

Failure Analysis of Internal Combustion Exhaust Valve

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Abstract. The exhaust valves system is very important for internal combustion engines and experienced severe physical and chemical environment including frequent impact, high and varying temperature, exhaust gas' chemical corrosion and deposition of fine dust, et al. This paper presents a failure analysis of two new internal combustion exhaust valves used not more than 200 houses. The fracture surfaces were investigated by SEM and optical microscope. And EDS was used the clarified the related chemical elements. Results of present investigation showed that instability of oxidation film that formatted on the seal face during the early stage, was a crucial factor of the failure. In this case, the film was thin and porous, so high temperature exhaust gas could reaction with matrix welding layer. Consequently, the welding layer loses its wear resistant property during the subsequence service procedure.

1. Introduction

Four-stroke internal combustion engines have been susceptible to valve system under severe conditions including high speed, heavy loading operation as in heavy truck and mine vehicle machine^[1]. Intake valve system allows new clear air or the air fuel mixtures enter the chamber, and close the mixture during the combustion period. Exhaust valve system force out exhaust gas. And each valve must operate once during one cycle and this is finished by a camshaft that operates tappet body and spring to open and close the valves.

The used materials for intake and exhaust valves are usual different because of the different operating condition to be subjected. While, exhaust valves operate in more harsh condition than intake valve, including high temperature, frequent impact during high press frictional wear^{[4][5]}, complex chemical erosion-corrosion of exhaust gas and possible particulates. And the erosion-corrosion of exhaust valves is a recognized failure mode of internal combustion engines^{[6][7]}. Valve guttering has generally been attributed to exhaust gas blow-by escaping cross the gap of valve surface and seat. Result in formation of a radial channel or gutter. Typical causes of leakage include valve distortion, face peening and degradation of face coating. The accumulation of combustion deposits on the valve surfaces interferes proper seating and promotes leakage and eventual failure. To increase the resistance of erosion-corrosion and wear ability, a welding layer of stellite alloy always been used on the seal face of exhaust valves.

Some fuel additives are used to increase the combustion efficiently, that may induce some potential problems, always been the focus of investigations. Tetraethyl lead is used for anti knock additive, where another problem occurs that PhO may corrode the exhaust valves. And increasing demand of environments protective legislations are proposed to replace it. But in some case, tetraethyl lead is also used for its high efficiently.

In this case, two exhaust valves were found distorted and broken in one new equipped engine, no more than 200 operation hours with fuel sample 'A'. But exhaust valves were never found failure with fuel sample 'B'. Fuel inspection found that, the lead content in sample 'A' fuel in high than sample B. The main objective of the present investigation is to analyse the mechanism of the exhaust valves operated under in sample 'A' fuel's condition. The erosion-corrosion and wear details are investigated using several analytical instruments, both on the surface and in cross sections.

2. Investigation methods

A ZEISS Discovery V20 stereo microscope was used to survey the perfect and failure valves. An LEICA DM 4000 metallurgical microscope was used to examine the cross section of the valve. Radial guttering and cross section were further evaluated using scanning electron microscopy (SEM) and energy dispersive spectrum (EDS) to characterize valve deposit morphology, microstructure and chemical element composition.

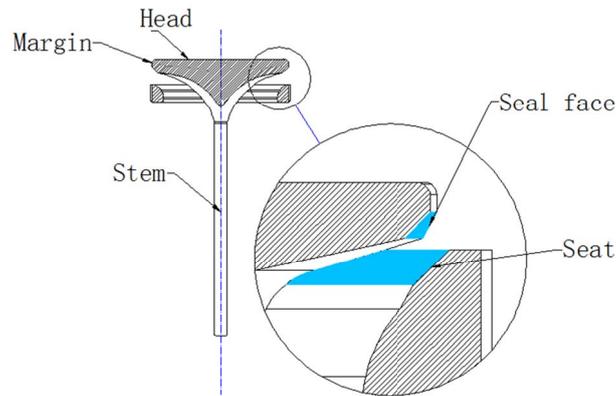


Fig. 1 Schematic diagram of exhaust valve

3. Observation Results

3.1 Macroscopic analysis

The base nomenclature used for exhaust valve is shown in Fig. 1, normally, exhaust valve include head, stem and seal face. During to valve train dynamic, seal face contact with seat under axial repeated loading. The failed exhaust valve are shown in Fig. 2(a and b), inside with corresponded head. Cracks initiated from the tapered plane and propagated toward head, which made the valve distortion and deformation.

Microstructure photograph of failed valves are shown in Fig. 3. Some concave pits were formed on the seal face of No.2 valve, and cracks initiated and propagated along radical direction on the seal face of No.4 valve. Advanced investigation with Scanning electron microstructure (SEM) shows that, even in relatively flat surface of No.4 valve, many micro-cracks were found. And no scratches are found on the surface. During dynamic operation process of internal combustion engine, flaming gas with high temperature and un-burned fuel flow along the cracks, as gas welding cut the head of exhaust valve, along radical direction.

3.2 Metallographic analysis

Cutting samples from head of failed valve, along with crack, and compared with new valve. It was found that the seal face of failed valve is wear-out form surface. And fracture face of crack show different color indicated that high temperature gas had flow and washing the crack. That was also proved by the microstructure of the fracture face, in accord with fig. 3d.

Cross section samples were carefully fabricated by cutting from the cracks along radical direction, and compared with new valve in fig 4a and fig 4b. Homogeneous microstructure and smooth seal face of the exhaust is found in the new valve. While significant depressed fracture is found in the welding layer along the seal surface, that mean seal face was wearing and dropped. Then, different color gradient change from seal surface to matrix may affected by the flame temperature's change that flow along the gap of crack.

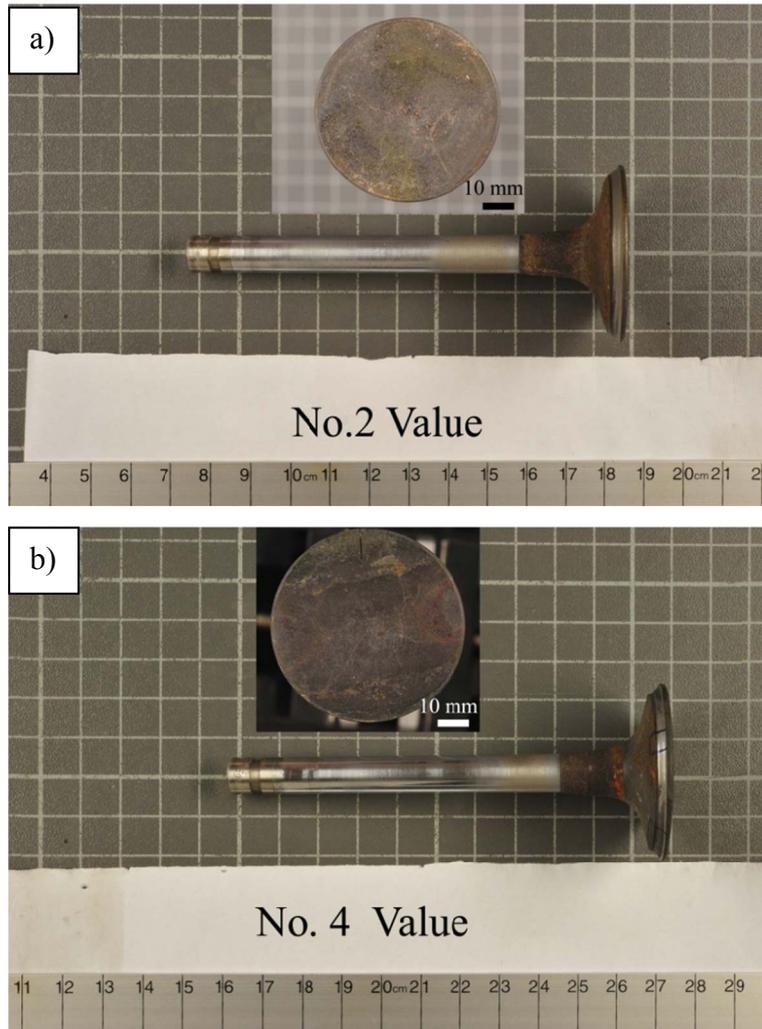


Fig. 2 Photograph of failed exhaust valves, inside with corresponded head

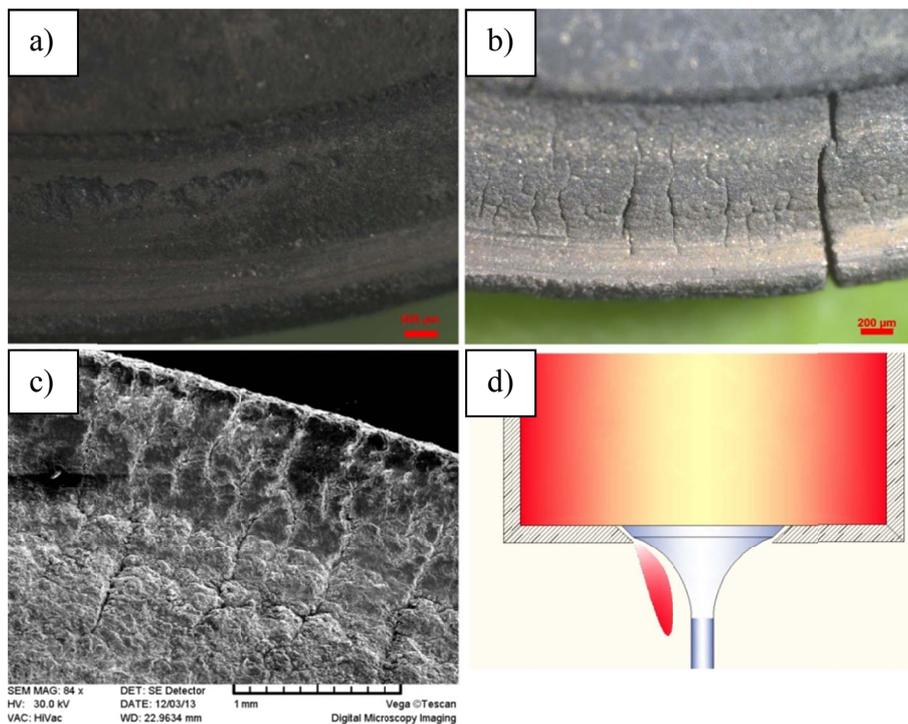


Fig. 3 Microstructure photograph of the seal face. a) No. 2 failed valve; b) No. 4 failed valve; c) Scanning electron microstructure of failed seal face; d) Schematic diagram of burning flame sour the seal face

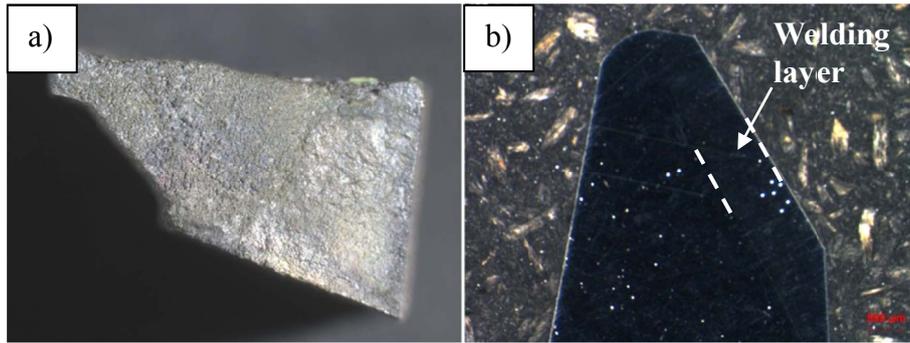


Fig. 4 Cross section of valves, a) failed valve (No. 4) and b) new valve

Metallographic sample were carefully cut from failed valve and new valve, and grinding with finishing papers, then polished, and etched with corresponding solution. The metallographic photographs are shown in fig. 5. Result show that surface of seal face is a weld hard face with stellite alloy, which is a cobalt chromium based alloy. And it is specifically designed for internal combustion valve, with high hardness and resistance to erosion and high temperature oxidation. Affected by the high temperature, the grain size of matrix materials is gradient change from deep to interface. Grain of welding layer with significant dendritic structure distribute from interface to surface, which may influencing by high temperature.

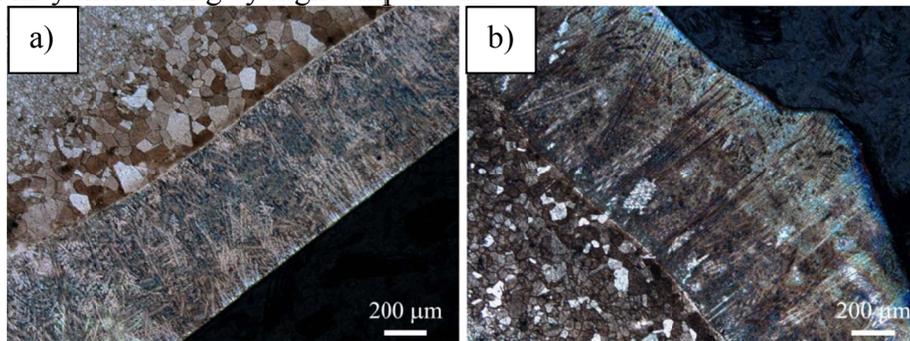


Fig. 5 Metallographic photograph of new valve and failed valve, a) new valve, b) failed valve

3.3 Welding layer and deposit analysis

The microstructure of welding layer of failed valve is show in fig.6 on cross section. The outermost layer about 20 μm appears spotty and full of cavities. The layer is formed by the combustion process, from the original welding layer and combination of oxidation and residual of combustion. The matrix material nearby the surface with many cavities too, is eroded or oxidized along the flow lines.

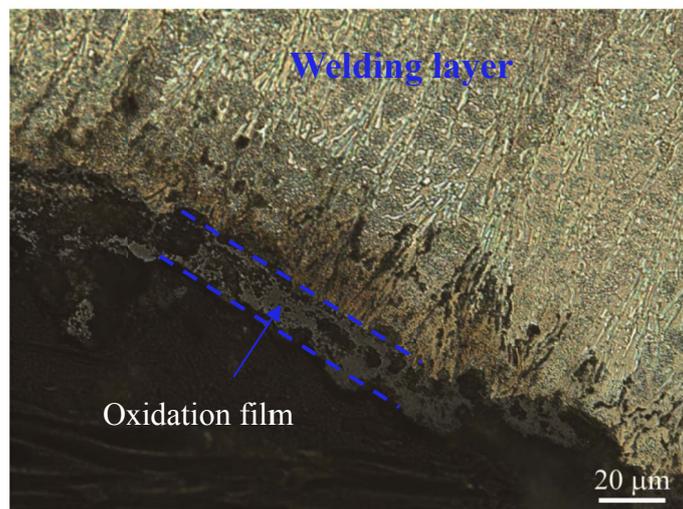


Fig. 6 Metallographic photograph of welding layer (stellite alloy) of failed valve on polished cross section