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INVESTIGATION OF SEIZURE FAILURE OF HEAVY DUTY ENGINE PISTON: A REVIEW

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Abstract – In IC engine piston failure is a common phenomenon, but it is very serious problems which still exist. It is only the component of IC engine that encountered failure from different origins like thermo-mechanical stress, wear, fatigue, extreme temperatures etc. In the present works the problem of piston seizure failure of a four stroke diesel engine we observed one seized engine piston of four stroke heavy duty diesel engine at different parameters. We also believe that there exists a theoretical gap in technology of the seizure physics and hence advanced theories should be developed to enhance the understanding of this complex seizure mechanism.

Index Terms— Heavy Duty Piston, IC Engine, Seizure physics, FEM analysis

I. INTRODUCTION

Engine pistons are one of the most important and complex components among all kind of automobiles & automotive components. Lot of research works has been done and also going on for engine pistons & its technology with a continuous improvement over the last many years. [1]

The main reason of this continuous effort of evolution is based on the fact that the piston may be considered the heart of an engine. The piston is one of the most stressed components of an entire vehicle pressures at the combustion chamber may reach about 180–200 bar And Speeds reach about 25 m/s and temperatures at the piston crown may reach about 400 o C . The piston must be so designed that it can withstand the extreme heat and pressure of combustion. It also should light enough to keep inertial loads on related parts at minimum. It should also help in sealing the cylinder to prevent the escape of combustion gases and also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall. [2]

Today's engines run cleaner work harder and run hotter than ever before. At the same time they are expected to last longer and with minimal maintenance. Despite this technological evolution there are still a significant number of damage pistons. Failure may be occurs at different regions due to mechanical stresses, thermal stresses, temperature degradation, oxidation mechanisms etc. [3]

In spite of continuous evolution and research on pistons, its failure is still a common phenomenon. It is the only component of the engine that encounters failure from different origins like thermo mechanical stresses, fatigue, wear, extreme temperatures, etc. and engine operating conditions like lean carburetor jetting, advanced ignition timing, foreign material trapped inside, inappropriate piston-to-cylinder clearance, low octane fuel, loss of lubrication, high compression ratio, etc. [4].

II. LITERATURE REVIEW

Piston overheating seizure can only occur when something burns or scrapes away the oil film that exists between the piston and the cylinder wall.

When two moving metallic parts lose lubrication between them, scuffing is likely to occur. Scuffing is the process by which the metals weld themselves together and then break loose. Welding can occur between the piston or piston rings and the cylinder walls when the piston stops at TDC.

As the piston starts back down from TDC, this weld breaks. The rough surface that results wears ridges in the cylinder wall and on the piston ring or the piston itself. Scuffing can also be caused by detonation, which causes higher temperatures and pressures in the combustion chambers.
Dyson [5] considered that scuffing was due to the breakdown of the lubrication film at the inlet half region of the contact in sliding. Scuffing caused by lubrication breaking-down is supported by many experimental observations, such as the Al–Si alloy/steel scuffing experiment by Rohatgi and Pai [6].

Block [7] suggested a critical temperature criterion, which states that scuffing occurs when the total temperature at the contact surface reaches a critical value. Following this criterion, many experiments were conducted revealing that the critical temperature was affected by material properties, operating conditions, and physical/chemical interactions of a rubbing system. Based on the lubricant molecule physics option theory, Lee and Cheng [8] proposed a critical lubricant temperature–pressure criterion for lubricated steel/steel counter formal contacts. In this model, the concentration of absorbed lubricant molecules, which is affected by temperature, pressure, and material properties, was used as the scuffing criterion.

Shen et al. [9] captured three scuffing mechanisms in a low-speed steel conformal contact: thermo-mechanical breaking-down leading to plastic deformation; higher rate of lubricant desorption than that of the adsorption on contacting surfaces; greater rate of wear than that of the growth of an oxidation film. They proposed a simplified model based on an oxidation-wear-related scuffing mechanism to predict the scuffing of materials in such low-speed operations.

Semenov [10] proposed an energy criterion: scuffing would occur when the energy level of the crystal lattice exceeded the energy barrier. Cocks [11] studied the interaction of sliding metallic surfaces and found that scuffing happened when wear particles deposited on the rubbing surface created a high tendency for adhesion. Guo [12] reported that micro-scuffing could self-heal in further running; otherwise macro-scuffing might occur. These mechanisms and scuffing criteria promoted several mathematical models to predict scuffing.

The Al–Si alloy/steel material pair is widely used in automotive\ industries. Nautiyal and Schey [13] found that aluminum transfer to a steel surface might occur even in the presence of a substantial amount of lubricant. Reddy et al [14] found that in un-lubricated Al–Si alloy/steel contact, the transition from severe wear to scuffing was related to surface temperature, and that friction coefficient increased with load in severe wear regions. Reddy also reported that scuffing loads increased with silicon content and decreased with sliding speed and proposed a scuffing criterion for this type of contact, stating that scuffing would occur if the traction force was larger than the allowable shear stress of the surface material.

[15] He. X. specified the three lines of defense against scuffing for an Al–Si alloy/steel interaction—the lubricant film, the chemical film (oxides or chemical layer formed by reaction between the surface and the lubricant) and surface protective layers and the criteria for failure transitions with respect to these layers. Wang et al. [16, 17] evaluated the tribological behavior of and compatibility between coated piston skirts (with either composite polymer coatings (CPCs) or nickel/ceramic composite coatings) and aluminum or cast iron bore counter faces.

R. Buchta[18] suggest that The thermal load has been one of the bottlenecks in development for further intensified performance of diesel engines, such as higher power output per liter, better emission and higher efficiency, etc. Although it has been more than 100 years since the first diesel engine was manufactured in the world, the heat transfer process in diesel engine is still not systematically clear to researchers due to the complexity of the machine. Most of the early efforts were focused on empirical analysis due to the limitation of the means of research. Since the beginning of the 1980s, numerical approaches have been used to analyze the temperature distribution and to evaluate the thermo elastic behavior of engine pistons.

Li [19, 20] used a three-dimensional finite element model of an aluminum diesel engine piston to calculate operating temperatures, thermal and mechanical deformations due to thermo mechanical loads. He showed that skirt contours played an important part in the reduction of scuffing and friction.

Tahar Abbes et al. [21] presented the thermo mechanical behavior of a direct-injection diesel engine piston subjected to the combined thermal and mechanical loads. Liu and Reitz [22, 23] developed an axi-symmetric transient heat conduction model to predict the combustion chamber wall temperatures. Jenkin et al. [24] studied the near-wall temperature field in the burned and unburned gases, incorporating a turbulence model into the engine cycle simulation. Bohac et al. [25] used a resistance capacitance model to analyze the piston heat transfer. Esfahanian et al.

[26] compared three different combustion-side boundary conditions and investigated their effects on the thermal behavior of the piston. Lee and Kim [27] used the inverse heat conduction method to determine the optimum distribution of the coefficient of heat transfer (CoHT) at the top surface of the piston through a numerical implementation to analyze the temperature distribution of a liquid-petroleum liquid injection engine piston.

Previous work by Joyce et al. [28, 29] indicated that fatigue crack initiation in two near-eutectic piston alloys occurred mainly at primary Si particles at both ambient and elevated temperatures (200 ◦C and 350 ◦C). They did not observe any fatigue crack initiation at porosity despite pores measuring up to ~100 μm in diameter being observed in one of the alloys with low Cu (0.94 wt%) and Ni (0.96 wt%). However, about 20% of initiation events were observed at inter metallic clusters of Al3(CuNi)2 particles, but only in the alloy with higher Cu (3.1 wt%) and Ni (2.27 wt%) contents and at room temperature. The authors suggested that inter metallic particles may dominate fatigue performance with the reduction of primary Si particles. Moffat et al. [30], investigated a eutectic Al–Si piston alloy containing 12.45 wt% Si, 3.9 wt% Cu and 2.8 wt% Ni, and confirmed that fatigue crack initiation occurred not only at primary Si particles but also at several inter metallic compounds.

The main inter metallic that appeared to initiate fatigue cracks was Al9FeNi, although others such as Al7Cu4Ni and Al3 (CuNi)2 were observed adjacent to crack initiation sites. Furthermore, small pores (maximum dimension ~50–75 μm) were often observed associated with the inter metallic at initiation sites [31]. Moffat et al. [32] further investigated the fatigue behavior of three other model alloys with similar alloy content except for reduced Si levels of 6.9 wt% (unmodified and Sr modified) and 0.67 wt%. For the Sr-modified alloy with 6.9 wt%Si, It is clearly apparent from Moffat et al.'s work [33] that lowering Si levels reduces the role of Si particles in fatigue crack initiation with inter metallic particles (particularly, the Al9FeNi phase) taking a more dominant role. However, the reduction of Si is also accompanied by increased porosity due to poor cast ability. J.A. Taylor [34] which then dominates fatigue behavior especially for the low Si alloy.

Junker [35]The piston is one of the most stressed components of an entire vehicle pressures at the combustion chamber may reach about 180–200 bar a few years ago this value was common only for heavy-duty trucks but nowadays it is usual in HDSI engines. Speeds reach about 25 m/s and temperatures at the piston crown may reach about 400 oC . As one of the major moving parts in the power-transmitting assembly, the piston must be so designed that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep inertial loads on related parts to a minimum. The piston also aids in sealing the cylinder to prevent the escape of combustion gases. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall.

Taylo[36] As one of the main components in an engine, pistons technological evolution is expected to continue and they are expected to be more and more stronger, lighter, thinner and durable. The main reason is because the mechanical efficiency of an engine is still low and only about 25% of the original energy is used in brake power

Kajiwara H [37] one thing that has not changed is the basic function of the piston. The pistons form the bottom half of the combustion chamber and transmits the force of combustion through the wrist pin and connecting rod to the crankshaft. Payri F[38] the basic design of the piston is still pretty much the same. So what has changed? The operating environment. Today’s engines run cleaner, work harder and run hotter than ever before. At the same time they are expected to last longer and with minimal maintenance. Developments have been achieved in different fields: Yamagata Hiroshi [39] Joyce MR [40] examples may be found on the following papers of piston geometry/combustion flow. Materials/mechanical and thermal behavior . Materials/wear and lubrication (coatings).

Friedrich C and Takiguchi M [41, 42]; analytical tools – FEA Cho JR and Vijaya Babu M [43, 44]; processing technologies Nakajima K and Sulaiman S [45,46]; etc. Notwithstanding this technological evolution there are still a significant number of damaged pistons.

As ICE will be run in higher speed, larger pressure and heavier load, it results in more burdening working conditions for piston skirts ZHU Li-min [47]. Consequently, it is necessary to improve the design and manufacturing process of piston skirt. Recently, light-mass design has been widely spread in metal forming CHOI H and SHI Yu-liang [48, 49]. According to this concept, studies on aluminum alloy instead of steel to be the main material of piston skirt have attracted more and more research interests, which may benefit energy conservation and environmental protection. SHAN D B and RUSZ S [50, 51]. Another technical renovation is about manufacturing process. Forging is adopted to substitute for casting to gain a better metal structure quality. Isothermal forging is a metal forming process developed since 1960s, in which dies should be heated and kept at the same temperature as the billet during the whole process.

This technology may improve the homogeneity of metal flow, enhance the plasticity and decrease the deformation pressure, which is important to shape the complex surface with accurate dimensions. Therefore, it is proposed to trial-produce an aluminum piston skirt by isothermal forging. Due to lack of experience about how to integrate these technologies, it is critical to further research thoroughly and urgently. SONG et al [52, 53] experimentally studied the influence of the deformation condition on the isothermal forming for type 240 aluminum piston skirt.

YOU and MA [54] discussed the isothermal extrusion process of 4A11 alloy piston skirt. Using CAE (computer aided engineering) technology, ZHOU et al [55, 56] analyzed the deformation load and relative effects by different billet profiles during forging process of LD11 aluminum alloy.

III. CONCLUSION

From [5-12] piston failure due to scuffing occurs on the different region, there are various causes by which scuffing and scoring have been identified end explained by many authors. From [13-18] material composition review have been explained. From [19-28] piston failure occurs due to thermal property changed have been explained by many authors. Thermal failure occurs due to overheating and overload on the engines, lubrication is also a cause for thermal failure. From [29-33] various fatigue failure has been identified in the internal combustion engine. From [34-45] piston damage due to various reason like seizure, fatigue overheating scoring etc. from [46-56] failure of high speed engine piston have been explained by many authors.

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