A Failure Analysis of the Exhaust Valve of EMD Locomotive Engine

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***Abstract*- In this paper, failures of valves in cylinder head of diesel locomotive are contemplate and analyzed. The design of the diesel engine has persistent to procure over the years. Many of the things ware alternated in response to the customer's increasing horsepower demands. There are many things are there which make a valve fail. The usual causes are thermal and mechanical overstresses, longitudinal cyclic stress, and creep conditions, forging defects etc. these leads to copious troubles in performance of Engine. The valve troubles embrace valve breakage, valve face wear, Steam and guide wear, necking of valve stem and other valve problems. Further because of pressure, the density of exhaust gases is also comparatively high and if the valves do not receive adequate cooling, they can overheat, burn and fail. The changes in microstructure, Compositition and material properties of valve were studied and analyzed with help of many tests. The specimens were prepared out of failed engine valve whereas new valves were also analyzed for sake of comparison. Anything that interferes with valve cooling or creates extra heat in the valve can lead to premature valve failure and another is escape of flue gases from Cylinder head which causes decrease in Efficiency of engine. In order to investigate the effect of failure modes on damaged valves, a failed valve taken from a plant was examined. This paper describes a detailed metallurgical investigation and fractographic analysis on that particular exhaust valve of a diesel locomotive engine, which catastrophically failed in service.**

Index terms- EMD (Electro Motive Diesel), DPT, MPT, Guttering, recession, Microstructure, XRD, Spectroscopic Analysis, Scanning Electron Microscopy

I. INTRODUCTION

The EMD Diesel engines are the engines used in Locomotives are of a 2 strokes and V type design and are manufactured in 8, 12, 16 and 20 cylinder models. The Internal combustion two-stroke engine consists of 4 valves out of which two for inlet and two for exhaust of gas. They are very important engine components that are used to control the flow and exchange of flue gases in internal combustion engines. They are used to seal the working space inside the cylinder against the manifolds and are opened and closed by means of what is known as the valve train mechanism. The Valves are very important components in the internal combustion engine. The Valves operates open and close as and when needed. The fresh charge is induced inlet valve and the products of combustion get discharged to atmosphere exhaust valves.

The analysis performed in the comparison of a used valve and unused new valve. In the first inspection the valve has two types of the precipitate formed on the valve seat and valve shaft, So the first aim is to determine the weather these precipitates formed are similar or not and reason behind the formation of the extra material on the valve. After that to check whether the precipitation is formed because of the unburned fuel or the less oxygen supply. For determining exact reasons of the failures the valve is examined under different computational, metallurgical, fractographic and physical analysis to determine the exact reason behind valve failure. the different tests included spark testing to determine the exact composition of the material of valve, microstructure testing for studying the inside material composition structure of the valve, Dye penetrating testing to find cracks in the valve, Spectrographic analysis magnetic penetrate testing to determine the cracks which were not able to found during DPT, X-Ray diffraction test analysis for comparison of two types of precipitations or combustion residual founded on the valve.

Figure: Failed and New Valve Comparision

Any type of valve failure affects the engine performance thus making it mandatory to give due importance to failure analysis of internal combustion engine valves. Possible modes of valves failure are wear failure, valve face recession, fatigue failure, thermal fatigue, erosion / corrosion of valves, overheating of valves, carbon deposits on valves etc. Available research literature about valve failures indicates that valve design is a complicated task because the valve is subjected to various loads at any point of time, such as reverse loading at a high temperature, stress concentration at the keeper groove area and under carbon deposits at exhaust valves. The valves generally fail by fatigue. Valves are subjected to cyclic loading due to valve train dynamics. The keeper groove area is subjected to tensile stresses and becomes a critical section due to geometric stress concentrations.

II. MODES OF FAILURES

A. Failure Due to Fatigue

There are three important categories of fatigue failure they are Mechanical failure due to fluctuating stresses due to cyclic load at high temperature, Thermal fatigue due to cyclic changes in component material temperature, Thermo mechanical fatigue due to fluctuating stress change and cyclic loading because of these fatigue failure occurs in the valve.

B. Failures Due to fluctuating Temperature

Electromotive diesel locomotive engine valves are mainly operated above temperature 600oc and subjected to cyclic loading. The Elastic and plastic deformation caused at the neck surface area of the valve. The exhaust valve stem fails by overheating because the temperature of the exhaust valve is about 600 ºC. The fracture surface of the valve stem is covered with a black or white oxide scale formation. With high loading, multiple cracks are initiated if the valves are subjected to high temperatures and, under such operating conditions, it would be expect that failure would occur within a few million cycles. It was found that a lot of carbon deposition appears on the plate surface.

Figure: Failure due to Fluctuating temperataure

C. Failure of Valve Due to Erosion-Corrosion

The scale formations are on the valve which corrodes the surface of valve due to exhaust flue gases. Surface material is removed in service life and it is the result of erosion by small, solid, impacting particles. In most elevated - temperature erosion environments, the eroding surface is undergoing corrosion as well as erosion. Hot gases escaping at seat of an adjacent valve are directed at shot-blasted fillet area and erode surface material. Valve guttering generally occurs because of flow of exhaust gas across the valve face surface, resulting in the formation of a radial channel or gutter. Typical causes of gas leakage include valve distortion, face pinning and degradation of face deposits.

Figure: Corrosion on Valve

D. Failures Due to Valve materials

The inlet and exhaust valves are divulged to varying operating conditions in High Horse Power engines, so the materials used in their manufacturing are also must have specific properties that it can overcome any operating condition. Specifically, the material used for exhaust valve must have high resistance to corrosion erosion at the excessive operating temperatures, sufficient strength and hardness to combat tensile forces and wear, high fatigue and creep strength, coefficient of thermal expansion should be low to avoid exorbitant thermal stresses and most importantly they should have a high thermal conductivity for superior heat dissipation. Exhaust valves of in High Horse Power engines are predominantly made of alloys. In diesel locomotive engines the exhaust valves have high levels of cobalt, nickel, iron, chromium, titanium and other elements to accrue hardness and strength.

E. Failure of Valve Due to Wear

At the sealing face of valve and valve seat which slide on valve stem guide, wear failure occurred at this area. There are two major factors, due to which wear failure occurs

a. The impact force between sealing face of valve and seat insert
b. Due to sliding of the valve on the seat insert during the action of combustion pressure.

Figure: Valve Face Wear

The origin of valve face wear is improper valve spring tension, high speed and excessive heat, loose valve adjustment, and excessive abrasive dirt in intake. Continue operation with this type of wear leads to cupping. It is theorized that "initial" valve face wear rate is greater than the rate of wear after break in, under normal condition.

F. Failure Due to Loading and Seating

Studies have shown that the exhaust valve sear wear mainly involves two distinct mechanisms. The first one is the impact of valve on the seat as it closes and second mechanism is Micro-sliding, caused by the elastic deformation at the valve seat interface as the valve head is pressed into its seat by the high combustion pressure. Experimental work performed also show that combustion load, valve misalignment and most importantly, the valve closing velocity have a significant effect on valve face recession

Figure: Valve Sear Wear Due to cyclic loading

G. Valve recession

Valve recession is said to have occurred if wear of the valve and seat insert contact faces has caused the valve to 'sink' or recede into the seat insert, thereby altering the closed position of the valve relative to the cylinder head. Valve recession is the most common form of valve wear in gas-fired engines; valve recession occurs gradually over thousands or tens of thousands of hours. The recession occurs by metal abrasion, high temperature corrosion, frictional sliding, and adhesion mechanisms. Excessive amount of valve recession leads to incorrect or incomplete seating which leads to losses in the cylinder pressure Valve and Seat recession mostly occur due to impact of valves on the seat, and by the systematic gouging, dulling, deformation and eventual wear out, of the exhaust valve or seat insert material.

H. Guttering

In case of the valve not seating properly, which might be due to valve deformation or due to the interference of the solid deposits, the pressure inside cylinder will be lost in the form of a leakage path for the exhaust gases. This leakage path will lead to material losses in the valve and its seat by means of an erosive-corrosive mechanism. Over repeated engine cycles, this leakage path will widen and will eventually lead to valve guttering which can be easily identified in leaked engine cylinders by a distinct hissing sound. Literature Study about the ash deposits or scales on the valve sealing face have clearly confirmed their influence in the valve guttering process. Guttering of exhaust valves will eventually result in an alarming leakage of the cylinder compression, and will also manifest in the form of power loss due to misfiring.

III. FAILURE ANALYSIS

A. Microstructure Test

Specimens of standard dimensions for microstructure analysis on Scanning Electron microscope (SEM) are prepared using used and new exhaust and inlet valves. The preparation involves cutting and surface finishing with different grades of emery papers, clothing, and finally etching by an etching solution with HCL: HNO_3, Each specimen is etched for 3 to 5 minutes and then dried completely in oven. Each specimen now passes through a scanning electron microscope (SEM) which is an electronic microscope that produces images of a sample by scanning it with a focused beam of electrons. The white colour spots in the images indicate the presence of carbides in the valve material. If the distribution of the carbide is fine, it increases the hardness of the material but a coarse distribution of the carbides makes them shift towards the grain boundaries with an accompanying reduction in the hardness and weakening of the material. The grain boundaries shown in the SEM image shows that they are broken and grains are not uniformly distributed. The size of grains increases after working at high temperatures.

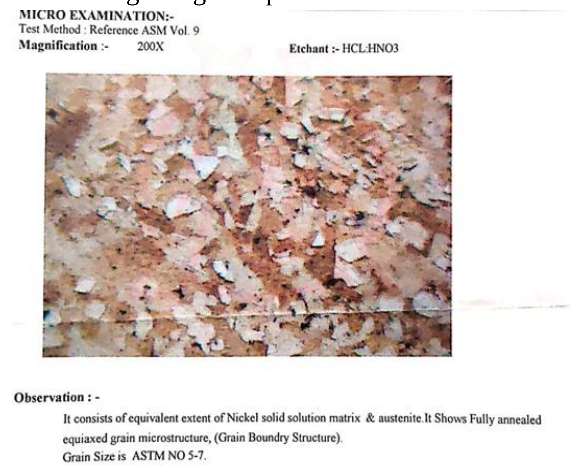

Figure: Microstructure Test

B. Spark Test-Composition of Valve

Spark test was performed on new valve and destructed valve to determine the composition. Our aim of this test was to compare change in composition of valve due to physical and chemical changes. Characteristics of spark are colour, volume, nature and light of spark. All elements were found in range of standard values set by AISI except Molybdenum and Aluminum. Chemical composition confirmed to ASTM B637 UNS NO 7750.

Element	Standard Values	Observed Values
Carbon	0.080 max	0.040
Silicon	0.50 max	0.23
Manganese	1.00 max	0.30
Sulphur	0.010 max	0.003
Chromium	14.00-17.00	16.04
Nickel	70 min	71.60
Niobium+tantalum	0.70-1.20	0.96
Titanium	2.25-2.75	2.60
Aluminum	0.40-1.00	0.52
Iron	5.00-9.00	7.63
Copper	0.50 max	0.010

Table: Material composition of valve

C. XRD (X-Ray Diffraction) Test

In visual inspection test we identify residual powder settlement on stem, neck and face of valve. Due to accumulation of these residual powder heat dissipation is hindered on neck and stem area. On face white residual powder is accumulated due to combustion of fuel. On stem and neck black residual powder is accumulated due to incomplete combustion and possibility of burning of lubrication oil. If lubrication oil is burnt then it is of serious concern. For these we did XRD test to compare white residual and black residual sample. XRD is used to identify single crystal, to reveal the structure of single crystal. It is used for phase detection and provides information on unit cell dimensions. The X-rays are generated by cathode ray tube directed towards the sample. The interaction of incident rays with sample produces constructive interference when conditions satisfy Bragg's law. As on exhaust valve two types of residue formation was seen. The above graph shows the XRD results of both the residues named as black residue and white residue. Black residue was formed on stem part of the valve and white residue was formed on the valve base portion. As on valve these residues may be formed due to reasons like incomplete combustion, mixing of lube oil, etc. To know the presence of different elements in these residues, XRD analysis was conducted i.e. to check the purity of the sample.

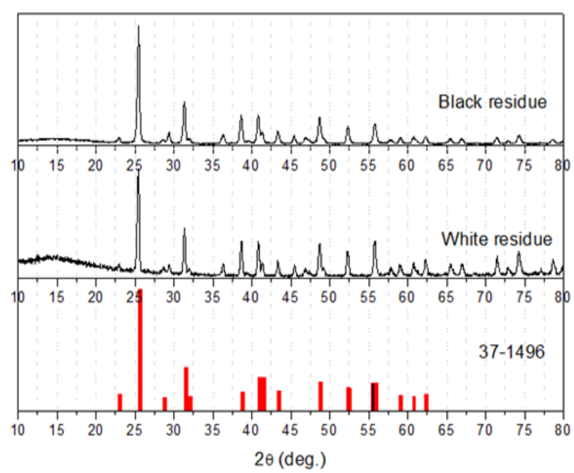

Figure: X-Ray Diffraction test result

D. Spectroscopic Analysis

Spectrographic analysis of used crankcase oil is valuable tool in providing warning about abnormal wear, which may lead to major breakdown such as piston or bearing seizure. It does not, however, give prior indication of a sudden failure of any component due to fatigue. It may be said that spectrographic analysis of the used lube oil is analogous to the blood test of human body with a view to detect the abnormality of the system. The spectrographic analysis of the used crankcase oil helps in

- Predicting the required maintenance.
- Scheduling the overhauls, thus avoiding unexpected down time and thereby increasing the locomotive availability.
- Preventing engine failure resulting from the incipient wear of engine components.

During calibration of spectrograph it should be ensured that temperature, humidity and other conditions in spectrograph Ph labs are maintained as per the manufacturer's recommendations. The equipment shall be calibrated with the primary standard supplied by the manufacturer. Spectrographic analysis of used oil samples shall be done after calibrating the spectrograph against the fresh oil samples and adjusting the fresh oil values to zero. The correlation between wear elements and the engine condition is given in the table below:

For Locomotives Fitted With General Motors Diesel Engines. (WDG4/WDP4 Locomotives)

Element	Normal	Borderline	High
Iron	0-75 PPM	75-125 PPM	Above 125 PPM
Copper	0-75 PPM	75-155 PPM	Above 150 PPM
Lead	0-50 PPM	50-75 PPM	Above 75 PPM
Tin	0-20 PPM	20-40 PPM	Above 40 PPM
Chromium	0-10 PPM	10-20 PPM	Above 20 PPM
Aluminum	-	5 PPM	-
Zinc	0-10 PPM	Above 10 PPM	Above 20 PPM
Silicon	0-15 PPM	15-20 PPM	Above 20 PPM
Boron	0-10 PPM	Above 10 PPM	Above 20 PPM
Sodium	0-30 PPM	30-50 PPM	Above 50 PPM

Table: Spectroscopic Analysis

The Combustion Product Deposited over the Surface of Exhaust Valves ware analyzed using JEOL XRD.

IV. CONCLUSIONS

The exhaust valves were analyzed to be typical of Nickel based super alloy Inconel-751. This alloy is commonly used for high performance valves. The valves probably failed as a result of overheating. The possible cause for overheating is lack of tappet clearance, which results in light seating and carbon build up on the seating face. Both factors lead to destruction of the thermal heat path outlet from the valve face through the valve seat to the coolant. This causes a considerable rise in valve head temperature, particularly in the valve face area. Eventually, the conditions exceed the material's resistance to hot corrosion or burning. As the localized gas leak increases, so does the torching effect through the gap, eventually producing the characteristic gutter. The significant over aging of the alloy caused the particle coarsening which subsequently resulted in the decrease of hardness. There are some traces of low melting point compounds in the valve surface deposits which can cause hot salt corrosion that attacks the grain boundaries. The grain size in the failed valve indicates that performed heat treatment had not achieved the aim of optimal creep resistance. Probably the microstructure is set to achieve optimal fatigue resistance. The microstructure of the failed valve indicates without doubt on the creep type of fracture.

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