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ANALYSIS OF PISTON FAILURE: A REVIEW

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ABSTRACT

In automotive failures has become a major concern. Piston is one of the main parts of the engine. In this report a study is conducted on the piston failure by using different methods. The major causes are increase in temperature, improper carburization techniques, improper coating, improper combustion, the improper combustion causes carbon deposits etc. There are different types of methods are used to analyze the piston failures they are wear bench test, hardness test Vickers meter to know the depth of carburized layer etc. Visual examination is conducted by the SEM (Scanning Electron Microscopy), EDS (Energy dispersive spectrometry), EDX (Energy Dispersive X-ray spectroscopy). Spectroscopy Chemical analysis is used to know the chemical composition in the piston. The failure of the piston was studied using finite element software such as ABACUS and ANSYS.

Keywords: Piston, FEA, SEM, EDM, Carburization.

I. INTRODUCTION

Piston is the disc or cylindrical component fitting closely within an engine cylinder as depicted in the figure 1. It is the Reciprocating part of the engine it moves up and down against a liquid or gas used in internal combustion engine. The piston converts the energy released during combustion into mechanical action and transfers it to the Crankshaft work. There are different types of pistons are available in the automotives. The piston is made up of different alloy materials. Finite Element Analysis or FEA is the simulation of a physical experience using a numerical mathematic technique referred to as the Finite Element Method, or FEM. This process is at the core of mechanical engineering, as well as a variety of other disciplines. It also is one of the key principles used in the development of simulation software. Engineers can use these FEM to reduce the number of physical prototypes and run virtual experiments to optimize their designs.

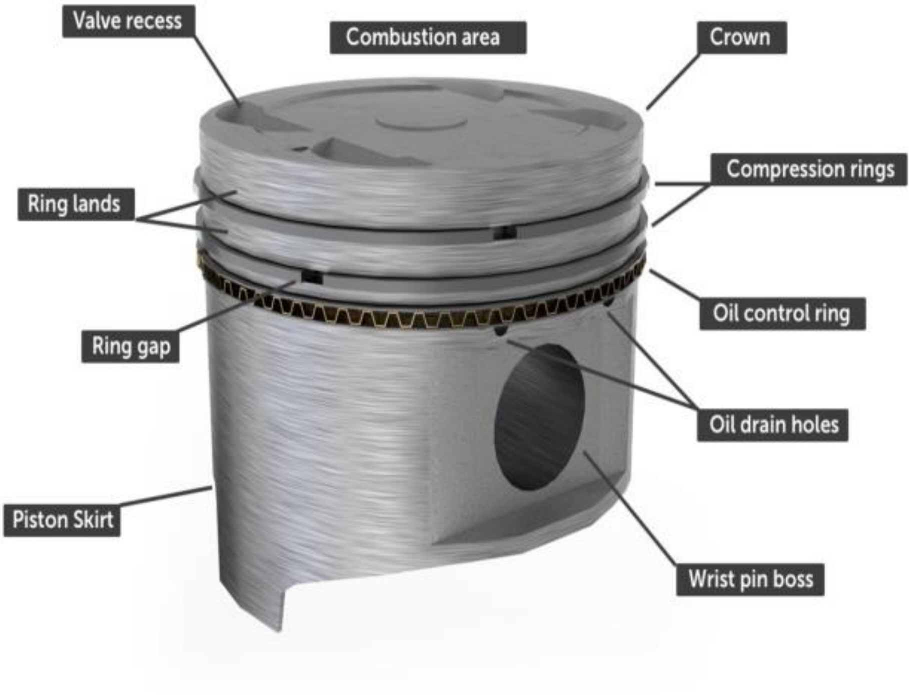

Figure 1. Different parts of piston

The mathematical model of optimization is established firstly, and the FEA is carried out by using the ANSYS software. Based on the analysis of optimal result, the stress concentrates on the Upper end of piston have evaluated, which provides a better reference for restore of piston that shows in figure 2.

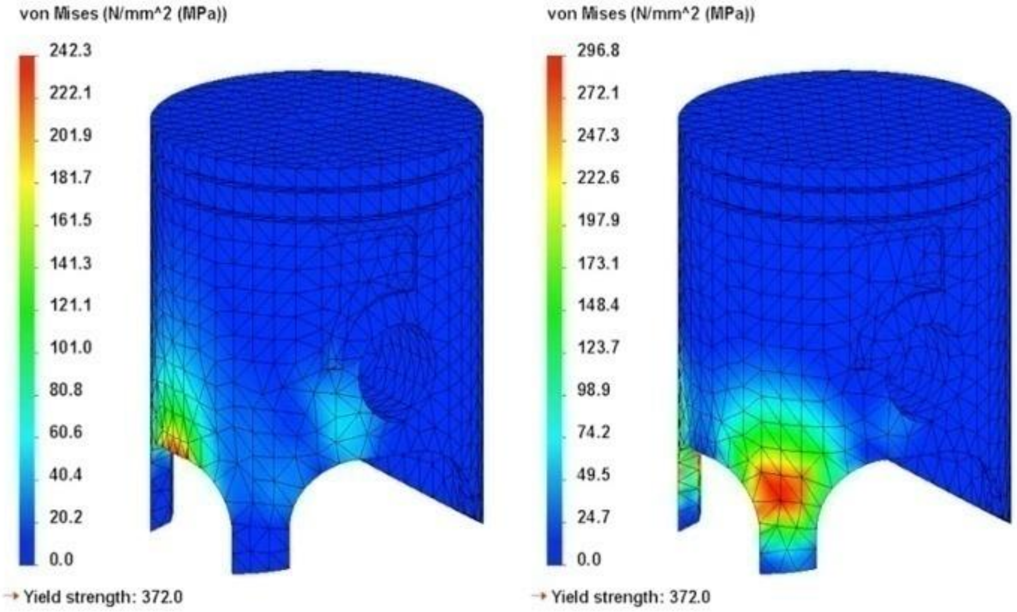

Figure 2. Finite element analysis of piston

II. LITERATURE SURVEY

Zhiwei hu, et. al., [1] finds that the Longitudinal and transverse cracks were happened on the surface of the piston. The internal piston entire surface is where the cracks first appeared, and they then spread to the external holes. Chemical analysis using spectroscopy was used to assess the chemical composition of the failing piston-pin material by Zhiwei Hu et al. The test results reveal that the piston failure is caused by incorrect carburization technique, as evidenced by the carburized layer that was exposed on the internal hole surfaces as shown in figure3. In addition to carburization, main decarburization also occurred on the surface region of the internal hole. Decarburization lowers the piston's fatigue strength and causes cracks to appear on both the piston's internal and external surfaces. Although the piston-external pin's circle surface is less hard than the specification calls for, the depth of the carburized layer is 0.5-0.8mm deeper than the highest limit of the requirements. In the area of the interior hole surface, a decarburization layer with a thickness of about 0.5mm was formed.

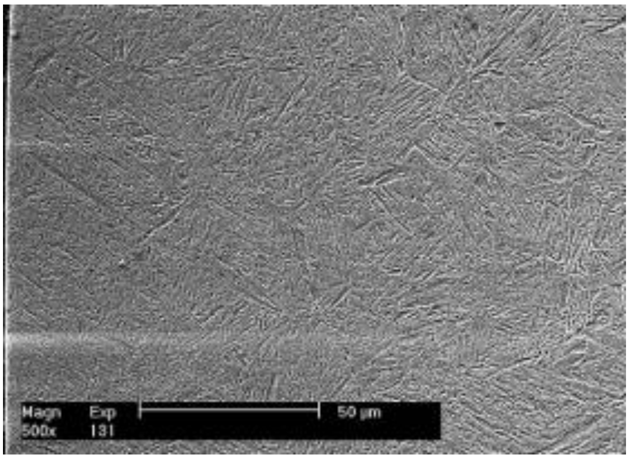

Figure 3. Microstructure of the carburized layer on the external circle surface [1]

Nachiket Kulkarni, et. al., [2] studied the failure analysis of the piston. They study shows that the when the piston undergoes more temperature and pressure in that case some failures occur with the piston. Pistons typically fail in a variety of ways, including carbon deposits, ash deposits, debris marks, chipping, etc. Figure4 shows the piston skirt deposition. These problems occur when the piston gets too hot and experiences increased temperature and pressure. Mechanical fatigue is the term used to describe when the shape of the piston changes or deforms. Cracks or fractures result from fatigue. Before the piston fails it exhibits any early signs. We must accurately maintain the piston and provide it with sufficient lubrication and a better cooling system in order to prevent these problems.

Table 1. Shows the damage of various pistons

	Mileage of engine, km				Total number of engines
	<1000	50000-100000	100000-150000	>150000	
Faulty engines(working)	2	58	100	296	456
Completely breakdown engines	1	12	17	28	58

Figure 4. Piston skirt shows deposition [2]

DaniloD'Andrea et. al., [3] focuses on the cyclic wear and axial piston pump cylinder block failure. He conducted a wear bench test on the blocks with an anti-friction coating collected of high-level bronze, and the results revealed that some of the cylinder coating failed within a short period of time. They used scanning electron microscopy and energy dispersive spectroscopy to test the piston cylinders. Confocal topography was used to look at the cylinder blocks of axial piston pumps for wear, and the results of the test reveal that inaccurate coating is primarily to blame for segregation since the casting process's slow cooling rate leads in the formation of space. Higher cooling rates, correctly dispersed segregations, and coatings with good wear characteristics should all be used to prevent this kind of casting failure. Poor wear of the piston is caused by slow cooling, which leads to poor segregation.

Ali Mamedov. et. al., [4] Review the failure analysis of the piston from the primary standard pressure unit. The piston already has the fracture. An EDX spectrometer was used to analyse the material, and a scanning electron microscope was used to look at the fracture surfaces. According to the findings, the piston's substance is only capable of bearing compression load. But even when the piston experiences only minor bending and torsion, or torsion and bending combined, the fracture was brought on by external torsion loadings as shown in figure5. In its usual operation condition, the piston is safe for compression loading. The piston has failed when it is subjected to any form of force, including bending and torsion. All that is compressive about the material utilized in the piston is that. The term "EDX spectrometry" refers to the chemical characterization of a trial and energy dispersive x-ray element analysis.

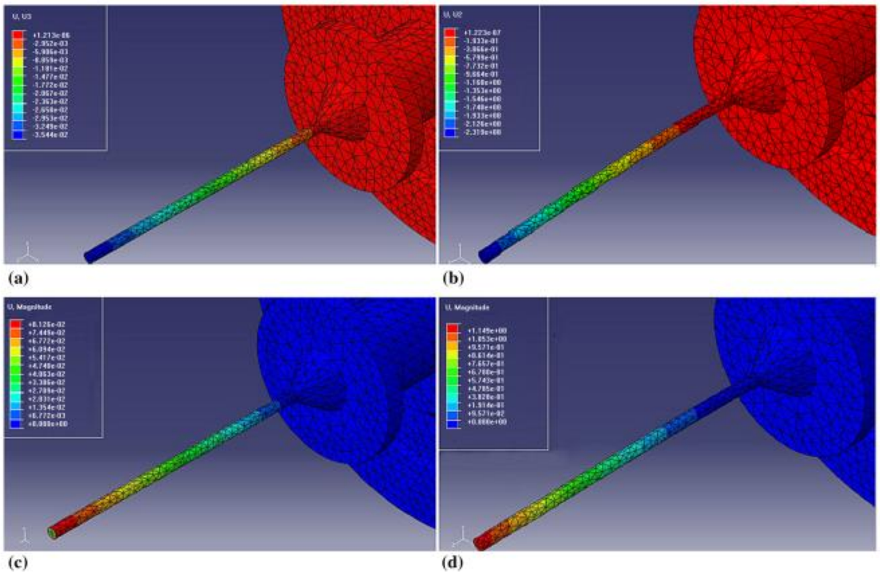

Figure 5. Deflection of the piston under (a) compression, (b) bending, (c) torsion, (d) combined bending/torsion loadings [4]

Jialin wang, et. al.,[5] examined the impactor's pneumatic downfall mechanism for failure. The occurrence of the carbide coating on the piston causes the piston to crack. Using the SEM as shown in figure6 and nano identification, they examined the microstructure and hardness of the piston. Vickers hardness tester is used to determine the piston's hardness. The ABACUS finite element method was used to study the stress condition process. The carbide face cracks when the piston impacts the bit, according to outcome from the use of finite elements. Higher von Mises stresses on the outside edge and carbides in the carburized layer were the main contributors to the piston failure. The beginning of the piston cracks is due to the excessive Vonmises stress. Controlling the carbon potential during the carburizing process is crucial to prevent unnecessary precipitation of large-sized carbides in the carburized layer, which causes the carbides in the carburizing layer to first crack during contact.

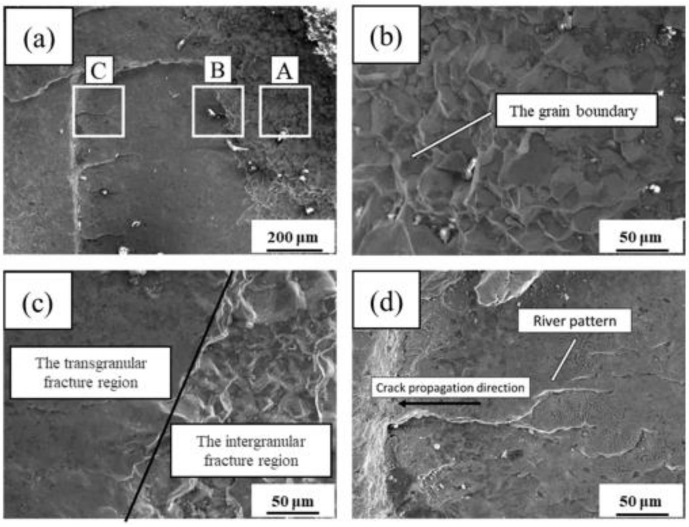

Figure 6. SEM showing the fracture surface of the piston, a) The overall fracture surface, b) The inter granular fracture surface (region A), b) The boundary between inter granular fracture and trans granular fracture (region B), d) The trans granular fracture surface (region C)

Osman, et. al., [6] investigated on a piston rod end used in a hydraulic cylinder of an aircraft landing gear. The piston was failed. According to failure element analysis, the cracks started on the piston, the piston rod's end broke, and mechanical damage occurred on the most stressed area. Different experimental techniques were utilized on the piston, including visual inspection, to conclude where the breakdown occurred. The piston is shown in intensity in the photo documentation approach. To determine the piston's material composition, chemical analysis is used. To determine the hardness of the piston material is hardness test is used and the figure7 shows the microhardness test profiles of the piston rod end close to the failed region. To see the failure marks, a scanning electron microscopy (SEM) investigation is performed. To see the failure, utilize the scanning electron microscope (SEM) examination. The failing piston rod end's material was determined by scanning analysis and mechanical testing to be alloy steel in a hardened and tempered state. Visual inspection reveals that failure was a bench-marked, typical fatigue fracture.

Table 2. Chemical composition of the failed piston rod end and SAE 4340 alloy steel

Element	Failed piston rod end	SAE 4340 alloy steel
C	0.328	0.30-0.38
Si	0.282	0.15-0.40
Mn	0.625	0.40-0.70
Cr	1.512	1.40-1.70
Ni	1.657	1.30-1.70
Mo	0.176	0.15-0.30
P	0.021	0.035(max.)
S	0.030	0.035(max.)
Fe	Balance	

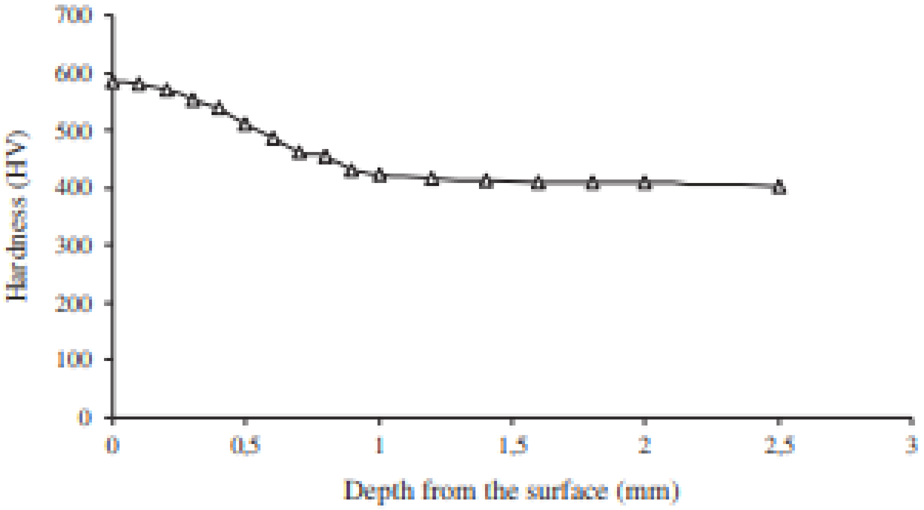

Figure 7. Micro-hardness profiles of the piston rod end close to the failed region. [6]

Venkatachalam, et. al., [7] studied the experimental investigation of diesel engine piston. In this paper the failures of the diesel engine piston are analyse by using different experimental methods. The piston's typical value is 61 HRB (hardness Rockwell in B scale) can observe in figure8. The piston is made of aluminium alloys. A high silicon content lengthens the life of the piston, but silicon cannot bear up high temperatures. The microstructure of an alloy mostly determines its strength and hardness. For pistons, aluminium alloys are outstanding. However, there are also some downsides, which include failure-causing issues like cracks in the piston cylinder and erosion on the piston head from wear. Experimental techniques included visual inspection to locate the failure zone and identify marks on the piston, chemical analysis to determine the materials' composition, a hardness test to determine the material's hardness, and optical inspection to determine the microstructure—the microstructure being crucial to the piston's long life. Finally, scanning electron microscopy (SEM) was observed in figure 9 was used to see where the piston had failed.

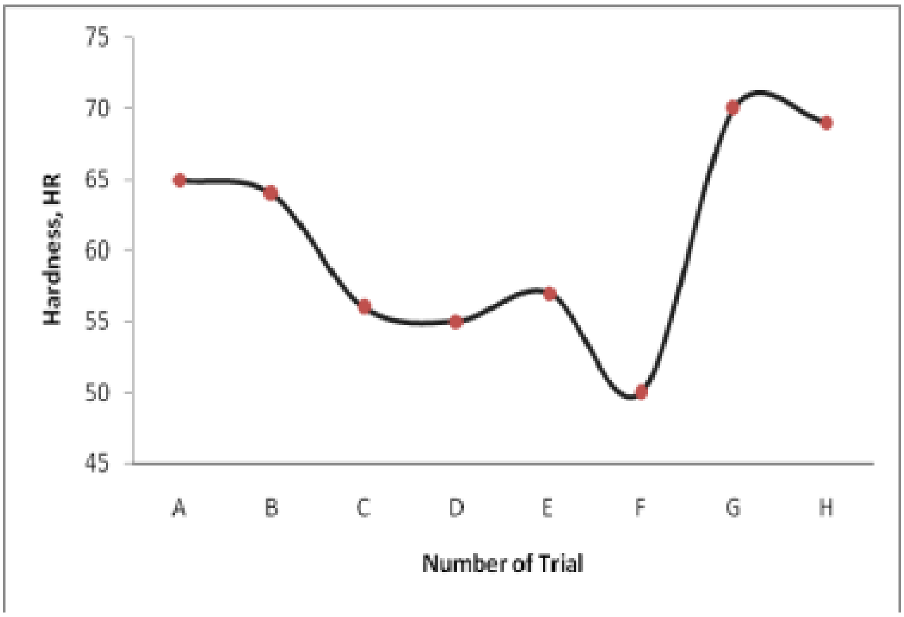

Figure 8. Hardness values for various locations [7]

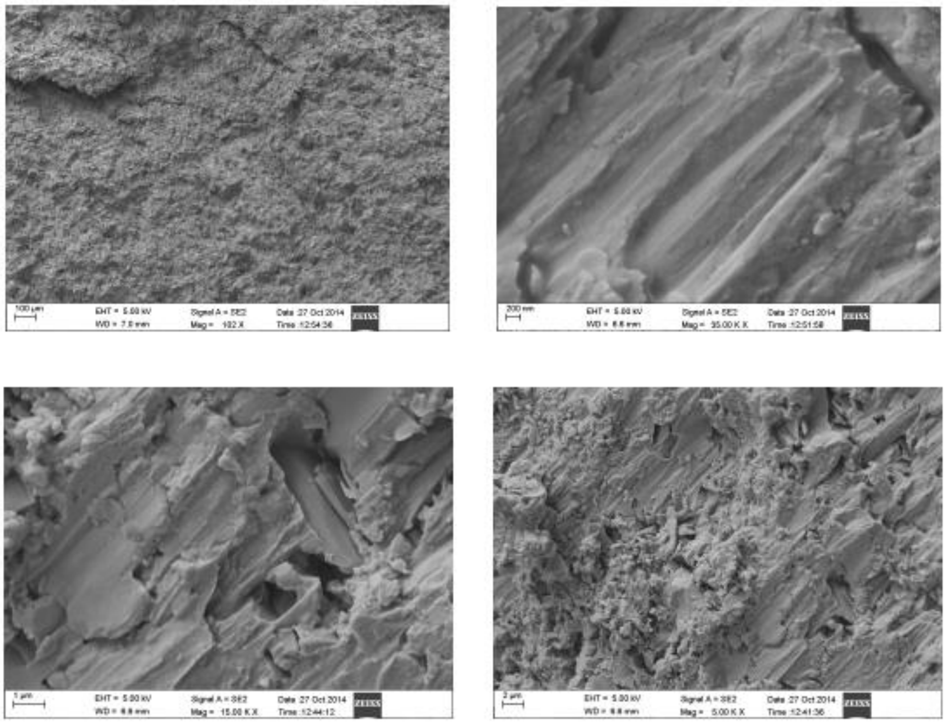

Figure 9. SEM micro-structure of the piston [7]

Gaurav kumar, et. al., [8] studied that the stress distribution in the four-stroke engine piston by using the Finite element analysis (FEA) software. One of the primary parts of the engine is the piston. Compared to petrol engines, diesel engines have superior fuel efficiency. The engine's minimal heat rejection contributes to its high thermal efficiency. The engine's primary factor is its operating environment. Therefore, testing the engine's thermal efficiency is crucial. Piston temperature field and feature analysis software are integrated in thermal analysis. Commercial engines use diesel engines because of their high-power needs and low power consumption, however in order to achieve these needs, the piston must survive important heat loads. One of the most important things to keep the piston at the right temperature is cooling. Thermal fatigue can result in cracks and seizures in the piston skirt as shown in figure 10 if it is brought on by temperature variations within the piston and poor coolant supply.

Pritam Ghadge et.al., [9] describes the stress distribution of aluminium alloy piston by using CAE Tools. These pistons were studied using condition from a four-stroke, four-cylinder engine. The process for analytic piston design is made with aluminium alloy. CATIA V5 software is used to create a parametric model of a piston, and ANSYS 14.5 software is used to analyse that model. Based on factors such Von Misses Stress and deformation for a four-wheeler piston, the optimal aluminium alloy material is chosen using ANSYS 14.5 software. One of the most important parts of an internal combustion engine is the piston Mechanical and thermal stresses are the main causes of piston failure. The stress and displacement distribution caused by the flue gas pressure and temperature, both individually and jointly, are calculated in this article using the finite element method. Software from CAD and CAE does the FEA.

a b

Figure 10. A crack on the piston pin: a) cracked piston head; b) cracked piston skirt [8]

Festus O. Isa et. al., [10] conducted an experiment on piston of a single cylinder four-stroke diesel engine using ZS1115NM diesel engine by using 3Dmodelling. The modelling of the piston used SOLIDWORKS 2013 3D Computer Aided Design (CAD) software as shown in figure 11 and figure 12. By demonstrating the designing process step by step, this method produces particular results. Due to many characteristics of aluminium, including its excellent thermal conductivity, an alloy called A92618 was chosen as the material for the piston (approximately 3 times than that of cast iron). Additionally, it is crucial to use the right material while rising and manufacturing a conventional piston

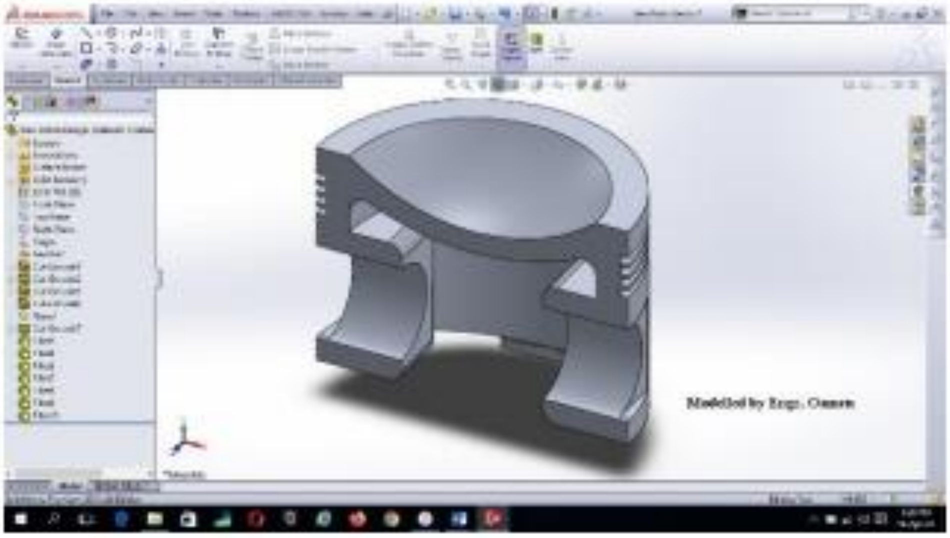

Figure 11. Sectional view of the modelled conventional piston [10]

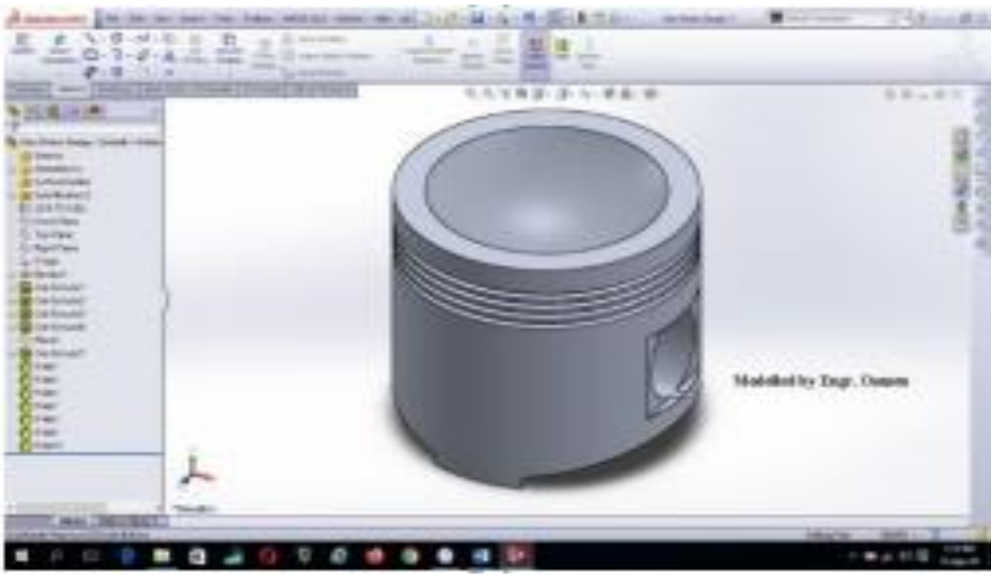

Figure 12. Isometric view of the 3D modelled conventional piston [10]

V.R. Deulgaonkar et. al., [11] Deals with the failure analysis of heavy-duty diesel engine piston used in transport utility vehicles. The piston under thought has failed at 302763 km. Failure mode and effect analysis (FMEA) method is used to identify the engine component having significant input failure. Identification of piston failure has been carried out using FMEA and risk priority number (RPN) for engine components. Experimental analysis of failed piston has been carried out using Scanning Electron Microscopy (SEM) was observed in figure 13, Energy Dispersive Spectrometry (EDS) and X-Ray Diffraction (XRD) techniques. SEM was employed to speculate the type of failure of piston. Carbon deposition on the piston surface has been observed. EDS of failed piston has also been carried out to identify levels of unnormalized component elements causal to piston failure. From EDS, presence of unnormalized carbon and oxygen reveal conformability with the failure analysis. Significant percentage of carbon and oxygen at different locations on the piston surface is observed, leading to finish of temperature variations inside the cylinder during working. Inferences drawn from piston failure analysis reveal the causes and consequences of failure reasons. The presence of excess carbon on the piston surface indicates the knocking and overheating phenomenon. corrective measures in addition to periodic maintenance of engine and replacement of worn-out gasket to avoid piston failures are presented in this research.

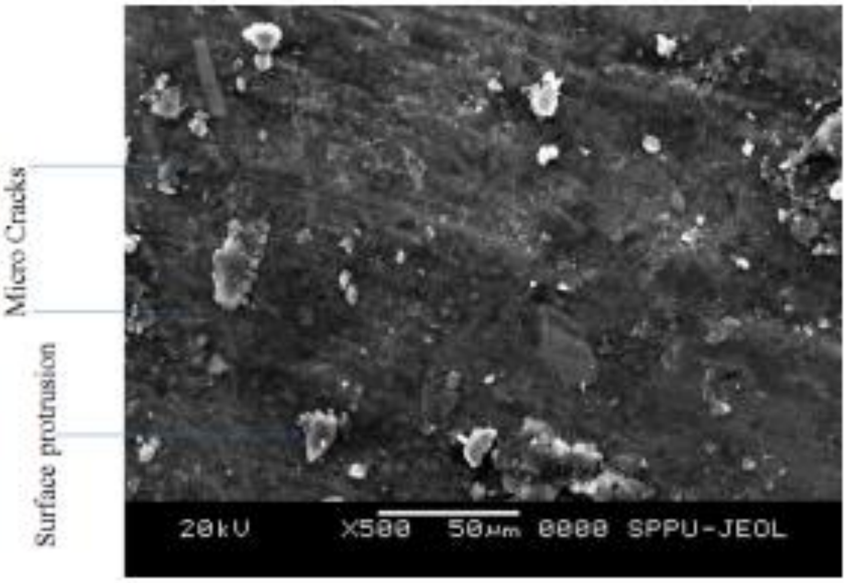

Figure 13. SEM observation of piston head surface showing cracks and protrusion [11]

Festus O. Isaac et. al., [12] conducted the bench test of the original piston, which induced knock combustion by monitoring of the pressure signal in the cylinder. The results show that the failure process mainly includes the erosion damage of the original passive film and the following peeling of the surface material which was proved by XRD, optical and scanning electron microscopy method as shown in figure 14, 3D Confocal laser scanning microscope and other research methods. During erosion damage, carbon deposit on the crown of piston reacts with the surface of the aluminum matrix to form weak phase (Al_4C_3 and Al_2O_3). In addition, the remaining hardness in the cross section of the damage zone decreases considerably as the ablation level increases.

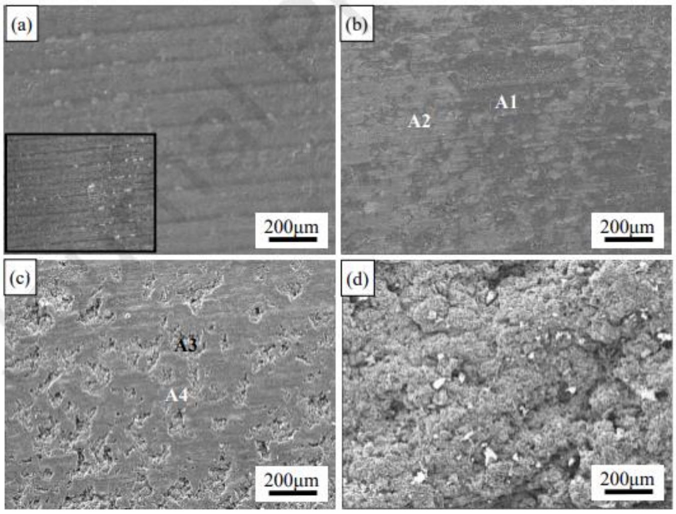

Figure 14. SEM morphology with different degrees of ablation [12]

Shuoguo Zhao et. al., [13] Designed the Engine Piston. Piston working state is very important to engine, so it is very important for structural analysis of the piston. The piston was analyzed and it was observed in figure 15, calculates the piston by Pro\ENGEER software to gain a result, which improves and optimizes the structure of the piston

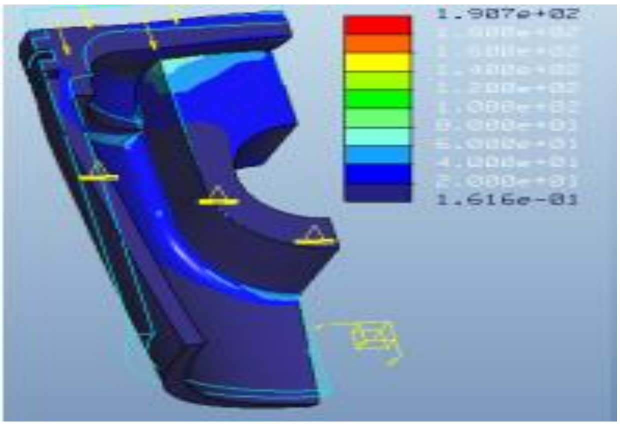

Figure 15. Stress concentration of piston head [13]

Wang Yet. al., [14] evaluated the protective impact of applying various Mullite thermal barrier coating thicknesses to the top surface of the piston using the method of hardness block temperature measurement and three-dimensional modelling. The piston seat's maximum temperature dropped from 358.6 to 338.9 C as the ceramic coating's thickness grew from 0.2 to 0.7 mm as shown in figure 16. This demonstrated how the use of Mullite thermal barrier coating may lower the working temperature of the aluminium alloy piston at the maximum load operating point and appreciably increase the constancy of engine components.

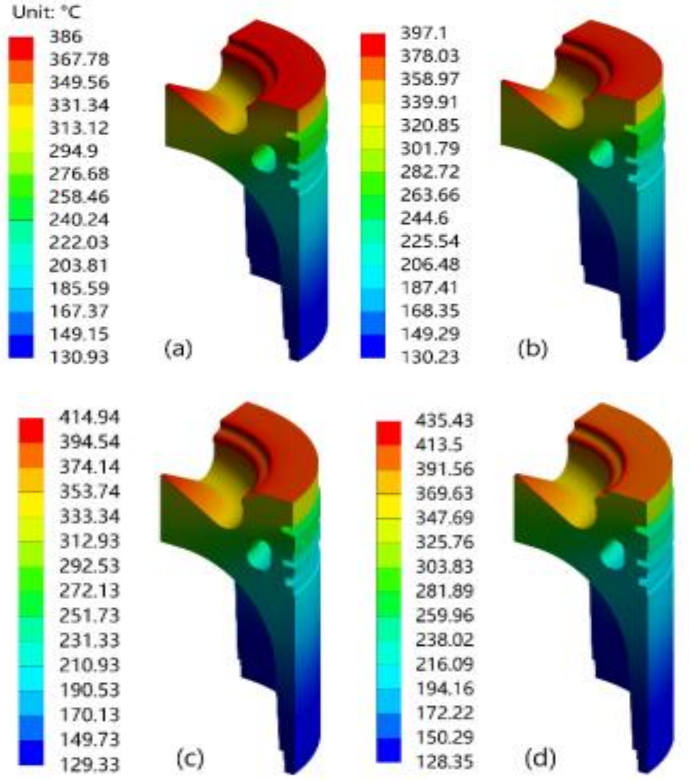

Figure 16. Thicknesses: (a) 0.2 mm, (b) 0.3 mm, (c) 0.5 mm, (d) 0.7 mm.[14]

Vinod Junju et. al., [15] made an effort to lessen the thermal energy is made silicon nitride as a ceramic material for the piston to survive mechanical strains and structural stresses Because the material used for the piston's crown (the top piece) is fragile and the skirt Nature makes material ductile. The space between them was filled with a ceramic-reinforced fiber strip. To prevent the fragile ceramic crown from breaking owing to the Al alloy skirt's construction, when it experiences impact loads as a result of a gas explosion during combustion. When the piston material used was work Eutectic Al Alloy (Si 11–13%). at the opening thermal and a structural analysis of an Al Alloy piston without a silicon nitride crown was done, and then Using silicon nitride crown and ANSYS. the silicon nitride crown is superior than the piston in its ability to bear high temperature and structural loads. doesn't have a silicon nitride crown arranging it. when the piston is set by ceramic crown the maximum stress intensity is 226 N/mm^2, this is within the design value of 240 N/mm^2. but the maximum stress intensity in the piston without arranged by ceramic crown is 278 N/mm^2 this is exceeded the design value was observed in figure 17. Similarly, when the piston is arranged by ceramic crown the temperature distribution is 317^0C only whereas when the piston is without arranged by ceramic crown the temperature distribution is 601^0C.

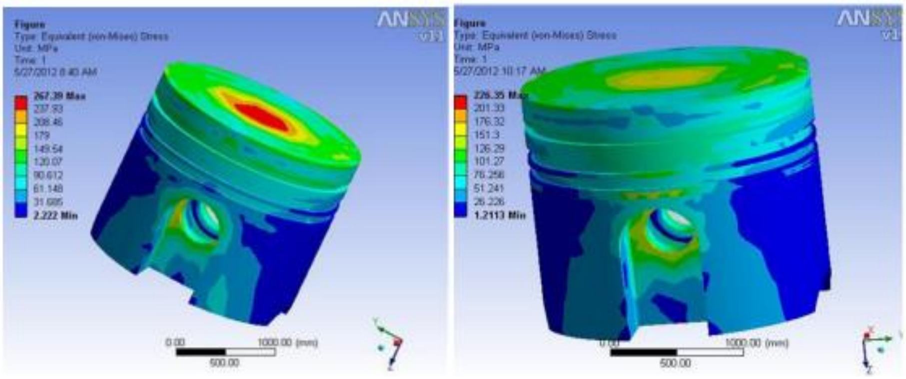

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Figure 17. a) Stress distribution in Al alloy piston b) Stress distribution in ceramic crown piston [15]

S. Srikanth Reddy et. al., [16] was made research to evaluate the distribution of the piston's thermal stress under actual engine conditions during combustion. This thesis explains. The crucial location and increased stress by optimizing the mesh using finite element analysis method on the constituent. The primary focus of this work is the study of the thermal behavior of correctly graded coatings were created on zirconium and aluminium using the commercial code ANSYS.. The analysis is conducted to lessen the tension on the top end, (Piston head/crown, piston skirt, and piston sleeve) of the piston. Using NX/Catia computer-aided design software is be used to create a structural model of a piston.

Matrin et. al.,[17] was made research on the piston after 1276 hours of operation, a diesel engine that had failed in service was used for study in an effort to identify the cause of the failure and depicts the failed piston shows in figure18, which may have a crack that extends from the crown to the top of the gudgeon pin hole. Failure of the piston was caused by a high-porosity location at the upper edge of the combustion chamber bowl where a fatigue fracture growth process began. This is an uncommon location for the start of a crack; typically, it starts at the gudgeon pin hole and progresses to the piston's crown. This region must have experienced stresses that were far higher than would have been predicted, and the only way this could have happened is if the fuel had too early exploded or burned. The crown and skirt both tested at 67 HV20 and 98.5 HV20, respectively, for hardness. It revealed that the piston crown had weakened as a result of contact to the combustion gases, but there was no sign that excessive heat growth had caused any harm.

Lucia Zulova et.al., [18] shows that t is necessary to keep an eye on the steps throughout the machine's building and operation since noise produced by the machine's use can have a harmful effect on people and the environment. Modern technology enables these machines' mechanical systems to be properly optimized. Utilizing pneumatic tuners is one idea being studied for mechanical system improvement. The purpose of this paper is to illustrate how the pneumatic tuner affects mechanical system noise, even in the event that a mechanical drive component fails. The results of an experimental measurement show how altering the pressure of a gaseous medium in the compression region of a pneumatic tuner alters the noise in a mechanical system.

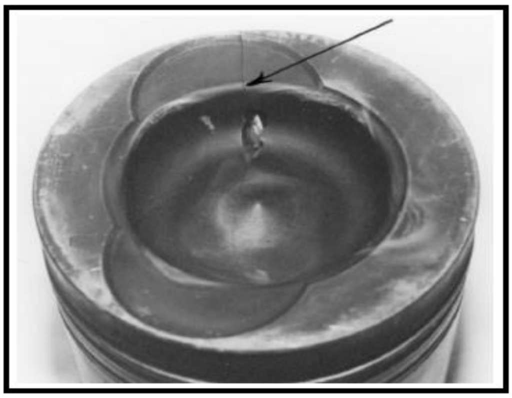

Figure 18. Looking down the hole formed from the combustion chamber to the lower ring.
The cracks initiated at the edge [17]

Vikas Deulgaonkaret.al., [19] The existing project examines the timing device piston and vanes failure in the supply pump of a gasoline pump system used in transport utility vehicles. Investigations are conducted to assess the timing device piston and supply pump failure in transport utility vehicles. On the surface of a failed timing device piston, cracks are visible. Figure 19 shows that the original and failed veins. The crack development is recognized to a lack of fuel, which causes dry running and increases friction. The failure of the piston in the timing device is also influenced by the presence of fuel contaminants. The primary factor behind supply pump failure and vane failure has been determined to be increased friction between the rotor and vane housing (i.e., vane housing). Vane failures have an impact on the engine's efficiency and result in partial fuel combustion. Dry pump operation and surface rusts brought on by water presence are reasons for the vane failure. The failed apparatus has undergone scanning electron microscopy and energy-dispersive spectroscopy. The current work has provided corrective measures to stop the failure of the supply pump's piston and vanes and the timing device.

Figure 19. Original and failed veins of supply pump [19]

Xiao-lei et. al., [20] shows that a piston-pin from a diesel engine that was working in a truck during service had longitudinal cracking and a transverse fracture as shown in figure 20. The central section of the longitudinal fracture exhibits the banded pattern that runs the whole length of the fracture. The piston-longitudinal pin's fracture spread toward the piston-internal pin's hole surface and outside circular surface after beginning in the banded texture. By using spectroscopic chemical analysis, the piston-pin material was investigated. A scanning electron microscope (SEM) and optical microscope (OPM) were used to study the microstructure at different sites (SEM). By using X-ray energy-dispersive spectrometry, the work of the material's inclusions and the micro-composition on the fracture surface were both identified (EDS). With a load of 1000 g, the Vickers system created microhardness profiles from the surface to the interior in various places to find out the depth of the carburized layer.

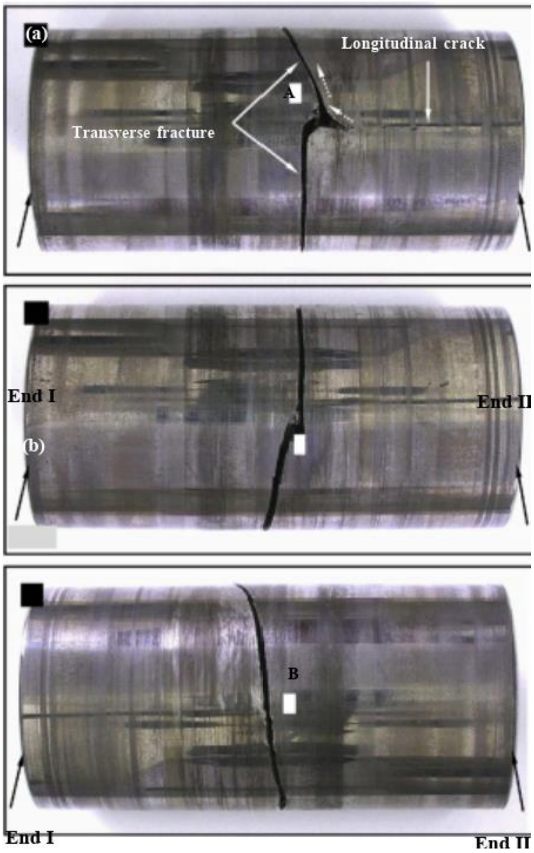

Figure 20. Failed piston pin showing crack morphology at three different locations [20].

III. CONCLUSION

On the basis of earlier works that have been reported on piston failure, the findings below have been formed.

- From earlier works shows that the piston failure mainly caused by higher stresses on the outer edge and due to of thisstress cracks were formed.

- The results show that the cracked surfaces get damaged by exposing due to combustion gases.
- Most of the researches shows that the piston is modelled using SOLIDWORKS software.
- SEM results shows that the failure is due to improper carburization and decarburization.
- Some of the works shows that the FEA confirms that the critical stress locations resulting from the contact of the piston skirt against the cylinder wall, and analyse of the fracture surfaces confirms the beginning and propagation of the fatigue cracks.
- Most of the researches shows that the ABACUS finite element method maximum stresses occurs in the piston strikes the small piece causing carbide face to crack.
- The results of thermal analysis of pistons with different thicknesses of Mullite coatings showed that the surface temperature of the coated pistons was considerably higher than that of conventional pistons
- From earlier works, that shows that the Stress distribution and temperature distribution in silicon nitride crown piston is 226 N/mm^2, 317^{0}C respectively. Whereas in the piston without silicon nitride crowns the stress and temperature distribution is 278 N/mm^2, 601^{0}C respectively.
- It means stress and temperature distributions have been reduced in piston which is arranged by ceramic crown.
- The piston's deformation is a major factor in the stress distribution on the piston. Therefore, in order to reduce the stress concentration, the piston crown should have enough hardness to reduce the deformation.

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