ANALYSIS OF VALVE AND VALVE SEAT INSERT DAMAGE MORPHOLOGY OBSERVED AFTER DIFFERENT ENGINE TEST

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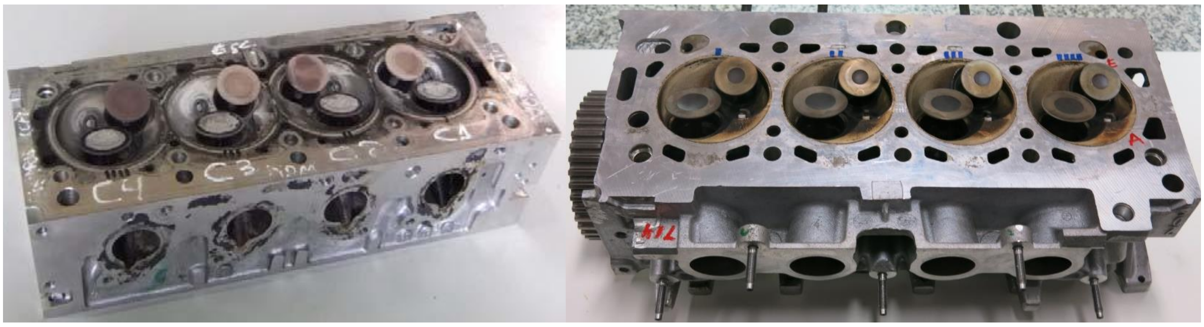
ABSTRACT
This paper presents visual examination results and topographic analysis of two 8-valves engines intake and exhaust valves and valve seats in order to characterize wear damages as part of the *"FAPESP – Desafios tribológicos em motores Flex-Fuel – TRIBOFLEX"* project. One of the engines was tested in dynamometer through thermal shock test, operated from idle to full load regime. The other engine was tested using conventional vehicle in injection system test. The terminology used to describe observed damages was not lined up with the commonly used designations in the literature, to avoid preconceived ideas of the damage. The damage was documented using scanning electron microscopy (SEM) with an energy-dispersive X-ray spectroscopy (EDS) and photographically using optical microscopy (OM). Many damages were observed in both: intake and exhaust valves of both engines, although some damages, such as oxidation, was observed only in the exhaust valves. The damages characterized as: presence of deposits, polishing and oxidation were observed. Through detailed description and documentation of valves damages it is expected to contribute to the characterization of valves wear morphology by the automotive industry.
KEY WORDS: wear, valve, valve seat, engine.

1.- INTRODUCTION
The constant technology evolution of internal combustion engines made possible the production of engines with higher energy efficiency, lower fuel consumption, reduced emissions, improved performance and the use of alternative fuels, such as ethanol. With all these changes, there was also an increase in mechanical demands of its components, requiring more knowledge of their modes of operation and mechanical stress. The terminology used to describe observed damages was not lined up with the commonly used designations in the literature, to avoid preconceived ideas of the damage. The engines were identified by MT-1 and MT-2. MT-1 engine were tested in dynamometer through thermal shock test, which consist of temperature variation from 110 to 40 degree Celsius, and engine were operated from idle to full-load regime, i.e., the combustion chamber pressure varying from idle to full load operation. The engine was run-in for 10 hours with regular gasoline and the dynamometer test was performed with ethanol E100 fuel for the period of 200. The other engine, MT-2 was tested using conventional vehicle in injection electronic system test, using the standard road cycle (SRC) under normal operating conditions. Intake and exhaust valves and valve seats of cylinder number one of both engines will be analyzed.

2.- VISUAL INSPECTION

The valves and valve seats surface wear damages were evaluated through visual examination of the valve surface in contact with valve seat using a low-magnification Nikon SMZ800 model stereo-microscope with Nikon 1200F digital camera. The combustion chambers of both engine heads are shown in Figure 1 and were identified as C1 to C4, from right to left for MT-1 and I to IIII for MT-2.



(a) (b)

Figure 1. Cylinder head of 8-valve engines. Combustion chambers engine (a) MT-1 (b) MT-2.

The analyses of wear were conducted on the intake and exhaust valves and valve seats, as can be seen in Figure 3a and 3b. The region analyzed in this work is identified in Figure 2 as "contact width".

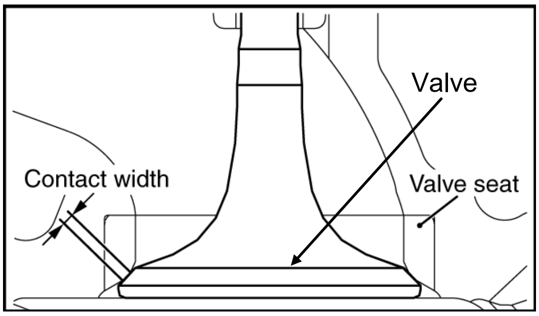


Figure 2. Contact width between valve and valve seat of engine.

Table 1 summarizes the comparison of damage found on intake and exhaust valves and valve seats of both analyzed engines (MT-1 and MT-2) and is shown below. It can be observed that many damages occurred in both: intake and exhaust valves and valve seats, however, some of the damages were observed only in one of the valves such as rust which was only observed in the exhaust valves. It was also observed that more than one type of damage could occur in many valves and valve seats, such as deposits, circumferential scratches, observed in the intake valve of the first cylinder of both 8-valve engines. Surface damages as wear step and wear on central region were not found in this analysis.

Figure 3 present the intake/exhaust valves and valve seats of cylinder one of both engines. The intake valves of both engines were covered by black sticky deposit, typical of high temperature thermal decomposition of lubricant, while the exhaust valves were covered by gray deposit of material probably consisting of ash from the combustion residue of the lubricant.

Figure 3. First cylinder with intake and exhaust valves of engine (a) MT-1 (b) MT-2.

Table 1 – Damage observed on contact surface on the intake and exhaust valves and valves seats.

Damage	Engine							
	MT-1				MT-2			
	Valve		Valve seat		Valve		Valve seat	
	Int	Exh	Int	Exh	Int	Exh	Int	Exh
Step								
Wear on central region								
Deposit	X	X	X	X	X	X	X	
Clear central band	X							
Indentation	X							
Oxidation		X		X		X		
Polishing	X	X						
Circumferential scratch	X	X	X		X		X	X
Radial scratch			X					
Oblique scratch	X							
Circumferential grooves and ditches	X	X	X					

2.1.- Intake

The Figure 4 shows the surface contact of the intake valve of the engine MT-1 by MO and SEM. It is possible to separate the area (surface) into two regions with different characteristics denoted by 1 and 2. The region 1 appears in both edges of contact and is characterized by having circumferential scratches (machining) and deposits. Region 2 is defined by a clear central band and smooth polished surface.

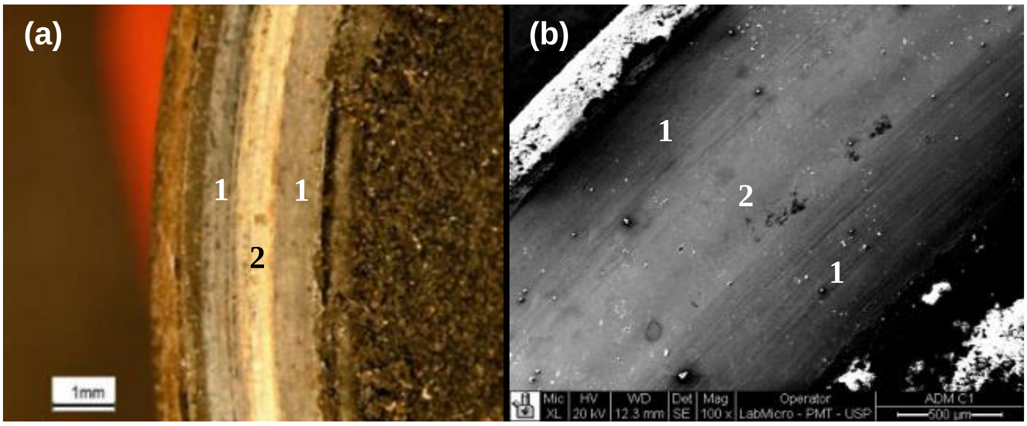


Figure 4. OM (a) and SEM (b) images of the surface of intake valve (MT-1).

In Figure 5 it can be noticed material deposition on the contact surface, indicated by orange color in Figure 5a. This can be derived from the interaction between the valve seat material with the compounds of the air-fuel mixture. It also can be seen grooves as shown in Figure 5b. The grooves were caused by small particles that also left a deposit material as seen in the image of SEM.

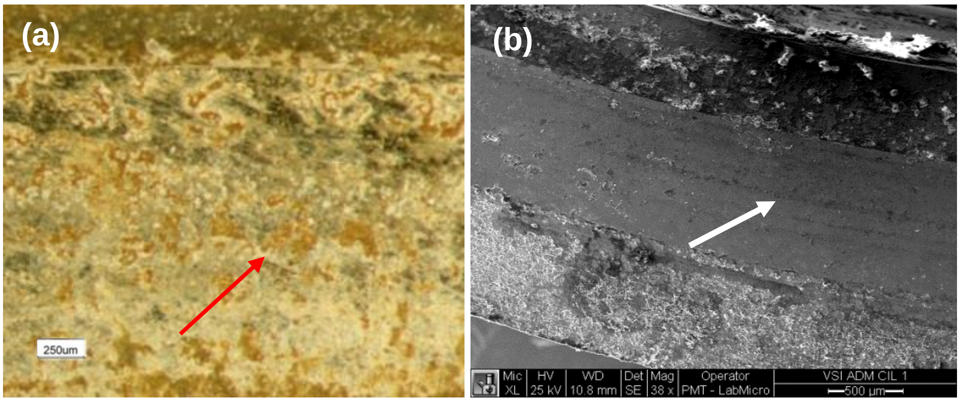


Figure 5. OM (a) and SEM (b) images of the surface of intake valve seat (MT-1).

The surface of the intake valve is presented in Figure 6 of the engine MT-2. The contact surface is divided into two regions with different characteristics, denoted by 1 and 2. The region 1 has more homogeneous grayish appearance and region 2 has a surface with more evident circumferential scratches.

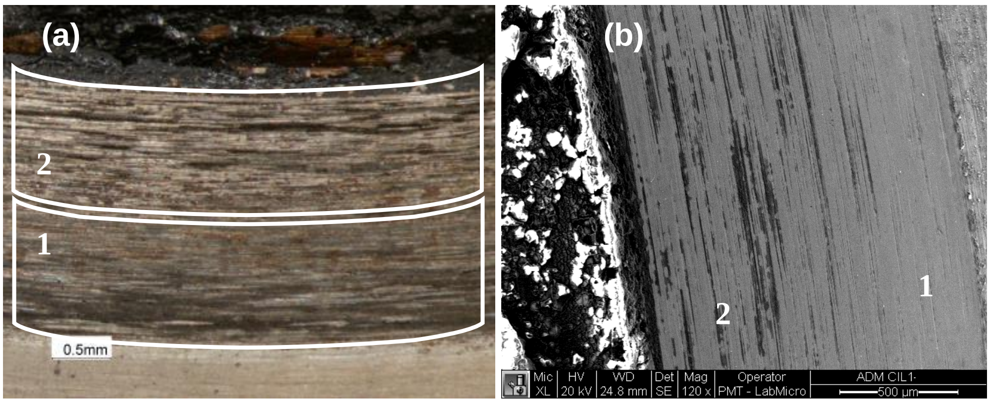


Figure 6. OM (a) and SEM (b) images of the surface of intake valve (MT-2).

In another region of the valve seat, presented in Figure 7, it can be observed a different coloring. However, this does not represent a change in surface wear, but a deposition of material, as seen in the image obtained by SEM.

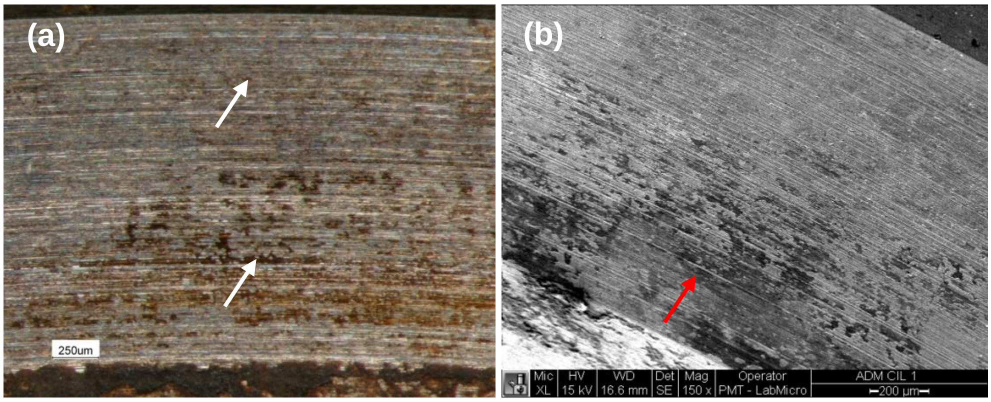


Figure 7. OM (a) and SEM (b) images of the surface of intake valve seat (MT-2).

2.2.- Exhaust

The surface of the MT-1 engine exhaust valve shown in Figure 8 is divided into two regions. Region 1 has marks of circumferential scratching and grooves due to detachment of material caused by small particles or surface with protuberances. Region 2 (Figure 8b) has a smooth surface. It can be also observed a spot, possibly a result of oxidation caused by the high temperatures of the exhaust gases. The oxidation can be better seen with angled illumination of 45°. In the images obtained by SEM, Figures 8c and 8d, it can be noted that there is deposition of material at the edges of the stain.

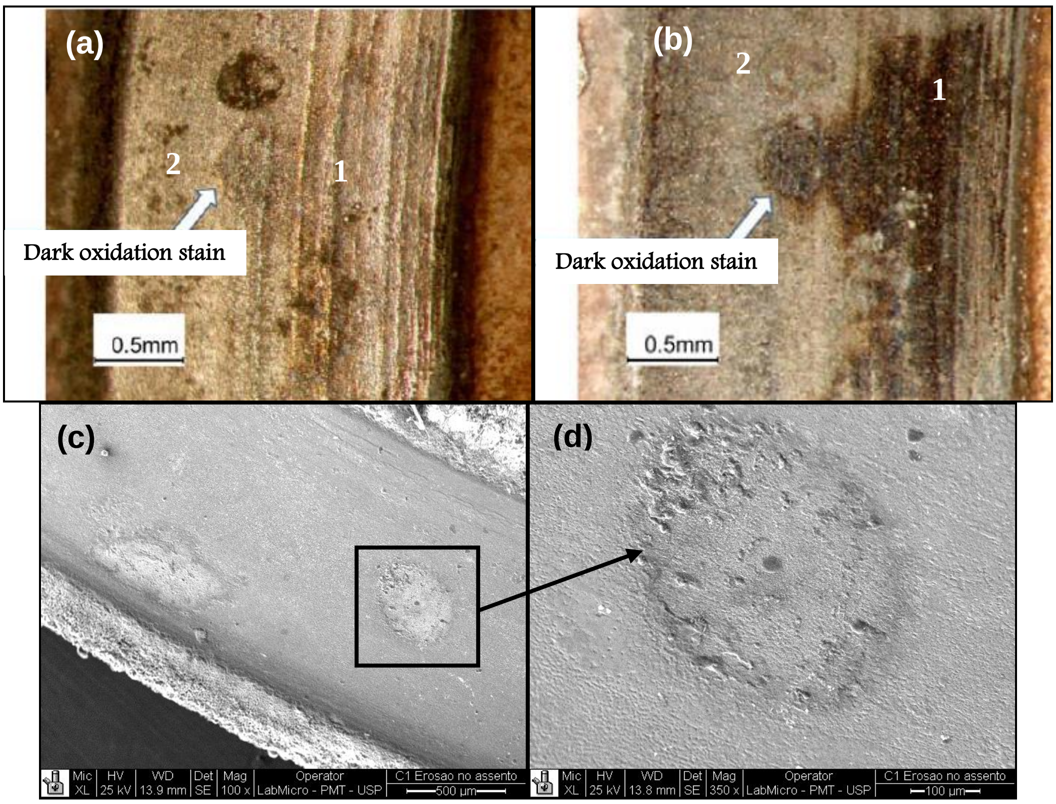


Figure 8. OM image with normal illumination (a) and angled illumination (b) of an oxidation stain. SEM images of the same region (c) and (d) of the surface of exhaust valve (MT-1).

The contact surface of the exhaust valve of the engine MT- 2 shown in Figure 9 can be divided into three regions, which have different coloring and aspects indicating that wear occurred in different ways.

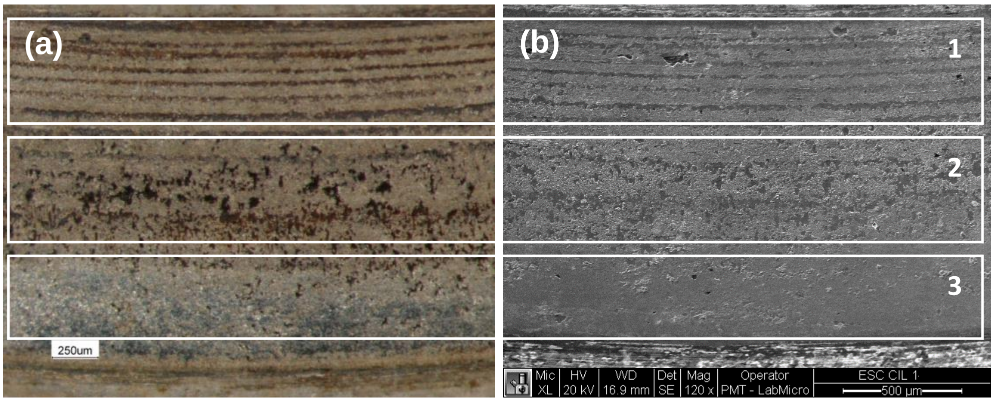


Figure 9. OM (a) e SEM (b) images of the surface width of exhaust valve (MT-2).

The region 1 show deposits, dark spots and circumferential machining scratches, which can be seen in Figure 10a. Region 2 has a transition characteristic between regions 1 and 3. The region 3 exhibits a smooth surface with disorganized deposition of material, which indicates, as mentioned above, increased wear in this region.

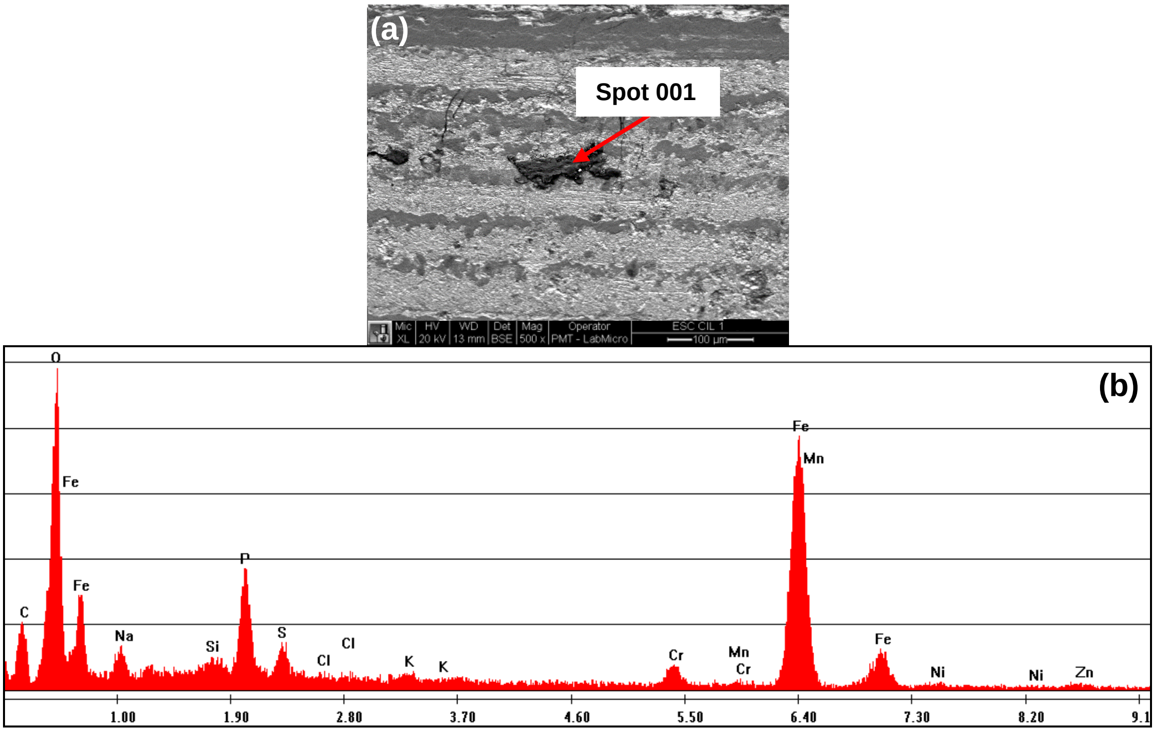


Figure 10 – SEM image (a) of region 1 in the surface of exhaust valve (MT-2).
EDS analysis of spot 001 (b).

An energy-dispersive X-ray spectrometry (EDS) analysis was performed in the dark spot. In Figure 10b can be observed the presence of elements such as Fe, C, Si, K, S, Mn, Ni and Cr, constituent elements of the valves and valve seats, but it was observed a peak of oxygen which indicates oxidation at this location. The presence of Na, P and Zn, may indicate that occurred a deposit of material from the lubricating oil.

In Figure 11, it can be observed deposition of material, which occupied the whole contact surface. In the image obtained by OM it is noticed that the deposit has orange coloring with early stage of oxidation in the region indicated by the arrow. In the image obtained by SEM can be observed that the deposition has no defined distribution pattern, showing that this deposit is not related to the wear caused by contact between the valve and the valve seat, but by the interaction with the hot combustion gases.

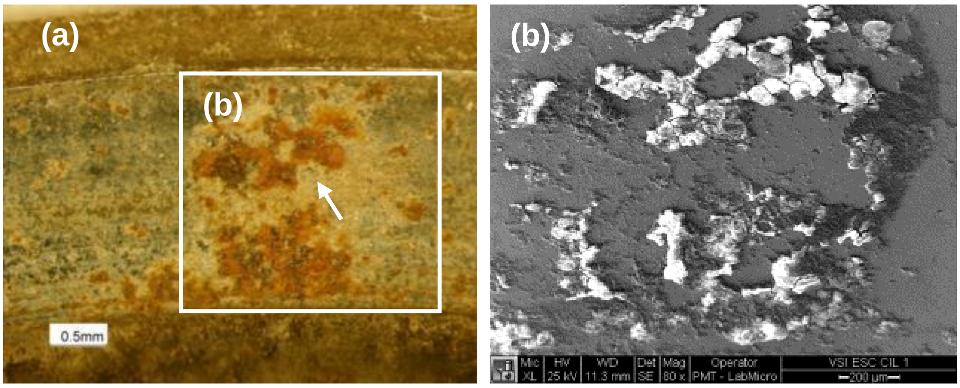


Figure 11. OM (a) and SEM (b) images of the surface of the exhaust valve seat (MT-1).

The surface of the exhaust valve seat of the engine MT-2 shown in Figure 12 was divided into three regions with different aspects and coloring. Region 1 is characterized by having surface with less roughness than the others regions closer to the inner edge (region 3), characterized by the circumferential machining scratches and deposits. Region 2 has a transition characteristic between regions 1 and 3. This fact indicates that the region 1 suffered more severe wear (as explained in Figure 13).

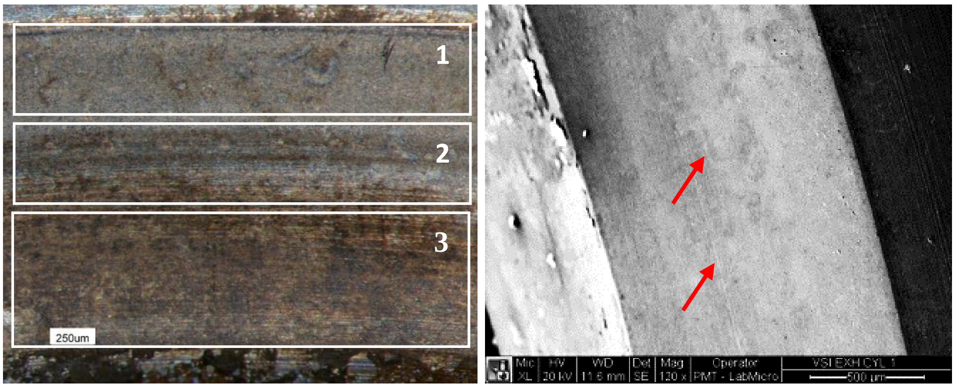


Figure 12. OM (a) and SEM (b) images of the surface width of exhaust valve seat (MT-2).

Some regions of the valve seat surface had different appearance as can be seen in Figure 12a. In the central region there are circumferential scratches, as shown in Figure 12b obtained by SEM. Despite different coloring obtained by optical microscopy, the wear mechanism occurred in both regions was not different from that described for the reference section, as seen in the SEM image.

The wear was more severe possibly due to the higher contact pressure that occurs at the outer edge, indicating that wear increases from the inner edge to the outer edge of contact surface. This may occur due to the project recommendation between valve and valve seat, in which is desirable that the first line of contact occur in the region close to the outer edge, in order to ensure the sealing of the contact, as shown in Figure 13.

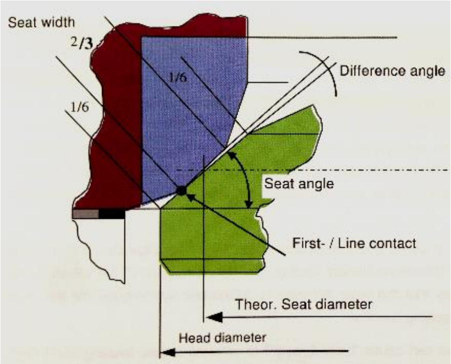


Figure 13. Contact scheme in the design of valves – valve seats.

Visual inspection of intake and exhaust valves and valve seats of 8-valve engines revealed occurrence of surface damages produced not only by tribological phenomena but also by engine operating condition and by corrosion process, such as the presence of oxidation, in addition to the circumferential machining scratches due to the manufacturing process.

Many of the damage were observed in both, intake and exhaust, valves and valve seats; however the oxidation occurred only on the exhaust valves of both examined engines, suggesting it was produced by high temperature conditions during engine operation. Due to the severity of the operating conditions of exhaust valves and valve seats, their wear was more pronounced when compared with the intake valves and valve seats. Damages: step and wear in the central region were not found in tribological pairs analyzed.

The most significant changes occurred in the surface of the valve seats, due to the known definition of project, in which, in general, the wear in the valves should be 1/3 of the total wear and the remaining 2/3 occur in the valve seats.

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