (c) Specimen slide against hardened disk (d) Electronic balance]

The cylindrical pins of diameter 8 mm and length 30 mm were prepared for wear test to be performed on pin-on-disk tribometer as per ASTM G99-95 standards [7]. These specimens were hardfaced at their cross-section on one side and subsequently machined to specified size as shown in Figure 2 (a). The pin-on-disk test apparatus (TR-201, Ducom, India) used in this study is shown in Figure 2 (b).

The wear tests were performed at atmospheric temperature and under dry sliding conditions. The pin slides against the hardened disk (62-65 HRC) made of hardened steel as shown in Figure 2 (c). Before and after the test, all the specimens taken for analysis were cleaned and then weighed using an electronic balance as shown in Figure 2 (d) with a least count of ± 0.0001 g. During the wear test, the sliding velocity of pin against the hardened disk was maintained at 1 m/s at different applied loads of 20 N, 40 N and 60 N for 90 min. cycle time.

2.2.2 Field Test Procedure

2.2.2.1 Blade Preparation and Configuration

The deposition of hardfacing alloys on the leading edge of tiller blade was carried out by the same operator to minimize the imperfections as much as possible. About one and a half inch width of the leading edge was hardfaced as it has been elucidated by Karoonboonyanan et al. [3] that the wear to have mostly occurred on the leading edge towards the outer end. The welding speed, deposition rate, intensity, fumes, spark and other parameters of welding process were closely controlled. One un-hardfaced and four hardfaced tiller blades were fitted at different planes of the tiller as shown in Figure 3 (a-d). The blades were positioned at outer planes of the tiller since it has been investigated by Salokhe et al. [8] that the tiller blades which were located at the outermost planes i.e. the left side of
the left flange and the right side of the right flange, suffered the extreme wear damage. The least wear damage was observed at the innermost planes.

![Figure 3 Position of hardfaced blades fitted on rotary tiller: (a) 5HCr and 7.5HCr hardfaced blades; (b) 8HCr (c) 12HCr (d) Standard heat treated (un-hardfaced) blade](image)

2.2.2.2 Field Trial and Assessment

In order to ascertain the wear behaviour of un-hardfaced and hardfaced tiller blades in field condition, a 50 acre of a rice field full of stubbles was selected for field test in Sanghera village, Barnala district, Punjab state, India. After paddy harvesting, the condition of soil in this area was hard, dry and sandy. A significant amount of wear was observed on blades even after tillage of very small area due to the high abrasiveness of the soil and high dynamic load on the blade surface.

The tiller was driven by a tractor (Arjun 605 DI, powered by 3192 cc, 60 HP, 4- cylinder, water cooled) through its power take-off (PTO) shaft at the speed of 580 r.p.m. The average tillage speed was about 1.5 km/h, yielding theoretical field capacity of about 1.2 acre/h. Owing to extra turning time at headland and idle time for removing entangled residue, the real field capacity was found to be 1 km/h.

The weight loss of each blade was recorded before and after each experimental period to assess the wear behaviour in field conditions. This weight loss was then used as an indicator of the amount of wear. The wear rate was then calculated simply by dividing weight loss with tilled area, the unit is gram per acre (g/acre). Thereafter the term wear resistance index (WRI) was calculated as the wear rate of the un-hardfaced blade divided by that of the hardfaced one. The higher the WRI, the hardfacing is more protective.

3. Results and Discussions

3.1 Laboratory analysis

The percentage wear loss at different normal loads applied to the specimens is presented in Fig. 4 (a-c). The graphs were plotted between the percentage of Chromium present in substrate and hardfacing alloys and the percentage of wear loss. The minimum amount of wear loss was observed with hardfacing alloy having 12% Cr content. On the other hand un-hardfaced (EN-14B) observed maximum wear loss with chromium 0.41%. It is clearly depicted from Fig. 4 (a-c) that the wear loss remains between these limits for the hardfacing alloys having Cr content as 5%, 7.5% and 8%. It shows that as the percentage of Cr increased, the wear resistance of hardfacing welds has increased. This increase in wear resistance has been attributed to the formation of larger amounts of primary and secondary carbides in the ferrite matrix which is in accordance with the investigations of Amirsadeghi.
& Sohi [9] and Kumar et al. [10]. The wear loss trend also revealed that as the normal load applied to the specimen increases from 20 N to 60 N, the amount of weight loss owing to wear increases.

The cumulative weight loss as a function of a sliding distance for different materials at different normal loads is shown in Fig. 5 (a-c). The wear loss for all the materials increases linearly with an increase in sliding distance and normal loads. It is evident from Fig. 5 (a-c) that the wear loss of hardfacing alloys is lower than that of un-hardfaced EN-14B. The hardfacing alloy 12HCr exhibits a minimum cumulative weight loss. The present study was conducted at constant normal loads (20 N, 40 N and 60 N) and at fixed linear sliding velocity of 1 m/s. Hence, it is expected that the variation in cumulative wear loss in different hardfacing alloys and substrate is primarily due to the variation in their microstructure, chemistry and hardness. These above facts may also lead to different wear mechanisms for different hardfacing alloys. A ploughing type of wear mechanism prevails in soft materials whereas cutting type dominates in harder ones. The trend of sliding wear shows that the weight loss of the hardfacing alloys decreases as the Cr percentage increases. This behaviour is attributed to the chromium surface alloying that lead to the formation of hard chromium carbide which enhanced the high load bearing capacity of alloy, similar results were reported by Amirsadeghi & Sohi [9] and Selvi et al. [7].
Figure 5 Variation of cumulative weight loss with the dry sliding wear distance at (a) 20 N; (b) 40 N; (c) 60 N.

3.2 Microscopy of Wear Surface

Figure 6 Micrograph of the wear surface of (a) Un-hardfaced (b) 5HCr (c) 7.5 HCr (d) 8HCr (e) 12HCr; at 60 N

As discussed above, the occurrence of different types of wear mechanisms may depend upon the chemistry, microstructure and hardness of the material [6]. To assess which wear mechanism dominates among the different hardfacing alloys and substrate, the micrographs of the worn surfaces of the specimens were examined. The micrograph of un-hardfaced specimen in Fig. 6 (a) shows much deeper and wider grooves along the wear track
which resulted into more damaged regions. This specifies the ploughing type of wear mechanism is prevailing in un-hardfaced EN-14B steel. Fig. 6 (b) shows comparatively less deep and wider grooves than un-hardfaced one, which also indicates a ploughing type wear mechanism. In comparison to this, as shown in Fig. 6 (e), significantly shallower and finer and more continuous wear grooves along the wear track indicate that micro-cutting was the dominating wear mechanism in 12HCr. Whereas moderate depth and width of wear grooves was observed for worn surfaces of 7.5HCr and 8HCr as shown in Fig. 6 (c & d) respectively. These suggest that both ploughing and micro-cutting mechanisms are equally responsible for the wear of 7.5HCr and 8HCr hardfacing alloys.

The un-hardfaced substrate contains a matrix of ferrite which has higher ductility and lower hardness, causing ploughing to become the dominating wear mechanism, whereas 12HCr causing cutting to be the dominating wear mechanism owing to hard chromium carbides. However, for 8HCr and 7.5HCr hardfacing alloys, both these mechanisms, cutting and ploughing, were taking place simultaneously.

3.3 Field Trial Observations

A field test has been carried out on a rice field after mounting the un-hardfaced and hardfaced blades on a tiller. The blades show various amount of wear as shown in Fig. 7 as observed from the field test results. The wear damage trend of all the blades showed that the wear starts from outer end of the leading edge and moving inwards, towards the base of the blade, same results were reported by Kang et al. [2] and Karoonboonyanan et al. [3]. The un-hardfaced blade (standard heat treated blade) exhibits the maximum amount of weight loss during the field test as shown in Fig 7 (e). The shape of the outer end of the leading edge changed to a complete curvature and nearly whole leading edge has worn out. The extent of wear is rather severe even though the test was conducted on short area of 50 acre. This is owing to the high abrasiveness of the soil particles, which can greatly accelerate the wear process.

In contrast, the blade hardfaced with 12HCr alloy shows significantly lower wear damage as shown in Fig. 7 (c) compared to un-hardfaced one. The leading edge is still retaining its profile and weld overlay is present along the edge. This is because of the high wear resistance of hard chromium carbide which is induced at the surface of blade’s leading edge by hardfacing. The underlying substrate is just exposed along the outer end of the leading edge. On the other hand, the leading edge near the base of the blade is completely covered by the hardfacing alloy.

The blades hardfaced with 8HCr and 7.5HCr shows moderate wear damage as shown in Fig. 7 (b & d). The change in blade contour and dimensions at the outer end of the leading edge indicates the wear of underlying substrate. The wear damage most occurred at the leading edge, which is responsible for the significant weight loss after field test. The weld overlay at the leading edge close to the base of the blade is partially abraded.

Figure 7 Hardfaced rotary tiller blades after field test of 50 acre (a) 5HCr. Hardfaced alloy is almost completely removed and large metal removed from leading edge (b) 8HCr. Hardfacing alloy is significantly removed, still partially retaining leading edge profile (c) 12HCr. Significant amount of hardfacing alloy is still present at leading edge (d) 7.5HCr. Large underlying substrate is exposed (e) Un-hardfaced. Large amount of metal is removed from leading edge and complete curvature of outer end profile.
As shown in Fig 7 (b), the blade hardfaced with 5HCr underwent severe wear damage. The wear appears to start from the leading edge where most wear damage occurred, exposing a large area of the underlying substrate. Under the aggressive environments, the overlayed hardfacing alloy on the leading edge as well as the substrate is totally removed because of extreme abrasive qualities of the soil. This hardfacing alloy does not provide much abrasive wear resistance in comparison to others.

3.4 Weight Loss and Wear Rate Assessment

The results of the field tests were plotted between the cumulated weight loss and tilled area of the field test at various intervals as shown in Fig 8, in order to ascertain the precise wear rate of each blade. The weight loss of the un-hardfaced blade for the first 10 acre of field test was 25 gm, whereas for blade hardfaced with 5HCr, 8HCr, 12HCr and 7.5HCr hardfacing alloys were 40, 25, 18 and 37 respectively.

The WRI is defined as the wear rate of the un-hardfaced blade divided by wear rate of the hardfaced blade. This indicates the superiority of the tested blade over the un-hardfaced blade. The WRIs of the tested blade are presented in Table 4.

| Hardfacing Type | Wear rate (gm/acre) | WRI |
|-----------------|---------------------|-----|
| Un-hardfaced blade | 7.08 | 1 |
| 5HCr | 5.02 | 1.4 |
| 7.5HCr | 4.3 | 1.6 |
| 12HCr | 2.84 | 2.5 |
| 8HCr | 4.22 | 1.7 |

It has been observed from the field test that for the tillage of about first 20 acres the wear rate of the un-hardfaced blade remain low in comparison to hardfaced blades. But slightly after 20 acres of field test, the wear rate of un-hardfaced blade overshoot the wear rates of hardfaced blades within the next 10 acre tillage as shown in Fig 8. In contrary to this, it can be stated that un-hardfaced blade perform well for the first 20-25 acres in comparison to hardfaced one. After studying the facts it has concluded that this type of wear behavior is attributed to the increase in leading edge thickness after hardfacing, which in turn increases the soil cutting resistance of leading edge. Owing to this, for the first few acres the hardfaced blades show more wear, however after around 20 acres of tillage their leading edges ground by the abrasive action of soil particles. This lead to the sharpening of the leading edges which sequentially decreases the resistance to soil cutting.

![Figure 8 Field test results of tiller blades (Cumulative weight loss Vs Tilled area)](image-url)
The hardfacing 5HCr can not provide additional wear resistance for the blade due to low fracture toughness, causing large amount of wear of hardfacing alloy on the leading edge. It gives only 1.4 times superiority over the un-hardfaced blade as tabulated in Table 4. The hardfacing alloys 8HCr and 7.5HCr shows only marginal increase in wear resistance. About 1.7 and 1.6 times superiority exhibited by 8HCr and 7.5HCr hardfacing alloys respectively. The blade hardfaced with 12HCr hardfacing alloy shows maximum wear resistance index at approximately 2.5 times. For 12HCr hardfacing, the leading edge retains its profile at outer end of leading edge even after 50 acres of field test.

4. Conclusions

The hardfacing alloys show clear superiority in abrasive wear resistance in contrast to un-hardfaced EN-14B steel under the conditions examined for laboratory and field tests.
1. The wear rates of the hardfacing alloys are lower than that of EN-14B steel.
2. The minimum wear rate was observed in the case of 12HCr hardfacing alloy. This may be due to the presence of hard chromium carbides.
3. The blades hardfaced with 8HCr and 7.5HCr gives marginally greater wear resistance in comparison to EN-14B steel.
4. The hardfacing alloy 5HCr does not provide much abrasive wear resistance over the un-hardfaced steel.
5. The laboratory and field results revealed that as the percentage of Cr increases, the wear resistance of the corresponding alloy increases.
6. The weight loss of the hardfacings increased linearly with sliding distance in dry conditions.
7. The un-hardfaced blade after field test show significant weight loss due to abrasive action of soil particles which have mostly occurred on the outer end of leading edge towards the base of the blade.
8. The ploughing type of abrasive wear mechanism dominates in EN-14B and 5HCr as the hardness is lower. Whereas both ploughing and cutting mechanism exists in case of 8HCr and 7.5HCr hardfacing alloys. But for 12HCr hardfacing alloy owing to higher hardness, the micro cutting mechanism dominates.

It can therefore be concluded that the blade overlayed with 12HCr hardfacing alloy shows a much higher wear resistance than un-hardfaced blade. The WRIs for 12HCr, 8HCr, 7.5HCr and 5HCr hardfaced blades are 2.5, 1.7, 1.6 and 1.4 respectively. Therefore, the rotary tiller blade overlayed with 12HCr will be more appropriate and more reliable for lengthening the working life of tiller blade. This will greatly reduce the idle time for reinstating the worn blade, which in turn reduces the cost of labor significantly.

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