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Wear behavior of weld overlays on excavator bucket teeth

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Abstract

An excavator is a typical hydraulic heavy-duty human-operated earth engaging machine tool used in general as a continuous digging machine in large-scale open pit mining operations. However, under dynamic loading, excavator bucket teeth are subjected to severe abrasive wear. The objective of this work was to improve the service life of the excavator bucket teeth in order to decrease the idle time required to reinstate the teeth periodically during excavation. This objective was carried out by overlaying the excavator bucket teeth (of high tensile steel) with four different wear resistant hardfacing alloys by manual metal arc welding. Comparative wear tests on a regular tooth and overlayed excavator bucket teeth were conducted in the field and laboratory (ASTM G-99, pin-on-disc apparatus), where the effect of hardfacing alloys on the extent of wear and the wear characteristics of the excavator teeth were examined.

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Keywords: Manual metal arc welding; Excavator bucket teeth; Pin-on-disc; Abrasive wear.

1. Introduction

Wear from earthen materials accompanied by moderate to high impact is often suffered by loader bucket teeth and trenching machinery. The major cost to industry and heavy equipment operators is equipment downtime. This is closely followed by the loss of productivity and associated cost of parts replacement. Abrasive wear produces the premature failure of many components of the extraction machinery with considerable economic costs.

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The processes by which excavator bucket teeth wear include impact, abrasion, chemical action and fretting. Generally, the life span of bucket tooth is determined by wear. The research to assess the wear of metal parts has mainly been concentrated on industrial materials related to large industries. In the heavy equipment sector, especially the excavator bucket tooth received little consideration in this area. Many researchers have developed several techniques over the years to increase the abrasive wear resistance of soil engaging tools in agricultural sector such as surface coatings by Karoonboonyanan et al. (2007), Kang et al. (2012) and hardfacing by Bayhan (2006).

A protective hardfacing of the proper metallurgy can be installed to protect the component from wear. Hardfacing is the most economical way to improve the service life and efficiency of wearing metal parts. The hardfacing alloy is homogeneously deposited on to the surface of substrate material (usually low or medium carbon steels) by welding, with the purpose of enhancing wear resistance without significant loss in ductility and toughness of the substrate as observed by Buchely et al. (2005). Dasgupta et al. (1998) stated that when abrasion conditions become too severe for ground engaging tools such as those used in mining, construction, and agriculture, or when the cost of equipment downtime requires more frequent parts replacement, then the expense of using hardfacing technique can be justified and at the same time the technique becomes less expensive than designing the entire component using improved strategic materials. Core components such as crushers are exposed to heavy wear and require efficient surface protection measures to avoid costly downtimes and to reduce costs for expensive spare parts as reported by Kirchgaßner et al. (2008).

In this present investigation MMAW process is selected as the component size is comparatively small and the process is an all-position process, highly versatile and most economical. The purpose of this case study was to ascertain the wear characteristics and wear resistance of excavator bucket teeth that were overlayed with four different commercial hardfacing alloys by manual metal arc welding (MMAW) and comparing these with the standard heat treated excavator bucket teeth under laboratory and field conditions of operation. The wear rates obtained from laboratory and the field test can then be used to predict service lives of the excavator bucket teeth. A thorough survey of pertinent literature reveals that until now no attempt has been made to enhance the service life of excavator bucket teeth.

2. Experimental Procedure

2.1. Materials and Weld Metal Overlays

Excavator teeth used in the experiment were made from high tensile steel (En-14B) with a composition given in Table 1. En-14B can be hardened and tempered to offers good combination of ductility and hardness combined with excellent resistance to shock. In the present application of excavator teeth, there is a great need for the combination of ductility and hardness with carbon maximum up to 0.3%. On the other hand, tool steels also offers good wear resistance but there are, however, conflicting consequences as high hardness in tool steels makes the material sensitive to notches. This may lead to large carbides acting as crack initiators in a fatigue process. Fatigue cracking occurs when the material is exposed to alternating/pulsating loads. Also, sharp corners or sharp edges in combination with high hardness may also act as sites for crack initiation at fatigue loading as stated by Kang et al. (2012). For these reasons, the high tensile steel with proper heat treatment is more appropriate for excavator bucket teeth. The teeth were oil quenched from a temperature of 840-880°C and tempered at 550-660°C to obtain a hardness of 508 HV. The hardfacing alloys are designated according to the percentage of chromium present in the composition as H33Cr, H23Cr, H6.25Cr and H2Cr with 33, 23, 6.25 and 2 percent of Cr respectively. The hardness of H33Cr, H23Cr, H6.25Cr and H2Cr hardfacing alloys deposited on substrate (En-14B) with MMAW process were obtained as 804, 722, 698 and 653 HV respectively.

Table 1 Chemical composition (wt. %) of high tensile steel (En-14B) applicable for excavator bucket teeth

Grade	% of constituents												
En-14B	C	Mn	Si	S	P	Al	Cu	Cr	Mo	Ni	Pb	V	W
	0.24	1.29	0.27	0.024	0.032	0.03	0.14	0.34	0.01	0.04	0.01	0.01	0.02

The welding parameters were kept within the selected range and the electrodes used were of 3.2 mm diameter size. The deposited layers with different combinations were obtained by using four electrodes. The characteristic feature of the electrodes used in this study is that they are used for overlaying to increase the wear resistance such as mining tools, parts of earth moving and mining equipment, ploughshares and tillage tools. To ensure the dryness of the electrodes, they were preheated in the electric oven at 180°C for about 1 hour. The typical welding parameters used are given in Table 2. 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.

Table 2 Welding parameters used in the test

Parameters	Hardfacing Alloys			
	H33Cr	H23Cr	H6.25Cr	H2Cr
Electrode diameter (mm)	3.2	3.2	3.2	3.2
Arc voltage (V)	24	22	17	23
Welding current (A)	125	120	120	125
Welding speed (mm/min)	100-120	100-120	100-120	100-120
Preheating for 1 hour (°C)	180°C	180°C	180°C	180°C
Deposition rate (kg/h)	2.3	2.1	2.14	2.35

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

Hardfacing electrode	Chemical composition (wt.%) of hardfacing electrodes										
	C	Si	Mn	Cr	Mo	Nb	P	S	V	Ni	Ti	Fe
H33Cr	4.8	1.4	1.1	33	1.7	-	-	-	0.2	0.5	-	Balance
H23Cr	5	2	0.7	23	7	7	-	-	-	-	-	Balance
H6.25Cr	3	2	-	6.25	-	-	-	-	5	-	4.75	Balance
H2Cr	0.75	4	0.6	2	-	-	0.03	0.03	-	-	-	Balance

In order to minimize the dilution rate, during the process of hardfacing, instead of single pass welding, three layered multi-pass welding was carried out. Primarily, the hardfacing was done as a 2 mm thick layers, and then the surfacing on the second and third layers were done with the similar electrodes. Deposition of stringer beads without any transverse oscillation of the electrode was employed throughout the process which controls the dilution rate within limits as specified by Selvi et al. (2008).

2.2. Laboratory Test

Wear test of un-hardfaced and hardfaced substrate with four different hardfacing alloys was performed using a pin-on-disc wear test apparatus (TR-201, Ducom, India). The pin-on-disc wear test apparatus used in this study is shown in Fig 1 (a & b). The wear tests were conducted at ambient temperature under dry sliding conditions as per ASTM G 99 standard. Specimens in the form of cylindrical pins of diameter 8 mm and length 30 mm were used for wear tests which were hardfaced at their cross-section on one side and subsequently machined to specified size. The pin slides against a disc made of harden steel (62 to 65 HRC) as shown in Fig. 1 (b). Before and after the test, all the specimens taken for analysis were cleaned and then weighed using an electronic balance with an accuracy of ± 0.0001 gm (see Fig 1 (a)). The wear tests were carried out at the linear velocity of 1 m/s with applied loads of 30 N, 40 N, and 50 N for 90 min. duration.

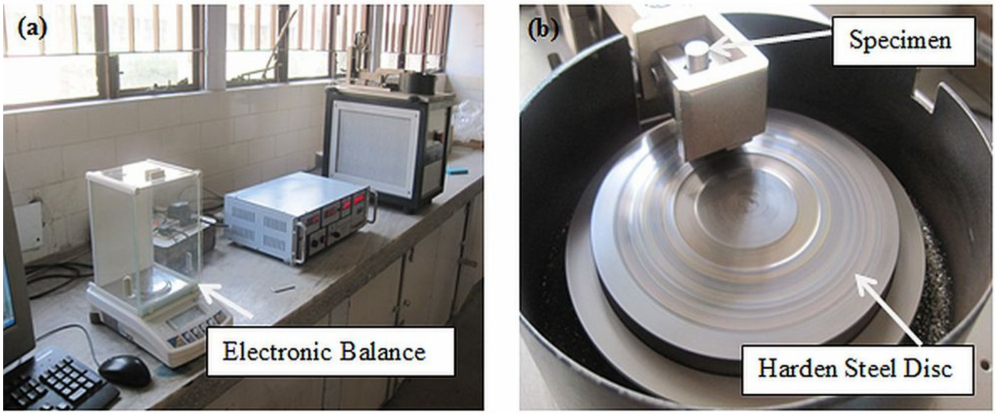

Fig.1 Pin-On-Disc Wear Test Apparatus as per ASTM G 99 standard

2.3. Field Trial

2.3.1 Teeth Preparation and Mounting

As already discussed, to minimize the dilution rate, instead of single pass welding, three layered multi-pass welding was carried out on excavator bucket teeth. The hardfacing of the teeth was carried out by the same operator to minimize as much as possible the imperfections during the hardfacing deposition. The intensity, fumes, sparks and other parameters of welding process were completely controlled. For the field experiment one un-hardfaced and four hardfaced excavator bucket teeth were fitted at different positions on the excavator bucket to get the meaningful data. All the teeth were coded appropriately in connection with their position for their later study. Fig. 2 shows the positioning of some hardfaced teeth on the excavator bucket.

Fig. 2 Teeth fitted on excavator bucket

2.3.2 Field Trial and Assessment

Both the un-hardfaced and hardfaced teeth were tested in the actual field environment for 480 hr. The Lehragaga town, Sangrur District, Punjab State, India was selected for the field test of teeth in order to observe the wear characteristics in field condition. The general condition of excavation in this area was hard and dry as the teeth were engaged in the excavation of deep ditches to lay the sewage pipes as shown in Fig. 3. The high abrasiveness of the excavated soil and high impact load on the teeth results in a significant acceleration of the wear of teeth.

Fig. 3 Excavator bucket working during field test

The excavator bucket was driven by JCB444, powered by 4.4 L, 84 HP, 4-cylinder, water cooled diesel engine. The wear of the teeth was assessed after each experimental period (80 hr.) by weighing each tooth to determine the weight loss. The weight losses were then used as an indicator of the amount of wear. Wear rate was defined as the weight loss divided by the duration of the field test; the unit is gram per hour (gm/hr). The wear resistance index (WRI) was calculated as the wear rate of un-hardfaced tooth divided by that of the hardfaced one. The higher the WRI, the hardfacing is more protective.

3. Results and Discussions

3.1 Laboratory test analysis

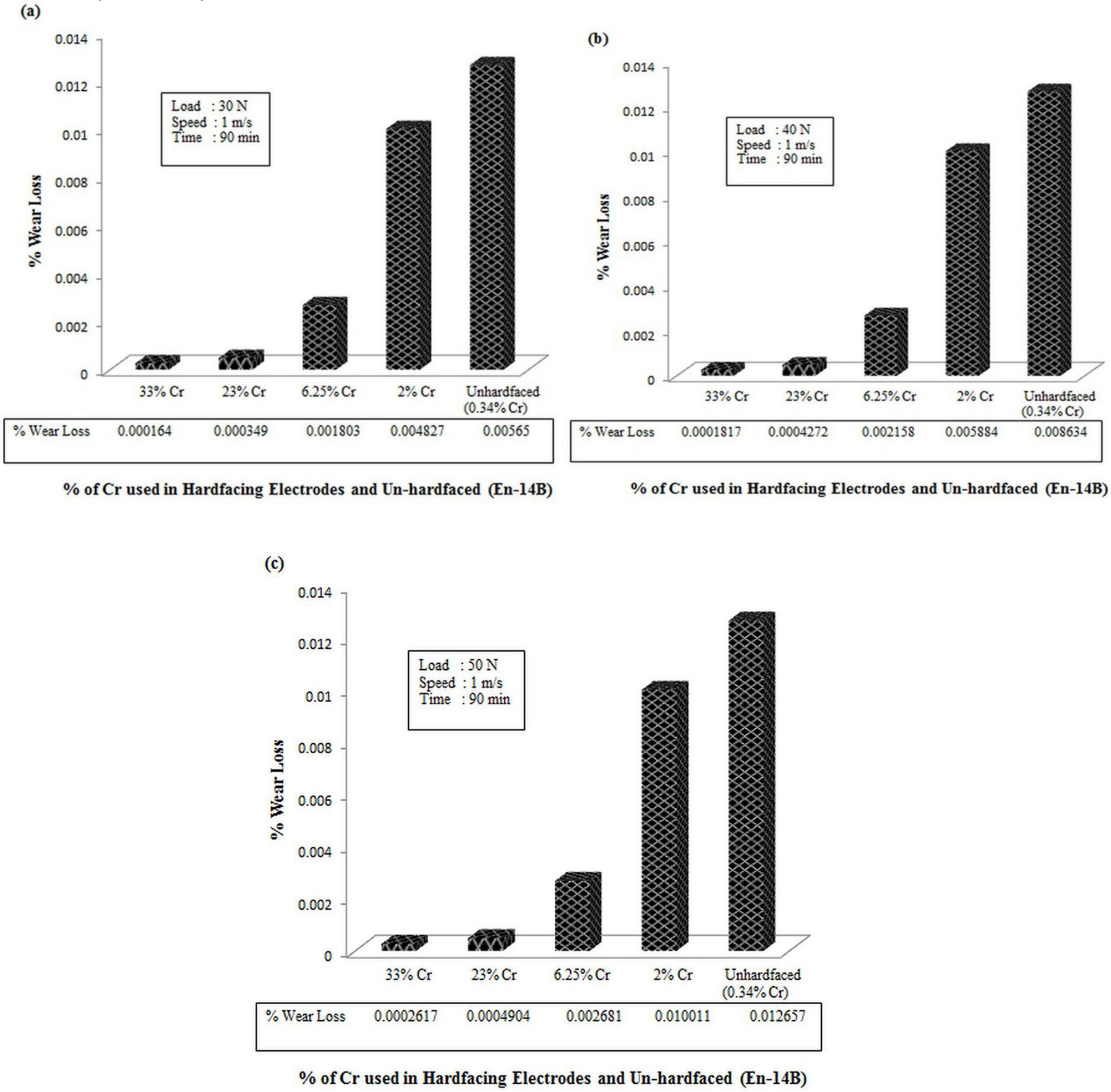

Fig. 4 Wear Test Analysis, %age Wear loss at Different loads: (a) 30 N; (b) 40 N; (c) 50N.

Fig. 4 (a-c) shows the experimental results of wear tests conducted on all the specimens. The graphs were plotted by taking the percentage of chromium contents of the electrodes chosen and the percentage of wear loss. The results show that the wear is minimum in specimens hardfaced with electrodes having 33% Cr followed by 23% Cr, 6.25% Cr, 2% Cr and 0.34% Cr (un-hardfaced specimen) at different normal loads applied to the specimens. The trend of wear loss showed that as the percentage of Cr increased, the wear resistance in the weld overlays has increased. This increase in wear resistance has been attributed to the surface alloying of chromium which is in accordance with the investigation of Amirsadeghi & Sohi (2008).

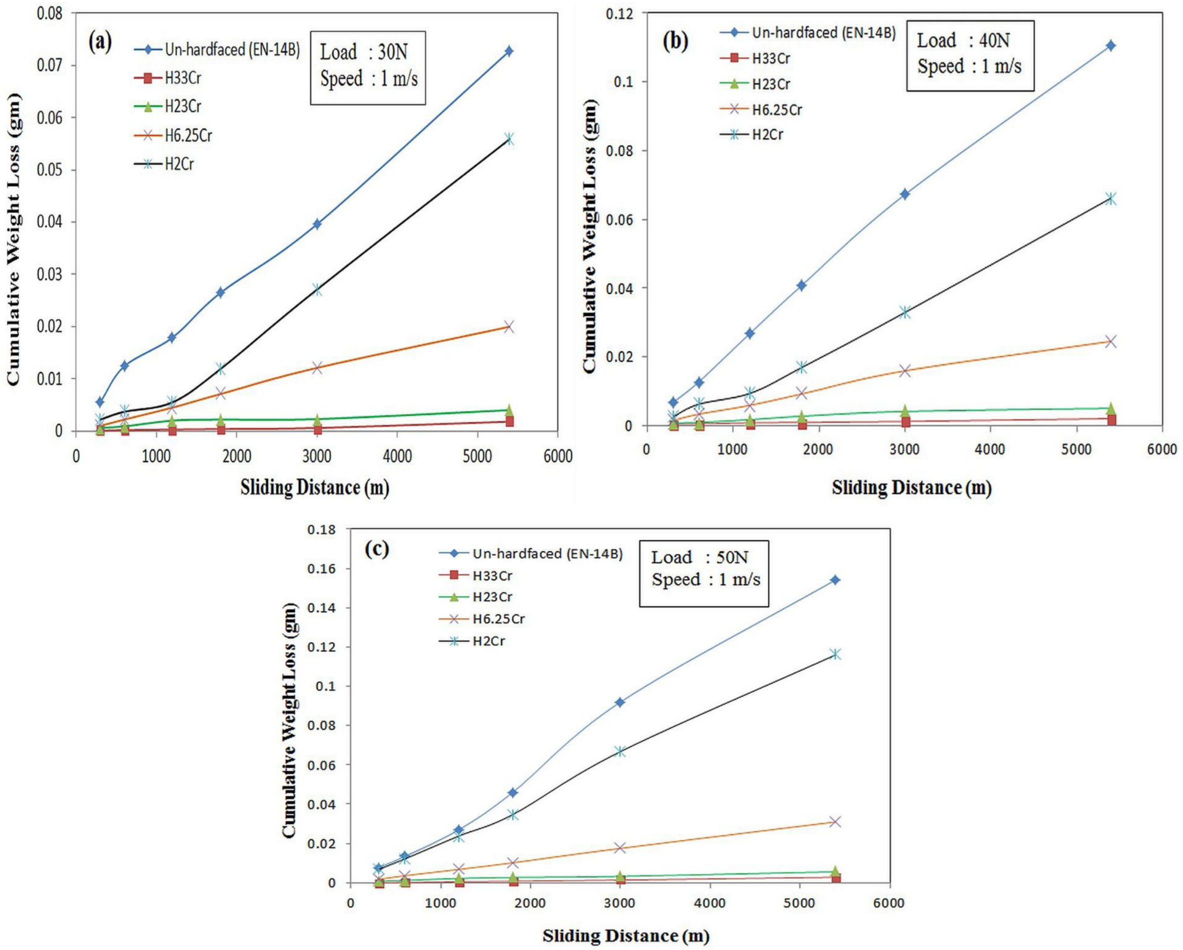

Fig. 5 Variation of cumulative weight loss with the dry sliding wear distance at (a) 30 N; (b) 40 N; (c) 50N.

The cumulated weight losses of the wear test at various intervals were plotted against the sliding distance of the specimen as shown in Fig. 5 (a-c). It shows the variation of the cumulated weight loss with the applied normal load for hardfaced and un-hardfaced samples. The wear loss for all the samples increases linearly with an increase in normal load and sliding distance. However, the H33Cr alloy exhibited minimum weight loss at all loads and sliding distances and this decrease in weight loss is due to the high load bearing capacity of the alloy and formation of the hard chromium carbide, similar results were reported by Selvi et al. (2008).

3.2 Field Trial Observations

The hardfaced teeth were fitted onto the excavator bucket in place of the standard heat treated excavator bucket teeth (Un-hardfaced teeth) and the field experiment was carried out. After the test, the teeth revealed various amount of wear as shown in Fig. 6. The large amount of metal through wear was removed from the leading edge of un-hardfaced tooth as assessed after the field test as shown in Fig 6 (e). The wear damage appears to be starting from the end of the leading edge and moving inwards, towards the base of the tooth where very little or no wear can be observed. Even though the field test was conducted for a short time (480 hr) in the area, the amount of wear is relatively severe. This is because of the high abrasiveness and hardness of the soil, which can greatly accelerate the wear process.

As observed from the field test, the tooth hardfaced with H33Cr show almost negligible wear damage. This is due to the high abrasive wear resistant quality of chromium carbide which is induced at the surface of tooth by hardfacing. The hardfacing still cover the leading edge of the tooth as shown in Fig 6 (a). The underlying substrate is not exposed even at foremost edge and as well as on the sides of the leading edge.

The tooth hardfaced with H23Cr also show very little wear damage after field test. The hardfaced area of tooth was partially abraded by the abrasive quality of the soil as shown in Fig. 6 (b), but at the same time the underlying substrate was not exposed even around the leading edge.

The H6.25Cr hardfaced tooth after testing show some wear damage. The hardfacing on the tooth was completely ground by the abrasive action of the soil as shown in Fig 6 (c). The change in the tooth dimension and curvature at the outer end 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.

As shown in Fig. 6 (d), the tooth hardfaced with H2Cr hardfacing 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 dynamic loading, the deposited hardfacing alloy on the leading edge as well as the substrate was totally removed due to extreme abrasive wear. There is no evidence of hardfaced alloy present on the tooth surface after the field test. Hardfacing alloy (H2Cr) does not provide much abrasive wear resistance in comparison to other hardfacings. The change in the profile of leading edges of un-hardfaced and hardfaced excavator teeth before and after field test can be evidently depicted from Fig. 7 (a & b) respectively.

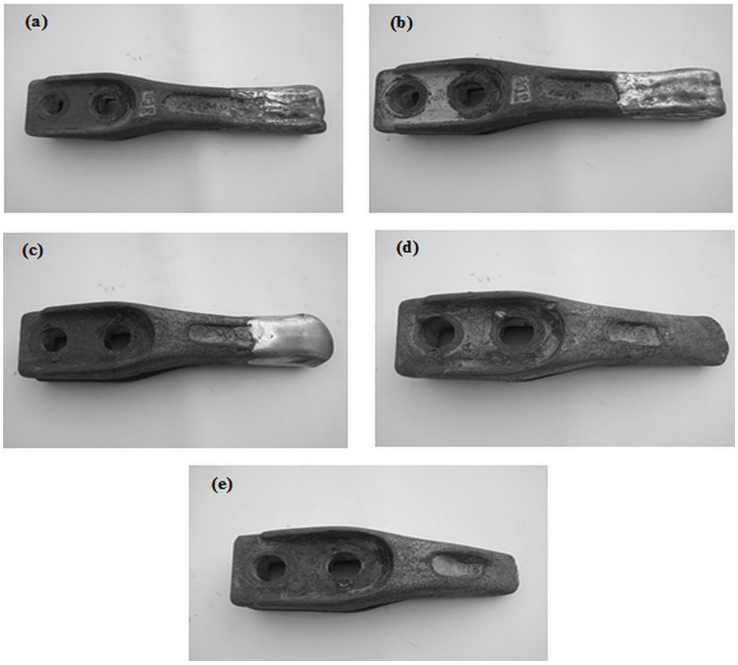

Fig. 6 Hardfaced excavator bucket teeth after field test for 480 hr. (a) H33Cr hardfaced tooth. Leading edge is still completely covered by hardfcaing. (b) H23Cr hardfaced tooth. Hardfacing partially removed from the leading edge. (c) H6.25Cr hardfaced tooth. Significant amount of metal was removed from the leading edge. (d) H2Cr hardfaced tooth. Hardfacing on the tooth was removed almost along the entire leading edge. (e) Un-hardfaced tooth. Large amount of metal was removed from the leading edge.

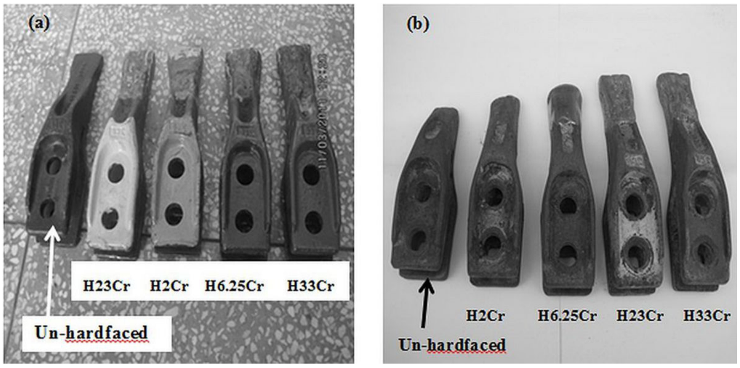

Fig. 7 Excavator teeth (a) before field test (b) after field test

3.3 Weight Loss and Wear Rate Assessment

The cumulated weight losses of the field tested teeth at various intervals were plotted against the duration of the field test as shown in Fig. 8, in order to obtain a precise wear rate of each tooth. The weight loss of the un-hardfaced tooth for the first 80 hrs duration of field test was 151 gm, whereas for teeth hardfaced with H33Cr, H23Cr, H6.25Cr and H2Cr hardfacing alloys were 8, 18, 78 and 121 gm respectively.

The WRI, indicating the superiority of the tested teeth in comparison with the un-hardfaced tooth is defined as wear rate of the un-hardfaced tooth divided by wear rate of the hardfaced tooth. The WRIs of the tested teeth are presented in Table 4.

Table 4 Wear rates and WRIs of hardfaced excavator bucket teeth in field test

Hardfacing Type	**Wear rate (gm/hr)**	**WRI**
Un-hardfaced tooth	1.906	1
H33Cr	0.120	15.88
H23Cr	0.247	7.71
H6.25Cr	0.929	2.05
H2Cr	1.437	1.32

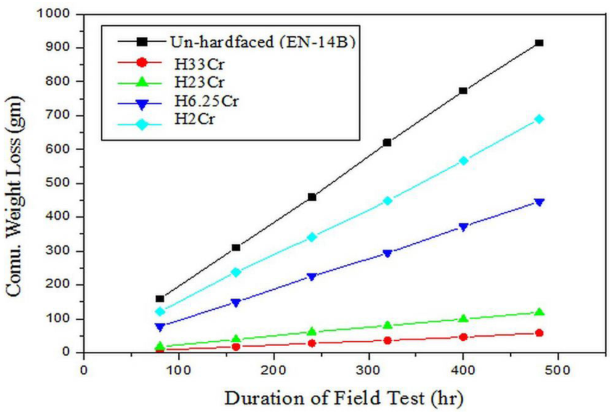

Fig. 8 Field test results of excavator teeth (Cumulative weight loss Vs Duration of Field Test)

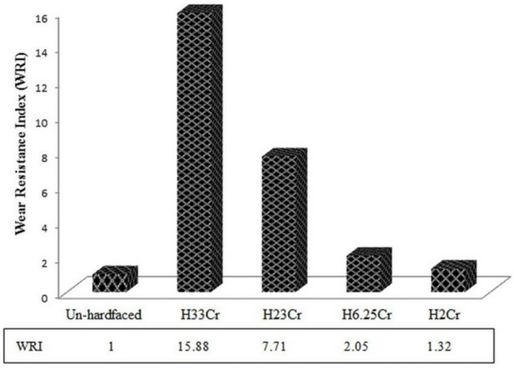

Fig. 9 Wear resistance indices for hardfacing alloys and Un-hardfaced En-14B

The outcome of the field test shows that the hardfacing H2Cr cannot provide additional wear resistance for the teeth due to low fracture toughness of the hardfacing, causing continuous wear of the weld metal overlay on the leading edge. It shows only 1.32 times superiority over the un-hardfaced tooth as tabulated in Table 4. The H6.25Cr hardfacing shows only marginal increase in wear resistance as shown in Fig. 8. It exhibits 2.05 times superior wear resistance than the un-hardfaced tooth. The tooth hardfaced with H23Cr hardfacing shows significant improvement in wear resistance. It reveals 7.71 times superior wear resistance than un-hardfaced tooth. The H33Cr hardfacing, on the other hand, exhibits superior wear resistance, at approximately 16 times better performance than the un-hardfaced teeth and more than 2 times the wear resistance provided by H23Cr hardfacing alloy. For H33Cr hardfacing, the wear did not reach the substrate, and the result shows a very small wear as shown in Fig. 8. The quick view of the comparison of WRIs of tested teeth is presented in Fig. 9.

4. Conclusions

The relative abrasive wear behavior of commercially available hardfacing alloys has been studied for excavator bucket teeth. There was clear superiority in wear resistance provided by the hardfacing alloys under the conditions examined for laboratory and field tests.

1. The mass loss of the hardfacings increased linearly with sliding distance in dry conditions.
2. The hardfacing process with electrodes was effective in reducing the wear on the excavator bucket teeth. It is possible to reduce wear on the excavator buket teeth by overlaying them with the above mentioned weld overlays.
3. All the four hardfacings have higher hardness than the regular heat treated bucket tooth (Un-hardfaced tooth).
4. The regular tooth after field testing show significant weight loss due to abrasive wear which have mostly occurred on the leading edge towards the base of the tooth.
5. H2Cr hardfacing alloy did not show much superiority in wear resistance, while H6.25Cr alloy show some improvement in wear damage compared to regular tooth.
6. H23Cr show very little wear damage, on the other hand H33Cr hardfaced tooth shows almost negligible wear damage. It (H33Cr) exhibits more than 2 folds superior wear resistance than provided by H23Cr.
7. It has been revealed from laboratory and field tests that the wear rates of overlayed excavator bucket teeth decreases as the percentage of chromium content increases in the weld overlays.

It can therefore be concluded that H33Cr hardfaced tooth shows a much higher wear resistance than regular tooth. The WRIs for H33Cr, H23Cr, H6.25Cr and H2Cr hardfaced teeth are 15.88, 7.71, 2.05 and 1.32 respectively. Therefore, the excavator bucket tooth hardfaced with H33Cr will be more appropriate and more reliable for enhancing the service life of the bucket teeth. This will greatly reduce the time spent on replacing worn teeth, which in turn reduce the cost of labor significantly.

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