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Microstructure Analysis of Inlet and Exhaust Valves used in LPG fueled Retrofitted Spark Ignition Engines

Ajay Pandey [1], R. K. Mandloi[2]
[1]*Department of Mechanical Engineering, MANIT, Bhopal, India*
[2]*Department of Mechanical Engineering, MANIT, Bhopal, India*

ABSTRACT: *Mechanically operated poppet valves are used, both as inlet and exhaust, for most conventional automotive engines in passenger cars. These valves are subjected to high temperatures throughout their operating cycle. A valve originally designed for a gasoline engine, when used for an LPG fueled retrofitted engine, goes through considerable mechanical damage, corrosion, erosion, wear and tear. It also demonstrates significant changes in its microstructure. This investigation focused on microstructure analysis and quantitative metallography of such inlet and exhaust valves using Atomic force microscopy (AFM) technique. The surface morphology of the valve material was studied and AFM measurements were used for quantitative characterization of the structure as also to gain useful information about crystallographic orientation of individual grains, the formation of cracks, identification of potential crack initiation and fracture sites, etc. A comparative evaluation of microstructure of worn - out valves with new valves was also carried out.*

Keywords: *AFM, LPG, microstructure, poppet valve and surface morphology*

I. INTRODUCTION

Valves used in LPG fueled retrofitted SI engines operate in a very hostile environment. These valves are not only subjected to high temperatures and pressures; they are subjected to impact loading, thermal stresses, and fatigue loading too. Since pressures and temperatures affecting the valves vary with the type of fuel used and its combustion characteristics, valves are exposed to different dynamic and thermal stresses [1]. The exhaust valve temperature is far more in comparison to an inlet valve and can touch 950°C for a retrofitted LPG fueled engine. Engine valves, being subjected to such high temperature and pressures, are extremely vulnerable against wear and consequent failure. Wear failure of valves is a commonly encountered phenomenon which is aided by fatigue crack growth. The wear mechanism in exhaust valves of heavy duty engines has been found to be a combination of oxidation and adhesive wear [2]. Valves also fail due to surface erosion and corrosion. The erosion - corrosion of exhaust valves ("valve guttering") is a recognized failure mode in internal combustion engines [3]. All these failure contributing mechanisms alter the microstructure of valves and metallographic images of these variations can be stitched together to provide an insight into valve behavior and its failure.

II. EXPERIMENTAL DETAILS

Valve Specifications

The valves chosen for this experimental investigation were standard poppet valves used in LPG – run, retrofitted passenger car engines in India. The valve specifications are L/TH/D/1, α 45° (inlet valve) and S/TF/D/1, α 45° (exhaust valve).The inlet valve dimensions are 31.6 mm (D) × 7.0 mm (d) × 110 mm (l) whereas the exhaust valve dimensions are 27.0 mm (D) × 7.0 mm (d) × 119.5 mm (l).

Sample Preparation

Valve specimens of adequate dimensions for microstructure analysis on Atomic Force Microscope (AFM) are prepared using worn - out and new exhaust and inlet valves. The preparation involves cutting and surface finishing with different grades of emery papers, cloth polishing, and cleaning by acetone solution. Finally, the specimen is dried completely in oven.

Experimental Technique and Equipment Details

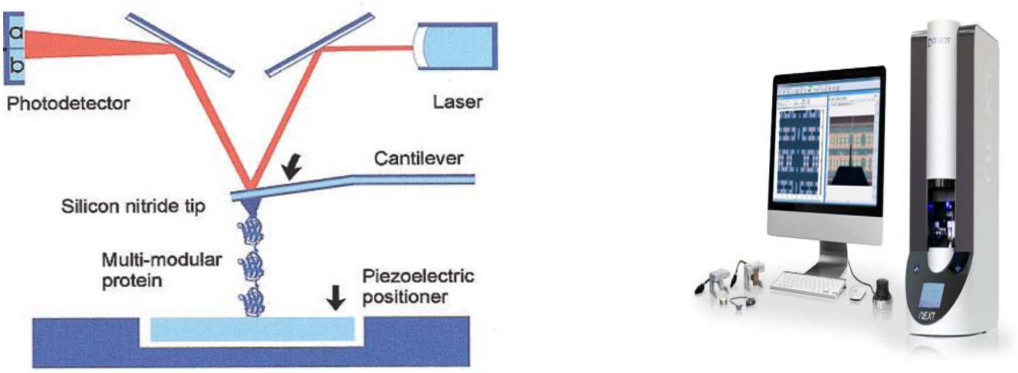


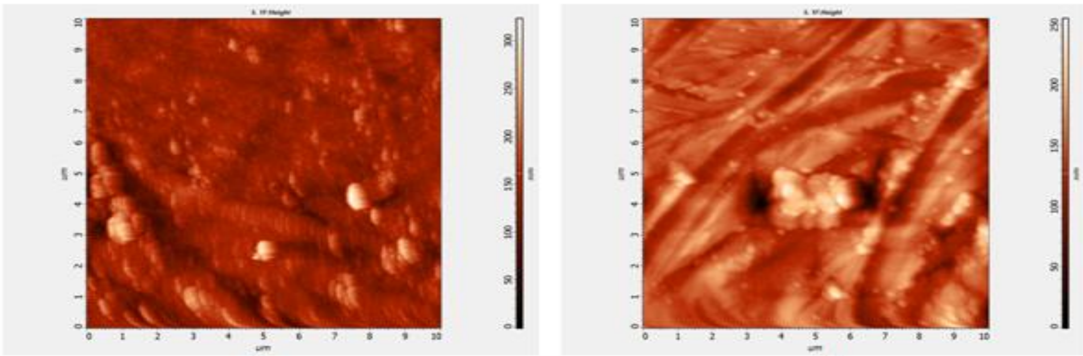
Figure 1: Schematic and actual image of an Atomic Force Microscope (AFM)

Atomic Force Microscopy is a technique introduced by Binning and Rohrer in 1986 [4]. AFM uses a microscopic probe mounted on a low force constant cantilever that is scanned across a sample surface. Short range atomic forces like van der Waals force are used to detect the surface morphology [5].The atomic force microscope (AFM) is a scanning probe microscope (SPM). SPMs are designed to measure local properties, such as height, friction, magnetism, etc., with a probe. To acquire an image, a small area of the sample is scanned with simultaneous measurement of the local property. AFMs operate by measuring force between the probe and the sample [6]. Normally, the probe is a sharp tip, which is a 3-6 µm tall pyramid with 15-40 nm end radius. Though the lateral resolution of AFM is low (~30 nm) due to the convolution, the vertical resolution can be as good as 0.1 nm.

The testing of samples was done on NT - MDT scanning device (Fig. 1). The scanning areas chosen were 10 µm × 10 µm, 5 µm × 5 µm and 2 µm × 2 µm. Images obtained were analyzed for evaluation and understanding of various parameters, as also for the purpose of relative comparison between a new and a worn – out valve.

III. OBSERVATIONS AND RESULTS

Some representative images for inlet and exhaust valves are shown below (Fig. 2 & 3). The image for the failed exhaust valve clearly shows the presence of a significantly large number of secondary particles that could well be silicates, oxides and / or carbides. The crack initiation sites are likely to surface across all projections. The effect of thermal stresses and mechanical failure causing agents is visible through material deformation and material drifting. The image for a new exhaust valve shows the inclusion of an abrasive particle. Some finishing patterns that are so typical of the manufacturing operations employed are also visible. The image for a failed / worn – out inlet valve exhibits pronounced effects of high chemical abrasion. A number of voids scattered across the section are an indication of a thermal shock wave and accompanying thermal stresses. The changes in the surface and its structure are an indication of the effect of temperature and chemical agents. The cracks at some locations may also be attributable to the escaping out of entrapped gases that result in appearance of secondary structures. The image for a new inlet valve is quite similar to the one for an exhaust valve with a number of minute granules distributed in a more or less uniform manner.



A B

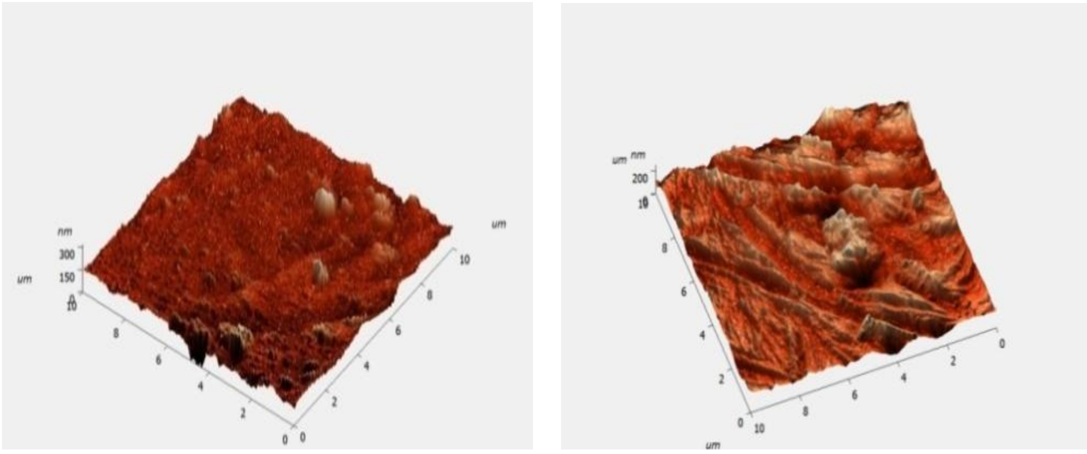
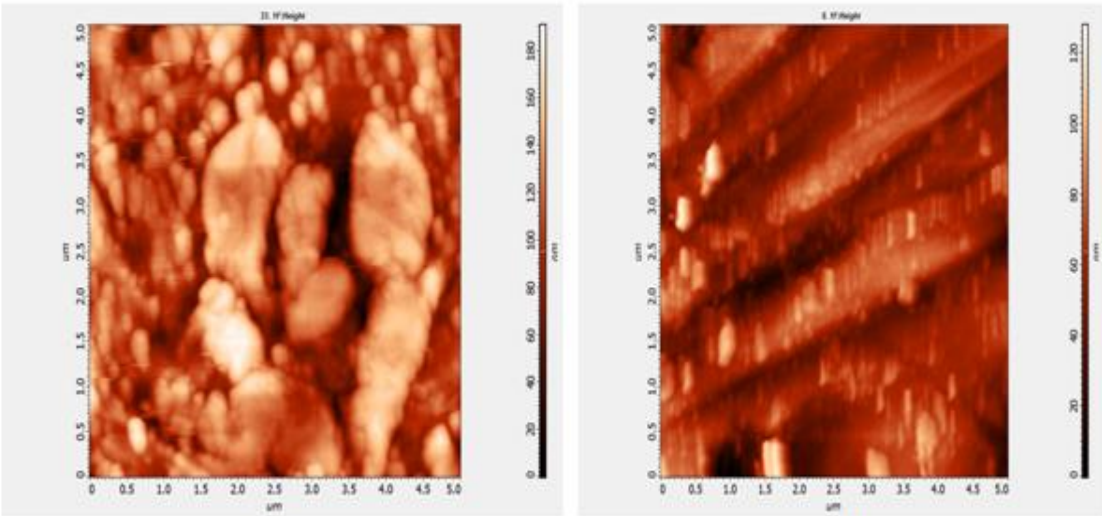
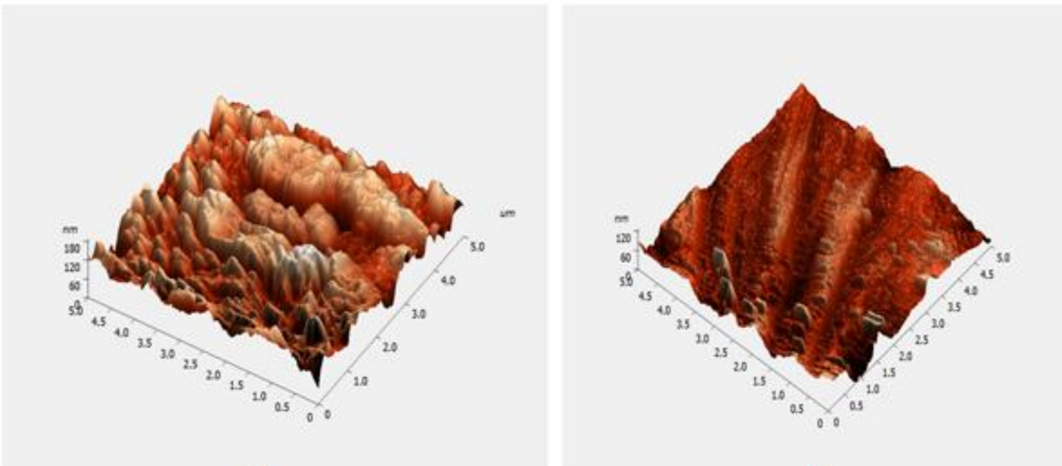


Figure 2: AFM images (2D & 3D) for worn – out exhaust valve (A, C) and new exhaust valve (B, D)



A **B**



C **D**

Figure 3: AFM images (2D & 3D) for worn – out inlet valve (A, C) and new inlet valve (B, D)

Table I: Statistical descriptors for failed and new valves

Valve Type / Statistical Descriptors	Failed Exhaust Valve	New Exhaust Valve	Failed Inlet Valve	New Inlet Valve
Amount of Sampling	65536	65536	65536	65536
Sampling Area (μm^2)	100	100	25	25
Mean (10^{-17} nm)	-185	-123	-411	625
Minimum (nm)	-142.661	-144.391	-113.382	-58.418
Maximum (nm)	179.959	110.025	77.227	69.409
Peak to Peak (nm)	322.621	254.416	190.610	127.828
Root Mean Square Value (RMS) (nm)	25.929	25.995	30.145	15.775
Roughness Average (nm)	18.425	19.457	24.073	12.552
Skewness (Ssk)	0.937	-0.252	-0.429	0.147
Kurtosis (Ska)	7.048	4.934	3.172	3.480

IV. CONCLUSION

The 2D images, corresponding 3D images and magnitudes of statistical descriptors (Table I) for failed and new inlet and exhaust valves provide useful information about the existence of surface asperities, grain sizes and crack propagation. The peak to peak value is the maximum for the failed exhaust valve which indicates that this valve has suffered a significant bit of mechanical damage which, to a large extent, is attributable to the high temperature the valve encounters in an LPG engine. The peak to peak values are less for inlet valves as they are subjected to lesser thermal gradient and lower highest temperature. The average roughness values exhibit exactly the opposite patterns for exhaust and inlet valves. The average roughness value for the failed inlet valve is almost double the value for the new inlet valve which is an indication of bulk surface deformation under thermal and cyclic stresses

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