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A failure analysis of the exhaust valve from a heavy duty natural gas engine

Muhammad Imran Khan[a,*], Muhammad Arsalan Khan[b], Abdul Shakoor[b]

[a] Institute of Petroleum Engineering, Heriot Watt University, UK
[b] Department of Mechanical Engineering, University of Engineering & Technology, Peshawar, Pakistan

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ABSTRACT

Increasingly stringent emission standards are changing the conditions that valve systems in heavy duty engines are exposed to. Increased pressures and temperatures are challenging system endurance. A consequence of these changing conditions is a reduction in the levels of soot production that had formerly generated protective films. In order to help combat this, nickel-based super alloys have been widely used in applications requiring strength at high temperature. This study presents a premature failure case of a set of exhaust valves belonging to a heavy duty natural gas engine; where the valves were manufactured from one of these alloys, the precipitation hardened Inconel-751. The failure occurred at approximately 5000 operating hours after its first commissioning, whilst the standard expected service life of the valves is 20,000 h. Several examinations employing multiple techniques were carried out in order to identify the root cause of failure, whilst comparing results against those of a new valve. It was found that there was some mechanical lapse in proper sitting of the valve, which had been responsible for unwarranted overheating especially at thinner sections. Microstructure examination revealed that overheating had been responsible for a creep-rupture failure accentuated by precipitation of undesirable constituents at grain boundaries.

1. Introduction

The Global demands for inexpensive and clean power is increasing day by day and in this regard, the market of stationary generators have proven to be one of the major sources of power providers globally. In Asia, generators powered by stationary gas engines are becoming increasingly popular in areas where natural gas is readily available. Currently Caterpillar Inc., GE Waukesha and Cummins Power Generation are the key players in Global and Asian gas engine market [1].

The inlet and exhaust valves are one of the vital components of an IC engine. The major function of an Inlet valve is to control the flow of air to the combustion chamber while the exhaust valves are used to monitor the outward passage of flue gases from the combustion chamber [2–4]. Their operation has a direct effect on performance parameters (power, torque, fuel consumption and etc.) and also the engine emissions. Wear and failure of the exhaust valves, is an unavoidable problem in Internal combustion engines which ultimately leads to under performance, large down time, and high maintenance costs. Numerous numbers of alterations in the design, material and production techniques have greatly enhanced the running life and performance of the exhaust valves, but these up gradations cannot keep their pace with the continuous rise in the requirements of enhanced engine performance in our global competitive environment [4,5].

* Corresponding author.
E-mail address: mk42@hw.ac.uk (M.I. Khan).

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Nomenclature

C—C	Carbon-Carbon
C—H	Carbon-Hydrogen
CH_4	Methane
DTA	Differential Thermal Analysis
EDS	Energy Dispersive Spectroscopy
IC	Internal Combustion
OEM	Original equipment Manufacturer
SEM	Scanning Electron Microscope
TGA	Thermo Gravimetric Analysis
XRD	X-ray Diffraction

There is very limited number of peer reviewed studies available about the failure analysis of exhaust valves especially that of Inconel-751. A failure analysis of the exhaust valve stem in a Waukesha P9390 gas engine was performed by Kwon OG et al. [6]. They observed a significant loss of hardness in valve material and concluded overheating as failure cause. The significant hardness loss, the extensive surface oxidation and fretting/galling on the valve stem were indicative of the overheating. Yu ZW et al. [7] performed a failure analysis and metallurgical investigations of diesel engine exhaust valves. Their fractographic studies indicated that formation of the lamellar structure in the material of the valve head was the dominant mechanism for the fatigue failures in the exhaust valve. Vardar N. et al., [8] investigated the failure of exhaust valve failure in heavy duty diesel Engine. This was carried out by using several experimental tests methods like optical emission spectroscopy, optical microscopy, scanning electron microscopy SEM and EDX. They concluded that the valve was failed and broken down prior to its desired service life. Very recently Witek L et al., [9] investigated the fracture problem of the exhaust valve of a passenger car diesel engine in order to explain the reason of premature fracture of the valve, author used finite element model consisting of the valve, the seat and the guide. The results shows that irregular depositions of the carbon on the seat face of the valve caused large amplitude of bending stress in the valve stem which subsequently caused the premature fatigue failure. Scott CG et al., [10] studied the effect of valve deposit morphology and composition on the erosion-corrosion of valve seat surfaces. The study provides some initial evidence that although valve seat deposits may have played a role in valve failure but the erosion-corrosion of exhaust valves was not exclusively related to the thickness of valve seat deposits. Forsberg P et al. [4] investigated the wear mechanism of three pairs of exhaust valves and valve seat inserts with the same material and design properties but with different service condition. The study revealed that oxidation and formation of a tribofilm was the dominant wear mechanism.

Although the alloy Incolnel-751 is being used extensively in modern heavy duty natural engines by various manufactures around the world but to the best of our knowledge, there is no systematic empirical research exists addressing the thermal performance of Inconel-751 in IC engines. The aim of this study is to analyze the failure mechanism of exhaust valves made of Inconel-751 failed due

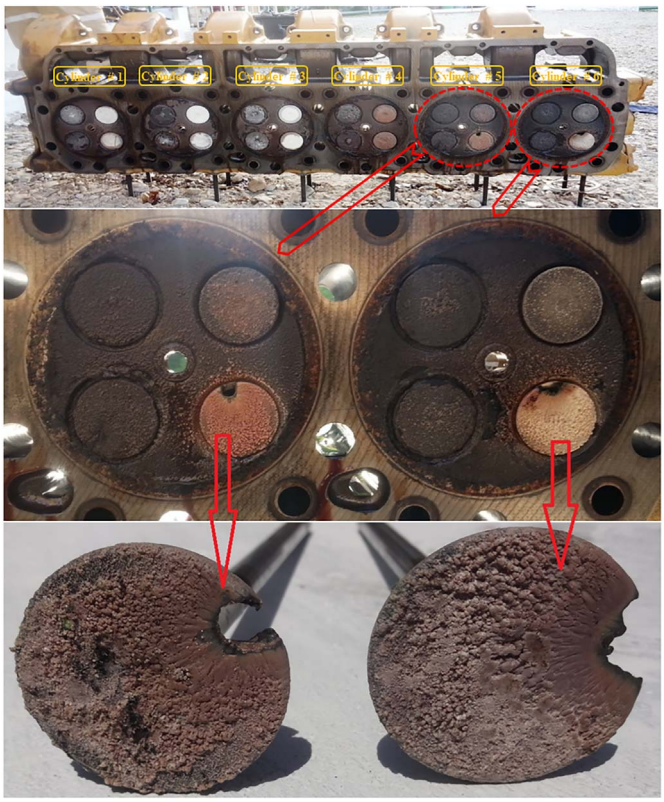

Fig. 1. Showing Cylinder head from a Caterpillar G3406 natural gas engine with guttered exhaust valves and showing high deposits after 10,000 h.