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A Wear Analysis Carried On Connecting Rod Bearings From Internal Combustion Engines

Juan Rodrigo Laguna-Camacho, Silvia M. Sánchez-Yáñez, Gabriel Juárez-Morales, Maria I. Cruz-Orduña, Luz M. Ramos-González, Cristóbal Cortez-Domínguez, Roberto L. Cabrera-Santiago and Javier Calderón-Sánchez

Abstract

In the present work, an analysis was carried out to know the wear modes present in connecting rod bearings from internal combustion engines. These mechanical elements were selected since they are exposed to different engineering failures such as incorrect assembly, severe loads, extreme temperatures, inadequate conditions, and loss of lubricity. In this particular case, the bearings that were selected had a service life of approximately 8 years. Different techniques such as SEM and optical microscopy, EDS analysis, hardness testing, and surface profilometry were used to characterize the unworn and worn bearings. Wear mechanisms such as sliding wear (scoring), fatigue wear with cracks where torn out material was clearly observed, discoloration areas, and two- and three-body abrasion wear (rubbing marks) were identified on the bearing surfaces.

Keywords: wear modes, sliding wear, fatigue wear, cracks, discoloration, connecting rod bearings

1. Introduction

A connecting rod is a mechanical element that, subjected to tensile or compressive stresses, transmits the articulated movement to other parts of the machine. In an internal combustion engine, this connects the piston to the crankshaft. The rod consists of a rigid rod designed to establish articulated joints at its ends. It allows the union of two operators transforming the rotary movement of one (crankshaft) in the reciprocating motion of the other (piston) or vice versa. Its cross section or profile can have the shape of H, I, or +. This mechanical element can be manufactured by steel, titanium, or aluminum alloy. In the automotive industry, these are produced by forging, but some companies can manufacture by machining.

This mechanical element is used in a multitude of machines that require the conversion between alternative continuous and linear rotary movement. Clear examples of some machines where they are used are steam engine, internal combustion engines, machines moved by the foot, water pumps, etc. The main stresses suffered by the connecting rod are compound bending at the moment of the maximum

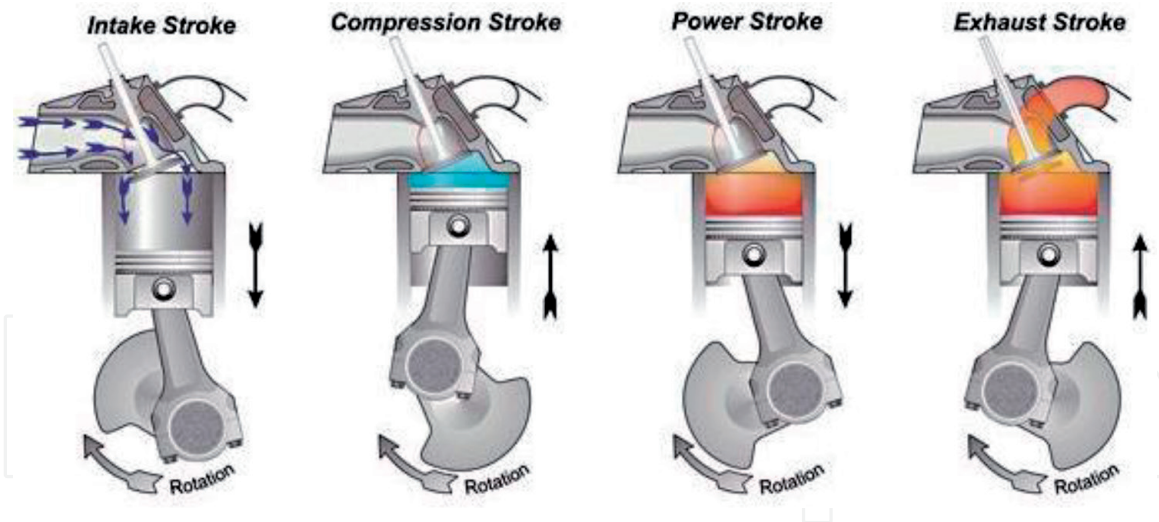


Figure 1.
Internal combustion engine [1].

load when exploiting the fuel mixture (expansion cycle) (third time in **Figure 1**). The compression would be given by the force component on the longitudinal axis of the connecting rod, the bending by the component transverse to it, and the same with the reactive torque provided by the load through the crankshaft when opposing the movement [1]. In addition, the rod undergoes a compressive stress again in the compression stage of the mixture. Due to this, two points are critical; they occur in different stages of the mechanical cycle; the first one is seen during the compression; this takes place in the middle part of the connecting rod; the second critical point is located in the lower part of the rod and occurs during the cycle expansion. The screws, on the other hand, support only a small percentage of the load.

In this work, an analysis of the wear that occurs in the connecting rod bearings from internal combustion engines was performed. It is due to the high stresses to which it is subject and to the direct contact with the crankshaft. This leads to faults due to metal-to-metal contact due to friction and sliding.

2. Experimental details

2.1 Visual examination

The tribological characterization of the connecting rod bearings was carried out once the worn bearings were extracted from the internal combustion engine. It was possible because the car engine was adjusted. It is important to mention that these bearings had a service life of approximately 8 years. In **Figure 2a–c**, it is possible to observe the complete crankshaft, the connecting rods, and a few worn bearings after disarming.

Firstly, small samples were extracted from worn bearings, approximately 1 cm^2 , from different areas to perform measurements of hardness, roughness, chemical analysis of the materials that compound these mechanical components, and of course to identify the wear mechanisms. Micrographs of the damaged surfaces and identification of the different chemical elements were obtained using a scanning electron microscope (SEM) Quanta 3D FEG (FEI) equipped with an energy-dispersive X-ray spectrometer (EDS). In addition, roughness profiles of worn bearings after real service from different zones are obtained. **Figure 3** shows the damage zones of the connecting rod metals that were slightly affected by the contact with the rod bearing journals from the crankshaft. It is assumed that in this particular case, the lead and tin layer was not completely detached, and the bearing only suffered normal wear due to



(a)

(b)



(c)

Figure 2.
Adjust of car engine: (a) and (b) crankshaft and (c) connecting rods and bearings.

friction, applied load, contact speed, contact temperature, and fine abrasive wear by small strange particles that could be the same oil or inserted debris.

On the other hand, the wear produced in the bearings shown in **Figure 4** is very intense. In the bearing on the left, it is possible to observe that the lead and tin layer was completely torn off in the central part and a dark color was clearly seen, which was due to the oxidation wear that occurred in the steel layer that is the base layer of the bearing. In addition, the bearing on the right exhibited pronounced wear, although in this case the reddish-orange copper layer was clearly located. Here, it is possible to identify wear mechanisms such as sliding wear that became high abrasive damage (scoring) for high loads, fatigue wear due to constant contact with foreign particles, and high temperature.

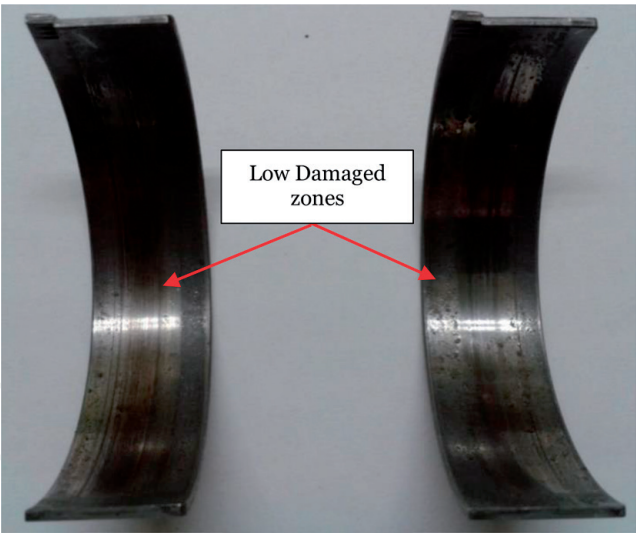


Figure 3.
Lower wear damage on bearings.

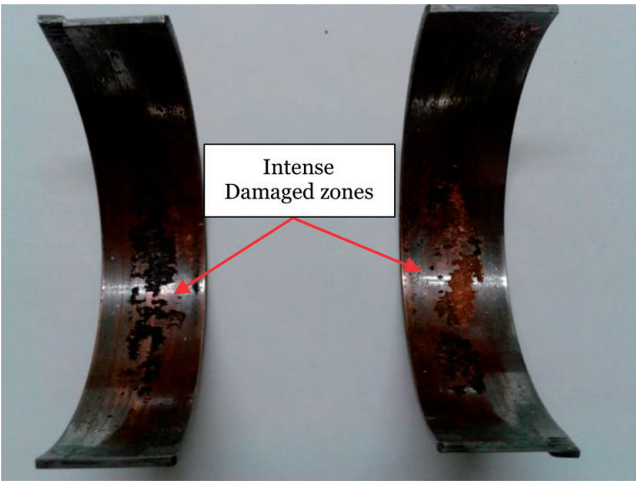


Figure 4.
Pronounced wear damage on bearings.

2.1.1 Hardness measurements

Hardness tests were carried out using a nanoindentation tester (TTX-NHT, CSM instruments). Ten hardness data from three different areas of the cross section of the bearing were calculated for each section, and an average value was obtained. The sections that were analyzed are shown in **Figure 5**. The applied load was 100 mN, the loading and unloading speed was 200 mN/min, and the duration of the measurement was 10 sec. In addition, the Young's modulus of the three different areas of the bearing was calculated as indicated in **Figure 5**. The microhardness results are presented in **Table 1** and **Figure 6**; the highest value corresponds to the outer layer of steel that is the one that makes direct contact with the rod body. In respect to the hardness of the central part, the values are very close to those of the outer layer, although this could be due to the use of copper or aluminum alloys which leads to a hardness increase. Of course, in the case of the inner layer, which is the one with the lowest hardness value, this corresponds to the Babbitt metal layer (lead-tin) that makes direct contact with the rod bearing journals from the crankshaft.

The results of the Young's modulus or modulus of elasticity (E) are shown in **Table 2** and in **Figure 7**. **Figure 8a–c** shows the traces of the pyramidal penetrator on the surface of the bearing in each of the examined areas.

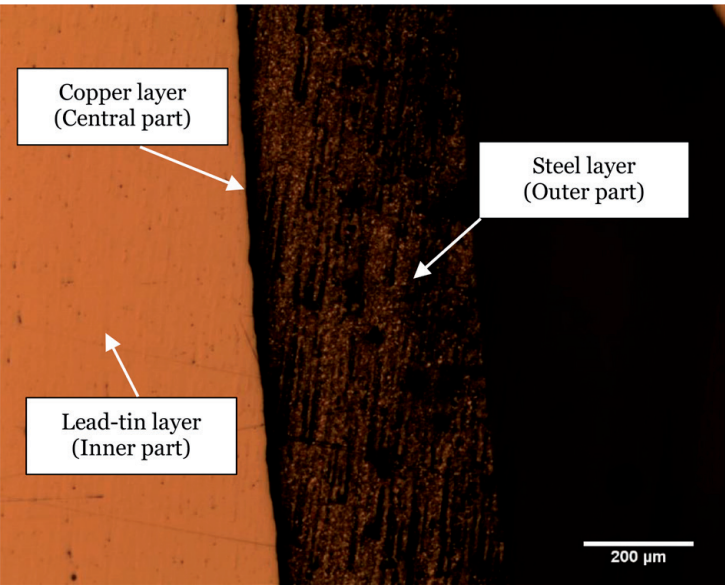


Figure 5.
Cross section of an unworn bearing.

Measurements (10)	Central part (HV)	Outer part (HV)	Inner part (HV)
Average value	192.97	196.61	21.89
Standard deviation	8.75	5.11	1.20

Table 1.
Hardness Vickers of the unworn bearing.

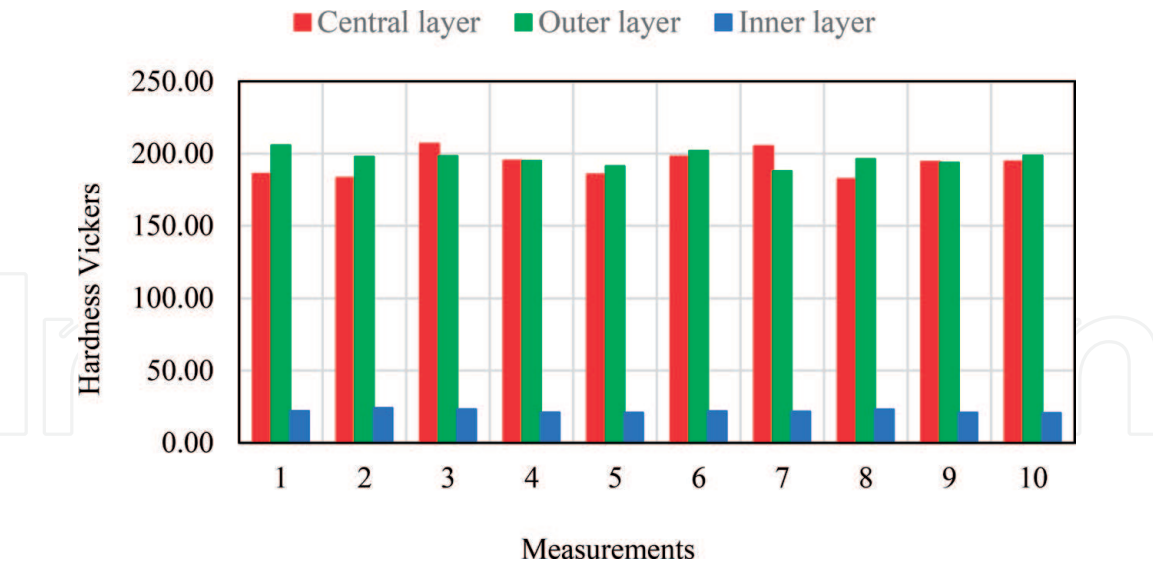


Figure 6.
Hardness measurements in different areas.

Measurements (10)	Central part (GPa)	Outer part (GPa)	Inner part (GPa)
Average value	209.56	211.19	37.67
Standard deviation	5.32	8.19	1.26

Table 2.
Young's modulus of the unworn bearing.

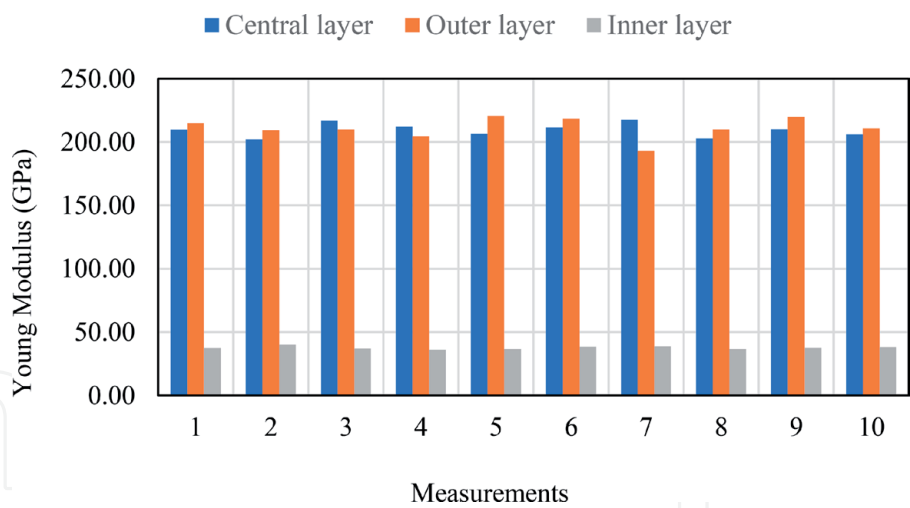


Figure 7.
Young's modulus measurements in different areas.

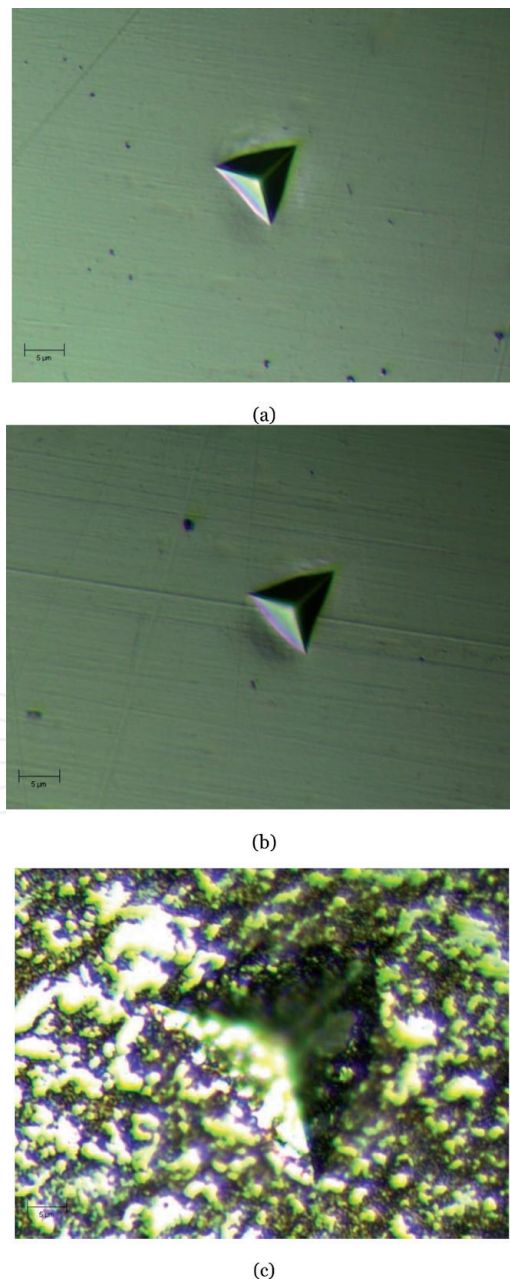


Figure 8.
Hardness Vickers indentations, (a) central part, (b) outer layer, (c) inner layer.

2.1.2 Roughness analysis

A roughness analysis was conducted in different wear zones of the connecting rod bearings; it was necessary to use a contour measuring instrument CV-500 (profilometer) located in the Laboratory of the Tribology Group at the National Polytechnic Institute. The profilometer is presented in **Figure 9**. Here, it is possible to observe the base where the piece of work is placed and the tip that slides on the surface; by means of this, it is possible to obtain the final roughness or depth results.

The photograph presented in **Figure 10a** shows how the surface of the damaged area changes in a consistent manner in the central part. In this particular case, the sliding wear was much less compared to **Figure 10b**, where the wear damage was more intense, with a high detachment of the outer layers, showing areas of greater depth due to the wear intensity.

2.1.3 EDS analysis

The chemical analysis was carried out using a scanning electron microscope model FE SEM JEOL JSM-7600F that can reach magnifications of $25\times$ to $1,000,000\times$ (see **Figure 11**). The unworn surface and the chemical analysis of the rod bearing layer that makes direct contact with the rod bearing journals from the crankshaft are shown in **Figure 12a** and **b**. Chemical elements such as C 20.86, Pb 60.05, Sn 3.89, and Sb 6.7 Wt% identified in the unworn surface.

On the other hand, once the rod bearings have been working during the actual service, the wear occurs on the surface as shown in **Figure 13a**. It was detected that the chemical composition was modified with respect to that presented with the bearing without any wear. Here, the Cu content was new, and this took place because the lead and tin layer was removed by the constant wear due to sliding, friction, and three-body abrasion that is generated by the wear debris insertion, contaminants, and foreign particles coming from of the oil filter or the atmosphere.

A comparison of the chemical composition of a rod bearing that suffered wear and an unworn bearing is presented in **Table 3**. In the chemical composition of the worn bearing, there is a reduction in the lead content (Pb) and an increase in the tin content (Sn). In addition, elements such as copper (Cu) and nickel (Ni) appeared after real service, which could be due to the foreign particles and contaminants produced during the contact with the crankshaft journal. This indicated that the layer of lead, tin, and antimony (metal Babbitt) was torn out from that area, so the copper content that is one of the intermediate layers in the bearing was clearly identified.

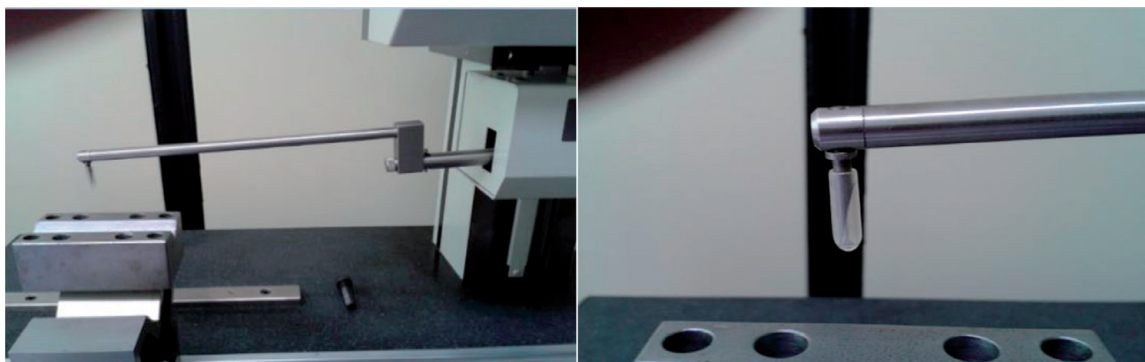
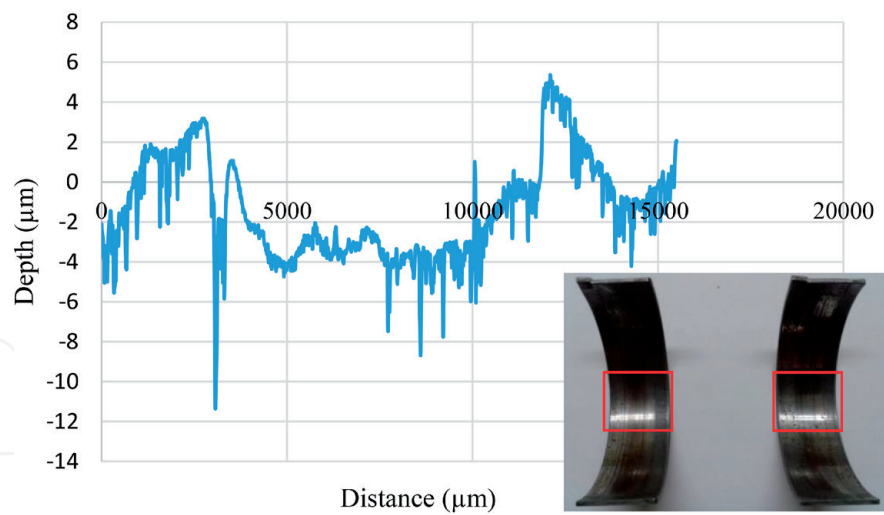
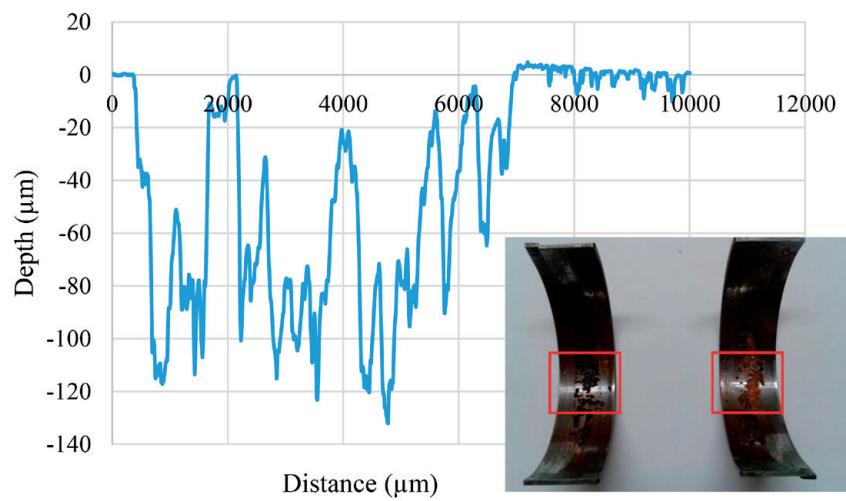


Figure 9.
Contour measuring instrument CV-500.



(a)

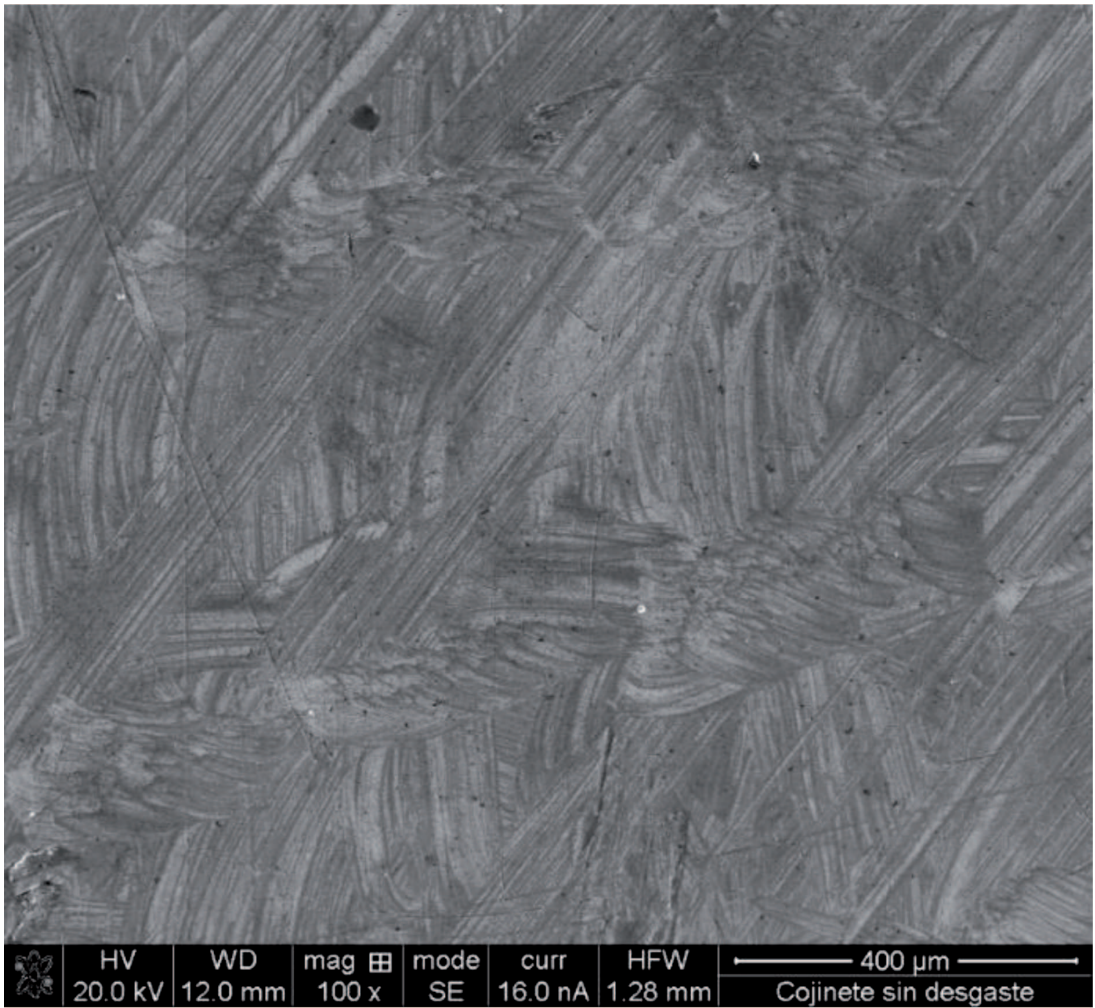


(b)

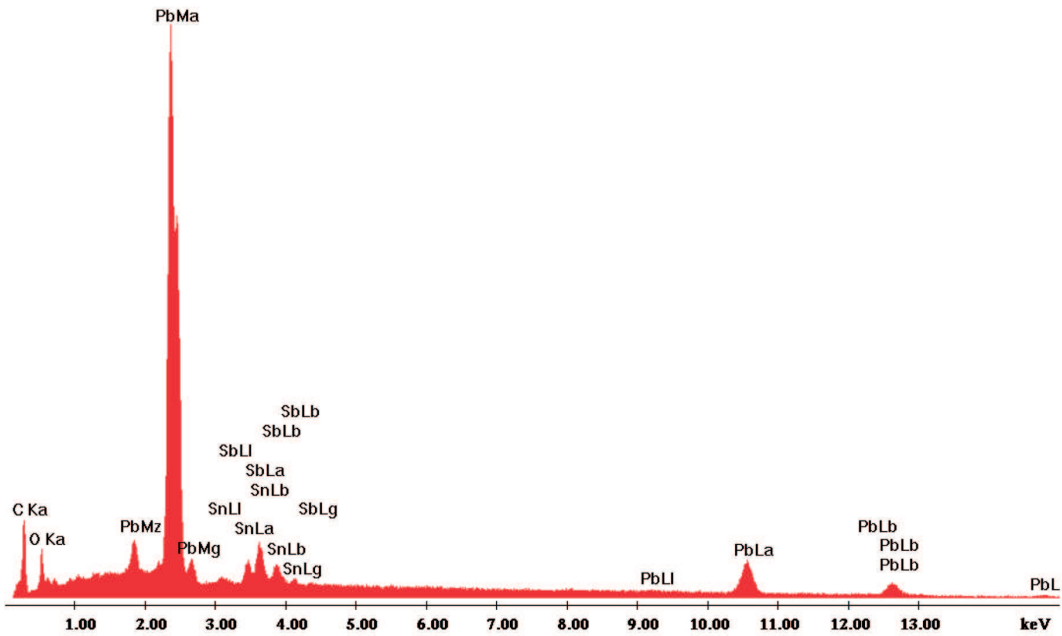
Figure 10.
Roughness profiles of the low wear area.



Figure 11.
Scanning electron microscope.

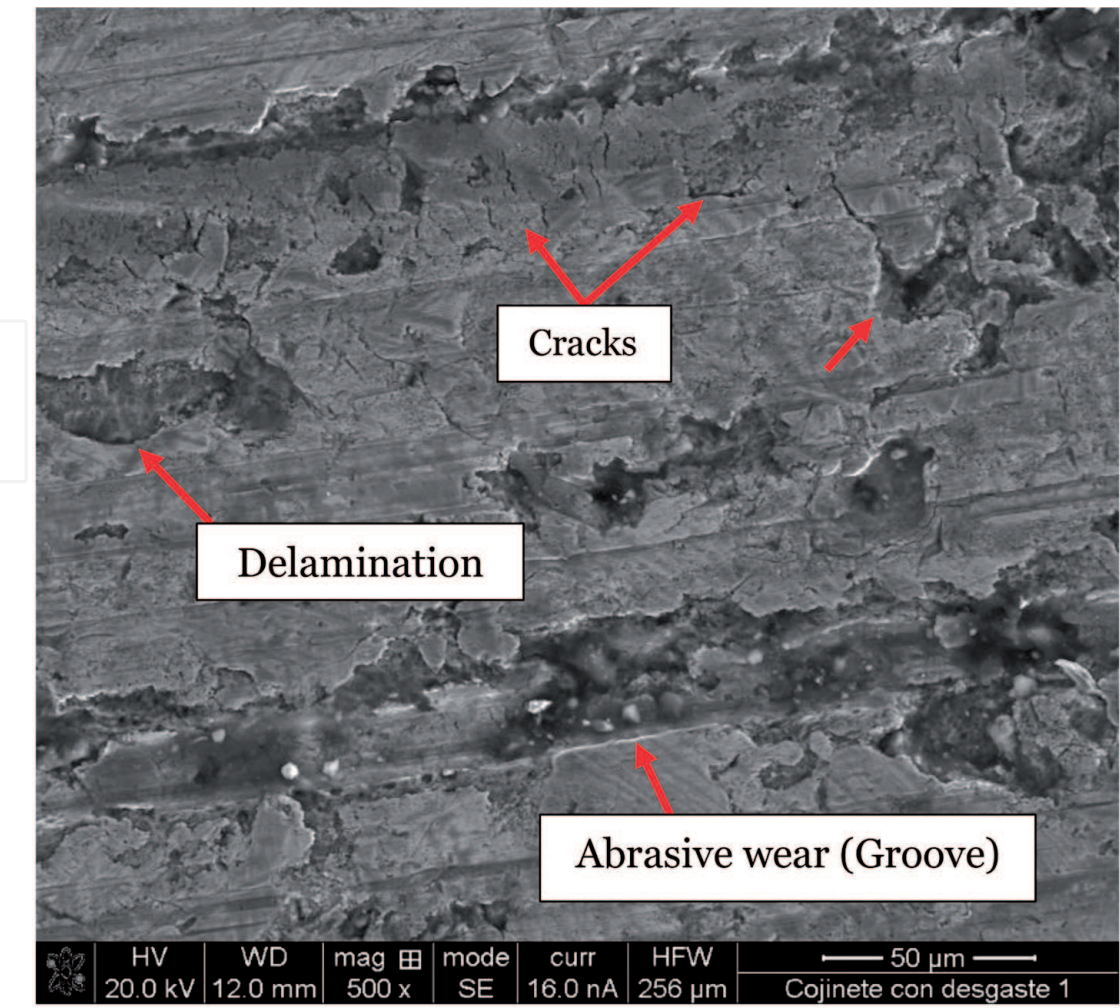


(a)

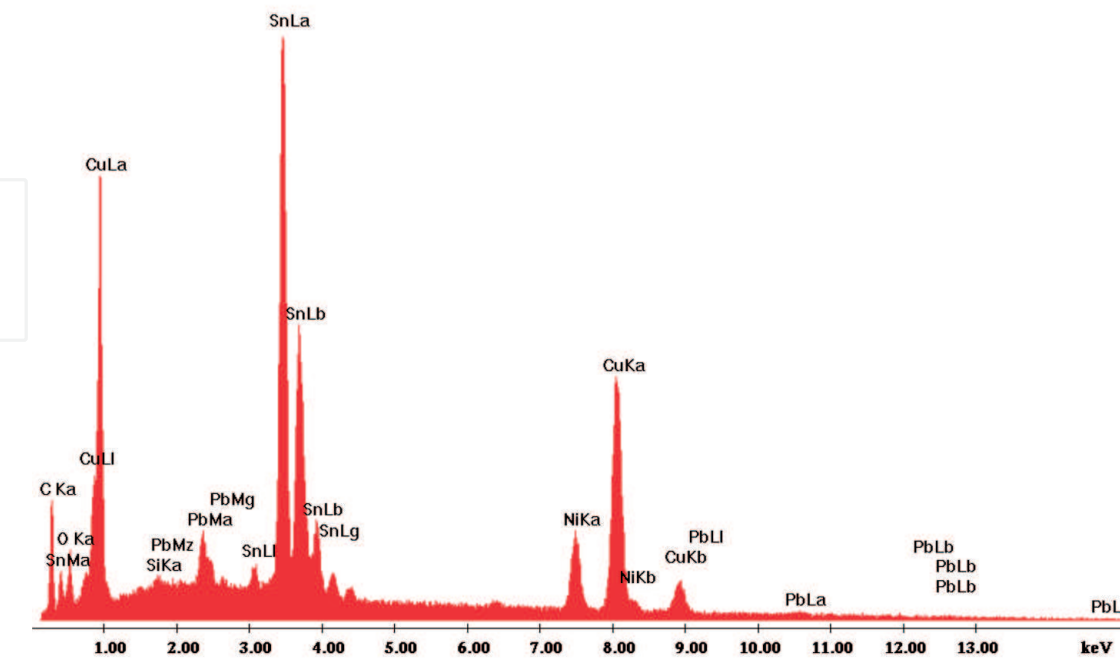


(b)

Figure 12.
(a) Unworn rod bearing surface and (b) EDS analysis.



(a)



(b)

Figure 13.
(a) Worn rod bearing surface and (b) EDS analysis.

Element	Wt%	
	Worn bearing	Unworn bearing
C	25.33	20.86
O	13.5	8.5
Pb	6.8	60.05
Sn	40.72	3.89
Ni	3.21	6.7
Cu	10.43	—
Total	100	100

Table 3.
Comparison of chemical analysis of worn and unworn bearings.

3. Wear mechanisms and discussions

The wear mechanisms were identified by using a scanning electron microscope shown previously in **Figure 11** and an Olympus GX-51 optical microscope. **Figure 12a** showed the surface of the rod bearings before suffering any type of

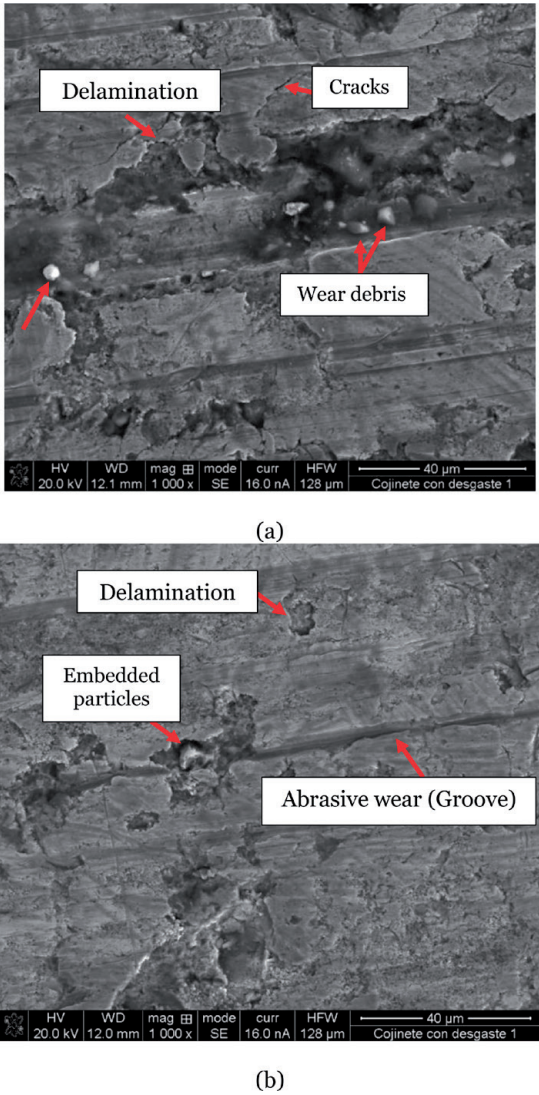
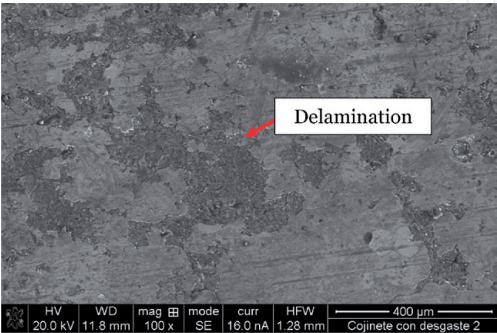


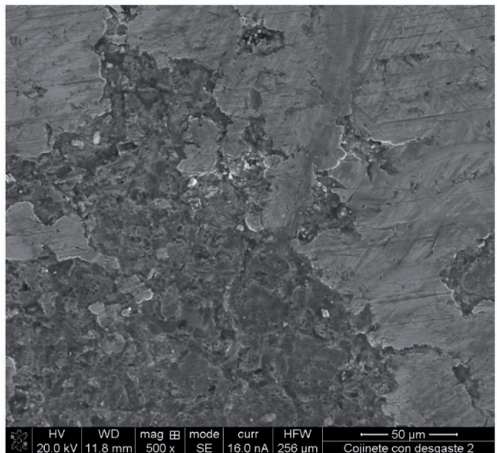
Figure 14.
(a) and (b) Worn rod bearing surface at 1000× in two areas.

damage. On the other hand, **Figure 14a** and **b** exhibited the damage caused in the bearings of the connecting rods after 8 years of actual service with proper and constant maintenance. On the bearing surfaces with the greatest wear (**Figure 4**), it was possible to observe cracks on the surface, delamination due to severe tearing of outer layers produced by sliding wear, and particles that were detached by the same action [2–5]. Some particles observed in the grooves are formed on the surface, and as the magnification of the damage area is increased, this wear mechanism is much clearer.

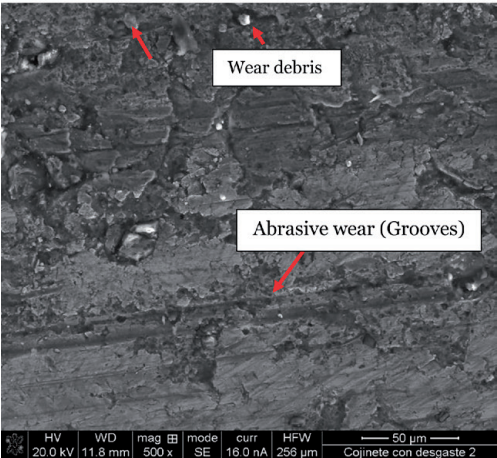
In the case of the bearing surfaces with the least wear (**Figure 3**), it is possible to mention that although the wear was less pronounced, delamination of the surface layers was observed, as the magnification of the damage zones increased (**Figure 15a–c**). In addition, it was possible to see particles embedded on the surface



(a)



(b)



(c)

Figure 15.
(a)–(c) Worn rod bearing surface at 100× and 500× in different damaged areas.

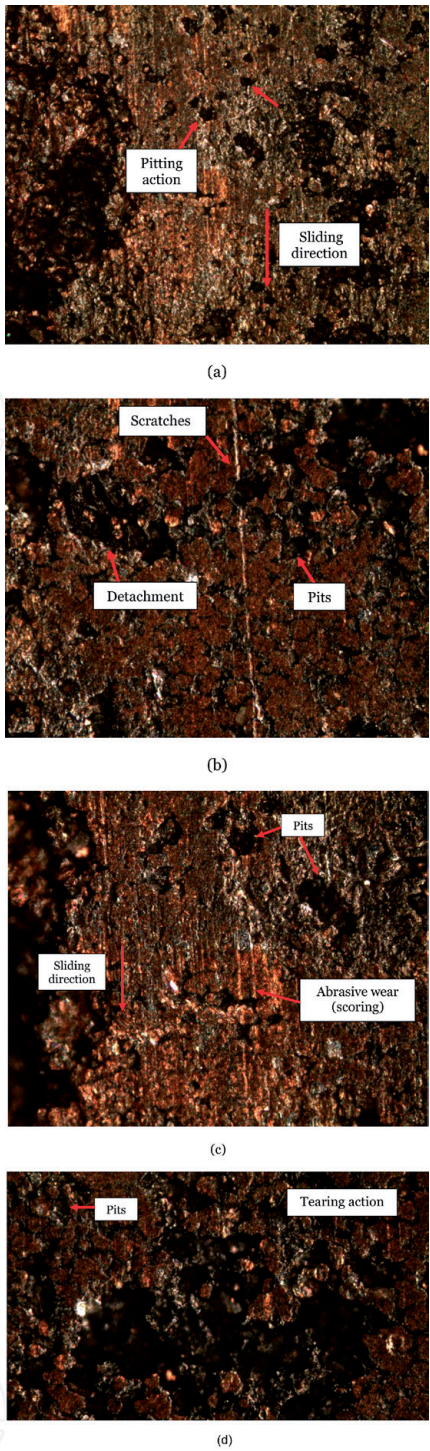


Figure 16.
(a)–(d) Worn rod bearing surface in different damage areas.

by the same sliding action of the two surfaces in contact and grooves with less depth and intensity than those observed in **Figure 14a** and **b**.

In **Figure 16a–d**, it is possible to observe images of the wear damage in the bearings shown in **Figure 4**, caused by the intense tearing of a part of the first protective layer (Babbitt metal layer, composed of lead, tin, and antimony). An Olympus GX-51 optical microscope was used to obtain these micrographs. In a magnification of the same area, it was possible to observe that the fatigue damage was important since there are areas of severe material detachment, pitting action was also identified. In this particular, high abrasion wear (scoring) was the main wear mechanism to be considered by the action of foreign particles of various shapes and sizes on the surfaces that could lead to accelerate the wear process [5–7].

4. Conclusions

In this study, it was possible to understand more about the wear damage caused in the bearings of connecting rods. These mechanical elements are continually exposed to natural deterioration due to sliding contact with the crankshaft journals, by the incrustation of contaminating, foreign particles or even residues of the same wear that occurs; of course factors such as working temperature, lubricant degradation, bad assembly, and inadequate conditions can influence to cause serious wear problems in our cars.

In relation to the rod bearings that suffered higher wear damage (**Figure 4**), it was possible to observe that a Cu content appeared after the real service in the chemical analysis which confirmed the severe wear rate was caused by the absence of correct lubrication due to the long service life, roughly 8 years, and probable foreign particles (dust, wear debris) in the interface between the bearings and the shaft. The common sliding/abrasion action with particles between the two surfaces could be a major factor to inflict the wear intensity. In addition, the wear areas could lead to an uneven distribution of the loads, causing an abnormally high pressure area in some specific points on the bearing surface. In addition, Sn content was identified in the chemical results. Both protective layers were totally shifted due to the high abrasive action in some areas. SEM images showed a number of particles embedded on the bearing surface, large cracks, and clear abrasive wear due to the particles acting directly on the surfaces. Optical images presented wear areas with material totally detached from the surface.

On the other hand, the bearings with the lowest wear exhibited high polished areas on the surfaces in the sliding direction as shown in **Figure 3**, two factors could be significant, the absence of an oil film between the bearing and the shaft led to a metal-to-metal contact, and initial wear debris could act as polisher in the surfaces. In addition, pits on the surfaces were caused by a few wear debris inserted on the bearings. It can be inflicted by the contact pressure between the bearing and the shaft.

The roughness results showed the surface modifications due to the contact action between the rod bearings and connecting rod journal shafts. The main changes were identified in the high wear areas in the rod bearings in **Figure 4**, where a higher depth was obtained in the profiles. The roughness behavior in the rod bearings with the lowest damage was consistent in all the measured section. Finally, hardness tests were performed to show the differences between the inner part (lead-tin layer) and the two protective layers (steel and copper). The results presented a low hardness value of the inner part (21.89 ± 1.20) compared to the other two, 192.97 ± 8.7 HV, copper layer, and 196.61 ± 5.11 HV, steel layer, with close values.

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Author details

Juan Rodrigo Laguna-Camacho^{1*}, Silvia M. Sánchez-Yáñez², Gabriel Juárez-Morales¹, Maria I. Cruz-Orduña¹, Luz M. Ramos-González¹, Cristóbal Cortez-Domínguez¹, Roberto L. Cabrera-Santiago¹ and Javier Calderón-Sánchez³

¹ Faculty of Electrical and Mechanical Engineering, Universidad Veracruzana, Veracruz, Mexico

² Facultad de Ciencias Biológicas y Agropecuarias, Universidad Veracruzana, Veracruz, Mexico

³ Universidad del Golfo de México Norte, Veracruz, Mexico

*Address all correspondence to: juanrodrigo.laguna@gmail.com

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