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Research article

A Description of the Wear Damage of Backhoe Bucket Teeth

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A B S T R A C T

In this research work, a description of the wear damage caused on a backhoe bucket tooth of a Caterpillar model, is presented. This mechanical component was subjected to intense excavation work for approximately six months. The methodology to describe the tooth wear was to first section small segments of different damaged areas. Then, a tribological characterization was carried out to obtain the hardness in random places to determine what material, coating, or thermal treatment was used to manufacture and reinforced these mechanical components. Additionally, surface profilometry was employed to measure roughness and acquired wear profiles to gain insight into the degradation of bucket tooth surfaces after actual service. Finally, optical microscopy was used to identify the wear mechanisms involved in the surfaces. These mechanisms were severe and consistent pitting in different areas, large random grooves similar to those observed in severe abrasive wear (two-body, three body abrasion, gouging) high corrosion due to the environmental conditions, scratches and cutting actions on tooth surfaces.

1. INTRODUCTION

The excavator bucket teeth are normally subjected to high contact stresses during excavation actions and hence to critical abrasive wear due to these mechanical components applying extreme forces to remove different soil elements such as stones, rocks, limes, glass, carbon, minerals, and other organic matter. The materials used to manufacture the bucket teeth are hard materials composed of carbon, chromium, vanadium, molybdenum, niobium, tungsten, and other chemical elements, and can be hard steels or cast iron that generally are coated by layers employing different welding processes [1-3]. For all of these fundamentals, the bucket teeth were an interesting topic to research.

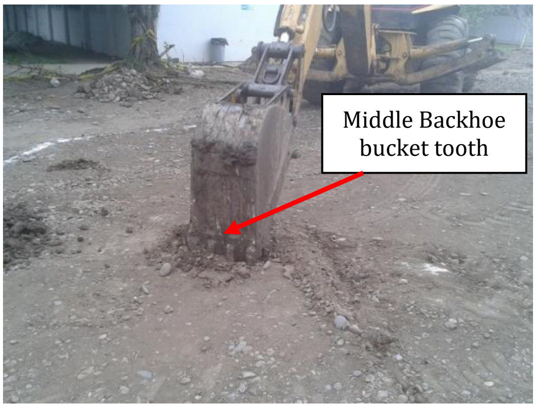
During the development of this investigation, was motivating to see how many authors around the world have been working with this significant theme. For example, Fernández et al. [4] evaluated the wear performance of hard alloys normally used to excavate teeth in the mining industry. These materials are coated by two layers by a welding process. The methodology for testing these materials considered two stages, firstly, the laboratory abrasive tests (ASTM G105-89), where the materials exhibited plowing and cutting actions on the surfaces and the abrasion rates showed that the hard alloy with a small content of C and elements as Cr, Mo, V and B, Si, Ti was the material with the highest weight lost. In this work, the alloys with the addition of elements as Cr-Nb-V and B presented the maximum abrasion resistance. Secondly, real condition testing in a mine was conducted on the same materials employing a bucket wheel of excavator and the results were comparable with those obtained in the laboratory tests. An interesting event occurred due to the teeth' position on the bucket since the teeth in the central part showed a higher abrasive damage than the lateral teeth. Then, Singla et al. [5] investigated testing the excavator bucket teeth overlaid by four different hard-facing alloys using manual metal arc welding (MMAW) and compared the results with heat-treated bucket teeth (unsurfaced). The abrasive tests based on ASTM G99 (pin on disc rig) were performed in a laboratory and the results showed that as the Cr content increased the wear resistance was greater. Unhardfaced specimens (heat-treated) exhibited higher wear rates than the hard-faced ones. The performance of the hard-facing and unsurfaced (heat-treated) materials was quite similar in both laboratory and field testing. Abrasive wear was the main wear mechanism involved in all the tested teeth due to the abrasiveness of soil and natural elements. Additionally, Dagwar & Telrandhe [6] conducted research to analyze the failure of a bucket tooth due to the constant and intense contact with extracted materials from natural soil particles during the digging process. This caused the bucket teeth to be replaced frequently, so it is imperative to find harder and more resistant materials or coatings to be able to withstand the workloads in the mining industry. In addition, the investigators found that severe abrasive damage was the main wear process involved due to the characteristics of the soil constituents. Ismail et al. [7] performed a work where heat-treated excavator bucket teeth from two brands (ND market product and X as cast, manufactured by their researchers) were tested by using the Ogoshi wear rig and field examinations. The results showed that one of the ND teeth with an average hardness of 51.9 HRC exhibited the greatest wear resistance than the other ND tooth and the X bucket teeth (as cast). An important feature to highlight was that the wear volume losses rose progressively with the advancement of the operation days. The main wear mechanisms were plowing, cutting actions, and holes on the surfaces. The outcomes from the Ogoshi and field tests were comparable, and the final trend was quite similar.

This work is related to the wear that occurs on the teeth used in an excavator. The main reason for carrying out this research lies in the constant damage that these mechanical elements suffer when they are exposed to soil, rocks, and different particles or contaminants, such as dirt, pieces of glass, or stones. The damage to these mechanical elements is characterized by deep scratches on their surfaces, holes caused by the embedding of angular (sharp), spherical, and oval particles, as well as cracks that cause them to fracture. Due to all this, this work aims to describe the wear mechanisms generated in these mechanical components.

2. EXPERIMENTAL DETAILS

2.1 Testing procedure

The tribological characterization was carried out on a middle backhoe bucket tooth from a Caterpillar model used in excavation duties, during the remodeling of the central plaza of the Faculty of Mechanical and Electrical Engineering at the Poza Rica campus, at ambient temperatures fluctuating between 35° to 40° C. Figure 1 shows the backhoe tooth (approximately 18 cm long and 9 cm wide) after real service (six months). Here, it was possible to observe that the abrasive wear was severe, specifically on the frontal tooth face and at the sides of the tooth tip (Figure 1c-e). The impact and sliding contact of natural soil particulates (ground, rocks, red blocks, clay, and glass) with the frontal face and tip of the bucket teeth at the exact moment of the disruption action led to inflict severe abrasive damage (Figure 1a). To conduct the characterization, firstly, small segments from different wear areas were cut by using a steel handle bow saw, with a size of roughly 1 cm^2 (Figure 2) to perform the measurements of hardness, roughness and wear profiles and of course to identify the wear mechanisms [8]. The examination was focused on the 2-7 tooth segments, mainly in the central area and bottom tip, as shown in Figure 2.



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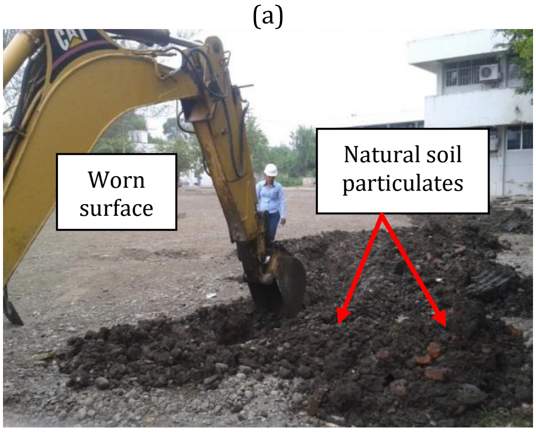

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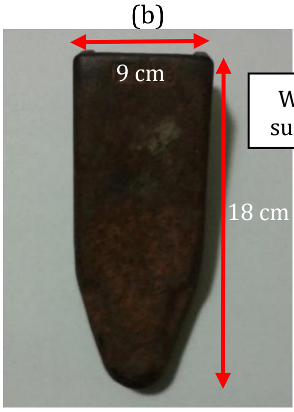

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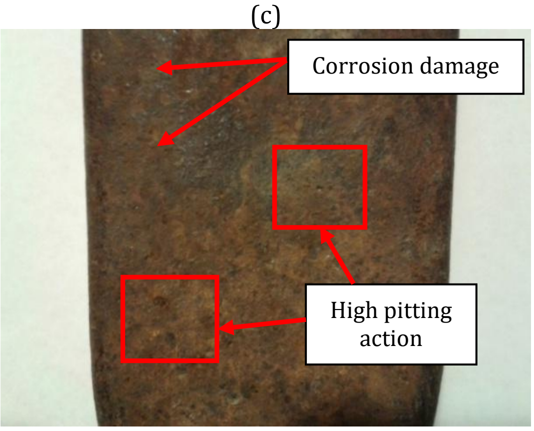

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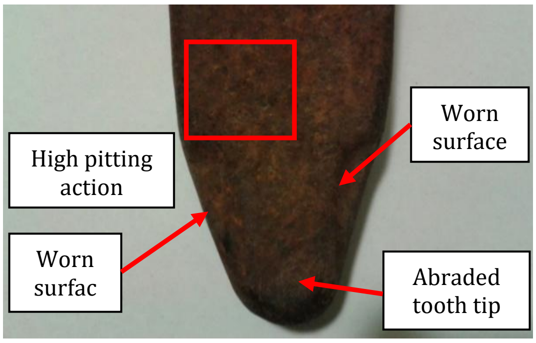

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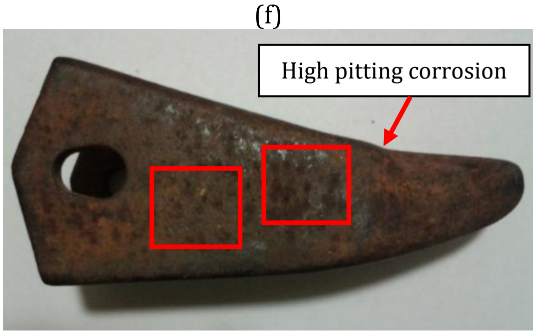
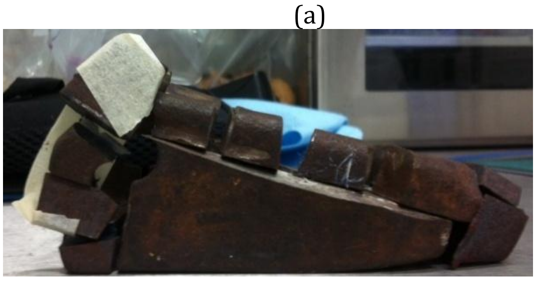


(g)

Fig. 1. (a-c) Backhoe bucket tooth in real service, Wear damage: (c) Tooth top section, (d) Tooth bottom section (e)-(f) Left-right sides.

(a)



(b)

Fig. 2. Backhoe bucket tooth segmented, (a) Marked areas 1-9, (b) Lateral section.

2.2 Hardness analysis

Hardness tests were carried out using a durometer (Microhardness Tester LECO LM 700) (see Figure 3). Ten microhardness values were acquired in the cross-section of one segment of the worn tooth (see Figure 2) and an average value was obtained, in accordance to ASTM E384-17 [9]. The average microhardness was 540.61 HV ± 1.07, the applied load to the Vicker's indentor (square-based diamond pyramid) was 1000 gf, whereas the dwell time was 15 s; this result was similar to one of the tested materials in another research works [4].

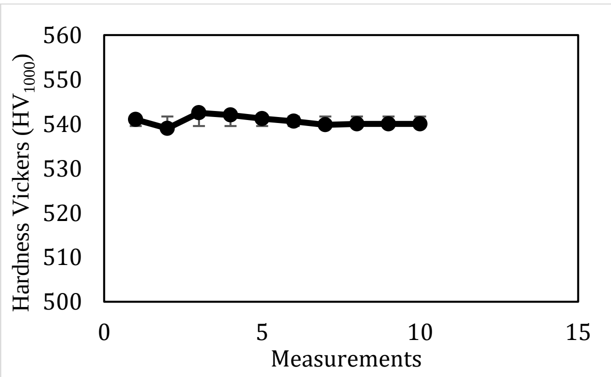
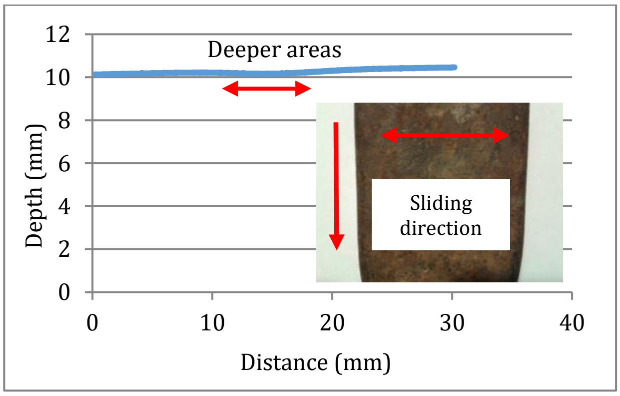


Fig. 3. Microhardness data obtained by using Microhardness Tester LECO LM 700.

2.3 Tooth Surface Roughness Analysis

To carry out the profile and roughness analysis in different areas of the bucket tooth, it was necessary to use a Contour Measuring Instrument CV-500 (profilometer). Figure 4a-b illustrates the depth of the holes on the surface of the excavator tooth. In this case, the distance that the needle traveled over the surfaces was between 25 to 30 mm. The analyzed areas are indicated in the photographs. The wear profiles were very consistent at the top and bottom sections of the tooth. The profiles correlate well with the wear damage observed on the tooth surfaces in Figure 1b-e. In this particular case, the profiles showed a certain degree of uniformity across the measured distance; however, at some points there are deeper areas characterized by changes in the profile. These areas correspond to the pitting actions, the measured depth oscillating between 0.04 to 0.07 mm. The average roughness in both examined zones was Ra= 304.16 µm, with a standard deviation of 78.16. Ten profiles of each area, both the upper and lower parts of the tooth, were taken, and two profiles were selected to be shown in this work.



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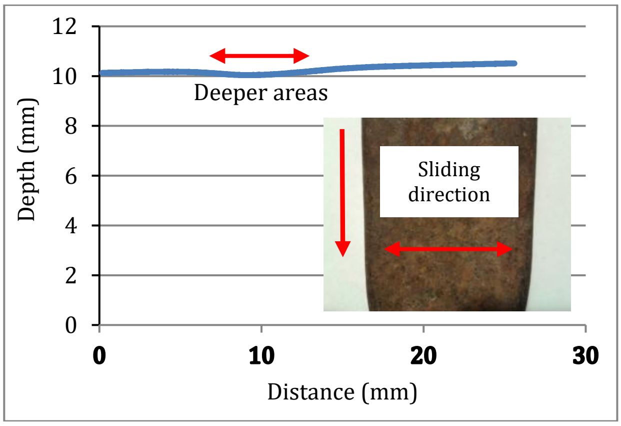
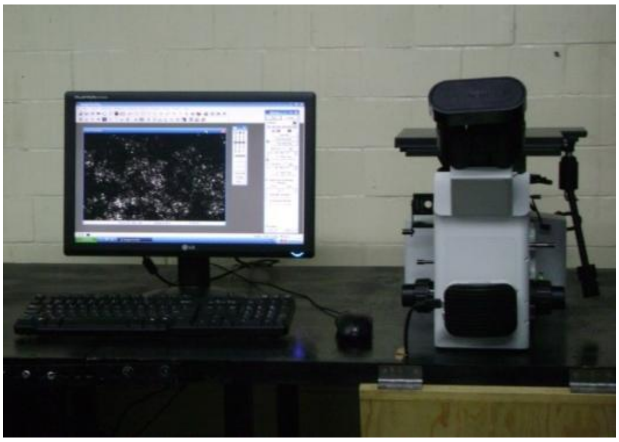


(b)

Fig. 4. Surface profiles, (a) Top section, (b) Bottom section.

2.4 Identification of Wear Mechanisms Using Optical Microscopy

The main damage area analysed, was the central part of the tooth, segments 4-7 in Figure 2, where the bigger holes and scratches are concentrated on the surfaces caused by the high contact, sliding, and impact of different particulates coming from the soil [5-6, 10].



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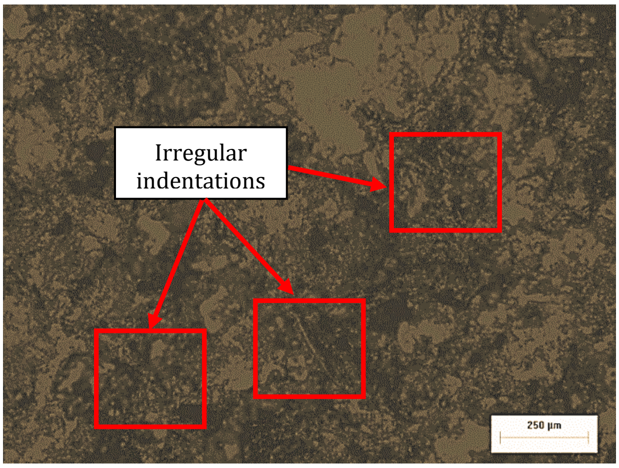

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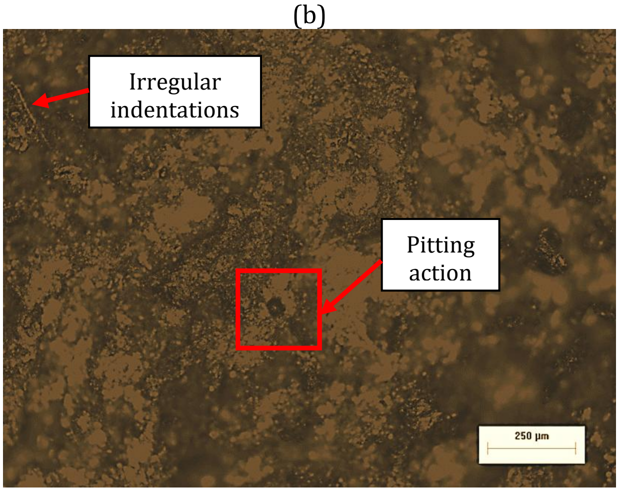

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Fig. 5. (a) Olympus GX51 optical microscope, (b)-(c) Wear mechanisms, irregular indentations, pitting, and scratches.

Micrographs of the surfaces were obtained using an Olympus GX51 optical microscope to analyze their morphology and identify the failure wear mechanisms (see Figure 5b-d). In the photographs, it is possible to confirm some of the wear mechanisms, such as scratches or irregular indentations, intense pitting with holes located in random positions by the high-impact contact, and some grooves observed, in other similar studies [11-16].

3. DISCUSSION OF THE RESULT

In this work, a description of the wear damage caused to the tooth of a bucket excavator was presented. It was not about solving the severe wear problem that exists in these mechanical components but rather about explaining how the damage occurs, why it arises, and what causes it.

A bibliographic review was carried out about the wear processes involved in the degradation of the backhoe bucket teeth and the different hard-facing alloys coated by manual metal arc welding (MMAW), welding layers on the underlying material. This welding process is currently playing a significant role in improving the performance of these mechanical elements against soil natural elements due to impact, sliding, and abrasion wear caused by distinct abrasive particles on the teeth. These mechanical components are quite important to carry out excavation, extraction, and mining duties.

The hardness testing in this work, showed that the obtained values are quite common in alloy steels used commonly to manufacture bucket teeth for bearing heavy-duty processes. A tooth surface roughness analysis was conducted and the average roughness in the top and bottom areas of the tooth was Ra= 304.16 µm, with a standard deviation of 78.16. The depth profiles were obtained in a perpendicular direction of the impact orientation and the profiles were quite consistent, however, some areas had cavities that were deeper. The wear mechanisms identified in this particular work using optical microscopy, were severe abrasive wear, irregular scratches or indentations, corrosion, and pits on the surfaces.

4. CONCLUSIONS

The results obtained were the hardness, the profilometry of the wear surfaces, their roughness, and the wear mechanisms such as severe abrasion caused on the backhoe bucket tooth, inflicted by the high contact stresses. The impact and sliding contact with different materials and natural elements of the soil, such as stones, glass, silica sand, quartz, and others, can lead to the rapid degradation of these mechanical elements.

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

Author contribution statement

All persons who meet authorship criteria are listed as authors, and all authors certify that they have participated sufficiently in the work to take public responsibility for the content, including participation in the concept, design, analysis, writing, or revision of the manuscript. Furthermore, each author certifies the present manuscript is original and has been developed in the Faculty of Mechanical and Electrical Engineering by all the authors included in the paper. The paper does not contain material, which has been published previously.

J. R. Laguna-Camacho, E. A. Gallardo-Hernández: Conceptualization, Methodology, Supervision, A. Aguilar-Melendez, M. Vite-Torres, J. A. Chagoya-Ramírez: Data curation, Visualization, Validation, J. Calderón-Sánchez, H. D. López-Calderón: Writing- Original draft preparation, Writing- Reviewing and Editing.

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