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REVIEW OF LITERATURE ON DESIGN AND ANALYSIS OF DIESEL ENGINE PISTONS

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Abstract

Various researches are conducted in the field of internal combustions engines especially in the area of Diesel pistons and on their designs, manufacturing techniques and also for their sustainability under various operating conditions. Much advancement took place in the piston designs since their invention especially in case of diesel pistons since diesel engines have high thermal and mechanical efficiencies over petrol or gasoline pistons. In this paper the various case studies and experimental studies conducted by the various novel researchers on pistons are studied, comprehended and reviewed.

Keywords:
Piston;
Diesel;
Fatigue;
Alloys;
Metals;
Temperatures.

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1. Introduction

In diesel pistons various factors like thermal stresses, mechanical fatigue, load, creep, ware resistance and alloy behaviour all together has made to have a review on design and manufacturing of pistons which helps research and developers to produce an advanced piston which can sustain and overcome present draw backs. Design developments is not the only way to have a piston which suits the working conditions but the utilization of perfect material also add on to it. After reviewing the various papers on pistons by different scholars it is observed that not only the internal factors but external working conditions also had its impact on the performance on the piston life. So the study on working conditions and their failures helps us to take a step further in pistons design and manufacturing.

2. Review

1.1 In research paper “Fatigue on engine pistons – A compendium of case studies” by F L Silva studied about damages caused to pistons by thermal and fatigue stresses. He analyzed fatigue-damaged pistons. Vandalize at the skirt, ring grooves, crown and pin holes are evaluated. A detailed examination of both thermal fatigue and mechanical fatigue damages is analyzed and presented in the paper. A linear static stress analysis, using ‘‘cosmos works’’, is used to resolve the stress distribution during the combustion. Stresses at various parts of the piston like acrown, piston rings and skirts are presented. Fractographic studies are conducted in order to confirm crack initiation sites.

After analyzing damaged piston, he concluded, fatigues are not the main cause for crack initiation and damages in pistons. And it has adverse effects on engines efficiency and fuel consumption. To satisfy all the requirements to utilize piston in high thermal and fatigue stress conditions it should have improved design, materials, processing technologies, etc.

1.2 A.J. Moffat, S. Barnes, B.G. Mellor and P.A.S. Reed paper on “The effect of silicon content on long crack fatigue behavior of aluminum–silicon piston alloys at elevated temperature” said microstructures ofprimary and eutectic silicon of aluminum alloy are present in the piston together with numerous intermetallics. Previous studies have shown that primary silicon influences both fatigue crack initiation and subsequent propagation behavior. But theeffect of varying silicon content on piston crack behavior has not clearly been defined. Therefore, anumber of pistons with varying silicon contents are analyzed. Long crack fatigue tests have been performed at room and elevated temperature typical of the gudgeon pin boss (200 oC) using a test frequency of 15 Hz. Microstructural characterizationof the test samples are imaged and being studied to know the crack behavior. The role of primary Si in enhancing crack growth rates at high DK levels has been confirmed. In the absence of primary Si the low DK level cracks growth behavior is dominated by matrix properties whilst the high DK level crack growth behavior is inter-dendritic and occurs along the weak path of the eutectic Si and/or intermetallic network.

The high Si content in the alloy has more influence on the crack growth at higher DK levels, which has caused increased contribution of static failure modes through thefailure of the coarse secondary phase particles, particularly the primary Si. This caused the increase in crack growth and deflections due to coarse Si particles at low DK levels. In the absence of primary Si, crack growth is principally intradendritic at low DK levels and controlled more by a-Al matrix properties. Near threshold performance has been enhanced because at high temperatures toughness is reflected in improved crack growth rate because secondary Si particles tend to bond at higher DK levels.

1.3 A paper by Q.G. Wang, D. Apelian, D.A. Lados “Fatigue behavior of A356-T6 aluminium cast alloys. Part I. Effect of casting defects” stated about the effect on Si modified A356-T6 piston. The numbers of cycles to failure of materials with various secondary arm spacing (SDAS) were investigated as a function of stress amplitude, stress ratio, and casting defect size. To produce pore-free samples, HIP-ed and Densale treatments were applied prior to the T6 heat treatment. From the studies, it is observed that casting defects causes the shortening in piston life and its performance. Compared to defect-free castings, defect castings shows at least some order of magnitude. The decrease in fatigue life is directly proportional to the increase of defect size. Thereexists a critical defect size for fatigue crack initiation, below which fatigue crack initiates from other competing initiators such as eutectic particles and slip bands. A fracture mechanics is used to find out the number of cycles necessary to generate a fatigue crack from an initial casting defect to final failure. Fatigue life of casting having defects can be analyzed by studying size of defects. Moreover, the fatigue fracture behavior of aluminum castings is well described by Weibull statistics. Porosity has more effect on fatigue when compared to oxide films.

After analyzing it is stated that casting defects have adverse effects on piston life and fatigue crack propagation. The decrease in fatigue life is directly related to the increase of defect size. In Si modified cast A356 alloy, the critical defect size is in the range of 25±50 lm at the loading conditions was used.

1.4 I.G. Wrighta , P.J. Maziasza , F.V. Ellisb , T.B. Gibbonsc , and D.A. Woodfordd in their paper "MATERIALS ISSUES FOR TURBINES FOR OPERATION IN ULTRA-SUPERCRITICAL STEAM" stated that in coal-fired supercritical-steam power plants, currently operating with steam temperatures at the inlet close to or slightly above 600°C. The utilization of recently-developed martensiticferritic steels is allowing this temperature to be raised to 620°C, which represents the capability of these advanced steels. Further, the increase in temperature will require the use of Ni-base alloys, and the researchers in this direction have been pioneered in Europe where the plant operating temperature on steam is at 700°C. In the U.S., remarkable effort focusing on sustainable alloys that could be used for tubing and piping to deliver steam at 720/760°C. In this paper they studied on the materials used for Eddystone 1 (649/566/566°C/340 bar) represented the latest high-temperature alloys of cast type 316 stainless steel was used for the nozzle blocks, inner cylinder, diaphragm, and vanes the rotor was forged from Disc alloy (Fe-25Ni-13.5Cr-Mo,Ti); and the blades were K42B (Ni-22Co-18Cr-TiAl).

1.5 R. Viswanathan and W. Bakker in their paper Materials for Ultrasupercritical Coal Power Plants—Boiler Materials: Part 1 stated the efficiency of conventional boiler/steam turbine fossil power plants is a strong function of the steamtemperature and pressure. The purpose and the need to reduce CO_2 emission have recently added an additional incentive to increaseefficiency. The most efficient steam power plant running on fossil fuels is at temperature 600^{o}C range, with increased temperature of 60^{o}C in last 30 years. In mere future, it is expected that this temperature will rise by another 50 to 100^o C in short span of time. Day by day development of advanced technologies made possible of developing materials which can sustain higher temperatures. Recent studies by EPIR stated that ferritic 9-12Cr steels can be used in boilers (ultra-supercritical power plants) at a temperature of 620°C. 12Cr ferritic steel is capable of long-term service temperatures 650°C.Austenitic steel with Ni and advance austenitic steel is used for service temperature 700°C in super and reheated engines and ASME have to approve these steels. ASME recently approved T-23, 2-1/2%Cr steel is preferable for Eddystone 1 for operating pressure 34.5Mpa. The main cause of the problems are due to heavy sectioned components in the boilers and here in this paper, they have focused on thedevelopment of advanced alloys for that they are developing the advanced alloys capable of sustaining high temperatures with additional elements like C, Nb, Mo,and V.

1.6 R. Viswanathan and W. Bakker in their research paper Materials for Ultrasupercritical Coal Power Plants—Turbine Materials: Part II stated that advanced ultra-supercritical power plant has to be constructed that can sustain temperature >625°C and pressure up to 34MPa. For developing this they are using alloys like TMK1, TR1100, TOS107, and a modified GE alloy for HP and IP steam turbines which can sustain a temperature >593°C.European and Japanese have been testing on TOS110, EPDC alloy B as rotors. Alloy HR1200 with low Al and Ni seems promising.

In recent times research has been evidenced that utilization of oxygen during combustion than air and technology is enabling to improve materials which can sustain high temperatures during combustion. These researched caused for the development of more advanced alloys. The study here is to identify, evaluate and qualifying materials that can be utilized at a temperature 760°C of pressure 35MPa. Fireside corrosion tests have been conducted under conditions simulating those of waterwalls and superheater/ reheater tubes. Austenitic steel is main material utilized in SH/RH tubing where resistance to oxidation and fireside corrosion along with creep strength is important. Keeping in mind about creep strength T-91 is limited to 565 °C and NF616 is limited to 593°C. Ni-based alloys are Haynes 230, Inconel 625has higher temperature retaining capacity than austenitic steels.

1.7 M. Priest, D. Dowson, C.M. Taylor in their research paper Predictive wear modeling of lubricated piston rings in a diesel engine stated that the performance of piston rings can be understood along with the study of lubrication and wear is considered. In this, both theory and experiment data areanalyzed and divided into two parts to find out the wear of piston rings tribological behavior. Firstly the model is used to study the lubrication effect on piston rings at constant load and speed at adifferent time interval. Firstly tribological behavior, wear in the engine is observed secondly the wear resistance of the compression ring is studied. After 120 hrs test run the top compression ring significant wear is studied during thetest. The surface roughness of piston ring and cylindrical wall is reduced after 120 hrs run. The top compression ring which faces center firing and where high loads are applied was predicted to have largest wear rates.

1.8 M.M. Haque*, A. Sharif in their research paper stated that "Study on wear properties of aluminium–silicon piston alloy" Low expansion aluminium–silicon eutectic alloys are cast to produce most of the automotive pistons and the properties of these alloys depends on various factors like heat treatment operations, cooling rate, modification and cooling rate. The wear behavior of both as-cast and heat treated specimens were studied under dry sliding conditions at room temperature using a pin on disc type wear testing apparatus.The wear and the damage areanalyzed by optical microscopy and weight loss measurement techniques. Heat treatment process shows high influence on wear properties of aluminium-silicon alloy piston which reduces the wear of the piston. Mechanical properties like hardness and high tensile strength are achieved and ductility is reduced due to heat treating process. The microstructural change also occurred in eutectic silicon structures.

Results from the experiment state that the increase in wear can be observed in both cast and heat treated steel with anincrease in load with respect to time. For heat treated specimens a mild wear is observed at the wear surface, and for theas-castspecimen, an adhesive wear with plastic deformation is observed. The heat treated aluminum–silicon piston alloy has higher strength, hardness and wear resistance properties.

1.9 M. Gupta*, S. Ling in their research paper Microstructure and mechanical properties of hypo/ hyper-eutectic Al-Si alloys synthesized using a near-net shape forming technique stated three aluminum-silicon alloys containing 7, 10 and 19 wt % silicon were synthesized using a novel technique commonly known as disintegrated melt deposition technique. In this process, 80% of yield strength is achieved after defacing the shrinkage cavity from processed ingots.

From the studies conducted on theMicrostructural characterization processed sample, the porosity increases with increase in silicon content. Porosity levels of 1.07, 1.51 and 2.65% attained in the case of Al–7Si, Al–10Si, and Al–19Si alloys. The aging results conducted on Al-Si alloy revealed similar kinetics irrespective of different silicon contents and increase in thematrix is observed in ambient temperature mechanical tests.

During analyzing the effect of extrusion on Al-19Si alloy revealed the significant assistance in reduced porosity and improved uniform microstructure, 0.2% yield strength, ductility and ultimate tensile strength as compared to processed Al-19Si alloy. The increased percentage of silicon in aluminum because of aging increases the peak hardness and solutionized this does not affect aging kinetics.

1.10 Zhiwei Yu, Xiaolei Xu *, Hongxin Ding in their research paper Failure analysis of a diesel engine piston-pin stated that the longitudinal and transverse cracking happened on the failed piston-pin and the cracks initiated from the internal hole surface and propagated toward the external circle. The fatigue fracture is originated by theoccurrence of fatigue striations on fracture of all origin regions indicate the failure mechanism of piston-pin. The internal hole and external circle surfaces are specified to be carburized. The depth of the carburized layer is determined by analyzing micro hardness profiles and microstructure on theinternal hole and external structure.Decarburizing decreases the fatigue strength of the internal surface which causes the initiation of crack from internal surface and travels towards the external surface. The improper carburizing technique is responsible for the decarburization on the internal hole surface. Thepiston-pin is defective for carburization technology.Longitudinal and transverse istook place in failed piston pin where pin fractured into a few fragments.

1.11 G.G. Martin in their paper "Failure of a Stationary Pump Engine Piston" stated Piston failures are not a common occurrence, but they do occur, and failure is usually associated with fatigue crack growth. Most failures begin at theskirt of the piston or in the gudgeon pin hole. They conclude small metallurgical discontinuities causesthe mode of failure and can cause these failures under the right circumstances. Hardness tests were conducted on the crown and skirt yielded 67 HV20 and 98.5 HV20, respectively. Failure of the piston in the area of porosity causes a fatigue crack growth mechanism. Crack unusually occurs in porosity area and usually occurs at thecrown and piston pinhole. Premature detonation of fuel causes higher stress in this region of gudgeon pin and this is the usual area for crack initiation. Porosity produces the casting defects along with manufacturing defects initiates and follows the crack to reach the bottom ring.

1.12 Nethula Arun and Dr. M Varaprasada Rao in their research paper Design and analysis of Diesel Piston analyzed the regular piston behavior of A 356 alloy and their drawbacks like wear resistance, thermal and fatigue resistance. To overcome these hurdles they utilized Inconel 625 and Haynes 556 alloys which are generally being used in ultra-supercritical power plants and cryogenics at high working temperature 650^{o}C and pressure 30 bars. So in order to increase the life expectancy of thepiston and to sustain the adverse effects in high temperatures and pressures like working conditions these advanced alloying materials are being designed and analyzed in computer modeling and the results show the sustainability of these materials at high temperatures and pressures as when compared to A 356 alloying elements. Utilization of these alloying elements Inconel 625 and Haynes 556 inautomobiles increase the life and wear resistance of the piston.

3. CONCLUSION

Based on previous papers and researchers on pistons, their materials, working conditions and their behaviors there are many designs, castings, working conditions and utilization of materials in pistons. The complexity of design and materials causes loss of energy, wear of piston and material which cannot sustain thermal and mechanical stresses and fatigue. The design development is not the only way of rectifying all the drawbacks, research and development of alloying materials also increase the life of the piston, wear resistance and can work under heavy loads. So future for the piston is to develop an advanced material which has good thermal conductivity, less wear and high yield strength even under extreme working conditions. These not solely increase the piston life but the individual working conditions and external factors also have their impact.

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